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Evaluation of Blue Bike-Lane Treatment in Portland, Oregon

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Many European cities use colored markings at bicycle–motor vehicle crossings to reduce conflicts. To determine whether such colored markings help improve safety at American bicycle–motor vehicle crossings, the city of Portland, Oregon, studied the use of blue pavement markings and a novel signage system to delineate selected conflict areas. The University of North Carolina Highway Safety Research Center (HSRC), under contract to FHWA, analyzed the project data. From 1997 to 1999, Portland marked 10 conflict areas with paint, blue thermoplastic, and an accompanying "Yield to Cyclist" sign. All of the sites had a high level of cyclist and motorist interaction, as well as a history of complaints. The crossings were all at locations where the cyclist travels straight and the motorist crosses the bicycle lane in order to exit a roadway (such as an off-ramp situation), enter a right-turn lane, or merge onto a street from a ramp. The study used videotape analysis and found most behavior changes to be positive. Significantly higher numbers of motorists yielded to cyclists and slowed or stopped before entering the blue pavement areas, and more cyclists followed the colored bike-lane path. However, the blue pavement also resulted in fewer cyclists turning their heads to scan for traffic or using hand signals, perhaps signifying an increased comfort level. The overwhelming majority of cyclists and close to a majority of motorists surveyed felt the blue areas enhanced safety. Colored pavement and signage should continue to be used and evaluated in bicycle–motor vehicle conflict areas.

In the last few years a variety of innovative on-street bicycle treatments have been implemented. These include bike boxes; raised bicycle lanes; bicycle boulevards; use of paint to delineate paths through intersections, define bicycle–motor vehicle weaving areas, and highlight paved shoulders; and others. This report focuses on colored (blue) pavement and accompanying signage used in Portland, Oregon, in weaving areas at or near intersections. The objective of this study was to determine whether the signage and blue paint highlighting these areas changed the behavior of the motorists and bicyclists and reduced the conflicts between the two modes.

Intersections and intersection-related locations account for 50 to 70 percent of bicycle–motor vehicle crashes (*1*). A countermeasure with the potential for reduction of conflicts and crashes at or near intersections, colored pavement (either painted or dyed) has been shown to be effective in other countries. At five intersections in Montreal, colored bicycle crossings were installed (Figure 1), with the pavement painted blue at bicycle path crossing points. After the markings were painted, bicyclists were more likely to obey stop signs and to stay on designated cycle path crossings. Improved bicyclist behavior led to a decline in the level of conflict between cyclists and motorists (*2*). In Denmark, the marking of bicycle travel paths (raised overpasses) at signalized junctions resulted in 36 percent fewer crashes with motor vehicles and 57 percent fewer cyclists who were killed or severely injured (*3*). Some of these crossings also used the blue color on the pavement.

A raised and painted bicycle path or crossing introduced at 44 intersections in Gothenburg, Sweden, reduced motor vehicle speeds by 35 to 40 percent for right-turning motor vehicles and increased cyclist speeds by 10 to 15 percent. The safety improvement was estimated by using a quantitative model and by surveying bicyclists and experts. The model estimated the combined effect of lower motorist speeds and higher bicyclist speeds to be a 10 percent reduction in the number of bicycle–motor vehicle crashes. Bicyclists perceived a 20 percent improvement in safety after the bicycle path was raised and painted. Experts estimated a 30 percent improvement in safety. However, the authors suggested that the total number of crashes should be expected to increase because of a 50 percent increase in the number of bicyclists using the improved crossings (*4*). A follow-up paper using a Bayesian approach for combining the results of the model and surveys estimated a risk reduction of approximately 30 percent, attributable to the raised and painted crossing (*5*).

SITE SELECTION

Working with the city of Portland, researchers chose a total of ten bicycle–motor vehicle weaving areas near intersections for inclusion in the study. Motorists and bicyclists had expressed safety concerns to the city about all of the locations selected. The sites could be categorized into three groups, as shown in Table 1, based on the maneuvers made by both the motorists and the bicyclists at these sites. Group 1 included Sites 1, 2, 3, and 4, and, because of roadway curvature and other factors, generally required both the motorists and bicyclists to turn slightly as they approached the weaving or conflict area (Figure 2). In most cases, the motor vehicle was exiting the roadway or entering an exit ramp at a relatively high speed. The one site in this group that is an exception is Site 1, which features a dual right-turn lane operation as described in Table 1 and simply does not fit well in any of the defined categories. Group 2 (Sites 5, 6, 7, and 8) involved the bicyclist traveling straight on the approach and the motorist weaving across the conflict area to enter an auxiliary right turn lane (Figure 3). In Group 3, the motor vehicle is approaching from an intersecting roadway or ramp and tends to cross the conflict area at an angle approximating 90 degrees (Figure 4). Sites 9 and 10 fall into this category.

