ASSESSMENT OF THE EFFECTIVENESS OF NARROW SEPARATORS ON CYCLE LANES

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ABSTRACT

Roading authorities desire to better provide for existing people cycling, and to encourage more people who wish to cycle but are discouraged due to safety concerns. There is widespread acknowledgement (supported by a substantial body of research) that providing increased physical separation between motor vehicle and bicycle space will help address these concerns and lead to an increase in cycling.

A wide variety of physical devices and delineators are available to provide separation. This research covers on-road trials of a 100 mm wide raised bicycle lane separator in Christchurch. ViaStrada was commissioned by VicRoads to design the empirical study, and evaluate and report on the findings. Christchurch City Council provided site support and Canterbury University helped to analyse the results.

Separators were placed in two locations where motorists were commonly encroaching into exclusive bicycle lanes. Road user behaviour was observed before and after installation, and qualitative feedback was also sought from site users.

The results show a significant effect on motor vehicle encroachments following installation, particularly when separators were supplemented by vertical posts. Very positive feedback was also received from existing cyclists. Some recommendations for best practice guidance on the most appropriate treatment locations and layouts are also suggested.

1. INTRODUCTION

Roading authorities desire to better provide for existing people cycling, and to encourage more people who wish to cycle but are discouraged due to safety concerns. There is widespread acknowledgement (e.g. Kingham *et al.* 2011) that providing increased physical separation between motor vehicle and bicycle space will help address these concerns and lead to an increase in cycling.

Christchurch's cycle facility network comprises many on-street cycle lanes, marked by painted lines. The majority of these facilities are well used by cyclists and offer a dedicated space on most of Christchurch's busiest roads. However, in certain areas, motor vehicles regularly encroach into marked cycle lanes and interrupt the safe passage of cyclists. A wide variety of physical devices and delineators are available to provide better separation and to encourage more people to use the cycle facilities.

As part of an extensive study by VicRoads of cycle lane separation effects, this paper takes a closer look at road user behaviour. ViaStrada was commissioned to design the empirical study, and evaluate and report on the findings. ViaStrada developed a proposal for on-road trials of bicycle lane separation in Christchurch to analyse smaller-sized low-profile separators (ViaStrada, 2012). For the trials, the so-called "Riley separators" (Figure 1) were used. Characteristics of the separators are presented in Table 1. Some flexible vertical posts were also used to supplement these separators.

The field work was undertaken from July to October 2012 on two street sections in Christchurch, which are known for motor vehicles encroaching into the existing on-street cycle lanes. One of the street sections was a road at a major intersection that contained two approach lanes and a kerb-side Advanced Stop Lane (ASL). The other street section included a slightly curved mid-block area with a kerb-side cycle lane. Christchurch City Council provided site support and video data collection and the University of Canterbury helped to analyse the results (Aussendorf 2012).

Figure 1: Riley separators and a vertical post installed on Kotare Street cycle lane line

Table 1: Characteristics of Riley Separators

Width	100 mm (160 mm to bumps)
Height	25 mm
Edge lip height	2-3 mm
Surface	Moulded pimples rising approx. 2 mm above surface
Reflectors	Small reflectors moulded into leading edges
Comments	1.2 m long sections; may be installed with a gap for drainage and cyclist entry/exit.

1.1. Objectives

The research aimed to determine how the implementation of low-profile separators on existing cycle lanes affects road user behaviour (especially the behaviour of motorists), and whether further treatments (e.g. vertical posts) are necessary to make the separation more effective if the initial results were not satisfactory. The sites have been surveyed before and after treatments using video observation techniques.

2. LITERATURE REVIEW

Several studies have investigated conflict situations between motor vehicles and cyclists. Walton *et al.* (2005) found that these situations are less likely to occur after the implementation of cycling facilities. Particularly on roads with high traffic flows and at major intersections, drivers are less likely to be aware of cyclists and, therefore, conflict situations occur more often. In these areas, vehicles tend to approach close to cyclists. The perceived safety of cycling is thereby decreased and, as a consequence, the number of people cycling might stagnate or decrease.

Hallett *et al.* (2006) observed that introduction of cycling facilities has an effect on the behaviour and position on-street of both cyclists and motor vehicles. Motorists seemed to be more comfortable approaching certain areas, as they rely on cyclists being inside the cycle lane. Cyclists are mostly positively influenced by the general presence of cycle facilities, the facility width and the expected number of other cyclists.

This impression was confirmed by Zangenehpour *et al.* (2013) in their study analysing the effects of advanced waiting facilities at several intersections in Montreal. Even if the focus was on cyclist behaviour change, it was noticed that the marked separation of motorised traffic and cyclists had a positive effect on road safety.

