Effects on Motor Vehicle Behavior of Color and Width of Bicycle Facilities at Signalized Intersections

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ABSTRACT

Research was undertaken in Christchurch, New Zealand to investigate motor vehicle behavior near bicycle facilities at signalized intersections. Motorists not keeping clear of such facilities may limit their usefulness and safety for bicyclists. The main research objective was to assess motorists' avoidance of colored facilities in comparison to uncolored ones. The research also investigated if wide combined bicycle and traffic lanes encourage drivers to queue side-by-side, thereby encroaching into bicyclist spaces.

18 sites were identified to evaluate the effect of colored surfacing and lane widths on the rate at which motorists encroach on marked bicycle spaces. The sites contained either Advanced Stop Lines (ASL) or Advanced Stop Boxes (ASB) and were a mix of colored and uncolored facilities with "narrow" and "wide" lane combinations. Manual surveys were carried out to observe the positions of motor vehicles in relation to the bicycle facilities. Four of the uncolored sites were then colored and "after" surveys conducted.

The results showed that drivers were much less likely to encroach on colored bicycle spaces in comparison to uncolored ones, particularly ASLs. Motorists were also more likely to encroach on bicycle lanes in "wide" lane combinations.

It is recommended that road agencies continue coloring new and existing bicycle facilities at intersections, with preference given to existing ASLs over ASBs and sites with wider approaches. Traffic and bicycle lane combinations greater than 5.0 m (16½ ft) should also be avoided if separate turning traffic lanes are not present.

INTRODUCTION

Cycling is an inexpensive, healthy and sustainable mode of transport, but there is still only a small proportion of people willing to bike despite these benefits. Safety concerns in the face of high traffic volumes and speeds and potential conflicts at busy intersections are some of the common reasons given for not bicycling (*1*). In New Zealand (NZ), more than 50% of bicyclist crashes in urban areas occur at intersections (*2*).

Since intersections present the greatest challenges to bicyclists, a lot of work has been done to help define positions for bicycles and motor vehicles in an effort to improve road safety. Provision of bicycle lanes with advance storage spaces has been a way of providing queuing space for bicyclists at complex signalized intersections and improving their visibility to drivers. However, although bicyclists appear to make good use of them, evidence suggests that drivers are not always keeping clear of these bicycle facilities (*3*), this limiting their usefulness and safety.

Christchurch city has the most extensive bicycle network in NZ, comprising many on-road bike lanes, off-road bicycle paths and specific intersection facilities. Red colored surfacing has been gradually applied on busy routes with high numbers of bicyclists or at "pinch-points" or areas of potential conflict.

The benefits of using highly visible colored surfacing on bicycle spaces are:

- Designation of separate road space for motor vehicles and bicycles promotes consistent behavior by all users
- The bright coloring serves to remind drivers about the presence of bicyclists
- Cyclists' actual and perceived safety is increased

Research was undertaken in Christchurch to investigate road user behavior near bicycle facilities at signalized intersections (*4*). The main objectives of the research were:

1. An assessment of bicyclists and drivers' compliance with colored bicycle facilities in comparison to uncolored ones.
2. To assess the effect of combined bicycle and traffic lane width on vehicle positioning with respect to bicycle areas. The research investigated if wide traffic lanes encourage drivers to queue side-by-side, thereby encroaching into bicyclist spaces.
3. To determine the relevance of the research outcomes for bicycling design standards.

The research focused specifically on two types of intersection bicycle facility:

- Advanced Stop Lines (ASL), whereby the bicycle lane is extended slightly in front of the traffic lane limit lines (see Figure 1), to improve bicyclist visibility particularly for turning motorists.
- Advanced Stop Boxes (ASB), whereby an area is located directly in front of the traffic lane (see Figure 2), to provide more queuing space and assist with right-turning.

Note that in NZ, vehicles drive or ride on the **left-hand** side of the road.