At all ten locations, the conflict areas, where the paths of the motorists and bicyclists were intended to cross, were outlined by dashed striping along both sides of the bicycle lane (Figures 2, 3, and 4). These conflict areas were the sections of the bicycle lane that

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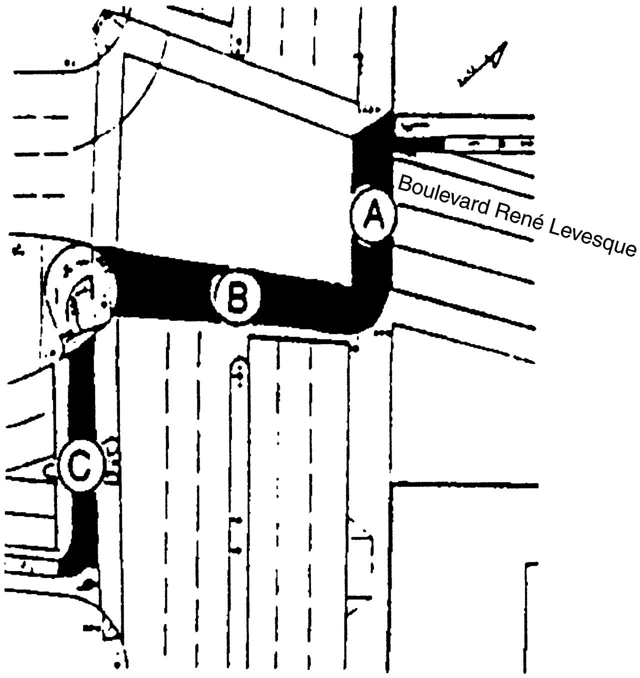

FIGURE 1 Colored bicycle crossing in Montreal (2).

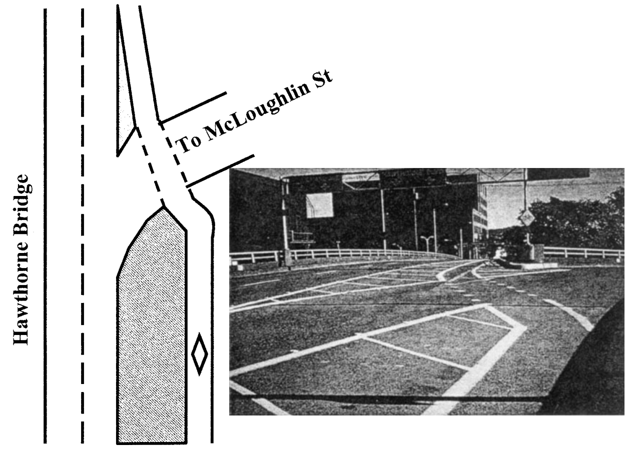

FIGURE 2 Bicyclists continuing on Hawthorne Avenue veer to left, while motorists exiting Hawthorne Avenue onto McLoughlin Street veer to right and cross conflict area (outlined by dash striping).

TABLE 1 Site Descriptions for Locations Included in Study

Site	Conflict Area	ADT	Site Description
Group 1: *Exiting Roadway or Ramp*			
1	NE Broadway, westbound at Williams (I-5 northbound entrance ramp)	35,000	Bicyclist heading west. Motorist crosses bicycle lane to access I-5 northbound entrance ramp.
2	SW Beaverton - Hillsdale Highway eastbound at Bertha	14,500	Bicyclist heading east. Motorist crosses bicycle lane while veering off to Bertha Blvd.
3	SW Multnomah Blvd, eastbound at Garden Home Rd	N/A	Bicyclist heading east. Motorist crosses bicycle lane while veering off to Garden Home Rd.
4	The Hawthorne Bridge, east end, eastbound at the McLoughlin off-ramp	13,200	Bicyclist heading east. Motorist exiting Hawthorne Bridge eastbound viaduct onto McLoughlin Blvd.
Group 2: *Auxiliary Right-Turn Lane*			
5	SE Madison, eastbound, between Sixth and Grand	10,500	Bicyclist heading west. Motorist crosses bicycle lane into right-turn only lane onto northbound Grand Ave.
6	SE 7th, southbound at Morrison	8,300	Bicyclist heading south. Motorist crosses bicycle lane into right-turn only lane onto SE Morrison.
7	East end of the Broadway Bridge, eastbound at Larrabee	15,200	Bicyclist heading east comes off sidewalk of Broadway Bridge onto roadway bicycle lane. Motorist crosses bicycle lane into right-turn only lane onto NE Larrabee.
8	SW Terwilliger, northbound at I-5 entrance ramp	<7,000	Bicyclist heading north. Motorist crosses bicycle lane into right-turn only lane onto I-5.
Group 3: *Intersecting Roadway or Ramp*			
9	East end of the Broadway Bridge, westbound at Interstate	32,000	Bicyclist heading west from roadway bicycle lane onto Broadway Bridge sidewalk. Two lanes of motorists from N. Interstate cross bicycle lane to use Broadway Bridge westbound.
10	NE Weidler, eastbound at Victoria (I-5 north bound off-ramp)	40,300	Bicyclist heading east. Motorist exits I-5, crosses bicycle lane as she/he enters eastbound NE Weidler St.