Fowler (2005) also analysed the effects of cycle lanes on cyclist safety and traffic operations. She concluded that, even if the on-site situation was improved, the impressions of cyclists and motorists differed. Fowler noticed that motor vehicles came very close to the cycle lane markings, when no cyclists were present. Prior to the cycle lane implementations, these drivers might have oriented their movement along the kerbside. When vehicles had to pass cyclists, the distance between them increased. However, the overall perceived safety amongst cyclists only increased slightly. A relatively high proportion of cyclists still ranked the risk of cycling on-street as too high and preferred travelling on the footpath.

The above studies outlined the general positive influence of the implementation of cycle facilities on road user behaviour and perceived safety. However, the studies also showed that basic improvements need to be increased by further treatments to get sufficient results. A possible treatment is marking the surface of cycle lanes with a noticeable colour.

A study on the effects of cycle lane colouring was done in Edinburgh (Rye *et al.* 2007). It was found that that coloured cycle facilities were less likely to be encroached upon by motorists than those that are not coloured. This impression was confirmed by the noted behaviour changes at a site that was upgraded with coloured surfacing during the observation. After the colouring, the encroachment of vehicles into the cycle lane dropped significantly at the site.

Another study about the effects of cycle lane colouring was done in Christchurch (Mangundu 2009). The study analysed the road behaviour before and after upgrading advanced waiting facilities for cyclists at several intersections and concluded that the treatment had raised the awareness of both cyclists and motorists for potential conflicts. It was also noted that the combination of coloured cycle facilities and narrower traffic lanes also improved the road user behaviour.

Another Christchurch-based study on coloured advanced waiting facilities for cyclists at intersections on behalf of the Christchurch City Council also identified positive effects of the treatment (Newman 2002). However, the results were considered not sufficient; a high number of vehicles still encroached into the cycle facilities. Therefore, it was recommended to investigate ways to increase the separation of cyclists and motor vehicles to significantly improve the situation for cyclists.

Over the years, a variety of cycle lane separation forms have been developed all over the world. SKM (2008a) compiled several of these treatments that have been successfully implemented on local sites and overseas. The highest degree of separation is provided by elevated (kerbed) cycle lanes such as the cycle lanes in Copenhagen. The use of solid obstacles, which are mountable by neither motor vehicles nor cyclists, is another form of separation. The obstacles are often designed as greenery containers or special kerbs. Gaps between these obstacles give cyclists the opportunity to enter or leave the cycle facility if needed.

Many of these options require a relatively high amount of construction effort and space and are, therefore, more applicable for reconstructed routes. However, in most cases, existing sites with limited space need to be treated. For these sites, smaller mountable separators have been developed. SKM (2008b) used low-profile separators that were originally designed to hinder vehicles from encroaching onto tram tracks. The results have shown that motor vehicles reduced their encroachments into the cycle lane significantly and increased their distance to the cycle lane. Cyclists also felt safer and had little difficulty riding across the separators in dry conditions. However, further research needs to be done on low-profile separators with other measurements.

3. SURVEY METHOD

3.1. Site Selection and Surveys

For this research, two sites with different features and traffic volumes were selected in the Christchurch urban area:

1. Strickland Street is a minor arterial road in south Christchurch with an AADT of 8,000 vpd and a bicycle flow of ~600 cyclists per day. The observed section at the northern end of Strickland Street comprises an advanced cycle lane and a combined left/through lane at a signal controlled X-intersection with Brougham Street (see Figure 2). Left-turning traffic tends to encroach into the cycle lane when approaching the turn. However, during the research period, the intersection operated as a T-junction and traffic from Strickland Street was only able to turn left or right, due to the temporary closure for road construction of the through-street immediately north (Antigua Street).
2. Kotare Street is a minor arterial road in west Christchurch with an AADT of approximately 12,000 vpd and a bicycle flow of ~450 cyclists per day. The main feature of the section located at the western end of Kotare Street is a left-hand curve (see Figure 1), in which vehicles, after entering Kotare Street from the Creyke/Clyde intersection upstream, tend to encroach into the existing on-street cycle lane.

Figure 2: Strickland Street Riley separators and posts approaching intersection

For the road user behaviour study, video data was collected at different stages of the separator implementation using a camera on top of a parked vehicle near each research area. All the surveys were carried out between July and October 2012. Prior to the surveys, the cycle lane on Strickland Street was slightly widened; it was anticipated that separators might become necessary and the researchers wanted to maintain adequate cycling space. This minor treatment was considered not influential to the resulting observed road user behaviour.

After implementing the separators on Strickland Street, their position was re-evaluated. The result was a slight shift of the separators to their current position on top of the existing cycle lane marking. However, the initial post-implementation survey made clear that many motorists were still ignoring the separators. Three flexible posts were subsequently installed to physically underline the separation between cyclists and motor vehicles (see Figure 2) and a third video survey was collected.

