Evaluation of Shared Lane Markings

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FOREWORD

The Federal Highway Administration's (FHWA) Pedestrian and Bicycle Safety Research Program's overall goal is to increase pedestrian and bicycle safety and mobility. From safer crosswalks, sidewalks, and pedestrian technologies to growing educational and safety programs, the program strives to make it safer and easier for pedestrians, bicyclists, and drivers to share roadways in the future.

This study was part of a larger FHWA research study to quantify the effectiveness of engineering countermeasures in improving safety and operations for pedestrians and bicyclists. This particular project focused on applications of shared lane markings, particularly the sharrow design, for bicycles and motor vehicles that have not yet been comprehensively evaluated in terms of effectiveness. The effort involved data collection and analysis to determine whether the sharrows resulted in changes in positioning of bicycles and motor vehicles on roadways, as well an examination of their interactions.

This report is of interest to engineers, planners, and other practitioners who are concerned about implementing pedestrian and bicycle treatments as well as city, State, and local authorities who have a shared responsibility for public safety.

Monique R. Evans
Director, Office of Safety
Research and Development

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16. Abstract
Shared lane markings help convey to motorists and bicyclists that they must share the travel way on which they are operating. The purpose of the markings is to create improved conditions for bicycling by clarifying where bicyclists are expected to ride and to remind motorists to expect bicyclists on the road. The purpose of this study was to evaluate the impact of several uses of shared lane pavement markings, specifically the sharrow design, on operational and safety measures for bicyclists and motorists. Experiments were conducted in three cities. In Cambridge, MA, there was interest in experimenting with the placement of sharrows at a 10-ft spacing from the curb to prevent dooring from parked vehicles. In Chapel Hill, NC, sharrows were placed on a busy five-lane corridor with wide outside lanes and no parking. In Seattle, WA, sharrows were placed in the center of the lane on a downhill portion of a busy bicycle commuting street. Prior to the sharrows, a 5-ft bicycle lane was added to the uphill portion of the street in conjunction with shifting the center line. A variety of hypotheses were examined, and results were generally positive. Sharrows can be used in a variety of situations, and increased use should serve to raise motorist awareness of bicyclists or the possibility of bicyclists in the traffic stream. It is recommended that trials similar to those performed in this study be continued in other locations and traffic settings to improve guidance for users.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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CHAPTER 1. INTRODUCTION

BACKGROUND

Shared lane markings (also referred to as *sharrows*) help convey to motorists and bicyclists that they must share the roads on which they are operating. The purpose of the markings is to create improved conditions for bicyclists by clarifying where they are expected to ride and to remind motorists to expect bicyclists on the road. In the absence of bicycle lanes, motorists often neglect to safely share travel lanes with bicyclists, which can compel bicyclists to ride closer to parked motor vehicles. Such a scenario can result in a dooring crash if someone opens a vehicle door as the bicyclist passes. Also, when bicyclists stay to the far right in narrow travel lanes, passing motorists often track too closely to the bicyclists. This can be unnerving for bicyclists, leaving little margin for error, and sometimes leading to crashes.

In 2008, a recommendation was made by the National Committee on Uniform Traffic Control Devices (NCUTCD) to include shared lane markings in the next version of the *Manual on Uniform Traffic Control Devices* (MUTCD).[1,2] That recommendation was made with limited research conducted on an 11-ft spacing from the center of a shared lane marking to the curb.[3] A literature review uncovered no additional research on other spacing options. The 2009 edition of the MUTCD includes provisions for shared lane markings, specifically the sharrow design, with guidance that the markings should be placed at least 11 ft from the curb face or the edge of pavement on a street with parallel parking. Further, on streets with no parking and an outside lane less than 14-ft wide, the centers of the sharrows should be placed at least 4 ft from the curb or the edge of pavement.[1]

The purpose of this study was to evaluate the impact of several uses of shared lane markings, specifically sharrows, on operational and safety measures for bicyclists and motorists. The following hypotheses were explored for sharrows:

- The markings may help indicate a preferred travel path and thereby improve bicyclist positioning relative to parked motor vehicles when riding in shared lanes with on-street parking.

- The markings may help to improve spacing or operations when motorists pass bicyclists on streets both with and without parking.

- The markings could improve bicyclist positioning relative to the curb or other hazards along the roadway edge including unsafe drain grates or uneven pavement.

- The markings could be used in a situation where a bicyclist needs to take control of the lane, such as on a section of steep downgrade where more operating space is needed and there is not enough width to provide a sufficiently wide bicycle lane. Another such situation might be on a narrow lane where bicyclists need to move away from the door zone or other hazards.

- The markings may reduce wrong-way and sidewalk riding, which can cause collisions.

- The markings may increase the distance of motor vehicles in the travel lane from parked motor vehicles or from the curb or edge of pavement in the absence of bicyclists, thereby providing more operating space for bicyclists.

A technical drawing of the sharrow marking is depicted in figure 1.

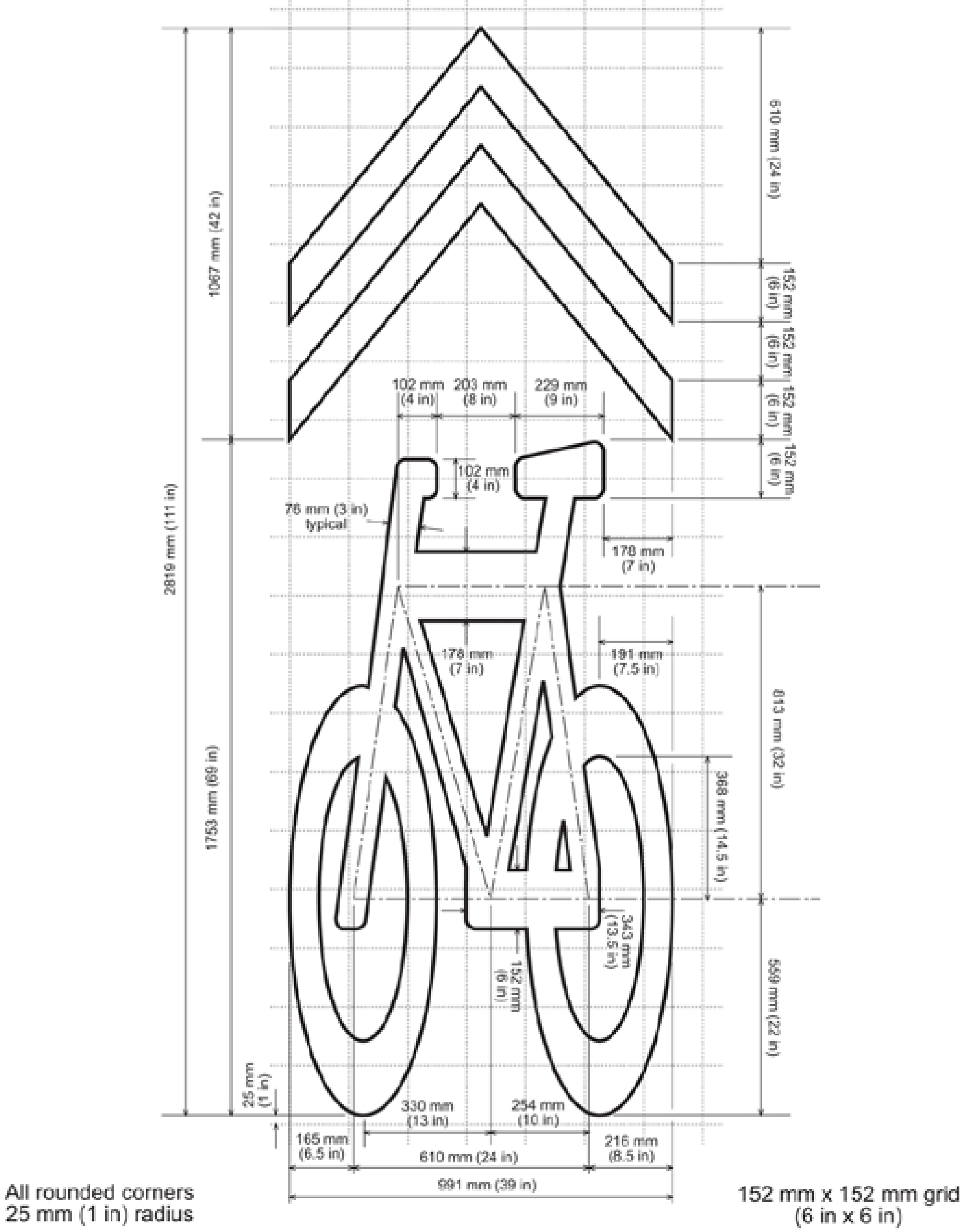


Figure 1. Illustration. Specifications for the sharrow from California MUTCD 2010.

EVOLUTION OF SHARED LANE MARKING DESIGNS

The original bike-in-house design that has been used or slightly modified in other locations for some time is shown in figure 2. This design was used in Gainesville, FL, in a wide curb lane situation and was previously evaluated by the Highway Safety Research Center (HSRC). It was found that the markings increased the safety margin for bicyclists riding near the curb. Additionally, sidewalk riding decreased.[4]

Figure 2. Photo. Bike-in-house marking.

The bike-in-house marking was modified to a bike-and-chevron marking, and the two designs were evaluated in San Francisco, CA. Superior results were associated with the bike-and-chevron marking shown in figure 3.[3] Based on feedback from bicyclists and motorists, the pitch on the chevrons was subsequently increased to resemble more of a directional guide. Given the results of the evaluation, the bike-and-chevron marking was added to the existing *2003 California Manual on Traffic Control Devices* through a policy directive in September 2005.[5] Additional evaluation detail is provided in chapter 2 of this report.