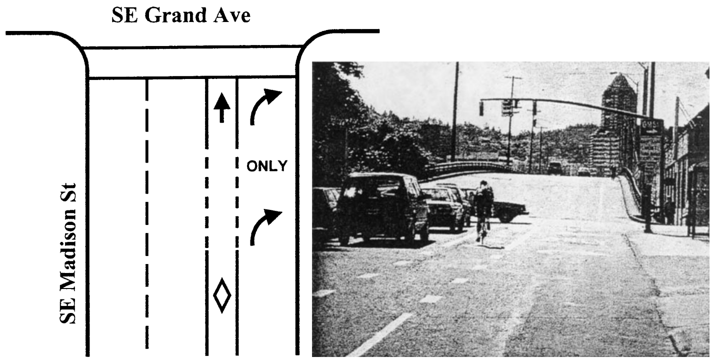

FIGURE 3 Bicyclists on this SE Madison Street approach travel on straight path to intersection, while motorists weave across conflict area (outlined by dash striping) to enter right-turn-only lane.

were treated with the blue markings. Prior to the conflict areas, all of the sites except the Hawthorne Bridge also used traditional regulatory signage that read "Yield to Bikes." The standard signage had been in place for some time and was in good repair. At Hawthorne Bridge, bicycles would yield to motor vehicles, but this was changed when the blue pavement and signage were added.

DATA COLLECTION

As previously noted, the study methodology was comparison of the operations of bicyclists and motorists at the selected locations, by use of videotapes made before and after the blue pavement treatment was installed. The timeline for data collection and for the installation of the treatment was as follows:

- Mid-September–early October 1997—Before data collected at seven of the ten sites (Sites 1, 2, 4, 5, 7, 9, and 10).
- Late October 1997—Blue paint was applied to the conflict areas at these seven locations.
- Early December 1997—First round of after data was collected at these seven locations.
- Spring 1998—Two sites (Sites 4 and 5) were eliminated from a second round of after data collection because of a 1-year-long closing of the Hawthorne bridge. Three new sites (Sites 3, 6, and 8) were selected to replace and supplement the affected locations.
- Early July 1998—Before data were collected for the three new sites.
- Late July–early August 1998—Blue thermoplastic was applied to the conflict areas at the eight sites remaining in the study.
- Late August–early September 1998—Second round of after data was collected, which resulted in two periods of after data for Sites 1, 2, 7, 9, and 10, and one round for Sites 3, 6, and 8.

For each before and after data collection period, 2 h of videotape were recorded. Depending on the peak-hour directional flow, the taping was done either between 7 and 9 a.m. or between 4 and 6 p.m. on days with good weather. The camera always faced the oncoming cyclist so that estimates of cyclist age and gender could be made. While the camera was visible, it was set back from the roadway and

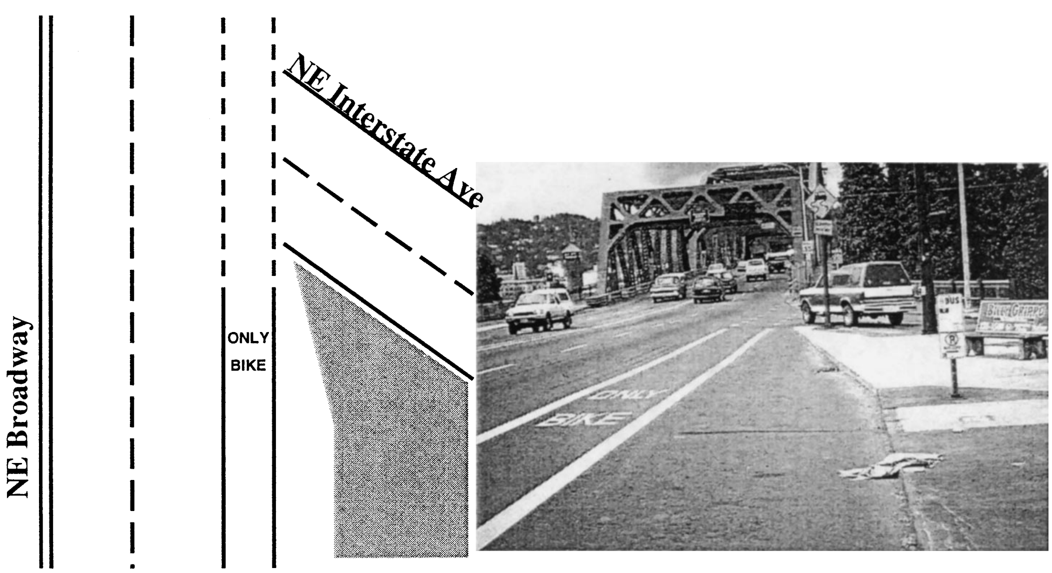

FIGURE 4 Bicyclists on the approach to Broadway Bridge travel straight, while motorists from Interstate Avenue cross conflict area (outlined by dash striping) at angle approaching 90 degrees.

a zoom lens was used to record bicyclist behavior over some 150 to 200 m. On the basis of observations made before videotaping began, there was no evidence that the camera presence affected either cyclist or motorist behavior. For each of the ten locations, 2 h of before data were collected, resulting in a total of 20 h of tape. For five of the locations, one after period was collected, and the remaining five locations had video recorded for two after sessions each, resulting in a total of 30 h of tape.

