Evaluation of the Blue Bike Lane Treatment used in Bicycle-Motor Vehicle Conflicts Areas in Portland, Oregon

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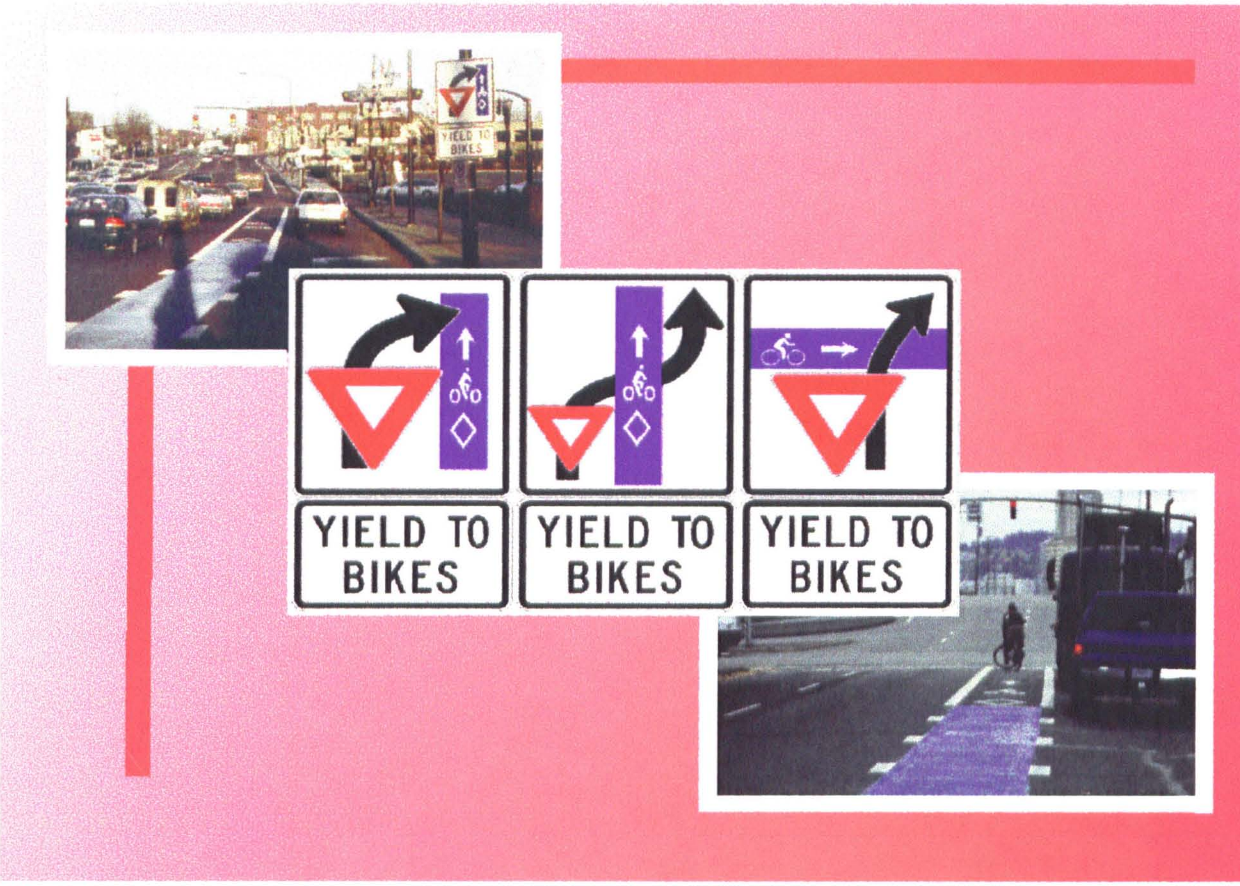

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Federal Highway Administration
Research and Development
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Pedestrian & Bicycle Safety

FOREWORD

During the past decade, the Federal Highway Administration's (FHWA) Pedestrian and Bicycle Safety Research Program activities have supported the congressionally mandated National Bicycle and Walking Study's goals of doubling the percentage of walking and bicycling trips and reducing by 10 percent the number of bicyclists and pedestrians killed or injured in traffic crashes. The FHWA's Pedestrian and Bicycle Safety Research Program has and will continue to focus on identifying problem areas for pedestrians and bicyclists, developing analysis tools for planners and engineers to target these problem areas, and evaluating countermeasures to reduce crashes involving pedestrians and bicyclists.

There is a variety of on- and off-road bicycle facilities – each with its advantages and disadvantages. A thorough evaluation of the various kinds of facilities implemented in pro-bicycling communities has been needed by the transportation engineering profession. As part of the Pedestrian and Bicycle Safety Research Program, evaluations of some innovative treatments to accommodate bicyclists were conducted. Many European cities use colored markings at bicycle-motor vehicle crossing to reduce conflicts. This report documents the evaluation of an application of a blue bike lane treatment to reduce bicycle-motor vehicle conflicts in Portland, Oregon.

The information contained in this document should be of interest to State and local bicycle and pedestrian coordinators and to transportation professionals involved in safety and risk management. Other interested parties include those in enforcement and public health.

Michael F. Trentacoste
Director, Office of Safety Research & Development

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16. Abstract

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, OR studied the use of blue pavement markings and a novel signing system to delineate selected conflict areas. The University of North Carolina Highway Safety Research Center (HSRC), under contract to the Federal Highway Administration, analyzed the project data.

From 1997 to 1999, Portland marked 10 conflict areas with paint and blue thermoplastic and an accompanying "Yield to Bikes" sign. All of the sites had a high level of bicyclist and motorist interaction, as well as a history of complaints. The crossings were all locations where the bicyclist travels straight and the motorist crosses the bicycle lane to exit a roadway (such as an off-ramp situation), enters a right-turn lane, or merges onto a street from a ramp.

The study used videotape analysis and found most behavior changes to be positive. Significantly more motorists yielded to bicyclists and slowed or stopped before entering the blue pavement area, and more bicyclists followed the colored bike-lane path. However, the blue pavement also resulted in fewer bicyclists turning their heads to scan for traffic or using hand signals, perhaps signifying an increased comfort level. The overwhelming majority of bicyclists and close to the majority of motorists surveyed felt that the blue areas enhanced safety.

Colored pavement and signing should continue to be used and evaluated in bicycle/motor vehicle conflict areas.

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INTRODUCTION

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 signing used in Portland, Oregon in weaving areas at or near intersections. The objective of this study was to determine if the signing and blue paint highlighting these areas changed the behavior of the motorists and/or 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 (Hunter, Stutts, Pein, and Cox, 1996). Colored pavement (either painted or dyed) is a countermeasure that has the potential for reducing conflicts and crashes at or near intersections and 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 bicycle-path crossings. Improved bicyclist behavior led to a decline in the level of conflict between bicyclists and motorists (Pronovost and Lusginan, 1996). 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 bicyclists who were killed or severely injured (Jensen, 1997). Some of these crossings also used the blue color on the pavement.