FIGURE 1 Typical Advanced Stop Line (ASL) in Christchurch, NZ

FIGURE 2 Typical Advanced Stop Box (ASB) in Christchurch, NZ

BACKGROUND

The Australasian road standards authority Austroads (*5*) suggests that where a wide approach can be provided it is desirable to provide “approach and stand-up lanes” for bicyclists to allow them space to proceed to the front of motor vehicles and to give them queuing space. Bicycles’ storage space at intersections can be provided in the form of ASLs and ASBs.

Austroads further suggests the use of color at intersections where provisions for bicyclists exist but safety problems still continue.

In NZ, Transit NZ (*6*) generally recommends the use of green colored surfacing in line with Australian practice; however historically Christchurch has used red surfacing (pre-dating national standards), and this practice has continued. Bicycle markings and layouts at intersections in NZ are guided by Transit NZ (*7*).

Advanced Stop Lines

These can be marked either to the curbside or between traffic lanes, and project forward of the traffic lane limit lines up to the pedestrian crossing lines. ASLs marked to the curbside will be investigated in this research, as shown in Figure 3. Motor vehicles are expected to remain in their traffic lane when stopped or driving and also to give way to straight through bicyclists when making a left turn.

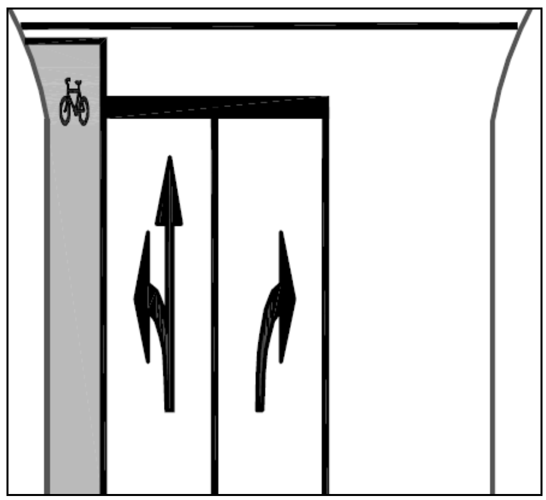

FIGURE 3 Typical NZ Curbside ASL Configuration (*7*)

Stopped motor vehicles at intersections will sometimes wait in the bicycle lane, blocking bicyclists' way to the ASL and reducing their visibility from motor vehicles. This results in bicyclists having to wait or weave their way through queued vehicles, inconveniencing them. Left-turning traffic going through the green signal might do so cutting off straight-through bicyclists or driving on the bicycle areas. For these reasons, many design guides recommend having a separate turning traffic lane to the curbside of the ASL (e.g. *8*, *9*). ASLs are not intended to help right-turning bicyclists.

Advanced Stop Boxes

Figure 4 shows the detailed layout of the type of ASB to be investigated (another ASB in front of the right-turning lane is also shown). Sometimes in constrained situations ASBs do not have a bicycle lane leading to them and cyclists must use the general traffic lanes. Motor vehicles are expected to stop behind the storage box during the red signal phase and not to drive on the adjacent bicycle lane during the green phase.

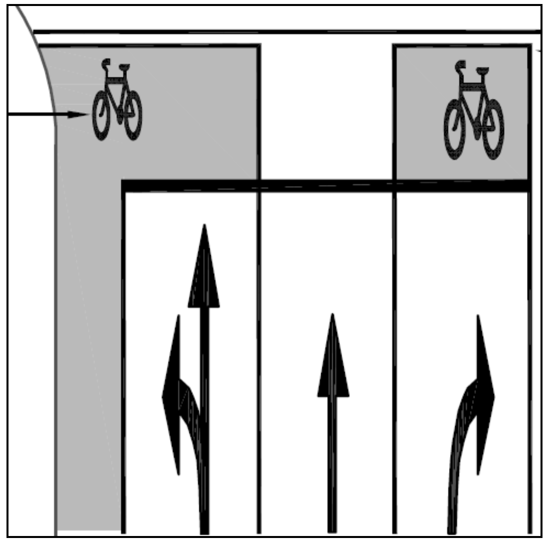

FIGURE 4 Typical NZ Curbside ASB Configuration (*5*)

Straight through and left turning bicyclists wait in the box in front of straight-through and left-turning motor vehicles. The advance box can also assist right-turning bicyclists but they can only use the space to position themselves to the right during the red phase. Some ASBs in Christchurch provide separate left-turn lanes immediately to the left that, like ASLs, provide better safety for bicyclists.