Following the implementation of the low-profile separators on Kotare Street, the behaviour of motorists towards the separators was rated as not satisfactory, and a cyclist also had a near-fall. Therefore, prior to the post-implementation survey, it was decided to install a flexible vertical post between the first two separators coming from Clyde Road (see Figure 1), to raise the awareness of the separators by all road users.

In addition to observations of the physical trials, qualitative feedback was also sought from site users via a survey. Flyers on-site and advertising via local cycling websites and email-lists directed people to an online survey to complete.

3.2. Data Collection - Strickland Street

The video data for the observation area Strickland Street/Brougham Street was taken on three days in July, September and October 2012 from approximately 8:40am (late starts due to the restricted availability of the survey vehicle) to 4:00pm. To analyse the data, the video material was divided in one-hour blocks starting at full hour, with the exception of the shorter morning period.

Table 2 shows the categorisations used to define motorist behaviour at Strickland Street. Motor vehicles were rated as fully encroaching when they were taking all space from cyclists.

If motor vehicles entered the cycle lane with one wheel or drove on the cycle lane marking, they were categorised as partly encroaching.

Table 2: Encroachment Types of Motor Vehicles (Strickland Street)

Group	Encroachment during red traffic signal phase	Encroachment during green traffic signal phase
F-F	Full	Full
P-F	Partly	Full
P-P		Partly
N-F	None	Full
N-P		Partly
N-N		None

For the pre-implementation survey, vehicles encroaching into the cycle lane beyond the limit line of the combined left/through lane were rated as not encroaching. In this case, it was assumed that the turning radius of motor vehicles made it unavoidable to turn without slightly entering into the cycle lane.

The first survey was observed from a side-on position that provided good detail at the intersection, but little about the approach. During the first post-implementation survey, the position of the observation vehicle was changed to get a better impression of the queuing behaviour of approaching vehicles (see Figure 3). While the categorisation of driver behaviour remained unchanged, the cyclist waiting area was not clearly visible and, often, the encroachment level of vehicles in this area had to be guessed.

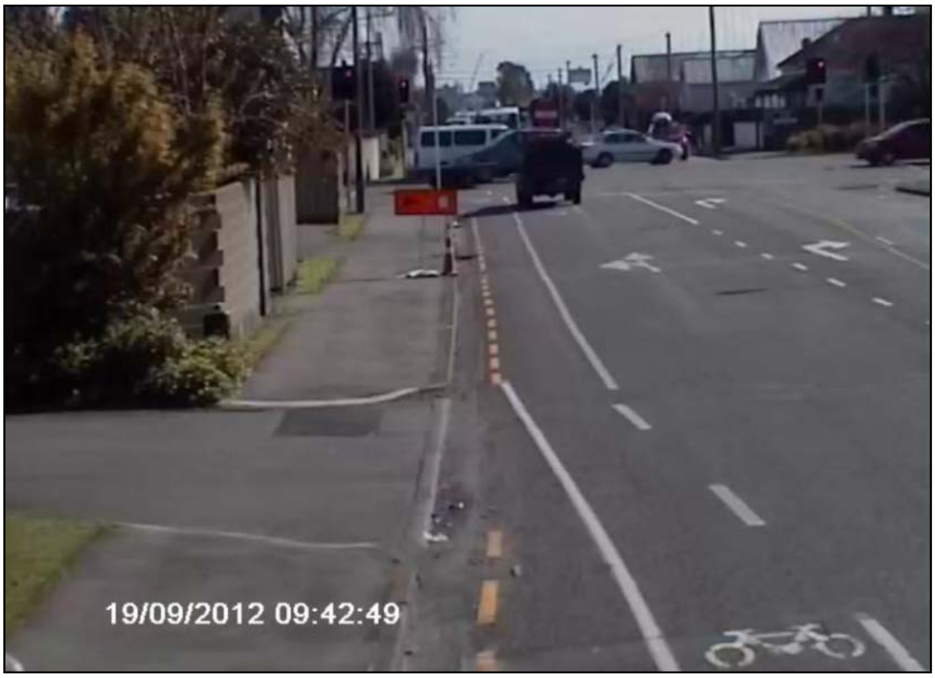

Figure 3: Camera angle, first post-implementation survey (Strickland Street)

For the second post-implementation survey, the position of the observation vehicle remained the same as during the first post-implementation survey. However, the camera angle was zoomed slightly closer to the intersection to get a better view on the separators.

3.3. Data Collection - Kotare Street

The video data for the observation area Clyde Road/Kotare Street was collected in July and September 2012, between approximately 8:20am to 4:00pm. As with Strickland Street, the video material was divided in one-hour blocks starting at full hour, with the exception of the shorter morning peak period.