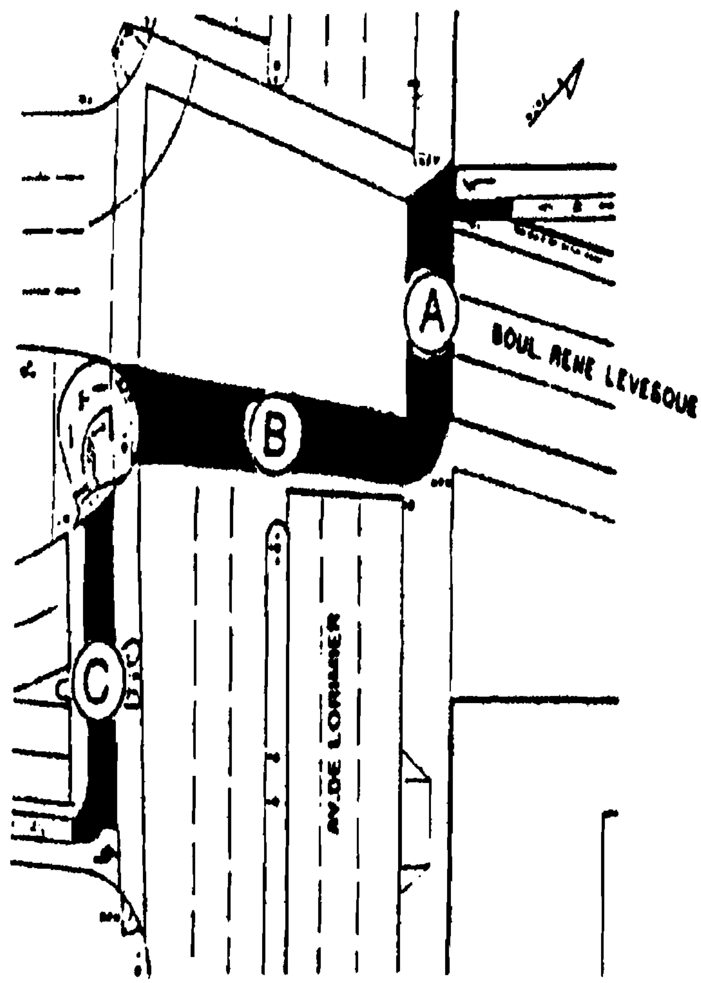


Figure 1. Colored bicycle crossing in Montreal.
Source: Pronovost and Lusignan, 1996

A raised and painted bicycle path or crossing (figure 2) introduced at 44 intersections in Gothenburg, Sweden, reduced motor vehicle speeds by 35 to 40 percent for right-turning motor vehicles and increased bicyclist 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 that 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 due to a 50-percent increase in the number of bicyclists using the improved crossings (Leden, 1997). A follow-on 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 (Leden, Gårder, and Pulkkinen, 1998).

Figure 2. A European raised and painted bike path (crossing).
Source: *Oregon Bicycle and Pedestrian Plan*, 1995

SITE SELECTION

Working with the city of Portland, 10 bicycle/motor vehicle weaving areas near intersections were selected for inclusion in the study. Both 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 generally required both the motorist and

Table 1. Site descriptions for locations used in the study.

Site	Conflict Area	ADT	Site Description
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	Hawthorne Bridge, east end, eastbound at the McLoughlin off-ramp	13,200	Bicyclist heading east. Motorist exiting Hawthorne Bridge eastbound viaduct onto McLoughlin Blvd.
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 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.
9	East end of 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 northbound off-ramp)	40,300	Bicyclist heading east. Motorist exits I-5, crosses bicycle lane as he/she enters eastbound NE Weidler St.

bicyclist to turn slightly as they approached the weaving or conflict area due to roadway curvature and other factors (see figure 3). 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 the table and simply does not fit as 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 4). 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 5). Sites 9 and 10 fall into this category.

At all 10 locations, the conflict area where the paths of the motorists and bicyclists were intended to cross was outlined by dashed striping along both sides of the bicycle lane (refer to figures 3, 4, and 5). These conflict areas were the sections of the bicycle lane that were treated with the blue markings. Prior to the conflict areas, all of the sites (except the Hawthorne Bridge) also used traditional regulatory signing to alert motorists to the fact that they were to "Yield to Bikes." The standard signing had been in place for some time and was in good repair. At Hawthorne Bridge, bicycles had been yielding to motor vehicles, but this changed when the blue pavement and signing were added.

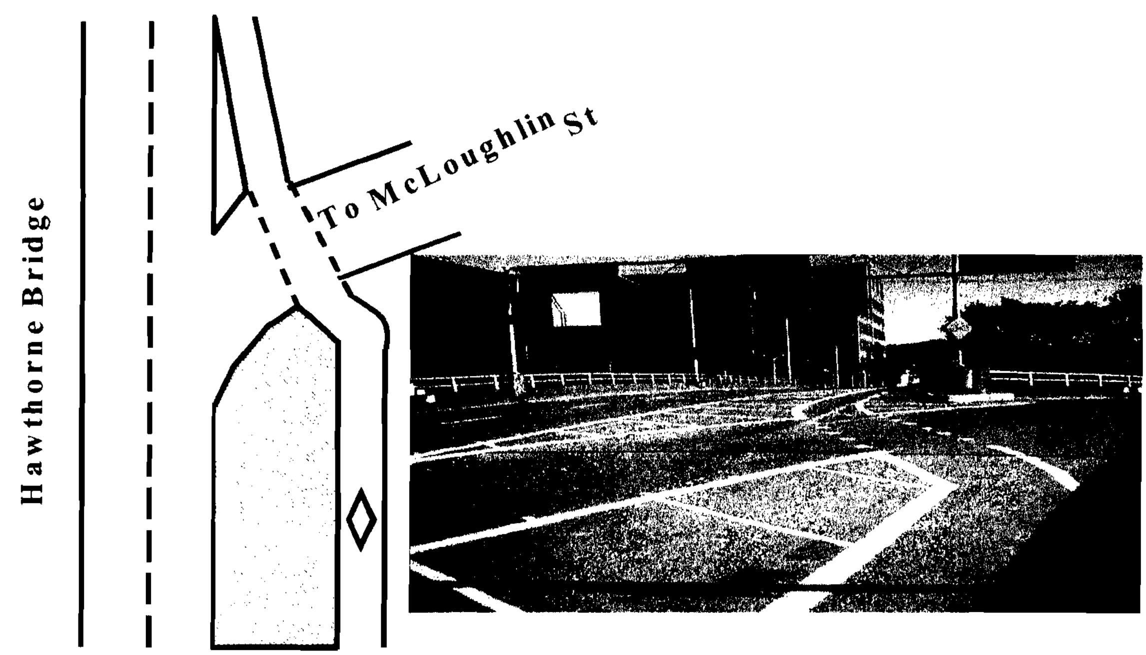


Figure 3. Bicyclists continuing on Hawthorne Avenue veer to the left, while motorists exiting Hawthorne Avenue onto McLoughlin Street veer to the right and cross the conflict area (outlined by the dashed striping) shown.

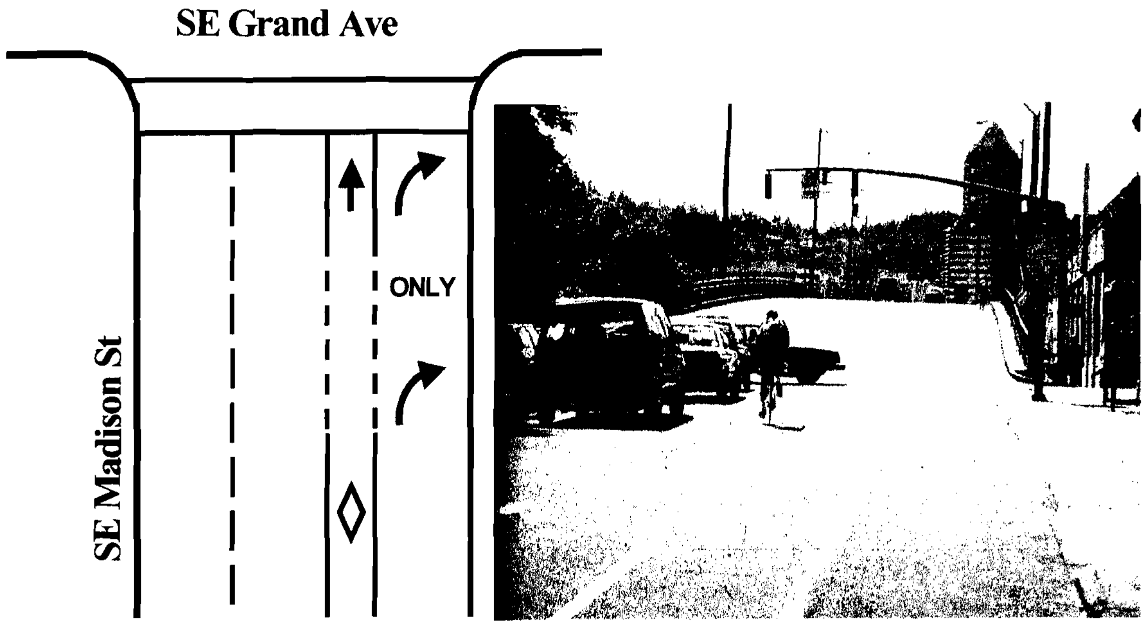


Figure 4. Bicyclists on this SE Madison Street approach travel on a straight path to the intersection, while motorists weave across the conflict area (outlined by the dashed striping) to enter the right-turn-only lane.