Advance boxes can be used only when the traffic signals are red; once the traffic is moving the advance box affords no protection. Cyclists are inconvenienced when vehicles block their way to the ASB or wait in the box. VicRoads (*10*) suggests that where more than three bicyclists stop during a red phase, then an ASB may be appropriate.

USE OF COLORED PAVEMENTS FOR ON-ROAD BICYCLE FACILITIES.

Different colored surface treatments have been in use around the world. In the UK, IHT *et al* (*11*) acknowledges that distinguishing areas of carriageway by surface color is a useful technique, with red traditionally used to indicate bicycle lanes or tracks although green has been used. IHT also indicates that coloring of bicycle lanes and waiting areas at intersections helps to keep motorists out. Sustrans (*12*) recommends that, on the approaches to and within junctions and crossings, the surface of the bicycle track or lane be provided with a color contrast treatment as a warning to bicyclists of the potential hazard, and to discourage motorists from encroaching into the bicycle facility.

Blue bicycle lanes are used in some parts of North America and Denmark. In the Netherlands, CROW (*13*) recommends that bicycle lanes and ASBs be colored in red.

ASLs and ASBs are also in use in Australia and referred to as “advanced waiting space” and “expanded waiting space” respectively. VicRoads recommends the use of green surface treatments on bicycle lanes and storage boxes to increase driver and bicyclist awareness of a bicycle lane and to discourage drivers from encroaching on them (*14*). In New South Wales, RTA (*8*) has also adopted green as the color for special bicycle facilities such as “inside head start” (ASL), right-turn and hook-turn storage boxes at busy intersections. According to RTA, other facilities that could be colored are contra-flow lanes, bicycle lanes at road narrowings and bicycle bypasses at bus stops.

Past research on the use of ASLs, ASBs and colored surfacing

A study was carried out by Christchurch City Council to assess the effects of ASLs and ASBs on vehicles and bicyclists behavior on intersections (*3*). Sites with and without the facilities were compared. This research was conducted as a before-and-after study following installation of ASLs and ASBs. Video recording was used to study the behavior of both drivers and bicyclists in each case. Results showed that the majority of users used the marked facilities correctly, but some vehicle drivers stopped whilst intruding into the ASBs or partially obscured a curbside ASL. Based on these results it was concluded that ASLs and ASBs are only partially successful in allocating correct space positions. Two recommendations were: further research into the effects of colored surfaces and combined lane widths on behaviour patterns.

VicRoads also investigated the behavior of road users before and after installation of ASBs in Melbourne (*15*). Results showed an overall improvement in bicyclist positioning behavior. However 67% of stopping motorists encroached into the ASBs. It is believed that the reason for the encroachments was due to the advance boxes being located behind the original stop line. Better behavior could have been achieved if the boxes had been in place in advance of the motor vehicle stop lines, as is the current set-up. No colored surfacing was considered here, but another study conducted in Melbourne found that the use of red color increased driver awareness of bicyclists and increased the bicyclists’ perception of safety (*16*).

Rye *et al* (*17*) investigated the effects of coloured surfacing on bicycle and bus lane compliance by motorists in Edinburgh, Scotland. They found that coloured surfacing markedly improved the moving vehicle compliance with bicycle lanes, although the results were not statistically significant.

Hunter *et al* (*18*) studied road user behavior before and after coloring blue bicycle lanes in Portland, USA. They found that, after coloring, significantly fewer bicyclists looked out for turning vehicles or used hand signals. Motorists were found to have slowed down on approaches but fewer drivers were observed using their turning indicators than in the before period. The overall behavior of all users improved, in terms of improved perceived safety by bicyclists and reduced conflicts between motor vehicles and bicycles.

A 1997 study carried out in Denmark found that use of (blue) color on bicycle lanes at intersections was associated with a 38% decrease in bicycle crashes and a 71% decrease in serious injuries and fatalities (*19*). Similar crash improvements were found in a more recent Danish study (*20*).