During the pre-implementation video evaluation, the research area was split up in three sections. Section 1 covered the length of the separators, Section 2 extended from the end of the separators a similar distance downstream, and Section 3 continued beyond that. During the post-implementation survey, the camera angle mostly focused on Section 1 (see Figure 4). Therefore, the remaining two sections were combined into one.

Vehicle movements were categorised as fully or partly encroaching into any of these sections. Motor vehicles were rated as fully encroaching, when they were taking all space from cyclists. If motor vehicles entered the cycle lane with one wheel or drove on the cycle lane marking, they were categorised as partly encroaching.

Figure 4: Kotare Street encroachment zones as viewed from camera

4. PRE-IMPLEMENTATION BEHAVIOUR

4.1. Strickland Street

During the survey period on 25 July 2012, over 900 left-turning motor vehicles were observed. The highest left-turning traffic volumes appeared in the morning and afternoon peak hour.

During the full traffic signal sequence (red and green phase), almost every motor vehicle encroached into the cycle lane at least partly. More than half of all vehicles encroached into the cycle lane during both red and green phases. Motorists were more likely to encroach into the cycle lane when they reached the intersection during the green phase.

Two thirds of the left-turning motor vehicles were encroaching into the cycle lane while the traffic signals were red (see Figure 5). Vehicles entering the cycle lane partly, while they were waiting for signal changing, form the second largest group. The minority of all left-turning vehicles did not enter the cycle lane during the red signal phase. The same was noticed for the green phase, where 3/4 of the left-turning traffic encroached into the cycle lane completely.

During the survey period, 51 cyclists were counted, with most appearing during the first hour of observation. In general, only half of the cyclists were biking inside of the cycle lane. Of the cyclists outside the cycle lane, the majority used the through-lane to get across to Antigua Street, despite the road closure.

Figure 5: Full encroaching motor vehicles while cyclists present (Strickland Street)

The impact on the survey results due to road construction has to be considered. With Antigua Street to the north of the intersection closed for traffic, it can be assumed that a certain percentage of vehicles observed turning left would usually drive straight across to Antigua Street. The same assumption can be made for cyclists. Although some cyclists were still using Antigua Street (via the footpaths and coned-off areas), a certain proportion changed their direction and turned left or right from Strickland Street. We know from prior observations by Mangundu (2009) that motor vehicle encroachment was common before the road closure. What was different, though, was the behaviour of through cyclists; the closure effectively created an exclusive left turning lane for motorists and many cyclists placed themselves to the right of the left turners in the vehicle lane to proceed straight ahead.

Cyclists were more likely to arrive at the intersection during the red signal phase when motor vehicles were already queuing. They often tended to wait in front of the Advanced Stop Lane (a hook turn box is present there, but incorrect markings in the box and a lack of coloured surfacing in the ASL mean that its purpose is not well understood). This behaviour was noticed even when no motor vehicle was present. Cyclists also used traffic gaps on Brougham Street and turned left during their red phase.

4.2. Kotare Street

During the survey period on 26 July 2012, over 2500 motor vehicles were observed. Over half of the vehicles did not encroach into the cycle lane at any time while driving along Kotare Street. Motorists entering the cycle lane were most likely to encroach into only one of the three sections, although encroachments of two or three sections were also reasonably prevalent (see Figure 6).

Encroachment was most likely in Section 1. Due to the short distance to the intersection Clyde Road/Kotare Street, this can be associated with the radius used by approaching vehicles during turning manoeuvres. An inappropriate turning radius caused motor vehicles to encroach into the cycle lane. If they did not adjust the radius, motorists were likely to encroach into the whole length of the cycle lane.

During the observation period, 68 cyclists were counted. Most of the cyclists were spotted from 3:00pm - 4:00pm; closely followed by the morning hours (8:40 - 10:00am). These numbers are influenced by educational facilities in the vicinity (e.g. the University of Canterbury is one block away). Cyclists almost exclusively cycled inside the cycle lane.

If cyclists were present, motorists were observed to not encroach into the cycle lane. Rather, they tended to keep a large distance to cyclists, even in areas where they were observed to be likely to encroach at other times. The short distance to the signalised Clyde/Kotare/Creyke intersection could have an influence on this behaviour. During the red phase, motor vehicles and cyclists wait together at the different approaches. Thereby, motorists are aware of the presence of cyclists and can adapt their driving behaviour, while proceeding into Kotare Street.

Some unusual behaviour was noticed when a motorist encroached in Section 1 while overtaking another vehicle that was waiting to turn into a property. Another unusual encroachment of Section 1 was by a motorist making a u-turn.