Opinions about the blue bicycle lanes were also collected through an in-field oral survey of bicyclists conducted in September 1998. More than 200 bicyclists were surveyed in the field just after they had traveled through the Broadway Bridge–Larrabee location (Site 7). This site was chosen because it potentially captured bicyclists who would also ride through several other nearby sites where the blue pavement and signage were used. In February 1999, license plate numbers were recorded for motor vehicles passing through Site 7. Surveys were mailed to approximately 1,200 motorists whose addresses could be located from Driver and Motor Vehicle Services records, with 222 responses received. These surveys were mailed at a later date because of limited staff resources of the city of Portland.

COLOR AND MATERIALS

As has been noted several times, the color selected for this application was a light blue similar to the color used to designate parking spaces for the disabled. This color was selected by Portland staff for several reasons. First, evidence from earlier studies conducted in Denmark and Montreal suggested that blue was a color that would be effective. Second, colors used in other countries, such as red or green, have very distinct meanings in the United States, and their selection for this application could result in some level of confusion. Third, blue is a color that can be detected by color-blind individuals (unlike red or other earth tones) and can also be detected relatively well in low-light and wet conditions. Finally, more than thirty presentations were given to the public at large by city of Portland staff, and participants were asked about color preference. Blue was the overwhelming choice.

With respect to the materials, both paint and thermoplastic were used. As the paint was being applied for the initial set of markings, glass beads were placed on the surface. The total cost, including materials and labor, for application of the paint was approximately $900. Unfortunately, the material lasted only a short time. Within a matter of 2 to 3 months, it was worn away at some of the locations with high traffic volumes. Thus, for the second round of treatments, a skid-resistant thermoplastic material was selected and applied at eight locations. The cost for this application included $9,700 in materials and $6,300 in labor. While the initial thermoplastic application is significantly more expensive, the life-cycle costs may be worth the investment if planners were to factor in the number of times paint would have to be reapplied to maintain the same level of retroreflectivity. Almost a year after the thermoplastic was applied at the eight sites, six of the locations showed very little wear, one was in fair condition, and the other was in poor condition. The poor condition of the latter location is believed to have resulted from incorrect installation.

Neither the paint nor the thermoplastic was found to be slippery, but neither material showed up at night as well as had been expected. The slipperiness was tested by wetting both paint and thermoplastic surfaces and having city of Portland staff perform bicycle test rides. Portland also has an extensive complaint system featuring postage-paid cards at bike shops and events, a website, and a 24-h complaint line. The system produces hundreds of complaints about issues like debris and potholes. No complaints were received about either surface being slippery.

One other feature of the blue bicycle-lane treatments was the use of rather novel signage in conjunction with the blue markings. One of three different signs, as shown in Figure 5, was used, depending on the motorist maneuver and the location of the bicycle lane. The first sign (Figure 5*a*) was used for situations in which the motorist tended to be making a right turn across the conflict area and path of the bicyclist, as when exiting a roadway; the sites in Group 1 above tended to meet this criteria. The second sign (Figure 5*b*) was used for those locations where the motorist crossed the path of the bicyclist to get into another lane, such as an auxiliary right-turn lane; the Group 2 locations fit this description. Finally, the third sign (Figure 5*c*) was used at those locations where the motorist was intersecting the bicycle lane nearly at a right angle, such as from an entrance ramp; the sites in Group 3 were candidates for this sign.

DATA REDUCTION

From the 20 h of before video data and 30 h of after data, the following measures of effectiveness and other attributes were recorded. The bicycle was the basic unit of analysis. For each bicyclist passing through a treatment site during the 2-h period, age and gender were coded, along with information related to scanning behavior (looking for conflicting traffic), use of hand signals, use of the bicycle lane, and slowing or stopping behavior upon approach of the conflict area. For motorists, data were collected on their turn-signal behavior and slowing or stopping behavior as they approached the conflict area in the presence of a bicyclist. With respect to the interaction of the two modes, data were recorded with respect to which party yielded and whether there were conflicts such that one of the parties had to change direction or speed suddenly to avoid a collision. Data were captured for 846 bicyclists and 191 motor vehicles in the before period and 1,021 bicyclists and 301 motor vehicles in the after period.