From past studies it can be concluded that the use of color has a positive impact on all road users’ behavior. However, the specific effect of colored surfacing as part of ASL or ASB installations does not appear to have been addressed. There also appears to be very little research with respect to appropriate combinations of bicycle and traffic lane widths at intersections.

METHODOLOGY

Initially a total of 18 observation sites were identified and subdivided as follows;

1. 6 sites with ASLs but no colored surfacing
2. 3 sites with ASLs and colored surfacing
3. 6 sites with ASBs but no colored surfacing
4. 3 sites with ASBs and colored surfacing

A mixture of sites of varying bicycle and traffic lane width combinations were considered in the selection process. Manual observations (using the same observer with a clipboard) were carried out on all the 18 sites between December 2008 and February 2009, during weekdays with fine weather. Depending on the peak hour directional flow, the surveys were undertaken either between 7-9am or 4-6pm (one per site). The number of motor vehicles and bicycles passing through the section being surveyed was recorded, as well as their respective positions. Three different positions of motorists were defined:

1. Outside marked bicycle facilities (i.e. complying)
2. Partially encroaching into bicycle facilities
3. Full encroachment into bicycle facilities

A "partial encroachment" is a situation where a small (but practically noticeable) part of a motor vehicle is on the marked bicycle space such that a bicyclist will still be able to use the remaining space (Figure 5). Too many partial encroachments could result in some bicyclists resorting to using pedestrian facilities due to the reduced distance between the motor vehicles and the bicycles.

FIGURE 5 Example of Partial Encroachments (laterally and longitudinally) on ASB

"Full encroachment" is where a motor vehicle stops or drives whilst covering the whole bicycle space and a bicyclist has to find an alternative route or waiting position (Figure 6). Too many full encroachments on a site with an ASL mean that the queuing space is not accessible to approaching bicycles. Similarly, a full encroachment on the bicycle lane side of the ASB is more hazardous than those on the advance box.

FIGURE 6 Examples of Full Encroachment on ASLs and ASBs

All levels of encroachment will result in potential bicyclist-motorists conflicts, with more serious ones resulting from full encroachments. The proportions of vehicles encroaching were determined from the traffic counts of relevant movements for that peak hour period. The behavior of bicyclists was also observed to assess if bicycle facilities were being used correctly.

Observation of encroaching vehicles were carried out during red and green signal phases separately to investigate if the problem is more associated with stopping motor vehicles during the red phase or motorists driving on bicycle facilities during the green signal. This is also important to assess how well bicyclists can safely use the ASBs or ASLs. High numbers of motorists driving on bicycle lanes may result in serious bicyclist conflicts compared to sites where motorists only stop in bicycle lanes.

Because of site-specific characteristics that could affect the encroachment rates at individual sites, discussions were held with Christchurch City Council about introducing colored surfacing to some previously uncolored sites. This would enable “before and after” testing of the same locations to be analyzed. Six sites (three ASLs and three ASBs) were selected for conversion; unfortunately, only four sites were upgraded before the study was completed. “After” surveys at the sites were then undertaken between January and February 2009. Including the repeated locations, a total of 22 “sites” were therefore surveyed for analysis.

Site Selection

All sites were located in Christchurch city at signalized intersections with a speed limit of 50km/h. Initially major bicycle routes were identified from Christchurch City Council maps and sites with a high level of bicyclist and motorist interaction were selected. A range of sites was chosen with varying traffic lane widths to investigate the effects of the wide and narrow lanes on motorist behavior.

Table 1 lists the survey sites; unless noted otherwise, each site had a curbside bicycle lane, a combined straight-left traffic lane, and a right-turn lane. The bicycle lane was generally 1.2-1.5 m (4-5 ft) wide from the curb.