Figure 3. Photo. Bike-and-chevron marking.

NCUTCD issued a technical committee recommendation in January 2005 that proposed adding a shared lane marking section to part 9 of the MUTCD.[1,2] Afterward, the Bicycle Technical Committee of the NCUTCD recommended that this proposal be sent to the Federal Highway Administration (FHWA) in January 2007. The proposal suggested that shared lane markings should be used to prevent bicyclists from being struck by opened doors of parked motor vehicles (commonly referred to as *dooring*). Furthermore, it was recommended that the markings be placed 11 ft from the curb to encourage bicyclists to track over the markings and increase the distance between bicyclists and the door zone.

SITE SELECTION

At the beginning of the project, HSRC staff contacted communities who had expressed interest in evaluating different uses of sharrows. Staff visited Cambridge, MA; Portland, OR; and Seattle, WA, as well as local officials in Chapel Hill, NC. Based on the site visits, they sent a memorandum to FHWA recommending the following sharrow evaluations:

- Cambridge, MA: The sharrows would be placed 10 ft from the curb on a four-lane street with parking on both sides to determine if this location would improve spacing of bicycles and motor vehicles and also prevent dooring. The city has many street cross sections where the recommended 11-ft spacing from the curb would not be feasible.

- Chapel Hill, NC: The sharrows would be placed near the curb along the corridor of a busy street with a five-lane cross section (four travel lanes and a center two-way, left-turn lane) with no parking. The street had previously been resurfaced, and the outside lanes were marked nominally as 15-ft-wide lanes. Of primary interest would be the spacing of bicycles and motor vehicles from the curb and situations in which motor vehicles pass bicycles.

- Seattle, WA: The sharrows would be placed in the center of the lane on a downhill section of a two-lane street with parking on both sides. The placement was meant to encourage bicyclists to take the lane on the downhill section. The centerline of the street would also be repositioned to allow a 5-ft bicycle lane and a parking line to be installed on the uphill section of the street. Sharrows would be used in the downhill direction because there would not be enough space for bicycle lanes on both sides of the streets.

These recommendations were accepted by FHWA, and this report describes the sharrow evaluations for each location.

The actual design of the sharrow has been evolving, and figure 1 reflects the design used in Cambridge, MA, and Chapel Hill, NC. In Seattle, WA, a version that was a few inches longer was created and used in the evaluation. Figure 4 illustrates a generic sharrow as it appears in the 2009 version of the MUTCD.[(1)]

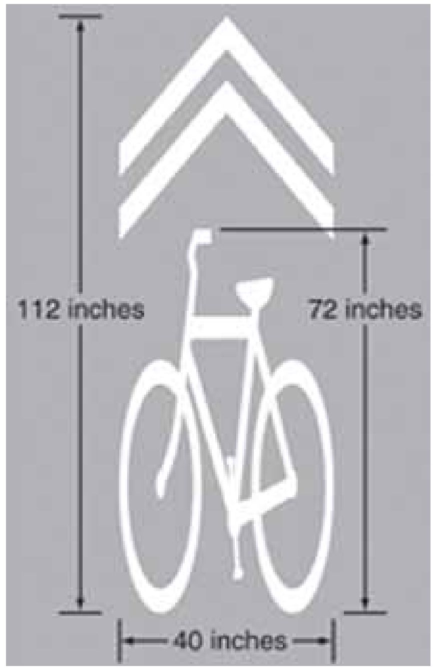


Figure 4. Illustration. Generic version of a sharrow.

CHAPTER 2. LITERATURE REVIEW

Many cities and States have started implementing shared lane markings to encourage the safe coexistence of bicycles and motor vehicles. However, few localities have formally evaluated the impact of these markings on safety or operations. The San Francisco Department of Parking and Traffic conducted an evaluation of the following two shared lane marking designs on streets with adjacent parallel parking: (1) a bike-in-house design and (2) a bike-and-chevron design.[3] First, researchers conducted assessments to determine appropriate spacing for bicyclists to be able to avoid the door zone, which is the area where bicyclists risk colliding with an open door of a parked vehicle. It was determined that the 85th percentile for the door zone extended 9.5 ft from the curb in the study areas (7 ft from curb edge to outside of vehicle and 2.5 ft occupied by an opened door). Thus, bicyclists needed to ride at least 30 inches from parked vehicles to be relatively safe from an opened door. The marking treatments were subsequently implemented with the center of the markings 11 ft from the curb face to suggest a bicycle tracking position. This distance was intended to accommodate the 85th percentile distance of door clearance (9.5 ft) plus 0.5 ft of shy distance (distance between the bicycle and nearest point of a motor vehicle beyond which the motor vehicle is not deemed to be an immediate hazard) and half of the average bicycle width (2 ft). The San Francisco, CA, study was a before-after evaluation where data were collected on six street segments before and after markings were introduced. Curb lane widths, including parking, ranged from about 17 to 19 ft on 4 four-lane roads, and the curb lane widths were 22 ft on 2 two-lane roads. Each of the streets had moderate (2,000–4,000 vehicles per lane per day) to heavy (more than 4,000 vehicles per lane per day) traffic. In each of these locations, the bike-in-house marking was painted along one side of the road, and the bike-and-chevron marking was painted on the other side. Both shared lane markings led to the following results:

- 25 to 35 percent fewer sidewalk riders.
- 3 to 4 inches more space between bicycles and parked vehicles.
- More than 2 ft of additional space between bicycles and passing motor vehicles in travel lanes.
- About 1 ft of additional space between motor vehicles in travel lanes and parked vehicles (no bicycles present).

There were also reductions in the proportions of wrong-way riders associated with the bike-and-chevron (similar to sharrow) design. Some potential confounding treatments were removed prior to the installation of the shared lane markings at two of the sites, but it is unknown whether these would have had an effect on before or after measurements and results. Because the bike-and-chevron marking was more readily understood by bicyclists to indicate a preferred travel path (although these conclusions were somewhat tenuous), this marking was the preferred choice and ultimately approved for inclusion in the *California Manual on Traffic Control Devices*.[5] Other agencies have since adapted the bike-and-chevron design with some minor modifications, although some are still employing the bike-in-house design.

Sidewalk and wrong-way bicycle riding have been overrepresented in collisions with motorists turning right on red, driving out at a midblock location, and proceeding through a junction.[6,7]

Hunter, Stewart, and Stutts found that both wrong-way riding and sidewalk riding were more prevalent at wide curb lane sites than at bicycle lane sites in a cross sectional study of operational factors and conflicts on the two types of facilities.(8) While the study was not conclusive regarding higher incidence of wrong-way riding at wide curb lane sites in general, markings that would reduce the incidence of wrong-way riding and sidewalk riding at wide curb lane sites could nevertheless enhance the safety of these facilities.

In the late 1990s, Pein, Hunter, and Stewart conducted a before-after study of a variant of the bike-in-house marking implemented on a four-lane high-volume (35,000 vehicles per day) arterial street with a 30-mi/h speed limit in Gainesville, FL.(4) The roadway had wide outside lanes 15 ft to the curb and no on-street parking. As a result, the lanes were wide enough to be shared side-by-side by bicycles and motor vehicles. However, a gutter pan had been paved over, and the 2-ft gutter pan area was included as part of the width of the outside lane. A seam 2 ft from the curb was present and conspicuous after the repaving, which influenced the decision of where to place the stencil. The center of the bike-in-house marking was placed 3.5 ft from the curb face, resulting in a 1.5-ft spacing from the old gutter pan seam. The marking was evaluated to determine whether it reinforced the correct direction of travel (with traffic) and reduced sidewalk riding by highlighting recognition of the wide outside lane as a bicycle facility. The other measures evaluated were the bicycle position from the curb, the space between overtaking motor vehicles and bicycles, and motor vehicle distance to the curb when no bicycles were present. Spacing distance of bicycles from the curb was measured with and without motor vehicles present in both periods. Potentially influential motor vehicles were present 82 percent of the time in the before period and 83 percent of the time in the after period.

There was a statistically significant increase in the proportion of bicyclists riding in the street in the correct direction (with traffic) from the before period (39 percent) to the after period (45 percent). Bicyclists riding in the street rode an average of 1.6 ft from the curb in the before period and 1.8 ft from the curb in the after period—a shift of about 3 inches. This change was statistically significant but not thought to be practically significant. However, there was also a larger proportion of bicyclists riding 1.75 to 2.5 ft from the curb, indicating that more bicyclists consequently had additional maneuvering space toward the curb in the event that motorists encroached into their space. This also potentially increased the comfort of bicyclists using the shared lane. Motorists allowed an average of approximately 1.5 inches additional space when passing bicyclists in the after period (6.1 ft) compared to the before period (6.0 ft); however, this difference was also not considered practically significant. The mean and median motor vehicle distance to the curb also increased slightly. Estimates of conflicts, adjacent lane encroachments, or motor vehicles completely changing lanes in order to pass were not studied in this evaluation.

Similar operational and spacing measures have been used in studies evaluating operational effects of bicycle lanes and wide curb lanes (without shared lane markings). It has generally been found both in comparative studies and before-after studies that the presence of a bicycle lane stripe reduces motor vehicle encroachment and increases tracking consistency for a given roadway width.(9–11) The studies also report small bicyclist shifts away from the roadway edge or parked vehicles.(11,12) The van Houten and Seiderman study examined the effects of sequential bicycle lane markings compared with a baseline of only a roadway center line and also found that there was less variability in bicycle tracking once the first bicycle lane stripe (toward the center line) was added.(12) It is possible that the use of shared lane markings would have effects on motorist tracking and encroachment as well as on bicyclist position and riding direction.