ANALYSIS RESULTS

Overview

The observed (videotape) data were analyzed to estimate before-to-after changes in several bicyclist and motorist behaviors. Two sets

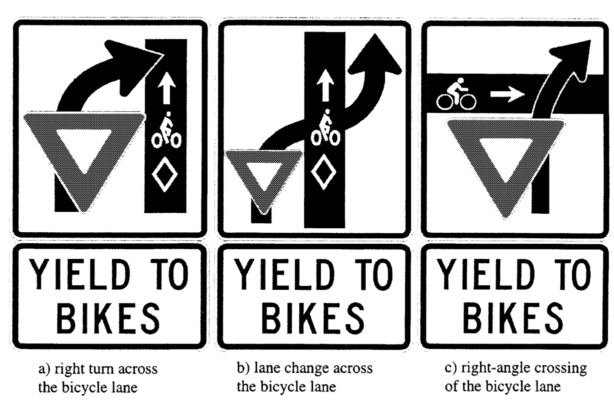

FIGURE 5 Examples of novel sign used in conjunction with blue pavement markings to alert motorists and bicyclists to conflict area and warn motorists to yield to bicyclists.

of after observations were made at different times for some of the sites. A comparison of the bicyclist characteristics of age, sex, and helmet use revealed no significant changes in the bicycling populations between these two sets of after observations. Therefore, it seemed most appropriate to combine the two sets into a single set of after observations to be compared with the before observations.

Provided below are the results of the analysis of both the videotape and the in-field survey data collected. Two different analysis approaches were used. The first analysis approach was to pool the data across all sites and statistically test (using chi-square tests) for differences in bicyclists' characteristics and in the variety of measures of effectiveness collected during the before and after periods. All of the results described below as significantly different were significant at a level of $p < .001$, which means that the differences in the distributions could be due to chance less than 1 time out of 1,000. Generally, the figures show all levels of a variable in order to convey more information to the reader; however, categories were grouped when necessary to permit appropriate statistical testing. In the text that follows, a single triangle (▼) is used to indicate a major individual cell chi-square contribution to a significant chi-square value for the overall distribution. Chi-square testing was not performed in cases in which the distributions produced zero cells due to all effects of a variable being directly related to the before or after period (i.e., presence or absence of the blue pavement).

Analysis of Pooled Data Across All Sites

Bicyclist Characteristics

Approximately three-fourths of the videotaped bicyclists were male and one-fourth were female. However, there were significantly fewer females (▼) in the after period (29 percent before, versus 21 percent after), most likely due to seasonal effects. The in-field survey also consisted of approximately three-fourths males and one-fourth females.

Ages of the bicyclists were estimated from observation of the videotapes and categorized into the following groups: under 16 years of age, 16 to 24 years of age, 25 to 64 years of age, and above 64 years of age. (Note: Only one bicyclist was coded as under age 16, and only one bicyclist was coded as above age 64. As for the remaining two groups, slightly more than half were ages 16 to 24, and another 47 percent were ages 25 to 64. There were no statistical differences in these two age groups in the before and after periods.) The average ages of those bicyclists included in the in-field survey were 35 for males and 33 for females.

Other characteristics of the videotaped bicyclists showed that slightly more than three-fourths of the bicyclists were wearing helmets, and there were no before and after differences. Also, none of the bicyclists captured on tape was carrying a passenger. Other characteristics of those bicyclists included in the in-field survey were that 79 percent were wearing helmets and that 72 percent considered themselves to be experienced bicyclists. "Experienced" was defined by following statement: "I feel comfortable riding under most traffic conditions, including major streets with busy traffic and higher speeds." The average number of miles per week for these individuals was 59 mi (95 km), or 64 mi (103 km) for males and 42 mi (68 km) for females, and 98 percent of these bicyclists were riding on the roadway, as opposed to on the sidewalk, when approaching the survey location.

Bicyclist Behavior

Several measures of effectiveness that pertained to behaviors of bicyclists while approaching or within the blue pavement areas were coded from the videotapes. Figure 6 shows that significantly more bicyclists approaching the conflict area turned their head to look for a motor vehicle before (▼) the blue pavement was put in place than after (43 percent before, versus 26 percent after). In similar fashion, significantly fewer bicyclists used hand signals to indicate their intended movement through the conflict area after (▼) the blue pavement was installed, although few bicyclists used hand signals even in the before period (11 percent before, versus 5 percent after). It should be noted that cyclists would not be expected to signal at sites where they were riding straight ahead (all but two sites).

During the before period, 85 percent of the bicyclists followed the marked path through the conflict area (Figure 6). During the after period, this percentage significantly increased (▼) to 93 percent. When the recommended path was not followed, bicyclists would usually opt for a straight path that crossed the path of the motor vehicle at an oblique angle, instead of the marked path that sometimes forced the bicyclist to travel an extra distance before crossing the path of motorists at a right angle.