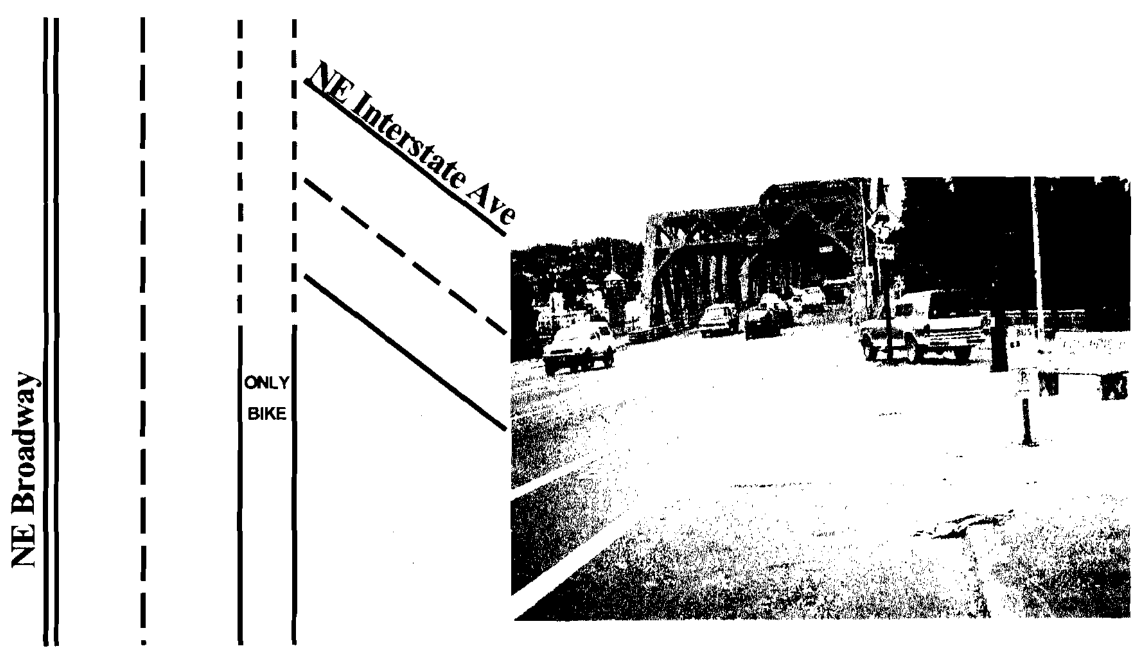


Figure 5. Bicyclists on the approach to the Broadway Bridge travel straight, while motorists from Interstate Avenue cross the conflict area (outlined by the dashed striping) at an angle approaching 90 degrees.

DATA COLLECTION

As previously noted, the study methodology was to compare the operations of bicyclists and motorists at the selected locations using videotapes made before and after the blue pavement treatment was installed. The time line for data collection and for the installation of the treatment was as follows:

- September/Early October 1997 – "Before" data collected at 7 of the 10 sites (Sites 1, 2, 4, 5, 7, 9, and 10).
- Late October 1997 – Blue paint applied to the conflict area at these seven locations.
- Early December 1997 – First round of "after" data collected at these seven locations.
- Spring 1998 – Two sites (Sites 4 and 5) were eliminated from a second round of "after" data collection due to the year-long closure of the Hawthorne Bridge. Three new sites (Sites 3, 6, and 8) were selected to replace and supplement the impacted locations.
- Early July 1998 – "Before" data were collected for the three new sites.
- Late July/Early August 1998 – Blue thermoplastic applied to the conflict area at the eight sites remaining in the study.

7. Late August/Early September 1998 – Second round of "after" data 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 4 and 6 p.m. on days with good weather. The camera was always facing the oncoming bicyclist so that estimates of bicyclist age and gender could be made. While the camera was visible, it was set back from the roadway and a zoom lens was used to record bicyclist behavior over some 150 to 200 m. Based on observations made before videotaping began, there was no evidence that the presence of the camera affected either bicyclist or motorist behavior. For each of the 10 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, while the remaining five locations had videotape recordings for two "after" sessions, 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 that was conducted in September 1998. More than 200 bicyclists were surveyed in the field just after traveling 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 signing 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 due to limited staff resources for the City of Portland.

COLOR AND MATERIALS

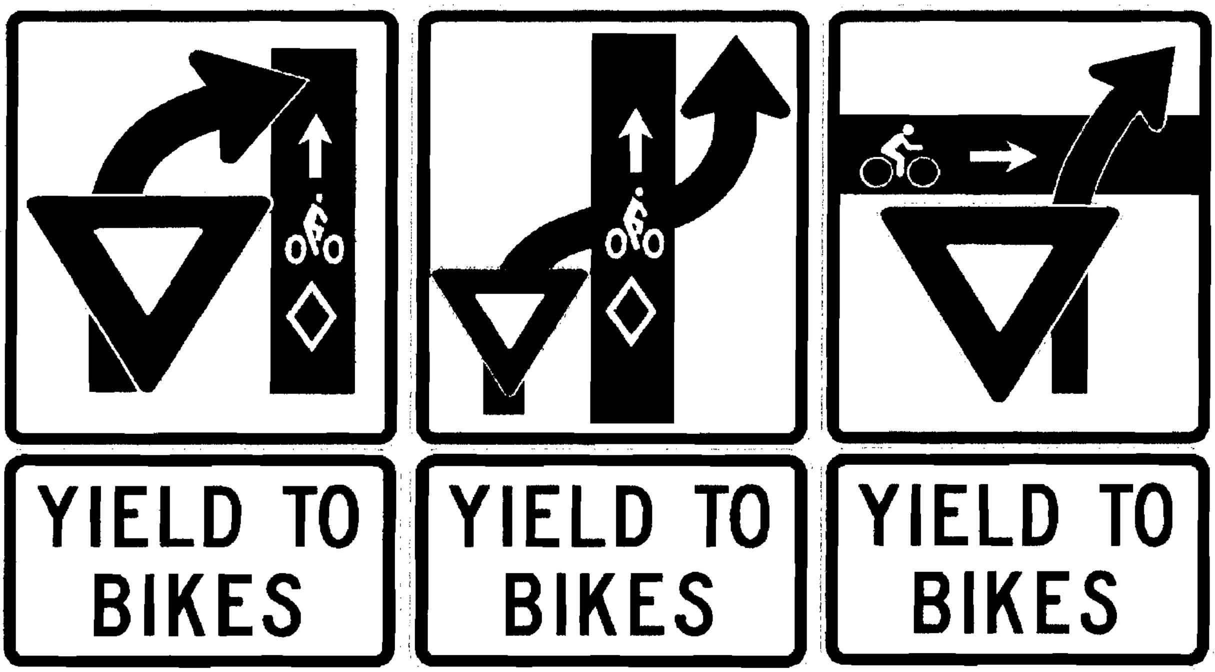
As has been noted several times, the color selected for this application was light blue, similar to the color used to designate parking spaces for the disabled. This color was selected by the Portland staff for several reasons. First, there was evidence that blue was a color that would be effective from prior studies conducted in Denmark and Montreal. Second, colors used in other countries, such as red or green, have very distinct meanings in the United States and could result in some level of confusion if selected for this application. Third, blue is a color that can be detected by colorblind individuals (as opposed to red or other earth tones) and can also be detected relatively well in low-light and wet conditions. Finally, more than 30 presentations were given to the public at large by the 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. The initial set of markings were painted with glass beads placed on the surface as the paint was being applied (figure 6). The