Figure 6: Partly encroaching motor vehicle in Section 2+3 (Kotare Street)

5. POST-IMPLEMENTATION BEHAVIOUR

5.1. Strickland Street

For Strickland Street, two post-implementation surveys were undertaken:

1st Post-Implementation Survey:
The first post-implementation survey was done on 19 September 2012, after the low-profile Riley separators were installed. During this period, over 1000 motor vehicles were observed. The largest traffic flows appeared in the late morning peak between 9:00 and 11:00am.

During this survey no driver behaviour pattern stands out during the full traffic sequence. There was a relatively even distribution of none/partial/full encroachments. While traffic signals on Strickland Street were red, over 50% of left-turning vehicles did not encroach into the cycle lane. However, while making the turn during the green signal phase, the majority of motor vehicles encroached fully into the cycle lane.

During this survey, the majority of the 61 cyclists used the cycle lane. Cyclists travelling outside the cycle lane were most likely to cycle in the through-lane towards Antigua Street. These cyclists used the space between queuing left and right-turning vehicles, even if the cycle lane was free of encroaching motor vehicles.

Even if cyclists used the cycle lane, they tended to wait close to the pedestrian crosswalk or in front of the ASL to increase the distance (and visibility) to waiting motor vehicles. Cyclists approaching the intersection with no vehicles encroaching the cycle lane tended to stay in the cycle lane when they noticed the separators. However, if motor vehicle encroachments were high, cyclists were forced to stop (especially during the green signal phase) or they would use the footpath.

Approaching motorists tended to base their queuing position on already waiting vehicles. If the first vehicle was waiting outside the cycle lane, the next vehicles were more likely to imitate this behaviour. However, the further back a vehicle was positioned in the queue the more likely it was to encroach fully into the cycle lane while turning, even if it queued outside the cycle lane.

Some motorists changed their position as they noticed the posts; others changed lanes completely after approaching inside the cycle lane as they noticed that Antigua Street was closed for motorised traffic. This demonstrates the effectiveness of the posts.

2nd Post-Implementation Survey:
The second post-implementation survey was undertaken on 25 October 2012, after the flexible posts were installed. During this period, over 800 motor vehicles were observed. The largest traffic flows appeared in the late morning peak between 9:00 and 11:00am.

Following the installation of the posts, the majority of the motor vehicles did not encroach during the complete signal sequence. If vehicles encroached, it happened partly during the red signal phase. The exception was one motor vehicle that used the cycle lane as a turning lane, thereby avoiding queuing behind two vehicles already waiting in the traffic lane. While driving completely into the cycle lane, it also straddled the footpath to avoid the posts.

In general, most of the cyclists stayed inside the cycle lane. Cyclists outside of the cycle lane were most likely to use the through traffic lane towards Antigua Street.

In general, motorists tended to keep a wider distance to the cycle lane than before the implementation of the posts. Particularly during the turning movement, motorists increased the distance to the posts and often adjusted their turning radius, even if they already had a decent distance to the separators while queuing. The distance of a waiting heavy vehicle to the separators was often so large that it encroached partly in the right-turning lane.

As noticed in previous surveys, approaching vehicles based their waiting position on already queued vehicles. When a higher number of vehicles were present, the later vehicles were more likely to approach closely to the separators or to encroach into the cycle lane while waiting. Often, they had to adjust their position quite abruptly when they noticed the posts. These reactions caused two slightly hazardous situations during the observation period. This behaviour was also noted when no other vehicle was present.

In general, the separation devices were accepted well by cyclists. A cyclist even used the posts as a diversion from waiting time by cycling slalom around them! Other cyclists used the space between the posts to get back into the cycle lane. These cyclists might be convinced by the presence of the posts that it is safer to use the cycle lane. However, some cyclists still chose the space outside of the cycle lane.

5.2. Kotare Street

During the post-implementation survey period on 25 September 2012, over 2900 motor vehicles were observed. The highest traffic flows were noticed in the morning and afternoon peaks, when also the most cyclists were present.

The majority of motor vehicles did not encroach into the cycle lane. If encroachment occurred, it happened mostly at the end of Section 1 or the beginning of Section 2. These results underline the effectiveness of the combination of separators and vertical posts. Due to the short distance to the intersection, one flexible post was sufficient to increase the separation between cycle lane and traffic lane. Approaching motor vehicles typically had relatively slow speeds, due to having come from the signalised intersection. Therefore, it was easier for them to adjust their driving radius to the changed situation and stay out of the cycle lane.

During the survey, 87 cyclists were observed. As in the pre-implementation survey, the highest cycle flow occurred in the morning and afternoon peak. Again, the majority of cyclists used the cycle lane for their journey on Kotare Street. Cyclists on the footpath were mostly pupils from the nearby school.

As in the pre-implementation survey, motor vehicles did not encroach into the cycle lane, when cyclists were present. They also tended to keep a large distance to cyclists.