TABLE 1 Survey Site Details

Site Type	ID	Location & Approach	Traffic Lane Width	Site Comments (cross-roads unless stated)
Colored ASL (LC)	L1	Straven/Kilmarnock/Kahui North approach	3.5 m (11½ ft)	
	L2	Riccarton/Straven North approach	3.0 m (10 ft)	Two straight-through lanes (one combined with left turn) available with high traffic volumes.
	L3	Hagley Ave/St Asaph North approach	3.8 m (12½ ft)	T-intersection with a painted (flush) median. No congestion observed.
Uncolored ASL (LU)	L4*	Barrington/Milton South approach	4.4 m (14½ ft)	ASL has a service cover at an incorrect level, sometimes avoided by bicyclists.
	L5*	Barrington/Milton East approach	3.5 m (11½ ft)	Low motor vehicle and bicycle numbers in the morning
	L6	Kilmanock/Straven West approach	4.7 m (15½ ft)	Busy intersection with high bicycle numbers.
	L7	Moorhouse/Antigua South approach	3.0 m (10 ft)	Long queues and high bicycle numbers observed during the morning peak period.
	L8	Brougham/Antigua South approach	4.4 m (14½ ft)	"Hook-turn" facility in front of the ASL
	L9	Waimairi/Maidstone East approach	3.5 m (11½ ft)	Slight left-hand roadway curvature on approach
Colored ASB (BC)	B1	Clyde/Creyke/Kotare South approach	4.0 m (13 ft)	
	B2	Memorial/Roydvale South approach	3.5 m (11½ ft)	No bicycle lane marked, only colored ASB on the front of the shared traffic lane.
	B3	Moorhouse/Deans North approach	3.3 m (11 ft)	Left-turn slip lane and two right-turn lanes (one combined with straight) for dominant movement
Uncolored ASB (BU)	B4*	Clyde/Creyke/Kotare East approach	3.5 m (11½ ft)	Low bicycle numbers during first survey period - carried out during the school/university holiday.
	B5*	Creyke/Ilam West approach	4.7 m (15½ ft)	Slight left-hand roadway curvature on approach resulting in high number of vehicle encroachments.
	B6	Milton/Strickland South approach	3.0 m (10 ft)	Long queues observed and route caters for commuter and school bicyclists.
	B7	Milton/Strickland West approach	4.3 m (14 ft)	High motor vehicle and bicycle numbers with high levels of turning vehicles encroachment.
	B8	Milton/Strickland North approach	4.5 m (15 ft)	Survey carried out during evening peak period.
	B9	Creyke/Ilam South approach	4.7 m (15½ ft)	Survey carried out during evening peak period.

* denotes sites that subsequently had a colored surface installed ("after" sites have an "A" suffix in Table 5)

Problems were encountered in finding similar suitable sites with colored ASBs, resulting in slightly different layouts at the three sites observed and some sites with low bicycle numbers. Site layouts for the other three site types are more consistent, with bicycle lanes leading to the waiting space at all the intersections.

Limitations of Research Method

Due to time constraints (following delays by the marking contractors), the "after" surveys for the four upgraded sites were carried out only two weeks after color installation, possibly before any "novelty effect" wore off. Some of the surveys were also conducted during school and university holidays, resulting in reduced numbers of bicyclists and possibly more drivers entering the bicycle lanes.

Simlarly, additional surveys at each site to compare encroachment rates against traffic volumes would have been useful but were not possible with the available student resources.

While motorist behavior (in terms of encroachments) was captured quantitatively, the behavior of bicyclists at all sites was only noted informally during surveys. Use of extra resources or video surveillance could have improved the intended research outcomes.

An initial classification of encroachments as coming from either turning or straight-through motorists did not work well with ASB sites where some left-turning vehicles could wait in the advance box and not on the bicycle lane. Splitting of ASB encroachments into all the relevant encroachment positions could have improved the accuracy of the results.

RESULTS

The objective of the data analysis was to assess the differences in the level of compliance for three characteristics:

1. all colored and uncolored sites;
2. before and after color surface treatment; and
3. "narrow" and "wide" traffic lanes.

The analysis included statistical testing using Chi-square tests to see if the differences in the level of compliance were significant, i.e. a very small probability that the difference was due to chance.