Figure 6. Blue paint and glass beads being applied to one of the conflict areas.

total cost, including materials and labor, for applying 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 treatment, a thermoplastic material that was skid-resistant 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 one 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 latter is believed to be due to incorrect installation. Neither the paint nor the thermoplastic was found to be slippery; however, neither material was as visible 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 web site, and a 24-h complaint line. The system produces hundreds of complaints about issues such as 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 signing in conjunction with the blue markings. One of three different signs, as shown in figure 7, was used,



(a) right turn across the bicycle lane

(b) lane change across the bicycle lane

(c) right-angle crossing of the bicycle lane

Figure 7. Examples of the novel sign used in conjunction with the blue pavement marking to alert motorists and bicyclists of the conflict area and to warn motorists to yield to bicyclists.

depending on the motorist maneuver and the location of the bicycle lane. The first sign (a) was used for situations where the motorist tended to be turning right across the conflict area and path of the bicyclist, such as when exiting a roadway; the sites in Group 1 tended to meet this criteria. The second sign (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 (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 the 30 h of "after" data, a number of 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/stopping behavior upon approaching the conflict area. For motorists, data were collected regarding turn-signal behavior and slowing/stopping behavior when approaching 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 (videotaped) data were analyzed to estimate "before"-to-"after" changes in several bicyclist and motorist behaviors. Two sets 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 population 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 for differences in bicyclist characteristics and the variety of measures of effectiveness collected during the "before" and "after" periods using chi-square tests. All of the results described below as significantly different were significant at a level of $p < 0.001$, 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 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 where 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).

Bicyclist Characteristics

As shown in figure 8, approximately three-quarters of the videotaped bicyclists were male and one-quarter 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-quarters males and one-quarter females.

The ages of the bicyclists were estimated from observing the videotapes and were categorized into the following groups: <16, 16-24, 25-64, and >64 years of age. (Note: Only one bicyclist was coded as <16 years of age, and only one bicyclist was coded as >64 years of age. For the remaining two groups, slightly more than half were ages 16-24, and another 47 percent were ages

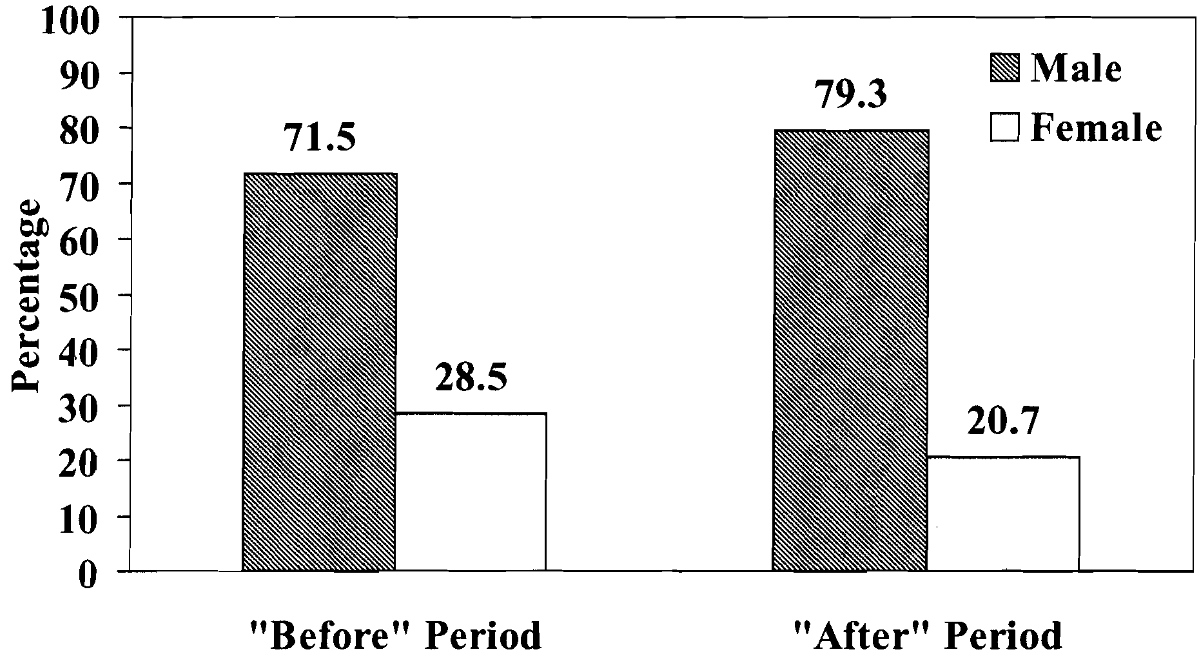


Figure 8. There were significantly more male bicyclists and fewer female bicyclists observed during the "after" period.

(25-64. There were no statistical differences in these two age groups in the "before" and "after" periods. The average age of those bicyclists included in the in-field survey was 35 for males and 33 for females.

Other characteristics of the videotaped bicyclists showed that slightly more than three-quarters of the bicyclists were wearing a helmet, and there were no "before"/"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 showed that 79 percent were wearing helmets and 72 percent considered themselves to be experienced bicyclists, where "experienced" was defined as the following: "I feel comfortable riding under most traffic conditions, including major streets with busy traffic and higher speeds." These individuals averaged 59 mi (95 km) per week (64 mi (103 km) per week for males and 42 mi (68 km) per week for females), and 98 percent of these bicyclists were riding on the roadway, as opposed to the sidewalk, when approaching the survey location.

Bicyclist Behavior

Several measures of effectiveness that were coded from the videotapes pertained to the behavior of bicyclists while approaching or within the blue pavement areas. Figure 9 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 (▾) (43 percent "before" versus 26 percent "after"). In a similar manner, figure 10 shows that significantly fewer bicyclists used a hand signal to indicate their intended movement through the conflict area after the blue pavement was installed (▾), although few bicyclists used a hand signal, even in the "before" period (11 percent "before" versus 5 percent "after"). It should be noted that bicyclists 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 11). During the "after" period, this percentage significantly increased (▾) to 93 percent. When the recommended path was not followed, this usually involved bicyclists who would 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 to then cross the path of the 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 shown in figure 12, 11 percent of the bicyclists slowed or stopped in the "before" period, compared to 4 percent after the blue pavement was in place (▾). All levels of slowing and stopping were also reduced in the "after" period (▾). This result may reflect a feeling of increased comfort on the part of the bicyclists when the blue pavement was in place.

Motorist Behavior

As with the bicyclists, several measures of effectiveness that were coded pertained to the behavior of motorists approaching and crossing the blue pavement areas. One of those measures was the use of turn signals. As shown in figure 13, 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. Whereas 71 percent of the motorists slowed or stopped in the "before" period (figure 14), 87 percent slowed or stopped after the blue pavement was in place (▾), a statistically significant difference.