Whether the bicyclist slowed or stopped when approaching the conflict area was coded to provide a surrogate measure of the bicyclists' comfort level. As Figure 6 shows, 11 percent of the bicyclists slowed or stopped in the before period, compared with 4 percent

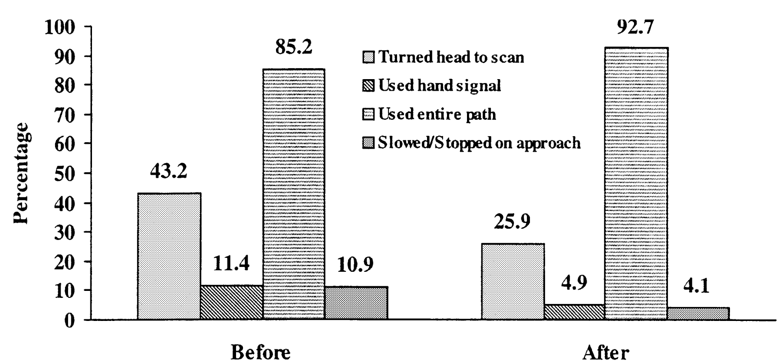

FIGURE 6 Bicyclists' behaviors before and after installation of blue pavement treatments.

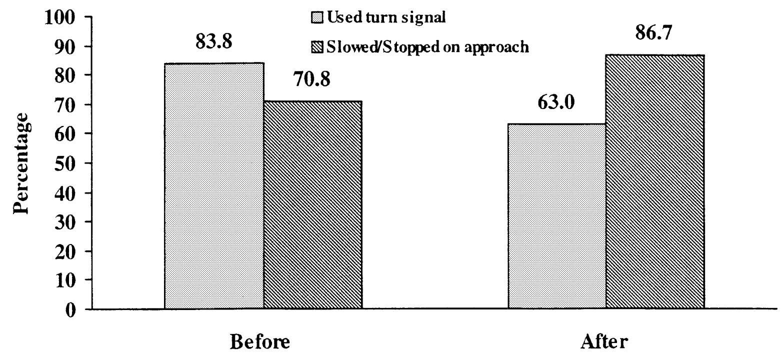

FIGURE 7 Motorists' behaviors before and after installation of blue pavement treatments.

after the blue pavement was in place (▼). This result may reflect a feeling of increased comfort level on the part of bicyclists, with the blue pavement in place.

Motorist Behavior

As with the bicyclists, several measures of effectiveness were coded that pertained to behaviors made by motorists approaching and crossing the blue pavement areas. One of those measures was the use of turn signals. As shown in Figure 7, significantly fewer motorists signaled their intentions (▼) after the blue pavement had been installed (63 percent after versus 84 percent before). Another measure obtained was related to the slowing or stopping behavior of motorists when approaching the conflict area. As seen in Figure 7, whereas 71 percent of the motorists slowed or stopped in the before period, 87 percent slowed or stopped after the blue pavement was in place (▼), a statistically significant difference.

Interaction Behavior

In addition to the rather independent behaviors of bicyclists and motorists just described, measures of effectiveness that examined the interaction between the two modes were also collected and analyzed from the videotape. The first of those measures pertained to whether the motorist or bicyclist yielded when approaching the conflict area. As shown in Figure 8, significantly more motorists yielded to bicyclists (▼) after the blue pavement had been installed (92 percent in the after period versus 72 percent in the before period).

Another measure examined was the number of conflicts that occurred between motorists and bicyclists. A conflict was defined as an interaction such that at least one of the parties had to make a sudden change in speed or direction to avoid the other, a rather stringent definition. Conflicts were infrequent, with eight coded in the before period and six after the blue pavement was in place. These small numbers resulted in conflict rates that were quite small: 0.95 per 100 entering bicyclists before and 0.59 after. All of the conflicts in the before period were minor in nature, and one of the conflicts in the after period was serious. In regard to location, four of the eight before conflicts were in the rectangular area to be colored, while five of the six after conflicts were in the blue pavement area. Five of the before conflicts occurred with bicyclists traveling eastbound on the Hawthorne Bridge (Site 4), where the recommended marked path through the conflict area has bicyclists crossing the path of motorists at a right angle. Four of the six after conflicts occurred at Weidler Street (Site 10), where motor vehicles are merging onto the street from a ramp.

Stratified Analysis of Bicyclist and Motorist Behaviors

To take individual site differences into account, stratified analyses were carried out where each site was a stratum. For this second level of analysis, initial before/after comparisons were made, by first reduc-

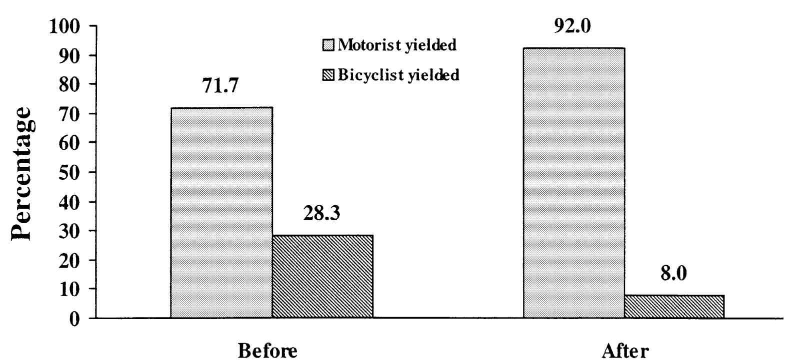

FIGURE 8 Yielding behavior of motorists and bicyclists before and after installation of blue pavement treatments.