CHAPTER 3. METHODS

The experimental design was to collect data from bicycles and motor vehicles operating in the traffic stream before and after the installation of the sharrows. While it would have been advantageous to have used an experimental design with comparison data, no adequate comparison sites were available. This is often the case in bicycle safety studies because slight differences in traffic flow, grade, pavement surface, or some other variable can greatly influence outcomes related to the bicyclist. One way to possibly obtain a comparison site is to install a treatment on part of a route and to use the remainder as a comparison. However, when a community is installing a treatment, almost invariably, the desire is to install the treatment along the entire route where the cross section is continuous.

Videotape data were collected by local staff hired and trained by HSRC. A camera was set up on a tripod in line with the outside edge of a parked motor vehicle or the edge of the roadway to provide a clear view of oncoming bicycles and motor vehicles. Zooming was used to follow the bicycles for several hundred feet. Videotaping was performed on weekdays when it was not raining during various times of the day in Cambridge, MA, and Chapel Hill, NC, and at early morning commuting time in Seattle, WA.

Supplemental data were collected in Cambridge, MA, and Chapel Hill, NC. Radar was used in both cities to collect speeds of free-flowing motor vehicles before and after the placement of the sharrows. In addition, data collectors in Cambridge, MA, measured the distance from the curb for both the front and rear tires of parked motor vehicles. In Chapel Hill, NC, data collectors used a form to note instances of sidewalk riding and wrong-way riding. No supplemental data were gathered in Seattle, WA.

From the before and after videotape data, a number of measures of effectiveness and other attributes were coded. The bicycle was the basic unit of analysis. Coding of the videotapes was performed to obtain information about the bicyclists and to examine the operations of bicycles and motor vehicles when a motor vehicle was following or passing a bicycle. In Cambridge, MA, and Seattle, WA, events related to the presence of parked motor vehicles were also examined, such as existing open doors or near dooring events and motorists pulling in or out of parking spaces.

For each bicyclist included in the selected video clips, gender and helmet use were coded along with the direction of travel.

For motor vehicles, coding was performed for the following:

- Whether the motor vehicle was following, passing, other, etc.
- Whether the motor vehicle moved to the adjacent lane part way, all the way, or not at all.
- Whether the motor vehicle overtaking the bicyclist (following and passing, if applicable) did so safely (i.e., no dangerous slowing or abrupt movements).

For bicycles, coding was performed for the following:

- Whether the bicyclist rode over the sharrows (in the after period).
- Whether the bicyclist was near a parked car, near center of the lane, or in another position.
- Whether the bicyclist took control of the lane to prevent a motor vehicle from passing.
- Whether there was an interaction between a bicycle and a parked motor vehicle such as a dooring event (bicycle struck an opened door), near dooring event (door opened as bicycle was in close proximity), bicycle struck existing open door, a motorist pulling in or out of the parked position, etc.

The occurrence of avoidance maneuvers and conflicts between bicycles and motor vehicles was coded. An *avoidance maneuver* was defined as a change in speed or direction by either party to avoid the other, while a *conflict* was defined as a sudden change in speed or direction by either party to avoid the other. If a yielding event took place, the party that yielded was coded, such as a bicyclist slowing down and giving way to a motorist pulling out of a parking space or a motorist slowing and giving way to a bicyclist to move to the center of the lane.

Avoidance maneuvers by bicyclists were coded as follows:

- The bicyclist kept moving safely.
- The bicyclist kept moving unsafely.
- The bicyclist made no change.
- The bicyclist slowed and stopped pedaling.
- The bicyclist made a slight direction change (typically a slight lateral movement).
- The bicyclist used the brakes.
- The bicyclist made a major direction change (typically a rapid shift to avoid a motor vehicle, object, pavement discontinuity, etc.).
- The bicyclist made a full stop.
- Unsure whether the bicyclist made an avoidance maneuver.

Avoidance maneuvers by motorists were coded as follows:

- The motorist made no change.
- The motorist slowed down.
- The motorist made a slight direction change (typically a slight lateral movement).

- The motorist changed lanes.
- The motorist used the brakes.
- The motorist made a major direction change (typically a rapid shift to avoid a bicycle, another motor vehicle, object, pavement discontinuity, etc.).
- The motorist made a full stop.
- Unsure whether the motorist made an avoidance maneuver.

The following spacing data were also obtained from images extracted from the videotapes:

- Distance between bicycles and parked motor vehicles (tire to tire).
- Distance between bicycles and the curb at the edge of the road (tire to curb) where there was no parking.
- Distance between bicycles and passing motor vehicles (tire to tire).
- Distance between motor vehicles in the travel lane and parked motor vehicles (tire to tire) or to the curb (tire to curb) when no bicycles were present.

SigmaScan® software was used to examine images from the videotapes so that the spacing measures of interest could be obtained.[13] SigmaScan® uses a calibrator of known length or height to determine the spacing distance. In Cambridge, MA, and Seattle, WA, where parking was present on both sides of the street, four sets of 3-ft grid lines were painted on the street at 75-ft intervals. In Chapel Hill, NC, 36-inch traffic cones were placed on the sidewalk beside the roadway. Observation indicated that neither the grid lines nor the traffic cones had an effect on the position of the bicyclist in the street. Once the sharrows were installed, these markings also served as a calibrator.

Chi-square tests were performed to examine the distributions of variables before and after placement of the sharrows. Analysis of variance (ANOVA) models were used to study the effect of sharrows on spacing and other performance measures. The independent variables were site characteristics, type of treatment, and a dummy variable to indicate whether it was a before or after condition. The sign and significance of the coefficient of the dummy variable was used to assess the effectiveness of the markings. None of the data were combined across sites because of the differences in the uses of the sharrows in each city.

CHAPTER 4. CAMBRIDGE, MA, EXPERIMENT

INTRODUCTION

In Cambridge, MA, the experiment was a before-after evaluation of sharrows placed at a 10-ft spacing from the curb to help prevent dooring crashes with parked motor vehicles. The objective was to determine whether the 10-foot spacing would have a positive effect on where cyclists and motorists were positioned compared with no sharrows. Assuming parked vehicles use 7 ft of space, this placement would result in the center of the sharrows being 3 ft from the parked vehicles. The 10-ft spacing would determine whether an alternative to the 11-ft spacing recommended in the 2009 version of the MUTCD would be effective.(1) An 11-ft spacing assumes that a motorist will move around a bicyclist. However, in congested urban situations, motorists frequently are not able to move into an adjacent lane, so they may track over the sharrow at 11 ft from the curb, resulting in bicyclists not being able to see the sharrows, as well as the markings wearing away.

The experiment was conducted on Massachusetts Avenue, a four-lane divided street with approximately 29,000 vehicles per day, parallel parking on both sides of the street, and a speed limit of 30 mi/h. The street is a busy transit corridor, and parked motor vehicle turnover is frequent. The number of peak hour bicyclists ranges from approximately 150 bicyclists in the morning peak to 200 bicyclists in the evening peak. The sharrows were placed 10 ft from the curb with approximately 200 ft of spacing on both sides of the street over approximately 2,500 ft before and after the immediate vicinity of where data were being collected (near Lancaster and Garfield streets). Information on the sharrows and the study was discussed at the city's bicycle advisory committee, the Cambridge Bicycle Committee, and posted on the city Web site, but no other direct outreach was made to road users. Figure 5 shows a view of Massachusetts Avenue in the before condition, and figure 6 shows the typical cross section sketch of Massachusetts Avenue, representing the before and after conditions. The cross section for Massachusetts Avenue in the study area is variable and is a few inches wider in the outbound direction (away from Boston) near Garfield Street. Other than the addition of the sharrows, no changes were made to the street.

Figure 5. Photo. Massachusetts Avenue in the before condition.