Interaction Behavior

In addition to the rather independent behavior of bicyclists and motorists just described, measures of effectiveness to examine 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 15, significantly more motorists yielded to bicyclists after the blue pavement was 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, where 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 in the "before" period and 0.59 after the blue pavement was installed. All of

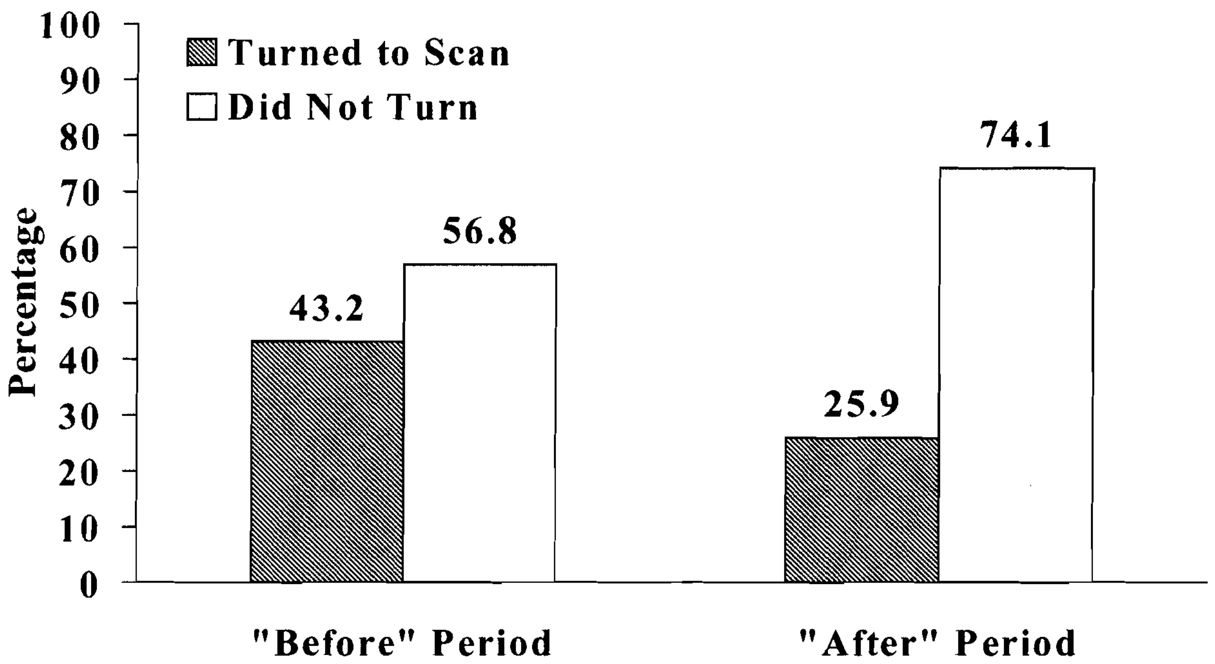


Figure 9. Significantly more bicyclists turned their heads to scan for conflicting traffic prior to the installation of the blue markings.

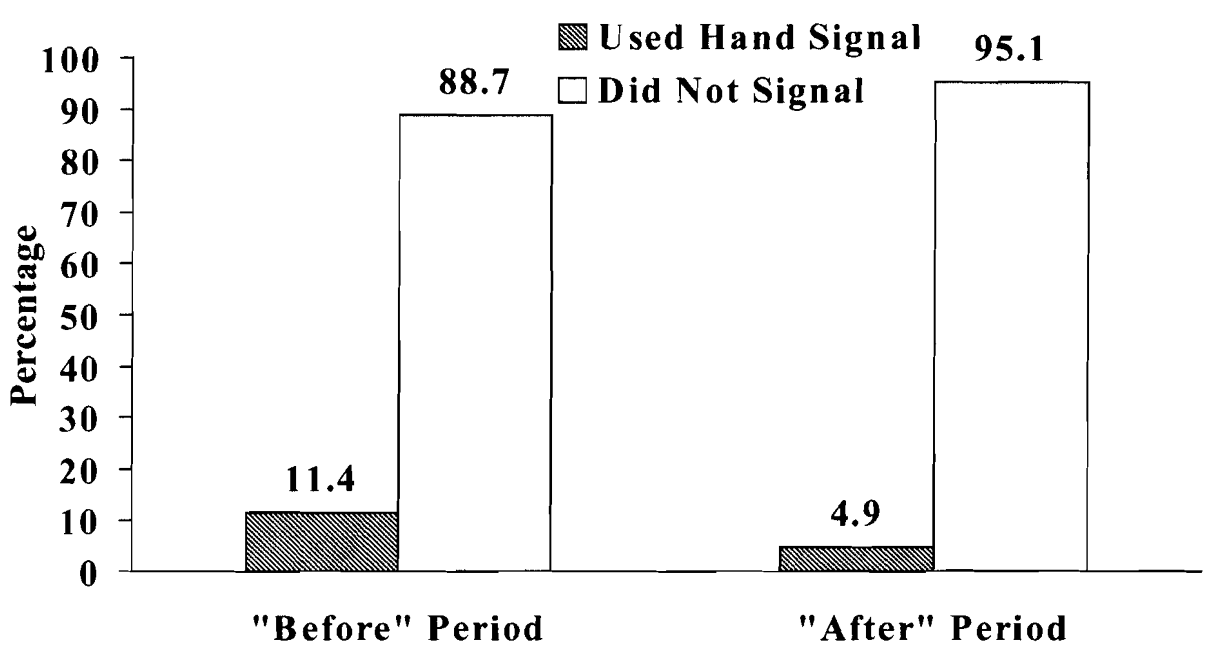


Figure 10. Significantly fewer bicyclists used hand signals to indicate their intended maneuver after the installation of the blue markings.

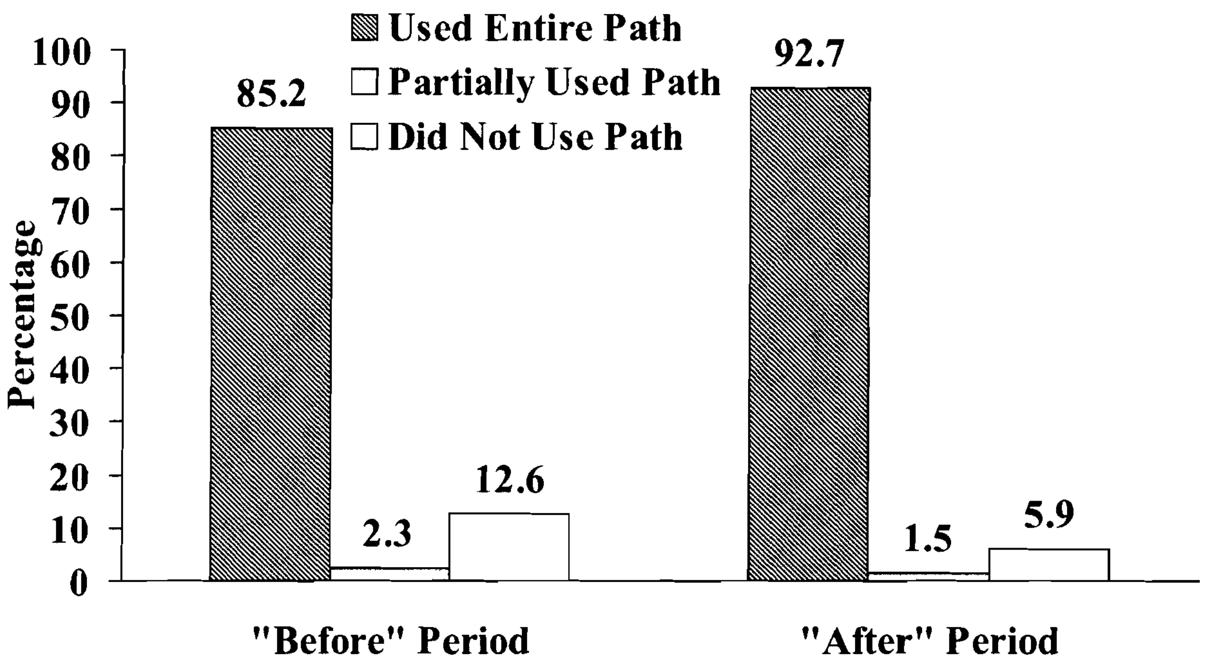


Figure 11. Significantly more bicyclists crossing the conflict area used the designated or marked path after the installation of the blue markings.