ing the number of levels of each characteristic or behavior to two, in some cases by omitting unknown or inapplicable cases and in others by combining certain levels (e.g., extent of slowing and stopping versus none). For a given characteristic for each site, a 2×2 contingency table that had at least one observation in each row and column was analyzed. The statistical significance of a change at a given site was assessed by either a Pearson χ^2-statistic or a Fisher's exact test if cell sizes were too small. A Cochran-Mantel-Haenszel χ^2-statistic was also computed in order to test for overall association across the tables (i.e., cumulative effects across the sites). This procedure is illustrated in Table 2, a before and after comparison of bicyclist and motorist behavior concerned with whether the bicyclist or motor vehicle yielded at the conflict area. The overall test of general association across the sites is shown at the bottom of Table 2 and indicates that significantly more motorists yielded to bicyclists approaching the conflict areas in the after period than in the before period.

TABLE 2 Before and After Comparison of Bicyclist and Motorist Behaviors—Who Yielded

Site 1	Bicyclist	Motorist		
Before	2 (50.00)	2 (50.00)	4	
After	6 (19.35)	25 (80.65)	31	$P_F = .218$
	8	27	35	

Site 2	Bicyclist	Motorist		
Before	2 (40.00)	3 (60.00)	5	
After	2 (28.57)	5 (71.43)	7	$P_F = 1.00$
	4	8	12	

Site 4	Bicyclist	Motorist		
Before	30 (40.54)	44 (59.46)	74	
After	8 (27.59)	21 (72.41)	29	$P_C = .220$
	38	65	103	

Site 5	Bicyclist	Motorist		
Before	0 (0.0)	18 (100.00)	18	
After	3 (10.71)	25 (89.29)	28	$P_F = .270$
	3	43	46	

Site 7	Bicyclist	Motorist		
Before	7 (28.00)	18 (72.00)	25	
After	1 (2.56)	38 (97.44)	39	$P_F = .004$
	8	56	64	

Site 10	Bicyclist	Motorist		
Before	4 (12.90)	27 (87.10)	31	
After	2 (2.33)	84 (97.67)	86	$P_F = .042$
	6	111	117	

NOTES: Numbers in parentheses are percentages of row totals.
Cochran-Mantel-Haenszel overall test of general association
$\chi^2_{1df} = 8.744$, $p = .003$

Other results from these analyses are detailed in Table 3 and include the following overall outcomes:

1. Bicyclist ages were similar in the before and after periods.
2. There were significantly fewer female bicyclists in the after period.
3. Bicyclist helmet use was similar in the before and after periods.
4. Significantly more bicyclists followed the recommended marked path in the after period.
5. Significantly fewer bicyclists turned their heads to scan behind for a motor vehicle in the after period.
6. The percentage of bicyclists using a hand signal was similar in the before and after periods.
7. Significantly fewer bicyclists slowed or stopped when approaching the conflict areas in the after period.
8. The percentage of motorists using a turn signal prior to crossing the path of the bicyclists was similar in the before and after periods.
9. The percentage of motorists slowing or stopping when approaching the conflict areas was similar in the before and after periods.
10. Significantly more motorists yielded to bicyclists when approaching the conflict areas in the after period.

Bicyclists' and Motorists' Opinions

As previously noted, in-field surveys were acquired for 216 bicyclists at one of the treatment locations. Mailback surveys from 222 drivers traveling across this same location were also received. In both surveys, opinions were solicited with respect to general safety and operational issues related to the blue pavement in the conflict areas. The results of the bicyclists' survey can be summarized as follows:

1. Did the blue pavement markings increase the slipperiness of the road surface?

   Five percent felt the road surface was more slippery, 2 percent less slippery, 39 percent the same as before, and 55 percent were not sure.

2. Are motorists yielding to bicyclists more or less often with the blue pavement markings in place?

   Some 58 percent felt motorists were yielding more than before, 0 percent less than before, 27 percent the same as before, and 15 percent not sure. Typical positive comments of the bicyclists were that the blue pavement made a big difference, that bicyclists were more visible to drivers, and that drivers were more aware of bicyclists. Typical negative comments were that bicyclists always felt nervous going through these areas, that more motorist education was needed, and that bicyclists still had to ride defensively.