After analyzing the raw data, it was decided to sum partial and full encroachments to come up with an overall effect on motorist positioning behavior. Generally, partial encroachments outnumbered full encroachments by about 2:1, but no particular pattern between them was discernible when analyzing the data by different categories. It was decided that either form of encroachment represented a potential problem for bicyclists. Even though cyclists could still use a partially encroached space, some might choose not to use it, depending on their level of cycling experience and confidence. The situation was further complicated at ASBs, where a motorist could encroach in one direction (e.g. into the advance box) but perhaps not in the other direction (e.g. laterally into the bicycle lane).

Encroachment Rates for All Colored and Uncolored Sites

Table 2 summarizes the number of encroachments at all sites, grouped by bicycle facility (ASL/ASB) and treatment (colored/uncolored).

TABLE 2 Motor Vehicle Encroachments on All Colored vs Uncolored Sites

Treatment		All ASL sites	All ASB sites
Uncolored	Number of sites observed	6	6
	Total number of turning motor vehicles	613	644
	Number of motor vehicles in bike lane/box	125	244
	Percentage encroaching in bike lane/box	**20.4%**	**37.9%**
Colored	Number of sites observed	5	5
	Total number of turning motor vehicles	577	535
	Number of motor vehicles in bike lane/box	77	152
	Percentage encroaching in bike lane/box	**13.4%**	**28.4%**
χ^2-test	p-value	0.0000	0.0000

From the above results, overall driver behavior improves at colored sites with highly significant differences in the rates at which they encroach on the bicycle spaces. These results show the benefits of color on bicycle facilities at intersections.

Before-and-After Color Treatment Results

The uncolored ASL sites L4 and L5 were surveyed, colored and re-surveyed. Table 3 shows the differences in the proportion of encroachments before and after color treatment. Only the proportions of (left) turning vehicles encroaching were considered in this analysis, as this is the only movement where motorists generally enter the bicycle lane.

TABLE 3 Before-and-After Color Treatment Survey Data for ASL Sites

		Site L4	Site L5
Before	Total number of turning motor vehicles	30	99
	Number of motor vehicles in bike lane	22	30
	Percentage encroaching in bike lane	**73.3%**	**30.3%**
After	Total number of turning motor vehicles	24	153
	Number of motor vehicles in bike lane	9	8
	Percentage encroaching in bike lane	**37.5%**	**5.2%**
χ^2-test	p-value	0.0008	0.0000

The rate of encroachment decreases significantly after coloring; this implies that drivers were more aware of the colored bicycle spaces after marking.

Encroachments associated with the ASB sites are either from left-turning or first-queued motorists waiting in the advance box or bicycle lane. Table 4 shows the proportions of turning vehicles in the bicycle lane or advance box and first-queued vehicles stopped in the advance box.

TABLE 4 Before-and-After Color Treatment Survey Data for ASB Sites

		Site B4	Site B5
Before	Total number of turning motor vehicles	33	22
	Number of motor vehicles in bike lane/box	4	22
	Percentage encroaching in bike lane/box	**12.1%**	**100.0%**
After	Total number of turning motor vehicles	146	67
	Number of motor vehicles in bike lane/box	28	37
	Percentage encroaching in bike lane/box	**19.2%**	**55.0%**
χ^2-test	p-value	0.1341	0.0000
Before	Total no. of motor vehicles at front of queue	77	77
	Number of motor vehicles in bike box	29	18
	Percentage encroaching in bike box	**37.7%**	**23.3%**
After	Total no. of motor vehicles at front of queue	153	125
	Number of motor vehicles in bike box	50	26
	Percentage encroaching in bike box	**32.7%**	**20.8%**
χ^2-test	p-value	0.0701	0.6665

After coloring, site B5 produced a significant reduction in encroachments by turning vehicles, in contrast to B4 where the encroachments actually increased (but not significantly). This increase could have been due to more congestion during the after survey as it was carried out during the school and university terms as opposed to the before coloring survey.

In terms of first-queued vehicles, there were small (but not significant) reductions in encroachments after coloring, implying that the advance boxes were slightly more accessible to bicyclists.