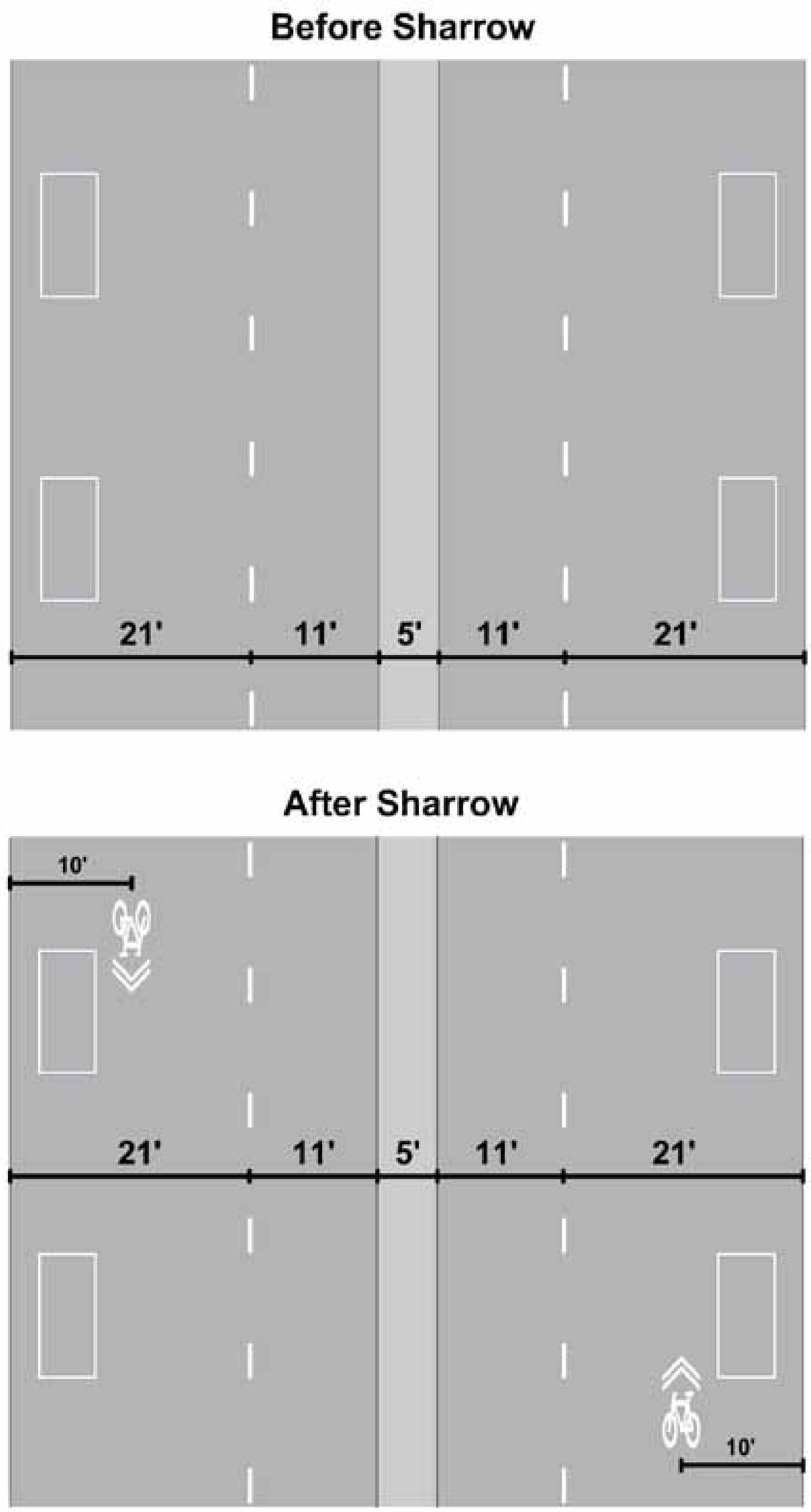


Figure 6. Illustration. Cross section view of Massachusetts Avenue before and after sharrow installation.

DATA COLLECTION AND REDUCTION

Local data collectors videotaped bicyclists riding along Massachusetts Avenue before and after placement of the sharrows along the street. Inbound traffic (toward Boston) was videotaped near Lancaster Street, and outbound traffic (away from Boston) was videotaped near Garfield Street. Videotaping was performed at various times of the day on weekdays when it was not raining. The before data were collected in fall 2007 and spring and summer 2008. The after data were collected in fall 2008. Overall, approximately 50 hours of videotape were collected.

Approximately 200 images were obtained from the videotapes for both the inbound and outbound directions for the following before and after conditions (total of more than 1,600 images): (1) bicycle to parked motor vehicle with a following motor vehicle present, (2) bicycle to parked motor vehicle with no following motor vehicle, (3) bicycle to passing motor vehicle, and (4) motor vehicle in the travel lane to parked motor vehicle with no bicycles present. All of these spatial measures were from tire to tire. SigmaScan® was used to examine images from the videotapes to determine the necessary spacing measures.[13]

Data for two other elements were also collected during the before and after periods. Free-flowing speeds of motor vehicle traffic were obtained with radar, and the distances from the curb for both the front and rear tires of parked motor vehicles were measured.

Besides obtaining the spacing images described previously, the videotapes were coded to collect information about the bicyclists and to examine the operations of bicycles and motor vehicles when a motor vehicle was following or passing a bicycle in the presence of parked motor vehicles, as well as interactions between bicycles and parked motor vehicles (e.g., existing open doors, near dooring events, or motorists pulling into or out of a parking space). Researchers systematically selected a pro rata share from each before and after videotape to accumulate the desired number of bicyclists and events, amounting to approximately 350 bicyclists in both the before and after periods and balanced by the inbound versus the outbound direction.

RESULTS

The results pertain to a number of variables and are derived from the spacing images extracted from the videotapes and from the coding of the bicycle and motor vehicle interactions. A total of 351 bicyclists followed by motorists or involved with parked motor vehicles were systematically selected in the before period, and 359 were selected in the after period. Bicyclist interactions with motorists were coded. Totals deviating from these numbers represent missing values, and chi-square tests were used to compare the distributions.

Bicyclist Data

Males accounted for 62 percent of the bicyclists, and females accounted for 38 percent. There was no difference in the before versus after periods. A total of 69 percent of bicyclists wore a helmet and 31 percent did not, and there was no difference in the before versus after periods.

Motor Vehicle Data

Table 1 shows the proximity of motor vehicles to bicycles by period. The table provides the frequencies with row and column percentages in parentheses. Such a table layout will be used throughout this report. In the before period, examination of the column percentages shows that 6 percent of motor vehicles were following bicycles, 73 percent were passing, and 21 percent were involved in another maneuver (the vast majority of which were parked vehicle events). In the after period, 14 percent of motor vehicles were following bicycles, 79 percent were passing, and 7 percent were involved in another maneuver. *Following* means that the motor vehicles did not attempt to overtake and pass the bicyclist, and *passing* means that the bicyclist was actually passed by the motor vehicle. The other parked vehicle events had a primary influence on the changes in this distribution. The differences were statistically significant ($p < 0.0001$).

Table 1. Motor vehicle proximity to bicycles, Cambridge, MA.

Motor Vehicle Proximity	Before Period	After Period	Total
Following	21 (6.0)[1]	51 (14.2)	72 (10.1)
Passing	256 (72.9)	284 (79.1)	540 (76.1)
Other	74 (21.1)	24 (6.7)	98 (13.8)
Total	351 (49.4)[2]	359 (50.6)	710 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Table 2 shows whether motor vehicles changed lanes when overtaking bicycles. In the before period, 11 percent of motor vehicles completely changed lanes, 37 percent moved partway into the next lane, 27 percent stayed in the lane behind the bicycle ("No movement"), and 24 percent were involved in a parked vehicle event ("Not applicable"). In the after period, 3 percent of motor vehicles completely changed lanes, 22 percent moved partway into the next lane, 65 percent stayed in the lane behind the bicycle, and 9 percent were involved in a parked vehicle event. The differences were statistically significant ($p < 0.0001$). When parked motor vehicle events were removed, the differences remained statistically significant ($p < 0.0001$).

Table 2. Motor vehicle lane changes, Cambridge, MA.

Method	Before Period	After Period	Total
Changed lanes	40 (11.4)[1]	11 (3.1)	51 (7.2)
Moved partway	131 (37.3)	80 (22.3)	211 (29.7)
No movement	95 (27.1)	235 (65.5)	330 (46.5)
Not applicable	85 (24.2)	33 (9.2)	118 (16.6)
Total	351 (49.4)[2]	359 (50.6)	710 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

In the before period, 94 percent of motor vehicle overtaking events were considered to be performed safely. In the after period, the percentage increased to 98 percent, and the differences were statistically significant ($p = 0.002$).

Bicycle Data

In the after period, 94 percent of bicyclists rode over the sharrows (see figure 7), 4 percent did not, and the position could not be determined for 1 percent of bicyclists.

Figure 7. Photo. Bicyclist riding over the sharrows.

In the before period, 8 percent of the bicyclists were considered to be near the center of the lane, and the percentage decreased to 5 percent in the after period. Similarly, 13 percent of the bicyclists were considered to have taken the lane (i.e., moved to a position so that a motor vehicle could not pass) in the before period, and the percentage decreased to 8 percent in the after period. The differences were statistically significant ($p = 0.0187$) and likely reflected the 94 percent of bicyclists who rode over the sharrow.

Table 3 shows the frequency of the distribution of parked motor vehicle events by period. Possible dooring events (i.e., the parked motor vehicle door was opened close to the time the bicyclist was passing) decreased from 4 percent in the before period to less than 1 percent in the after period. Figure 8 shows an example of a potential dooring event. Existing open doors decreased from 5 percent in the before period to 2 percent in the after period. Motor vehicles pulling into or out of parking spaces decreased from 11 percent in the before period to 4.5 percent in the after period. No parked vehicle events increased from 78 percent in the before period to 93 percent in the after period. There were no "other" events in the after period; most of these constituted double-parked motor vehicles in the before period. The differences were statistically significant ($p < 0.0001$).

Table 3. Parked motor vehicle events, Cambridge, MA.

Event	Before Period	After Period	Total
Existing open door	16 (4.6)[1]	8 (2.2)	24 (3.4)
Pulling in or out of parking space	39 (11.1)	16 (4.5)	55 (7.8)
Possible dooring	13 (3.7)	1 (0.3)	14 (2.0)
Other event	8 (2.3)	0 (0.0)	8 (1.1)
No parked motor vehicle events	275 (78.4)	334 (93.0)	609 (85.8)
Total	351 (49.4)[2]	359 (50.6)	710 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Figure 8. Photo. Potential dooring event.

Interactions Between Bicycles and Motor Vehicles

Table 4 shows the distributions of avoidance maneuvers and conflicts by period. In the before period, 76 percent of the bicycle-motor vehicle interactions resulted in avoidance maneuvers (change in speed or direction to avoid the other party), and less than 1 percent resulted in conflicts (sudden change in speed or direction to avoid the other party). Conversely, 37 percent of the interactions resulted in avoidance maneuvers, and less than 1 percent resulted in conflicts in the after period. Having neither an avoidance maneuver nor conflict (the "None" category) increased from 24 percent in the before period to 63 percent in the after period. Combining the avoidance maneuvers and conflicts and comparing them with "None" to produce a valid chi-square test shows that the differences were statistically significant ($p < 0.0001$). This indicates that there was a more segregated flow after placement of the sharrows, with less maneuvering between bicycles and motor vehicles.