The distance between motor vehicles and separators, when cyclists were not present, varied. Most drivers kept a large distance to the separators, while some approached very close without crossing them.

6. BEFORE/AFTER COMPARISON

The following before/after comparison includes a summary of the evaluation results of the video observations and statistical significance tests. Due to variations in time length of the different observation periods, a common time-frame 8:40am - 3:00pm was chosen to make the results of the different before/after surveys comparable.

6.1. Strickland Street

Comparing the results of the three different surveys (see Figure 7, values shown are percentages; refer to Table 2 for the encroachment group definitions), a reduction in encroachment during the full traffic signal sequence is obvious. While more than half of the motor vehicles encroached completely before the separator implementation, those numbers decreased immensely after the separators were installed. The proportion of encroachment decreased even more after implementing the vertical posts. Due to their position and appearance, the posts made it virtually impossible to encroach into the cycle lane, when vehicles were positioned in the traffic lane.

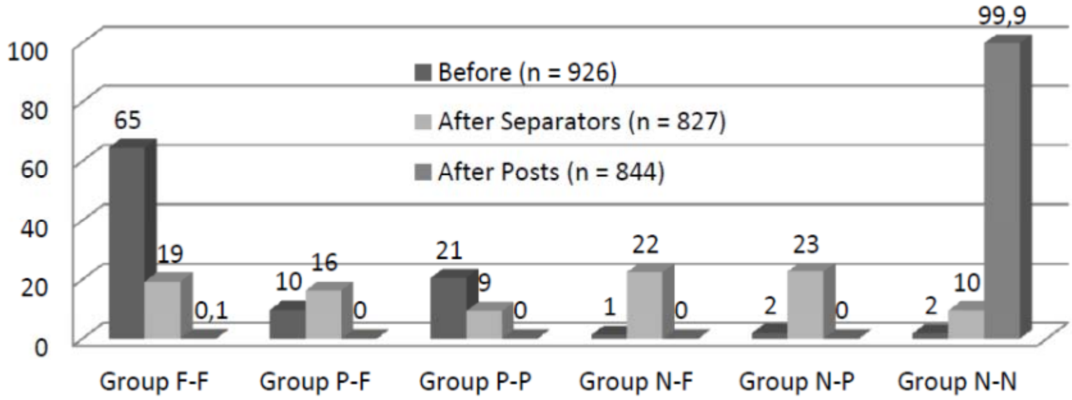

Figure 7: Before/After: driver behaviour during full traffic sequence (Strickland Street)

Regarding the two signal stages separately, the increase of no-encroachment is equally significant. During the red signal phase, driver behaviour changed drastically from nearly 2/3 of the queuing vehicles encroaching completely before the implementation to more than 50% not encroaching vehicles after the implementation of the low-profile separators. After the implementation of the vertical posts, the non-encroachment grew to almost 100%. This comparison shows the influence of the different separator types.

During the green signal phase, the behaviour change was less drastic, but still obvious. Implementation of the low-profile separators saw full encroachment drop from 76% to 58%, with corresponding increases in partial and no encroachments. Once the vertical posts were installed, encroachment into the cycle lane while turning left was virtually impossible, leading to near 100% compliance.

The Chi-Square test (Jones, 2012) was used to analyse the statistical significance of implementing just the low-profile separators on Strickland Street, in terms of partly or fully encroaching vehicles compared to not encroaching vehicles during the complete signal sequence. With one degree of freedom, the Chi-Square test statistic of X^2=51.3 indicates a high statistical significance of the observed behaviour change (p<0.005).

A Chi-Square value of X^2=531.2 for the red signal phase behaviour indicates an even higher statistical significance of separator effectiveness. Nevertheless, the on-site observations during the survey evaluations gave the impression that the practical effectiveness of the separators was not satisfactory enough and the number of motor vehicles encroaching into the cycle lane during the traffic signal sequence is still too high. Therefore, the decision was made to install the flexible posts as well.

After the implementation of the vertical posts, the Chi-Square value of X^2=1185.9 indicates an even stronger statistical significance of the effectiveness of combining the two different separator devices and reinforces the impressions from visual observation.

The adjacent construction works at this site created an unfortunate complication in that there was no need for left and straight traffic to queue in the same lane (there being no straight-through traffic allowed). This may or may not have affected driver propensity to use the cycle lane as an “alternative” left-turn lane, but it did influence cyclist behaviour (many left the cycle lane to go straight ahead). With the construction work now completed, a further follow-up survey is being arranged to assess the current effect of the separators on traffic behaviour.

6.2. Kotare Street

As seen in Figure 8, implementing separators and a flexible post on Kotare Street led to a near-elimination of encroachment. This underlines the effectiveness of the treatment at mid-block area. A minority still encroached into the cycle lane, but was significantly reduced compared to the pre-implementation survey results.