3. Do the blue pavement markings make the conflict areas more or less safe for bicyclists?

   Overall, 76 percent felt the locations with blue pavement were safer, 1 percent less safe, 9 percent no different, and 13 percent not sure. Typical positive comments were that motorists were more aware of the bike lanes, that motorists paid more attention to bicyclists, that the pavement made clearer where bikes were supposed to go, and that the defined area was respected by motorists. There were only a few negative comments to this question. One was that bicyclists were

TABLE 3 Comparisons of 10 Before Characteristics with Their After Values

1. Bicyclist age (1 case <16 & 1 case >64 were omitted)
   Results: Percent in 16-24 increased significantly at site 1 (p = .032).
   Otherwise some increased & some decreased.
   No overall change (p = .402)

2. Bicyclist sex
   Results: Percent of females decreased significantly, (p = .001) at site 9, and tended to be lower at many sites.
   Females decreased overall (p = .002)

3. Helmet use
   Results: Marginal increase at site 6 (p = .052)
   No overall change (p = .592)

4. Bicyclist followed recommended marked path
   Results: Percent of bicyclists following recommended marked path increased at site 4 (p = .003) and site 10 (p = .006), and decreased at site 5 (p = .047) and site 7 (p = .023)
   Overall increase (p = .021)

5. Bicyclist turned head
   Results: Percent turning head increased at site 7, (p = .009) but decreased at sites 9&10 (both p = .001).
   Overall decrease p = .001

6. Bicyclist used hand gesture
   Results: No significant changes

7. Bicyclist slowed/stopped (all levels of slowed or stopped combined)
   Results: percent not slowing/stopping decreased at sites 7 and 10 (p = .003 at each)
   Overall decrease in percent slowing/stopping (p = .022)

8. Motorist used turn signal
   Results: percent of motorists using turn signal increased at site 5 (p = .010)
   Overall: No change (p = .593)

9. Motorist slowed/stopped (levels combined)
   Results: No significant changes

10. Who yielded
    Results: Percent of times motorist yielded increased significantly for sites 7, (p = .005) and 5, (p = .042)
    Overall increase in motorist yielding (p = .003).

lulled into a false sense of security, and another was that the blue pavement was not reflective enough in low light or rainy weather.

Of the motorists surveyed, approximately 70 percent noticed the blue markings and 59 percent noticed the accompanying sign. Of those who noticed the sign, 55 percent stated that the blue markings meant to "yield to bicyclists," while 45 percent responded that they meant to "be careful." Of those that did not notice the signs, only 38 percent stated that the blue markings meant to "yield to bicyclists," and 43 percent responded that they meant to "be careful." When asked whether the blue markings made the conflict areas more or less safe, 49 percent thought the areas were made more safe, 20 percent thought the same, 12 percent thought less safe, and the remainder were not sure. Several of the motorists surveyed thought the markings helped to increase awareness of the conflict areas, while others expressed concern about creating a false sense of security for bicyclists.

CONCLUSIONS AND RECOMMENDATIONS

The use of colored pavement and accompanying signage to identify bicycle–motor vehicle conflict areas in a variety of traffic situations was an innovative approach. While colored pavements have been used to facilitate bicycle movement through intersections in Europe and Canada, such an application is a new concept for the United States.

Taken as a whole, these findings tend to point to safer conditions for bicycling as a result of the use of blue pavement and novel signage to define conflict areas between bicycles and motor vehicles. Overall, the percentage of bicyclists following the recommended marked path through the conflict areas increased in the after period, and the percent of motorists yielding to bicyclists increased in the after period. However, significantly fewer bicyclists turned their head to the rear to scan for approaching motor vehicles after the blue pavement was in place. In addition, significantly fewer bicyclists used hand signals to indicate their movement through the conflict area, although the percentage using signals was not high in the before period. These two results in combination might indicate a false sense of security generated by the blue pavement and signage.

In opposition to this notion, however, are the findings on conflicts between bicycles and motor vehicles. Although conflicts were rare, the rate of conflicts per 100 entering bicyclists decreased from 0.95 in the before period to 0.59 in the after period.

Results from an oral survey of bicyclists riding through some of the sites with blue pavement indicated that bicyclists felt (*a*) that the colored surfaces were no more slippery than before, (*b*) that motorists were yielding to bicyclists more than before, and (*c*) that the locations with blue pavement were safer than before. Motorists also thought that the locations were safer with the blue pavement in place and that the markings increased motorist awareness of the conflict areas.

Colored pavement and accompanying signage appears to be one way to heighten both motorist and bicyclist awareness of conflict areas and thus create a safer riding environment. This study provides a good introduction to the potential utility of colored markings for bike-lane crossings. However, more evaluations of the use of colored pavement and signage should be performed and reported so that guidelines on when and where such applications are appropriate and the types of materials and colors that should be used can be developed. Further study is also needed on the potential impact of the signage separate from the blue markings. The study purposely did not attempt to separate these two elements. The city of Portland decided that providing a regulatory message (sign) along with the blue marking was crucial; however, the city also decided that use of the sign alone, given that it was specific to the new treatment, could have confused both cyclists and motorists. The need to provide both the sign and marking was reinforced by the motorist survey, in which far more motorists who saw the sign (than did not) identified the meaning of the blue pavement correctly. Finally, follow-up efforts are needed in order that the long-term effects of these treatments on motorist and bicyclist behaviors can be determined.

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