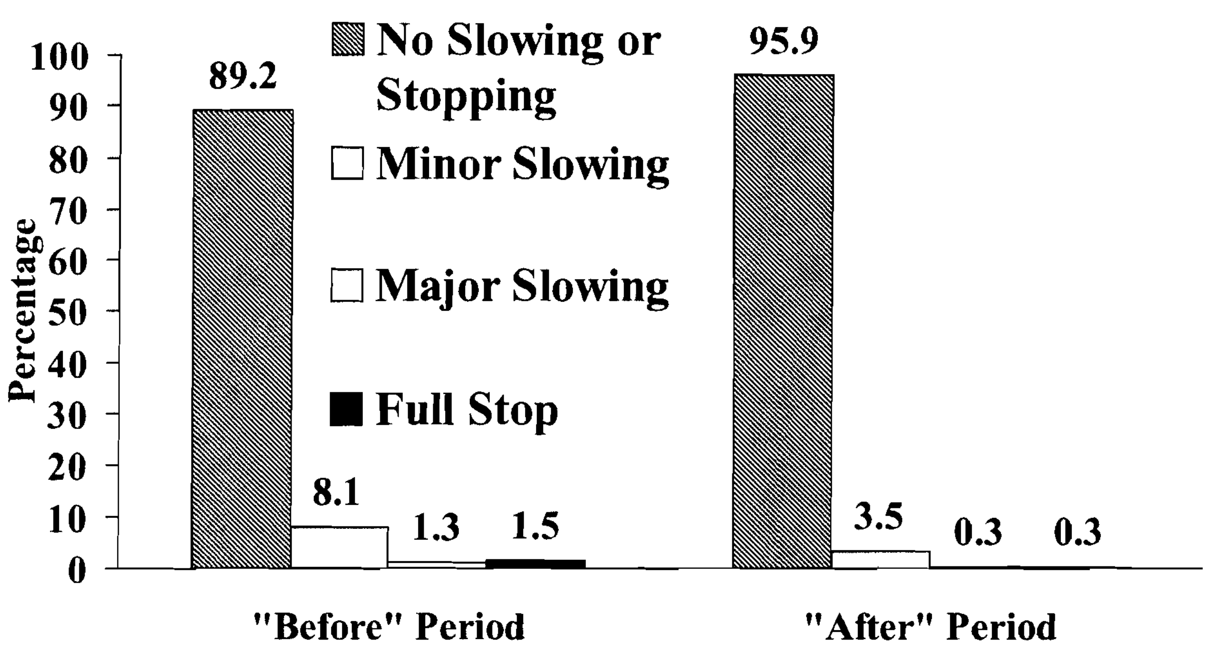


Figure 12. Significantly fewer bicyclists tended to slow or stop when approaching the conflict area after the installation of the blue markings.

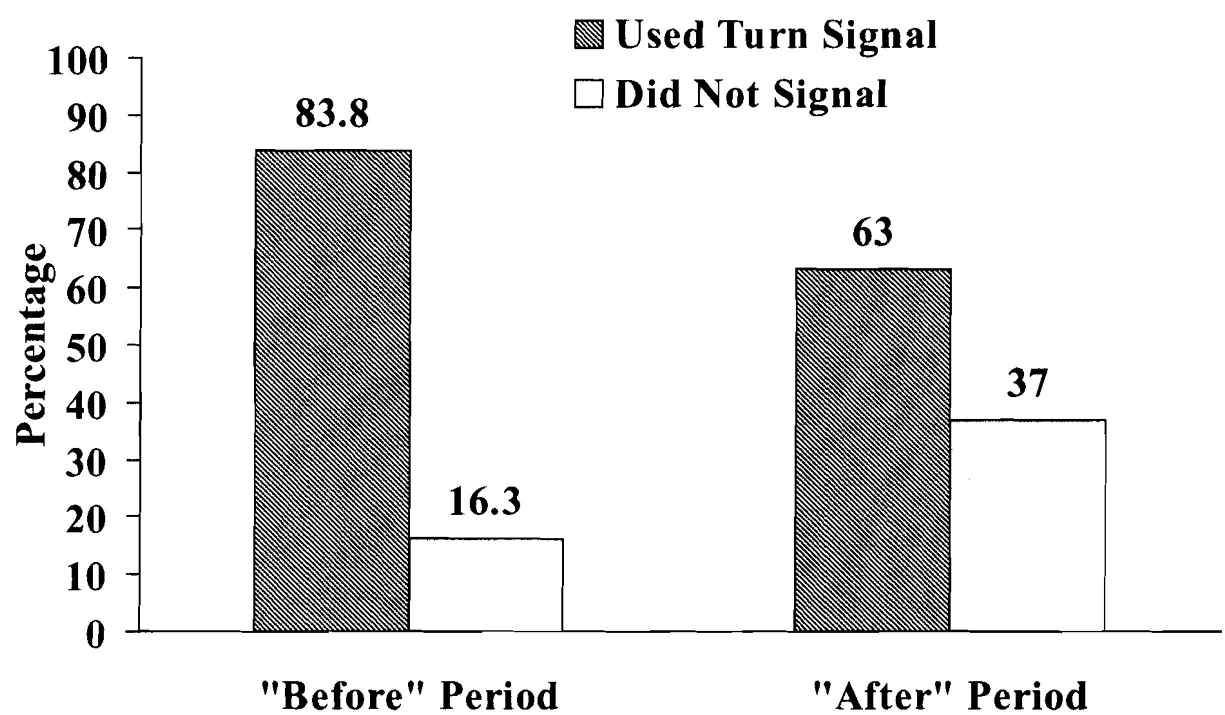


Figure 13. Significantly fewer motorists used turn signals to indicate their intended maneuver after the installation of the blue markings.