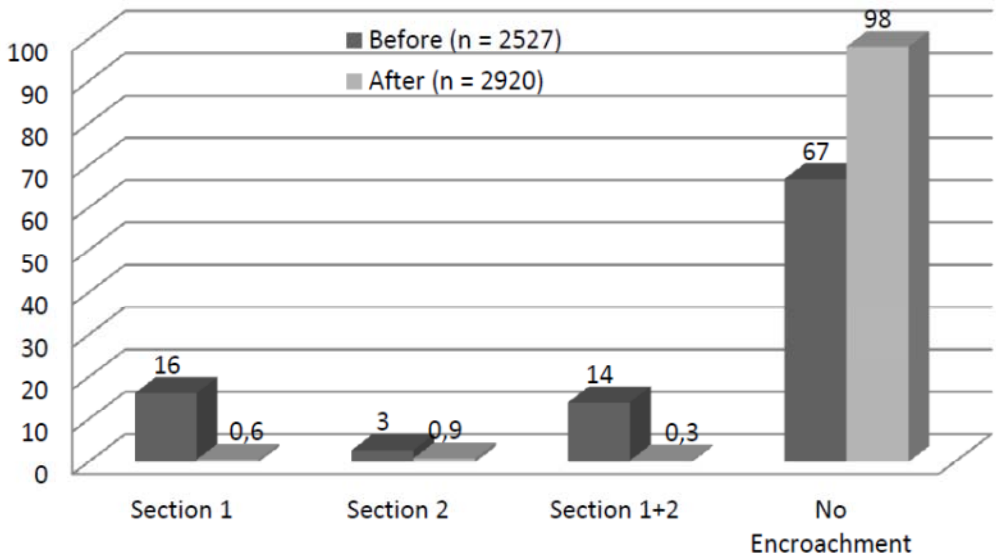

Figure 8: Before/After: driver behaviour change (Kotare Street)

The Chi-Square test was used to analyse the statistical significance of the implementation of cycle lane separators and a flexible post on Kotare Street, in terms of encroaching vehicles compared to not encroaching vehicles. With one degree of freedom, the Chi-Square test statistic of $X^2=974.3$ indicates a high statistical significance of the evaluated behaviour change ($p<0.005$). This result underlines the impression that combining cycle lane separators and flexible posts is effective to prevent motorists encroaching into on-street cycle lanes in mid-block areas.

6.3. Discussion and Study Limitations

Cyclists seemed to be confident to use the cycle facilities on both sites. However, the perceived safety of the cyclists travelling along the routes during the day might differ from the observed impressions. Although not reported here in detail, a separate questionnaire of road user perceptions (210 responses) found strong support for both trials and a desire to see such treatments in other locations (including high traffic volumes sites). A common concern was that the Kotare Street cycle lane now felt slightly too narrow at the apex of the curve.

The low-profile separators are installed directly on the cycle lane line on both sites. Due to their light colour and size of the separators, road users could have difficulty identifying the separators on the lane markings. A colour of higher contrast or a location next to the lane markings could increase the visibility of the separators and, thereby, the awareness of the road users. Also, due to their size, the separators can be crossed by vehicles without many difficulties (although they are deliberately designed like this). Different dimensions could be an effective treatment to increase the effectiveness of cycle lane separators, but this would also increase risk to road users, especially cyclists, when unintentionally hitting them.

Motorists on Strickland Street tended to ignore the low-profile separators and did not noticeably change their behaviour towards cyclists during the second survey. Only the implementation of flexible posts seemed to change their behaviour. However, drivers could now experience a lower perceived safety. Some near- collisions of approaching vehicles with the posts were observed. This could be due to lighting conditions on clear lane or sudden appearance of the posts while vehicles are waiting in a queue with mixed encroachment levels. Wider gaps between the posts and an earlier position of the first post might solve this issue. However, creating gaps too large could encourage motorists again to encroach into the cycle lane between the posts, when they are not aware of following posts.

The survey periods started relatively late and included only parts of the morning peak hour, a time period when both motorists and cyclists are more likely to be present. More data from the morning peak hour could have provided further information on road user behaviour, when a high number of cyclists are present.

The observation of Strickland Street was affected by the closure of Antigua Street. Motor vehicles approaching the intersection via Strickland Street were not able to travel straight ahead from the intersection due to the closure. It is unclear whether this situation would have increased encroachment (due to possibly longer queues) or decreased encroachment (as there was no need to form two separate queues in the shared through and left lane) during the first two video observations.

On Kotare Street, the general encroachment was less than on Strickland Street. Prior to the implementation, motor vehicles did not encroach into the cycle lane, when cyclists were present. After the implementation, the distance between vehicles and cyclists even increased. This leads to the assumption that other treatments such as the combination of low-profile separators and a coloured cycle lane surface could have also been effective here.