From the traffic counts it is evident that the two ASB sites were more congested during the "after" surveys, and a combination of more frequent stops and impatient drivers might have affected the compliance rate.

Given the limited sample of traffic volume combinations and sites, these findings should be considered exploratory and further surveys would be useful.

Analysis of Encroachment Rates by Traffic Lane Width

The percentage of turning vehicles encroaching on marked bicycle areas was analyzed in comparison with the available lane width. This is based on the hypothesis that straight-through motorists will not enter bicycle lanes and that wide traffic lanes may encourage left-turning and straight-through motorists to queue side-by-side.

Table 5 summarizes the survey data and lane width measurements for all the sites (sorted in order of combined width). All sites with combined traffic and bicycle lane width of 5.0 m (16½ ft) and below were classified as "narrow" and those above that were "wide" (the dashed lines indicate the demarcation). Note that most cars in NZ are typically of Japanese or Australian origin, with a width of about 1.8 m (6 ft).

Although there is some variation between individual sites, general trends of decreasing compliance as widths increase can be seen. Some anomalies could be explained by site characteristics; for example, site L3 (5.3m wide) exhibits somewhat better-than-expected behavior, which may be due to the painted (flush) median that was sometimes used by straight-through motor vehicles instead of the bicycle lane.

TABLE 5 Survey Sites and Lane Width Data

	Site	Traffic lane width	Cycle lane width	Combined width	Total turning traffic	Number of encroachm'ts	Percentage encroaching
Uncolored ASL (LU)	L7	3.0 m	1.3 m	**4.3 m**	106	2	**1.9%**
	L9	3.5 m	1.2 m	**4.7 m**	207	25	**12.1%**
	L5	3.5 m	1.2 m	**4.7 m**	99	30	**30.3%**
	L8	4.4 m	1.2 m	**5.6 m**	157	38	**24.2%**
	L4	4.4 m	1.3 m	**5.7 m**	30	22	**73.3%**
	L6	4.7 m	1.2 m	**5.9 m**	14	8	**57.1%**
Colored ASL (LC)	L2	3.0 m	1.5 m	**4.5 m**	204	2	**1.0%**
	L5A	3.5 m	1.2 m	**4.7 m**	153	8	**5.2%**
	L1	3.5 m	1.5 m	**5.0 m**	126	42	**33.3%**
	L3	3.8 m	1.5 m	**5.3 m**	70	12	**17.1%**
	L4A	4.4 m	1.3 m	**5.7 m**	24	13	**54.2%**
Uncolored ASB (BU)	B6	2.8 m	1.5 m	**4.3 m**	66	16	**24.2%**
	B4	3.5 m	1.3 m	**4.8 m**	33	4	**12.1%**
	B7	4.3 m	1.2 m	**5.5 m**	254	107	**42.1%**
	B8	4.5 m	1.3 m	**5.8 m**	77	29	**37.7%**
	B9	4.7 m	1.2 m	**5.9 m**	192	66	**34.4%**
	B5	4.7 m	1.5 m	**6.2 m**	22	22	**100.0%**
Colored ASB (BC)	B2	3.5 m	-	**3.5 m**	133	28	**21.1%**
	B4A	3.5 m	1.3 m	**4.8 m**	146	28	**19.2%**
	B1	4.0 m	1.2 m	**5.2 m**	54	46	**85.2%**
	B3	4.0 m	1.5 m	**5.5 m**	135	13	**9.6%**
	B5A	4.7 m	1.5 m	**6.2 m**	67	37	**55.2%**

The colored ASB sites probably exhibit the most variation and, because of the relative inconsistency between site characteristics, it may not be valid to draw as many conclusions from this group.

The data in Table 5 suggests that combined lane widths of a maximum of 5.0 m should be adopted, because wider roadways result in high encroachment rates typically ranging from 35% to 100%. This implies that, where there is insufficient space for an exclusive left-turn lane, the ideal traffic lane width should be no more than 3.5 m (11½ ft) wide if adjacent to a standard 1.5 m (5 ft) bicycle lane. Where high bicycle activity is evident, it may be best to allocate any excess space to the bicycle lane, as motorists may tend to queue side-by-side more when the actual traffic lane is too wide. Alternatively, extra width in any right-turn lane (or even a right-turn bicycle lane) may be a prudent idea.