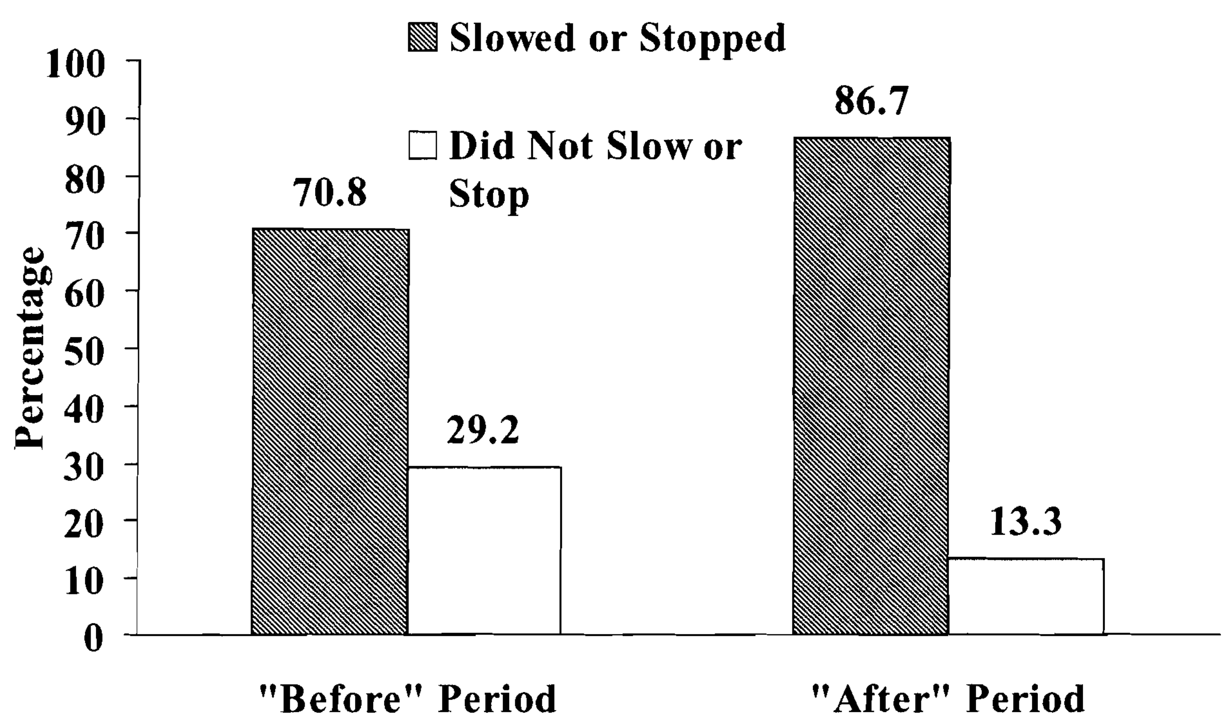


Figure 14. Significantly more motorists slowed or stopped upon approaching the conflict area after the installation of the blue markings.

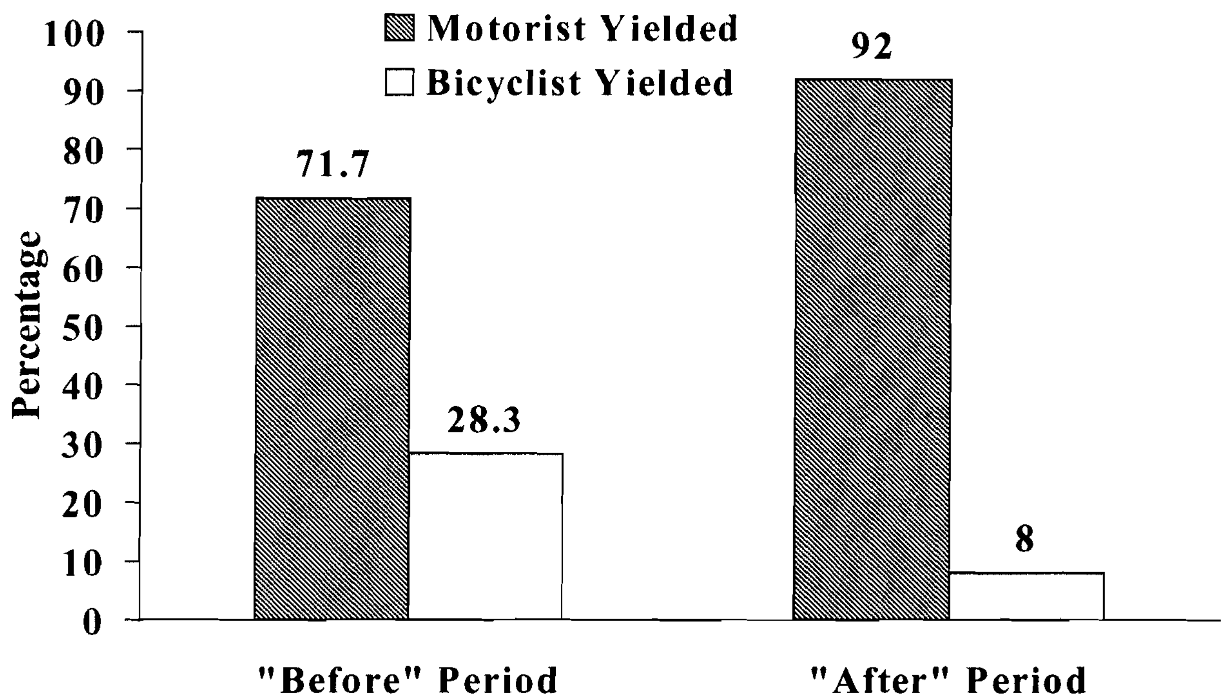


Figure 15. Significantly more motorists yielded to bicyclists upon approaching the conflict area after the installation of the blue markings.

the conflicts in the "before" period were minor in nature, and one of the conflicts in the "after" period was serious. With 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 Behavior

To take individual site differences into account, stratified analyses were carried out where each site was a stratum. For the second level of analysis, initial "before"/"after" comparisons were made by first reducing the number of levels of each characteristic or behavior to two, in some cases, by omitting unknown or not applicable cases and, in others, by combining certain levels (e.g., the extent of slowing and stopping versus no action taken). For a given characteristic, a 2 x 2 contingency table was analyzed for each site having at least one observation in each row and column. 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 to test for overall association across the tables (i.e., accumulating the effects across the sites). This procedure is illustrated in table 2 regarding whether the bicyclist or motorist yielded at the conflict area ("who yielded"). 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.

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.

Analysis of Pooled Data Across Sites Having Similar Characteristics

The final analyses involved pooling data across sites having similar characteristics. Three groups of similar sites were identified:

Group 1: Sites 1, 2, 3, and 4, where the bicycle travels straight ahead and the motor vehicle crosses over the path of the bicycle to exit the roadway, such as in an exit ramp situation.

Group 2: Sites 5, 6, 7, and 8, where the bicycle travels straight ahead and the motor vehicle crosses over the path of the bicycle to enter a right-turn lane.

Group 3: Sites 9 and 10, where the bicycle travels straight ahead and the motor vehicle crosses over the path of the bicycle to merge onto a street from an entrance ramp.

"Before" and "after" differences were then examined using chi-square analysis for the two pooled groups for seven behaviors: bicyclist slowed or stopped, motorist slowed or stopped, bicyclist used painted area, bicyclist turned head, bicyclist used hand signal, motorist used turn signal, and who yielded.

Table 2. "Before"/"after" comparison of bicyclist/motorist behavior—Who yielded.

Site 1	Bicyclist	Motorist	Total	
Before	2 (50.00)	2 (50.00)	4	
After	6 (19.35)	25 (80.65)	31	$P_F = 0.218$
Total	8	27	35	

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

Site 4	Bicyclist	Motorist	Total	
Before	30 (40.54)	44 (59.46)	74	
After	8 (27.59)	21 (72.41)	29	$P_C = 0.220$
Total	38	65	103	

Site 5	Bicyclist	Motorist	Total	
Before	0 (0.0)	18 (100.00)	18	
After	3 (10.71)	25 (89.29)	28	$P_F = 0.270$
Total	3	43	46	

Site 7	Bicyclist	Motorist	Total	
Before	7 (28.00)	18 (72.00)	25	
After	1 (2.56)	38 (97.44)	39	$P_F = 0.004$
Total	8	56	64	

Site 10	Bicyclist	Motorist	Total	
Before	4 (12.90)	27 (87.10)	31	
After	2 (2.33)	84 (97.67)	86	$P_F = 0.042$
Total	6	111	117	

Cochran-Mantel-Haenszel (CMH) overall test of general association, $\chi^2_{1df} = 8.744$, $p = 0.003$

Table 3. Comparisons of ten characteristics in the "before" period with their values in the "after" period.