Table 4. Avoidance maneuvers and conflicts, Cambridge, MA.

Interaction	Before Period	After Period	Total
Avoidance maneuver	266 (75.8)[1]	131 (36.5)	397 (55.9)
Conflict	2 (0.6)	3 (0.6)	5 (0.7)
None	83 (23.7)	225 (62.7)	308 (43.4)
Total	351 (49.4)[2]	359 (50.6)	710 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Table 5 shows the number of times bicyclists and motorists yielded in the before and after periods while interacting with each other. Bicyclist yielding (i.e., changed direction or speed to give way to a motor vehicle) decreased from 23 percent in the before period to 7 percent in the after period. Motorist yielding (i.e., changed direction or speed to give way to a bicycle) increased from 5 percent in the before period to 10 percent in the after period. The differences were statistically significant ($p < 0.0001$).

Table 5. Bicyclist and motorist yielding behavior, Cambridge, MA.

Yielding behavior	Before Period	After Period	Total
Bicyclist	80 (22.9)[1]	26 (7.3)	106 (15.0)
Motorist	19 (5.4)	34 (9.5)	53 (7.5)
Neither	251 (71.7)	298 (83.2)	549 (77.5)
Total	350 (49.4)[2]	358 (50.6)	708 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Table 6 shows the full distribution of bicyclist responses during their interaction with motorists by period. The coding scheme was described previously in chapter 3 of this report. Bicyclists were able to keep moving safely 90 percent of the time in the after period as compared to 73 percent in the before period. Slight direction changes (typically a slight lateral movement) decreased from 17 percent in the before period to 6 percent in the after period. Major direction changes (typically a rapid shift to avoid a motor vehicle, object, pavement discontinuity, etc.) decreased from 3 percent in the before period to less than 1 percent in the after period. Bicyclists continued riding unsafely in 2 percent of the after period interactions compared to less than 1 percent in the before period. Comparing the "Kept moving safely" responses and the "Slight direction change" responses with all other rows combined resulted in the distributions being statistically significant ($p < 0.0001$).

Table 6. Bicyclist responses during interactions with motor vehicles, Cambridge, MA.

Bicyclist Response	Before Period	After Period	Total
Kept moving safely	256 (73.1)[1]	322 (89.7)	578 (81.5)
Kept moving unsafely	2 (0.6)	7 (2.0)	9 (1.3)
Slowed, stops pedaling	14 (4.0)	4 (1.1)	18 (2.5)
Slight direction change	61 (17.4)	23 (6.4)	84 (11.9)
Major direction change	12 (3.4)	2 (0.6)	14 (2.0)
Full stop	3 (0.9)	1 (0.3)	4 (0.6)
Not applicable	2 (0.6)	0 (0.0)	2 (0.3)
Total	350 (49.4)[2]	359 (50.6)	709 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Table 7 shows the full distribution of motorist responses during their interaction with bicyclists by period. Motorists completely changed lanes in 12 percent of the interactions in the before period and 3 percent in the after period. Motorists had slight direction changes (typically a slight lateral movement) in 38 percent of the interactions in the before period and 22 percent in the after period. Motorists had no changes in 44 percent of the interactions in the before period and 65 percent in the after period. Motorists slowed in 5 percent of the interactions in the before period and 10 percent in the after period. Comparing the rows “Changed lanes,” “Slight direction change,” “No change,” and “Slows” with all other rows combined resulted in the distributions being statistically significant ($p < 0.0001$).

Table 7. Motorist responses during interactions with bicyclists, Cambridge, MA.

Motorist Response	Before Period	After Period	Total
Changed lanes	41 (11.7)[1]	11 (3.1)	52 (7.4)
Slight direction change	132 (37.7)	77 (21.6)	209 (29.6)
Brakes	1 (0.3)	0 (0.0)	1 (0.1)
Full stop	2 (0.6)	2 (0.6)	4 (0.6)
Major direction change, swerve	1 (0.3)	1 (0.3)	2 (0.3)
Slowed	19 (5.4)	35 (9.8)	54 (7.7)
No change	154 (44.0)	230 (64.6)	384 (54.4)
Total	350 (49.6)[2]	356 (50.4)	706 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Spacing Data

Bicycle to Parked Motor Vehicle

Assuming parked vehicles use 7 ft of space, placement of sharrows at 10 ft from the curb would result in the center of the sharrows being 3 ft from parked motor vehicles. This could potentially result in bicyclists riding near or within the approximate 30-inch door zone of parked motor vehicles. Table 8 shows the average spacing between bicycles in the travel lane and parked motor vehicles (tire to tire) along with the results of ANOVA that tested the differences in the average spacing. Researchers also looked at the percentage of spacing values within 30 and 40 inches to consider the effect of sharrows on the number of bicycles within or near the door zone.

Table 8. Bicycle to parked motor vehicle, Cambridge, MA.

Motor Vehicle Present	Direction	Analysis of Average Spacing				Analysis of the Percentage Within 30 inches				Analysis of the Percentage Within 40 inches				Number of Observations	
		Average Spacing (inches)		Results of ANOVA Test		Percent		Results of Chi-Square Test		Percent		Results of Chi-Square Test			
		Before	After	F(df1,df2)	*p*-Value	Before	After	Chi-Square	*p*-Value	Before	After	Chi-Square	*p*-Value	Before	After
Yes	Outbound and inbound	40.1	42.3	5.06 (1,406)	0.025	12.8	13.2	0.02	0.893	58.2	41.0	11.95	< 0.001	196	212
Yes	Outbound	42.7	43.1	0.07 (1,205)	0.791	8.0	11.2	0.61	0.434	44.0	38.3	0.69	0.434	100	107
Yes	Inbound	37.4	41.5	10.29 (1,199)	0.002	17.7	15.2	0.22	0.637	72.9	43.8	17.41	< 0.001	96	105
No	Outbound and inbound	45.8	45.0	0.35 (1,404)	0.553	5.5	11.2	4.24	0.039	37.5	44.7	2.15	0.143	200	206
No	Outbound	46.5	45.1	0.72 (1,203)	0.398	6.0	9.9	0.88	0.347	32.0	43.8	3.03	0.082	100	105
No	Inbound	45.1	44.9	0.01 (1,199)	0.931	5.0	12.9	3.82	0.051	43.0	45.5	0.13	0.716	100	101

Note: df indicates degree of freedom.

When a following motor vehicle was present, there was an increase in spacing of about 2 inches (from 40.1 to 42.3 inches) when data from both directions were combined. This increase was statistically significant ($p < 0.05$). However, most of this increase was for the inbound direction, where the increase was about 4 inches (from 37.4 to 41.5 inches). The percentage of spacing values within 40 inches decreased from about 58 to 41 percent when both directions were combined; thus, 59 percent of bicyclists were riding more than 40 inches from parked vehicles after sharrow placement. For the inbound direction, the percentage within 40 inches decreased from about 73 to 44 percent; thus, more than 56 percent were riding more than 40 inches from parked vehicles after sharrow placement. These percentage reductions were statistically significant. There was little change in the percentage with 30 inches.

When a motor vehicle was not present (i.e., bicyclists could choose their riding space), the change in average spacing between a bicyclist and a parked vehicle was negligible, approximately 45 inches before and after with outbound and inbound directions combined. The percentage of spacing values within 30 inches increased from 5.5 to 11.2 percent when data from both directions were combined, which was statistically significant. This may be a reflection of a number of bicyclists riding some distance from parked vehicles in the before period gravitating toward or riding over the sharrows in the after period. For the inbound direction, the percentage within 30 inches increased from 5.0 to 12.9 percent, which was statistically significant. When the percentage within 40 inches was examined, the outbound direction showed an increase from 32 to 43.8 percent, which was marginally significant ($p = 0.082$).

Bicycle to Passing Motor Vehicle

Table 9 shows the results from the analysis of spacing between bicycles and passing motor vehicles. Comparison of the mean spacing values showed little difference between the before and after periods (approximately 68 inches). In terms of direction, spacing for the inbound direction showed the largest increase in the after period (about 1.1 inches), but the change was not statistically significant. Additionally, in the inbound direction, the percentage of spacing values within 40 inches decreased from about 7 percent in the before period to 1 percent in the after period, and this difference was marginally significant ($p = 0.071$). None of the other changes was statistically significant.

Table 9. Bicycle to passing motor vehicle, Cambridge, MA.

	Analysis of Average Spacing				Analysis of the Percentage Within 40 inches				Analysis of the Percentage Within 50 inches					
	Average Spacing (inches)		Results of ANOVA Test		Percent		Results of Chi-Square Test		Percent		Results of Chi-Square Test		Number of Observations	
Direction	**Before**	**After**	**F(df1,df2)**	***p*-Value**	**Before**	**After**	**Chi-Square**	***p*-Value**	**Before**	**After**	**Chi-Square**	***p*-Value**	**Before**	**After**
Outbound and inbound	68.2	68.5	0.04 (1,438)	0.838	3.8	2.5	0.55	0.457	10.4	8.5	0.46	0.496	240	200
Outbound	68.7	68.3	0.05 (1,238)	0.823	1.4	4.0	0.70	0.402	7.1	9.0	0.74	0.390	140	100
Inbound	67.5	68.6	0.29 (1,198)	0.590	7.0	1.0	3.26	0.071	15.0	8.0	1.52	0.217	100	100

Note: df indicates degree of freedom.