7. CONCLUSIONS AND RECOMMENDATIONS

In this paper, the effects of implementing narrow separators on existing cycle lanes on road user behaviour, especially motorists, were assessed.

- On the Strickland Street intersection approach, many encroachments occurred at the observed area during the full traffic signal sequence prior to the separator implementation. The implementation of several Riley separators near the cyclist waiting area led to a decrease in encroachments, especially during the red signal phase. Although the behaviour change was statistically significant, the total number of encroaching vehicles was still rated as too high and, therefore, three flexible vertical posts were installed between the last separators to increase the separation between motor vehicles and cyclists. This treatment virtually eliminated the encroachment of motor vehicles during the green signal phase, although several approaching drivers still entered the cycle lane during the red signal phase before correcting themselves.
- Although not as prevalent as Strickland St, a reasonable proportion of encroachments were observed on the Kotare Street curve before the separator implementation. The implementation of several Riley separators shifted motor vehicles slightly out of the cycle lane, but there were concerns about their conspicuity and effect on road user behaviour. Therefore, the separation of cyclists and motor vehicles was increased by the installation of a single flexible vertical post between the first two separators. The combination of Riley separators and the post had a very strong effect on road user behaviour and minimised encroachments along the observed road section immensely.

In conclusion, implementing low-profile separators on existing roads has effects on road user behaviour. In the separated area, motor vehicles encroach less into the cycle lane. However, the encroachment reduction is only slight, and could perhaps increase again due to drivers becoming accustomed to crossing the relatively low separators. Therefore, the combination of low-profile separators and vertical posts is a relatively inexpensive way (especially compared with kerb reconstruction) to increase the effectiveness of cycle lane separation.
The vertical posts strongly prevent motor vehicles from encroaching into the cycle lane. The observations on Kotare Street indicate that a single post, in combination with low Riley separators, has a positive effect on the behaviour of motorists. On Strickland Street, implementing multiple flexible posts close to the intersection was necessary to influence motor vehicle behaviour. Too few posts or posts implemented too far from the intersection might be ignored or forgotten by queuing and turning vehicles. The combination of Riley or other low separators and vertical posts is also useful in areas similar to Strickland Street or Kotare Street. From the user surveys (the results are not reported here), most cyclists appreciated the perceived safety provided by the separators, but by themselves, they would not be sufficient to prevent motor vehicle encroachment. The results indicate that the separators combined with posts might be a suitable tool of making cycling more attractive.

7.1. Recommendations

Based on the results and observation from this research the following recommendations for future investigations are made:

- This research was based on daytime observations in good weather conditions. To assess the visibility and application of both types of separators under different, less optimal conditions, further observation should be undertaken at night or in rain. Hence, the possible safety hazard for motorists and cyclists can be revealed.
- The Riley separators used for this research were relatively small. Motor vehicles could cross them easily and, therefore, seem to ignore them, when no posts are installed. This behaviour was noted especially on Strickland Street. Trials could assess the optimal height and width for separators similar to the ones used in this research to prevent motor vehicles to cross without being hazardous for cyclists. The studies could be done by comparing the Riley separators with low-profile separators from other producers such as the rubber lane markings used in Auckland (ViaStrada, 2012).
- On both sites, the Riley separators were installed directly on the cycle lane markings. In combination with the light colour of the separators, this could cause visibility issues. Future research could analyse if positioning separators next to lane markings has an effect on the awareness and acceptance by road users due to increased visibility.
- Currently, the distance between the posts on Strickland Street is relatively short and might seem restrictive to cyclists inside the cycle lane. Further studies could assess possible effects of wider distances between posts on road user behaviour.
- Building on earlier research by Mangundu (2009), further investigation into the effects of the combination of low separators and coloured cycle lane surfaces would be useful.
- The observation period started relatively late, so that only a small part of the morning peak hour was captured. However, the morning peak hour is important to get an overview of commuter traffic, including cyclists. Therefore, further observations should be started from 7:30am to get significant data for this important time-frame.

To increase separation between cyclists and motor vehicles on street sections similar to the ones observed in this project, several recommended practices are listed below:

- At signal controlled intersections, kerb-side Advanced Stop Lines should be equipped with a certain number of vertical posts to get a significant improvement in cyclist safety.
- Separators should be installed with the highest degree of visibility for all road users to help highlight their presence.
- For separation on the inside of curves, at least one vertical post should be installed at the start of a series of low-profile separators on the inside of curves to help highlight their presence to motorists and cyclists.
- If they are of relatively light colour, low-profile separators should be trialled slightly next to or only partly on the cycle lane line to increase the awareness of road users.
- Cycle lanes should be of adequate width (possibly wider than normal) before physical separators are installed.

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