1	Bicyclist age (one case < age16 and one case > age 64 were omitted): Results: Percentage in the 16-24 age range increased significantly at Site 1 (p =0.032). Otherwise some increased and some decreased. No overall change (p = 0.402).
2	Bicyclist gender: Results: Percentage of females decreased significantly (p = 0.001) at Site 9 and tended to be lower at many sites. Females decreased overall (p = 0.002).
3	Helmet use: Results: Marginal increase at Site 6 (p = 0.052). No overall change (p = 0.592).
4	Bicyclist followed recommended marked path: Results: Percentage of bicyclists following recommended marked path increased at Site 4 (p = 0.003) and Site 10 (p = 0.006), and decreased at Site 5 (p = 0.047) and Site 7 (p = 0.023). Overall increase (p = 0.021).
5	Bicyclist turned head: Results: Percentage turning head increased at Site 7 (p = 0.009), but decreased at Sites 9 and 10 (both p = 0.001). Overall decrease p = 0.001.
6	Bicyclist used hand gesture: Results: No significant changes.
7	Bicyclist slowed/stopped (all levels of slowed or stopped combined): Results: Percentage not slowing/stopping decreased at Sites 7 and 10 (p = 0.003 at each). Overall decrease in percentage slowing/stopping (p = 0.022).
8	Motorist used turn signal: Results: Percentage of motorists using turn signal increased at Site 5 (p = 0.010). No overall change (p = 0.593).
9	Motorist slowed/stopped (levels combined): Results: No significant changes.
10	Who yielded: Results: Percentage of times motorists yielded increased significantly for Sites 7 (p = 0.005) and 5 (p = 0.042). Overall increase in motorist yielding (p = 0.003).

For Group 1– Motor Vehicle Crosses to Exit Ramp:

11. The percentage of bicyclists using the painted area increased significantly in the "after"period.
12. The percentage of bicyclists turning their head to scan behind decreased significantly in the "after" period.
13. The percentage of bicyclists using a hand signal to indicate their movement decreased significantly in the "after" period.
14. The percentage of bicyclists slowing or stopping decreased significantly in the "after" period.
15. The percentage of motorists who yielded increased significantly in the "after" period.

For Group 2 – Motor Vehicle Crosses to Right-Turn Lane:

16. The percentage of bicyclists using the painted area decreased significantly in the "after" period. (This was primarily a function of bicyclists adjusting to make turning maneuvers at approaching intersections, more sidewalk riding, etc.)
17. The percentage of bicyclists turning their head to scan behind increased significantly in the "after" period.
18. The percentage of motorists using turn signals increased significantly in the "after" period.

For Group 3 – Motor Vehicle Crosses From Entrance Ramp:

19. The percentage of bicyclists using the painted area increased significantly in the "after" period.
20. The percentage of bicyclists turning their head to scan behind decreased significantly in the "after" period.
21. The percentage of bicyclists slowing or stopping decreased significantly in the "after" period.
22. The percentage of motorists who yielded increased significantly in the "after" period.

In summary, "before"-to-"after" changes in several bicyclist and motorist behaviors were assessed by examining the data at three levels of aggregation. At the most aggregated level, the data were pooled over all sites. Contingency tables were developed and the significance of "before"-to-"after" changes were tested using chi-square statistics. At an intermediate level, three groups of sites were identified as having similar geometrics. Group 1 (G1) consisted of Sites 1, 2, 3, and 4, where the bicycle tends to travel straight ahead and the motor vehicle crosses over the path of the bicyclist to exit the roadway, such as in an off-ramp situation. Group 2 (G2) consisted of Sites 5, 6, 7, and 8, where the bicycle travels straight ahead and the motor vehicle crosses over the path of the bicyclist to enter a right-turn lane. Group 3 (G3) consisted of Sites 9 and 10, where the motor vehicle was merging onto the street from a ramp. Again, the data were pooled over the sites within each group and chi-square tests were used to identify significant changes in behavior for each group. The third level of aggregation involved developing contingency tables for each site. Significant behavioral changes at a site were assessed by either a chi-square statistic or a Fisher's exact test when cell frequencies were too small. A Cochran-Mantel-Haenszel chi-square statistic was also computed to test for overall association across tables. This test is particularly sensitive to the consistency of relationships across the sites.

The results of these analyses are presented in table 4. An example of the site-by-site analysis was shown earlier in table 2.

Table 4. Summary of "before"-to-"after" changes in bicyclist/motorist behavior from three levels of analysis.

Behavior	Level of Analysis		
	Data Pooled Across Sites	Data Combined Into Three Groups	Site-by-Site CMH[1] Across Sites
1. Bicyclist helmet use	non-significant	non-significant	overall non-signif.
2. Bicyclist followed indicated path	increase in percentage following path	G1 - increase G2 - decrease G3 - increase	- increase at Sites 4 and10 - decrease at Sites 5 and 7 - overall increase
3. Bicyclist turned head	decrease in percentage turning head	G1 - decrease G2 - increase G3 - decrease	- increase at Site 7 - decrease at Sites 9 and 10 - overall decrease
4. Bicyclist used hand gesture	decrease in percentage using hand gesture	G1 - decrease G2 - non-signif. G3 - non-signif.	overall non-signif.
5. Bicyclist slowed or stopped	decrease in percentage slowing/stopping	G1 - decrease G2 - non-signif. G3 - decrease	- decrease at Sites 7 and 10 - overall decrease
6. Motorist used turn signal	decrease in percentage using turn signal	G1 - non-signif. G2 - increase G3 - no data	- increase at Site 5 - overall non-signif.
7. Motorist slowed or stopped	increase in percentage slowing/stopping	non-significant	overall non-signif.
8. Motorist yielded to bicyclist	increase in percentage yielding	G1 - increase G2 - non-signif. G3 - increase	- increase at Sites 7 and 10 - overall increase

[1] Cochran-Mantel-Haenszel chi-squared statistic.

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 bicyclist survey can be summarized as follows:

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

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

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

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

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

Overall, 76 percent felt that the locations with blue pavement were safer, 1 percent less safe, 9 percent no difference, and 13 percent were not sure. Typical positive comments were that motorists were more aware of the bike lanes, motorists paid more attention to bicyclists, the pavement made it clearer where bikes were supposed to go, and the defined area was respected by motorists. There were only a few negative comments to this question. One said that bicyclists were lulled into a false sense of security, and another said that the blue pavement was not reflective enough in low light and/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 it meant to "be careful." Of those that did not notice the sign, only 38 percent stated that the blue markings meant to "yield to bicyclists," while 43 percent responded that it meant to "be careful." When asked whether the blue markings made the conflict areas more or less safe, 49 percent thought it was safer, 20 percent the same, 12 percent less safe, and the remainder were not sure. Several of the motorists surveyed thought that 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 signing 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 in the United States.

Taken as a whole, these findings tend to point to safer conditions for bicyclists as a result of using blue pavement and novel signing 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 percentage of motorists yielding to bicyclists increased in the "after" period. However, there are some concerns. 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 a hand signal to indicate their movement through the conflict area, although the percentage using a signal 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 signing.

In opposition to this notion, however, are the findings with regard to conflicts between bicycles and motor vehicles. Although conflicts were rare, the rate of conflict 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 that: (1) the colored surfaces were no more slippery than before, (2) motorists were yielding to bicyclists more than before, and (3) 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 signing appear 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 into the potential utility of colored markings for bike-lane crossings. However, more evaluations of the use of colored pavement and signing should be performed and reported on to develop guidelines on when and where such applications are appropriate and the types of materials and colors that should be used. Further study is also needed as it relates to the potential impact of the signing separate from the blue markings. The study purposely did not attempt to separate these two elements. The City of Portland felt that it was crucial to provide a regulatory message (sign) along with the blue markings, because the use of the sign alone, given that it was specific to the new treatment, could have confused both bicyclists and motorists. The need to provide both the sign and markings was reinforced by the motorist survey, in which far more motorists who saw the sign correctly identified the meaning of the blue pavement. Finally, follow-on efforts are needed to determine the long-term effects of these treatments on both motorist and bicyclist behavior.

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