Motor Vehicle in Travel Lane to Parked Motor Vehicle

Table 10 shows the results from the analysis of the spacing between motor vehicles in the travel lane and parked motor vehicles when no bicycles were present. The introduction of the sharrows seems to have been associated with a significant increase in this spacing. For both outbound and inbound directions combined, the spacing increased 14 inches (from 80.9 to 95.0 inches). The increase in spacing was more pronounced in the inbound direction with a shift of 16 inches away from parked vehicles (from 77.4 to 93.6 inches) compared to the outbound direction, which experienced a shift of 12 inches away from parked motor vehicles (from 84.5 to 96.5 inches). All of these differences were statistically significant ($p < 0.001$). This result demonstrates that the sharrows were effective in moving motor vehicles in the travel lane away from parked motor vehicles.

Table 10. Motor vehicles in travel lane to parked motor vehicles, Cambridge, MA.

	Average Spacing (inches)		Results of ANOVA Test		Number of Observations	
Direction	**Before**	**After**	**F(df1,df2)**	***p*-Value**	**Before**	**After**
Outbound and inbound	80.9	95.0	113.92(1,398)	< 0.001	200	200
Outbound	84.5	96.5	44.95(1,198)	< 0.001	100	100
Inbound	77.4	93.6	74.60(1,198)	< 0.001	100	100

Note: df indicates degree of freedom.

Distance between Tires of Parked Motor Vehicles and the Curb

Table 11 shows the results from the analysis of the distance between the back and front tires of parked motor vehicles and the curb. When both directions were combined, there was little change in the distance between the tires and the curb after the introduction of the sharrows. However, in the outbound direction, the distance between the back tire and the curb increased by an average of almost 2.3 inches, and this increase was statistically significant ($p = 0.038$). The distance between the front tire and the curb increased by about 1.3 inches, but this increase was not statistically significant. In the inbound direction, the distance between the back tire and the curb decreased by about 0.7 inches, and the distance between the front tire and the curb decreased by about 1.5 inches. These reductions in the inbound direction were not statistically significant.

Table 11. Distance between tire and curb, Cambridge, MA.

Direction	Distance Between Back Tire and Curb: Average Distance (inches) Before	Distance Between Back Tire and Curb: Average Distance (inches) After	Distance Between Back Tire and Curb: Results of ANOVA Test F(df1,df2)	Distance Between Back Tire and Curb: Results of ANOVA Test *p*-Value	Distance Between Front Tire and Curb: Average Distance (inches) Before	Distance Between Front Tire and Curb: Average Distance (inches) After	Distance Between Front Tire and Curb: Results of ANOVA Test F(df1,df2)	Distance Between Front Tire and Curb: Results of ANOVA Test *p*-Value	Number of Observations Before	Number of Observations After
Outbound and inbound	9.0	9.7	0.63(1,196)	0.430	9.2	9.0	0.07(1,196)	0.798	115	83
Outbound	8.1	10.4	4.45(1,84)	0.038	8.6	9.9	1.65(1,84)	0.203	46	40
Inbound	9.6	8.9	0.39(1,110)	0.534	9.7	8.2	1.53(1,110)	0.219	69	43

Note: df indicates degree of freedom.

Analysis of Speed Data

Table 12 shows the average speeds of motor vehicles before and after sharrows. When speed data from both directions were combined, the implementation of the sharrows was associated with about a 1.1-mi/h decrease in average speed. In the outbound direction, the reduction was about 2.7 mi/h, whereas in the inbound direction, there was an increase of about 0.5 mi/h.

Table 12. Average speeds before and after sharrows, Cambridge, MA.

Direction	Before: Average Speed (mi/h)	Before: Number of Observations	After: Average Speed (mi/h)	After: Number of Observations
Outbound and inbound	28.6	496	27.5	129
Outbound	30.0	246	27.3	73
Inbound	27.2	250	27.7	56

Figure 9 shows a histogram of the speed data for the before and after periods. The speed data in the before period is right-skewed. In the after period, the distribution is unusual and seems more like a modal distribution with one peak around 23 mi/h and another peak around 30 mi/h.

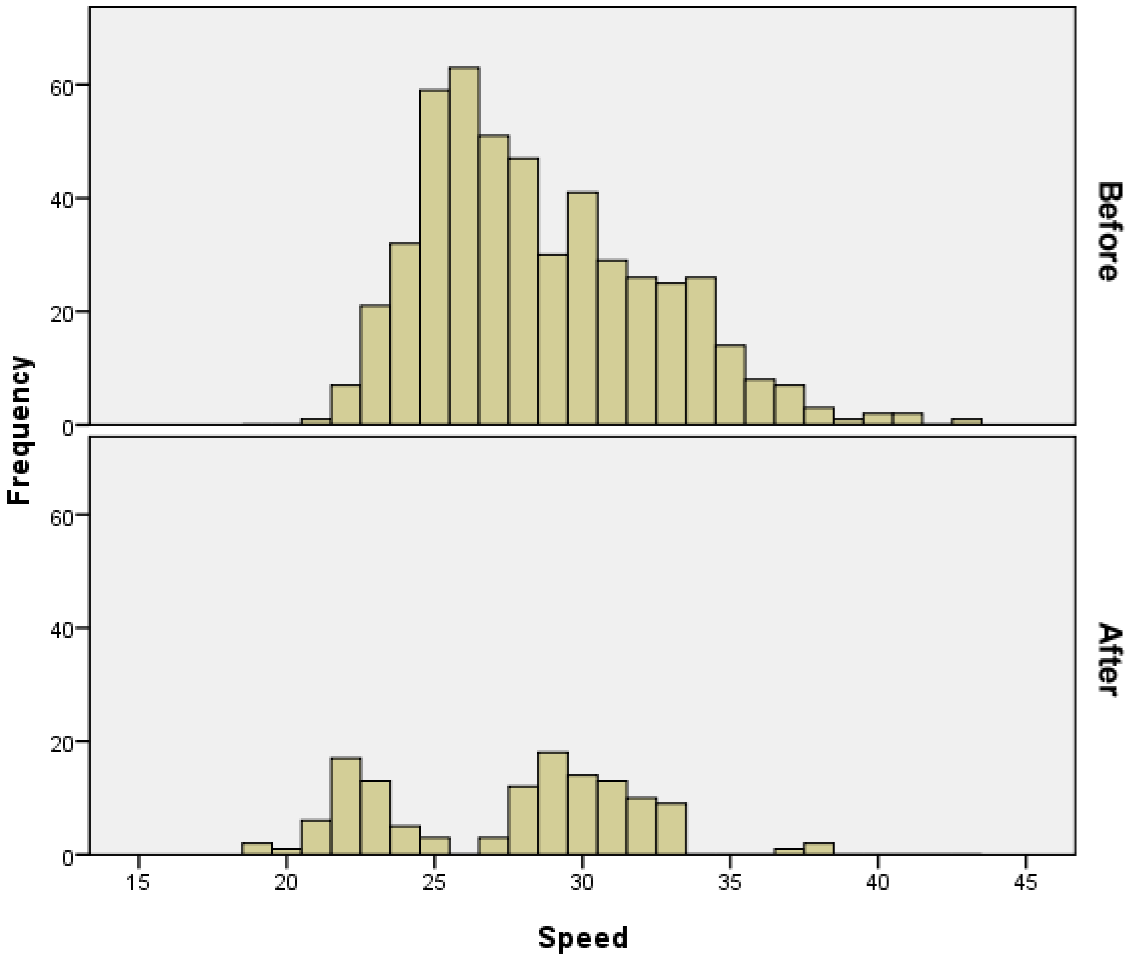


Figure 9. Graph. Speed data in Cambridge, MA.

For statistical analysis, the speed data were divided into three categories (0–25 mi/h, 26–31 mi/h, and > 30 mi/h) and examined through chi-square tests. The results shown in table 13 indicate that for the outbound and inbound combined row and separate outbound row, a larger percentage of speeds are in the first category (i.e., 0–25 mi/h) after the implementation of the sharrows. The chi-square tests confirmed that the distribution was indeed different in the after period in these two situations. This was not apparent until the data were analyzed near the end of the study, and another set of data was not collected. The speed distributions in the before and after periods for the inbound direction are much closer, and the chi-square test did not show a statistically significant difference.

Table 13. Analysis of speed data, Cambridge, MA.

Speed Category (mi/h)	Outbound and Inbound Direction				Outbound Direction				Inbound Direction			
	Before		After		Before		After		Before		After	
	Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	Percent
0–25	120	24.2	47	36.4	33	13.4	29	39.7	87	34.8	18	32.1
26–30	232	46.8	47	36.4	105	42.7	21	28.8	127	50.8	26	46.4
> 30	144	29.0	35	27.1	108	43.9	23	31.5	36	14.4	12	21.4
Total	496	100.0	129	100.0	246	100.0	73	100.0	250	100.0	56	100.0
Chi-square	8.322				24.918				1.71			
p-value	0.0156				< 0.0001				0.425			

SUMMARY

The following results include highlights from the data analysis of bicycles interacting with motor vehicles, comparing the after period to the before period:

- The percentage of motorists who made no movement to change lanes when overtaking a bicycle increased from 27 to 66 percent.
- The percentage of safe overtaking movements by motorists (approached and passed the bicyclist without difficulty) increased from 94 to 98 percent.
- A total of 94 percent of the bicyclists rode over the sharrows.
- The percentage of bicyclists who took the lane decreased from 13 to 8 percent.
- When a bicyclist was approaching, existing open vehicle doors decreased from 5 to 2 percent; opening of doors decreased from 4 to 0.3 percent, and motor vehicles pulling in or out of parking spaces decreased from 11 to 4.5 percent. No actual dooring events occurred in either the before or after period.
- The percentage of avoidance maneuvers decreased from 76 to 37 percent.
- The percentage of motor vehicles making no movement (i.e., continuing to follow) when following bicycles increased from 44 to 65 percent.
- The percentage of bicyclists who yielded (i.e., changed direction or speed to give way to a motor vehicle) decreased from 23 to 7 percent.
- The percentage of motorists who yielded (i.e., changed direction or speed to give way to a bicycle) increased from 5 to 10 percent.
- The percentage of bicyclists who kept moving safely increased from 73 to 90 percent.
- The percentage of bicyclists who made slight direction changes decreased from 17 to 6 percent.
- The percentage of motorists who made complete lane changes deceased from 12 to 3 percent.
- The percentage of motorists who made slight direction changes decreased from 38 to 22 percent.
- The percentage of motorists who slowed increased from 5 to 10 percent.
- The percentage of motorists who made no change while following a bicyclist increased from 44 to 65 percent.