The four different facility groups were compared separately using Chi-square analysis to see if the difference in encroachment rates between sites with narrow and wide lanes was significant. Table 6 summarizes the results.

TABLE 6 Motor Vehicle Encroachments on All Narrow vs Wide Lane Layouts

		Uncolored ASL (LU)	Colored ASL (LC)	Uncolored ASB (BU)	Colored ASB (BC)
Narrow Traffic lanes (≤5.0 m)	Total number of turning motor vehicles	294	483	99	279
	Number of motor vehicles in bike lane	57	52	20	56
	Percentage encroaching in bike lane	**19.4%**	**10.8%**	**20.2%**	**20.1%**
Wide Traffic lanes (>5.0 m)	Total number of turning motor vehicles	201	94	545	256
	Number of motor vehicles in bike lane	68	25	224	96
	Percentage encroaching in bike lane	**33.8**	**26.6%**	**41.1%**	**37.5%**
χ^2-test	p-value	0.0000	0.0000	0.0000	0.0000

Overall there is a highly statistically significant difference between motor vehicle encroachments at narrow and wide lanes. The effect seems relatively consistent, with an increase of about 15-20% in encroachments at wider sites. Hence, it appears that wider roadways at intersections do not necessarily assist in improving bicyclists' riding experience. So long as an adequate minimum bicycling width is provided, narrower sites appears to be safer due to reduced conflicts from motor vehicles, which are more likely to maintain their correct lane positions.

CONCLUSION

A comparative analysis of the effects of color and lane width on motor vehicle traffic positioning behavior with respect to marked bicycle facilities at signalized intersections was undertaken. A total of 22 sites of varying characteristics were surveyed and the variety of sites made it possible for some patterns to be deduced.

The overall conclusion of this research is that colored surfacing combined with narrower traffic lanes should be used to improve riding conditions for bicyclists as they result in positive outcomes on the desired behavior from motorists. Colored surfacing in particular appears to be a way of highlighting both motorists' and bicyclists' awareness of conflict areas, thereby creating safer intersection maneuvers. Coloring of ASLs appears to be more effective in achieving intended driver behavior in comparison to ASBs.

Narrower lane combinations were found to discourage motor vehicles to queue side-by-side, blocking the bicycle lane, both at sites with ASL or ASB. Narrower traffic lanes may also result in a reduction in traffic speeds, creating additional bicycle safety benefits. Traffic lane widths could be narrowed by allocating additional space to the bicycle lane or even creating an additional lane for right-turning bicycles.

It is acknowledged that there could be other unmeasured confounding factors (e.g. site-specific characteristics, traffic volumes) accounting for some of the results in this study. However, despite the limitations of the methodology, some consistent patterns have been produced, especially for ASL sites, supporting the fact that encroachment rates decrease with the use of colored surfacing and narrower lane combinations.

Recommendations

Based on the results from this research the following recommendations are made:

- Given that this research has demonstrated that colored surfacing is a positive step in achieving intended driver behaviour at signalized intersections and thus reducing the potential for conflicts, road agencies should continue coloring new and existing bicycle facilities.
- When coloring existing bicycle facilities, all other things being equal, preference should be given to coloring ASL sites before ASB sites.
- When coloring existing bicycle facilities, all other things being equal, preference should be given to coloring at sites with wider aproaches, given the likely encroachment problems already at these sites.
- At intersections, traffic and bicycle lane combinations greater than 5.0 m should be avoided, to discourage motorists queuing side-by-side and blocking progress for bicyclists.
- Further surveys of the before-and-after sites (with suitable control sites) would be useful to assess any possible "novelty effect".
- Further investigation into the effects of motor vehicle and bicycle volumes on encroachment rates would be useful.
- It was not clear from this research what the effectiveness of ASBs for right-turn bicycle movements is. Further studies should be carried out to investigate this issue.

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