All of these differences were independent of inbound and outbound direction. Taken together, the results portray a more segregated flow with less lateral movement of bicycles and motor vehicles.

Results from the spacing analysis in the *presence* of a following motor vehicle in the after period included the following:

- The distance from bicycles in the travel lane to parked motor vehicles increased from 40.1 to 42.3 inches when both directions were combined. For the inbound direction, the distance increased from 37.4 to 41.5 inches. For the outbound direction, the distance increased from 42.7 inches in the before period to 43.1 inches in the after period.

- The percentage of bicyclists who rode within 40 inches (near the door zone) of parked motor vehicles decreased, mostly in the inbound direction from 73 to 44 percent. The change in the outbound direction was from 44 percent in the before period to 38 percent in the after period.

- The percentage of bicyclists who rode within 30 inches (in the door zone) of parked vehicles showed no change (13 percent before and after).

In the *absence* of a following motor vehicle in the after period, spacing results were as follows:

- The change in distance between a bicyclist and a parked motor vehicle was negligible (approximately 45 inches before and after).

- The percentage of bicyclists who rode within 40 inches of parked motor vehicles increased from 37.5 to 45 percent, although this may reflect the high percentage of bicyclists gravitating toward or riding over the sharrow.

When motorists passed bicyclists in the after period, spacing results were as follows:

- The mean spacing values showed little difference (approximately 68 inches in the before and after periods).

- The overall percentage of spacing distance between passing motor vehicles and bicyclists within 40 inches decreased from 3.8 to 2.5 percent.

When motor vehicles in the travel lane tracked next to parked motor vehicles in the absence of bicycles in the after period, spacing results were as follows:

- The spacing increased 16 inches in the inbound direction (from 77.4 to 93.6 inches), increased 12 inches in the outbound direction (from 84.5 to 96.5 inches), and increased 14 inches combined (from 80.9 to 95.0 inches).

The distance between the tires of parked motor vehicles and the curb showed little change from the before period to the after period (approximately 9 inches before and after). However, in the outbound direction, the distance between the back tire and the curb increased by an average of 2.3 inches, and this increase was statistically significant ($p = 0.038$).

Overall, there appeared to be safety effects associated with the installation of the sharrows 10 ft from the curb on Massachusetts Avenue. Perhaps the most important effect was the 14-inch increase in spacing between motor vehicles in the travel lane and parked motor vehicles, which would increase the operating space for bicyclists. Other spacing results were variable. The distance from a bicycle in the travel lane to a parked motor vehicle increased, although the effect was present only in the inbound direction. The percentage of bicyclists who rode within 40 inches (near the door zone) of parked motor vehicles when a following motor vehicle was present decreased. When motorists passed bicyclists in the after period, the mean spacing values showed little difference, but the percentage of spacing distances within 40 inches decreased. The largest effects shown for the spacing variables were for the inbound direction. Even after review of data and discussions with the Cambridge staff, the reasons for the before-after differences in behavior between the two sides of the street were not immediately apparent. It is possible that the slightly wider street cross section in the outbound direction had an effect, as well as the increase in distance from the rear tire of parked motor vehicles to the curb.

A number of variables related to the interaction of bicycles and motor vehicles also showed positive effects. The overall results reflect more segregated flow with less lateral movement of bicycles and motor vehicles (see figure 10). The figure shows motor vehicles tracking behind each other while giving operating space to a bicyclist in the after period. It might be inferred that motorists in the after condition were traveling in a lane location to give bicyclists sufficient room and did not need to change lanes in order to pass safely.

Figure 10. Photo. Operating space for a bicyclist in the after period.

CHAPTER 5. CHAPEL HILL, NC, EXPERIMENT

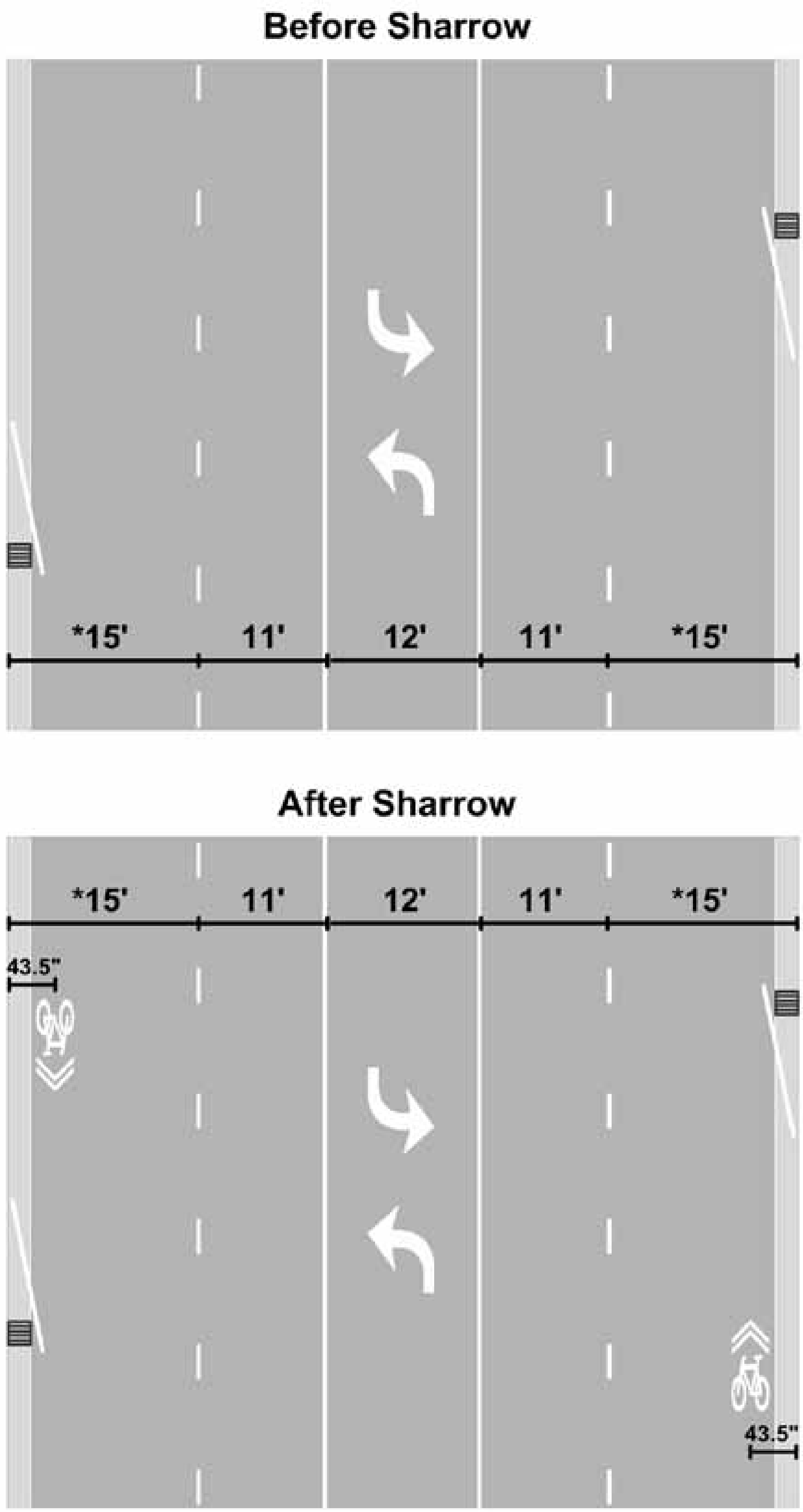
INTRODUCTION

In Chapel Hill, NC, sharrows were placed on Martin Luther King Jr. (MLK) Boulevard, which is a four-lane undivided route with a center, two-way left-turn lane. The route has no parking, 27,000 vehicles per day, and a speed limit of 35 mi/h. The street serves as a major corridor to the University of North Carolina (UNC) and has approximately 40–70 bicyclists per day. In previous counts, about one-third of the bicyclists were riding on the adjacent sidewalk. There is a 3 to 4 percent grade at the location where data were collected, allowing an examination of whether the effects of sharrows differ for downgrade and upgrade (see figure 11).

Figure 11. Photo. Outbound view of MLK Boulevard.

The MLK corridor serves several bus routes to campus and back. The outside lanes are nominally 15 ft wide, including a 2-ft gutter that was paved over when the street was resurfaced. Sunken 24-inch-wide drainage grates remain along the route, and there is some reemergence of a seam between the gutter pan area and the original travel lane (see figure 11). Each drainage grate is highlighted with a transverse marking; otherwise, there were no prior markings in the wide outside lane. These transverse markings were present throughout the study period. There are also sporadic "Share the Lane" signs along the corridor but none in the immediate area where data were collected.

Sharrows were placed 43.5 inches from the curb with approximate 200-ft spacing on both sides of a 1.25-mi corridor. Videotape data were collected at the midpoint of the corridor. Sketches of the cross section before and after installation are provided in figure 12.



* Indicates that a 2-ft gutter pan was included.

Figure 12. Illustration. Cross section view of MLK Boulevard before and after sharrow installation.

A variety of hypotheses were examined in this experiment. The sharrow placement served to identify a lane position for bicyclists that would place them outside of the drainage grate/gutter pan area and highlight that the lane was meant to be shared with motor vehicles. If bicyclists tracked over the middle of the sharrow, their placement would be 19–20 inches away from the drain grates. In addition to avoiding the unsafe drain grates, tracking further away from the curb could enhance bicyclists' visibility at junctions along the corridor and potentially provide greater space to maneuver when being overtaken by motorists. The sharrows might provide a cue for more consistent positioning or tracking, particularly if weaving around the drainage grates is present. The sharrows might also affect anticipation and interactions with overtaking motorists by promoting more consistent motor vehicle tracking, fewer sudden changes in speed or direction, and fewer unexpected encroachments into the adjacent lane that may result in conflicts with other motorists. However, tracking further from the curb could potentially place bicyclists closer to overtaking motorists if the motorists do not allow sufficient lateral spacing when passing.

In addition, sharrows could improve safety along this corridor by inducing more bicyclists to ride on the street with the flow of traffic compared to on the adjacent sidewalk or in the wrong direction. Frequent crashes occur between bicyclists riding on the sidewalk and motorists turning in and out of driveways and at intersections in this segment.

DATA COLLECTION AND REDUCTION

Local data collectors videotaped bicyclists riding along MLK Boulevard before and after placement of the sharrows along the street. Before data were collected from October 2007 through June 2008, and after data were collected from August 2008 through June 2009. Inbound (uphill) and outbound (downhill) traffic was videotaped at a midblock location south of Hillsborough Street. Videotaping was performed on weekdays when it was not raining. After videotaping was complete, SigmaScan® was used to examine images from the videotapes to determine the spacing measures.[13] Approximately 150–200 images were obtained for both the uphill and downhill directions for each condition. The categories of images included: (1) bicycle to curb without being affected by a following motor vehicle, (2) bicycle to passing motor vehicle, and (3) motor vehicle to curb with no bicycles present. The videotapes were also used to code other variables pertaining to the interactions of bicycles and motor vehicles.

Data for two other elements were also collected during the before and after periods. Free-flowing speeds of motor vehicle traffic were obtained with laser radar. In addition, counts of bicyclists according to riding position (in a travel lane or on the sidewalk) and by direction (in the direction of traffic or facing the flow of traffic) were obtained.

RESULTS

The results pertain to a number of variables and were derived from the spacing images extracted from the videotapes as well as from the coding of the bicycle and motor vehicle interactions. Because the bicycle counts were low, researchers extracted as many images as possible for the bicycle-to-curb category and obtained 155 in the before period and 191 in the after period. For the bicycle-to-passing motor vehicle category, researchers obtained 200 images in the before period and 195 in the after period as independent multiple motor vehicles sometimes passed the bicyclist. For the motor vehicle-to-curb category, researchers obtained 200 images for each period. When coding the interactions between bicycles and motor vehicles, researchers obtained 519 observations in the before period and 420 in the after period. Totals in the subsequent tables deviating from these numbers represent missing values. Chi-square tests were used to compare the distributions. The following sections pertain to the coded videotape data.

Direction of Travel

The number of bicyclists on the observed route was relatively low. For the coded videotape data pertaining to the interactions of bicycles and motor vehicles, the direction of travel was unbalanced (see table 14). In the before period, 48 percent of the interactions were uphill and 52 percent were downhill. In the after period, 59 percent of the interactions were uphill and 41 percent were downhill. These differences were statistically significant ($p = 0.0009$). The table reflects bicycle/motor vehicle interactions, and many bicyclists had multiple interactions with following or passing motor vehicles. Some of the differences could be a result of bicyclists needing more time to travel uphill for the inbound direction. Given more exposure, these bicyclists tend to be passed by more motor vehicles. The uphill versus downhill factor will be examined and described in subsequent tables where there were differences in the distributions.

Table 14. Direction of travel, Chapel Hill, NC.

Direction	Before Period	After Period	Total
Uphill	249 (48.2)[1]	248 (59.1)	497 (53.0)
Downhill	268 (51.8)	172 (41.0)	440 (47.0)
Total	517 (55.2)[2]	420 (44.8)	937 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Bicyclist Data

Males accounted for 86 percent of the bicyclists, and females accounted for 14 percent. Table 15 shows that there were differences in gender in the before period versus the after period ($p = 0.0371$). It is not known why the percentage of males increased in the after period, but it is believed that these differences were not related to the experiment. A total of 85 percent of bicyclists wore a helmet and 15 percent did not, and there was no difference in the before period versus the after period.

Table 15. Gender of bicyclists, Chapel Hill, NC.

Gender	Before Period	After Period	Total
Male	435 (83.8)[1]	372 (88.6)	807 (85.9)
Female	84 (16.2)	48 (11.4)	132 (14.1)
Total	519 (55.3)[2]	420 (44.7)	939 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

The percentage of female bicyclists decreased from 15 to 6 percent in the downhill direction, and the percentage of male bicyclists increased from 85 to 94 percent in the downhill direction from the before period to the after period ($p = 0.0085$).

Motor Vehicle Data

Table 16 shows the proximity of motor vehicles to bicycles by period. In the before period, 8 percent of motor vehicles followed bicycles (i.e., did not pass), and 92 percent passed. In the after period, 9 percent of motor vehicles followed bicycles, and 91 percent passed. The differences were not statistically significant ($p < 0.7092$). About 98 percent of the bicycles traveling uphill were passed.

Table 16. Motor vehicle proximity to bicycles, Chapel Hill, NC.

Motor Vehicle Proximity	Before Period	After Period	Total
Following	41 (7.9)[1]	36 (8.6)	77 (8.2)
Passing	478 (92.1)	384 (91.4)	862 (91.8)
Total	519 (55.3)[2]	420 (55.2)	939 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Table 17 shows whether motor vehicles changed lanes when overtaking bicycles. In the before period, 18 percent of motor vehicles completely changed lanes, 58 percent moved partway into the next lane, and 24 percent stayed in the lane behind the bicycle (“No movement”). In the after period, 17 percent of motor vehicles completely changed lanes, 52 percent moved partway into the next lane, and 32 percent stayed in the lane behind the bicycle. The differences were statistically significant ($p = 0.0409$).

Table 17. Motor vehicles that changed lanes, Chapel Hill, NC.

Method	Before Period	After Period	Total
Changed lanes	93 (17.9)[1]	70 (16.7)	163 (17.4)
Moved partway	300 (57.8)	217 (51.7)	517 (55.1)
No movement	126 (24.3)	133 (31.7)	259 (27.6)
Total	519 (55.3)[2]	420 (44.7)	939 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

For the downhill direction from the before to the after period, there were significant differences ($p = 0.0451$) as follows:

- The percentage of motor vehicles changing lanes increased from 17 to 21 percent.
- The percentage of motor vehicles staying in the lane behind the bicyclist increased from 26 to 34 percent.
- The percentage of motor vehicles moving partway into the next lane decreased from 57 to 45 percent.

The following uphill direction differences from the before period to the after period were not significant:

- The percentage of motor vehicles changing lanes decreased from 19 to 14 percent.
- The percentage of motor vehicles staying in the lane behind the bicyclist increased from 23 to 30 percent.
- The percentage of motor vehicles moving partway into the next lane decreased slightly from 58 to 56 percent.

Figure 13 shows a motor vehicle passing a bicycle when there is traffic in the adjacent lane after the sharrow was introduced.

Figure 13. Photo. Motor vehicle passing a bicycle after sharrow placement with traffic in the adjacent lane.

Table 18 presents data showing whether the motor vehicle overtaking event was considered safe (no sudden slowing or abrupt changes in trajectory). In the before period, 94 percent of the motor vehicle overtaking events were considered to be performed safely, 3 percent not safely, and a determination could not be made for 3 percent. In the after period, 96 percent of the motor vehicle overtaking events were considered to be performed safely, 1 percent not safely, and a determination could not be made for 3 percent. The differences were statistically significant (p = 0.0372).

Table 18. Safety of the overtaking motor vehicle, Chapel Hill, NC.

Safe Overtaking	Before Period	After Period	Total
Yes	488 (94.0)[1]	404 (96.2)	892 (95.0)
No	16 (3.1)	3 (0.7)	19 (2.0)
Unsure	15 (2.9)	13 (3.1)	28 (3.0)
Total	519 (55.3)[2]	420 (44.7)	939 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

For the downhill direction from the before period to the after period, there were also significant differences (p = 0.0233) as follows:

- The percentage of motor vehicles safely overtaking bicyclists increased slightly from 93 to 94 percent.
- The percentage of motor vehicles not overtaking safely decreased from 5 to 1 percent.

- The percentage of motor vehicles where overtaking was unsure increased from 2 to 5 percent.

The uphill direction differences from the before to the after period were not statistically significant, as follows:

- The percentage of motor vehicles safely overtaking bicyclists increased slightly from 96 to 98 percent.

- The percentage of motor vehicles not overtaking safely remained constant at less than 1 percent.

- The percentage of motor vehicles where overtaking was unsure decreased from 4 to 2 percent.

Bicycle Data

In the after period, 91 percent of the bicyclists rode over the sharrow, and 9 percent did not (see figure 14). The percentage of bicyclists who rode over the sharrow was 88 percent in the uphill direction and 97 percent in the downhill direction. In the uphill direction, the grade was such that the speed of the bicycle was relatively slow, and many bicyclists rode relatively close to the curb (see figure 15).

Figure 14. Photo. Bicyclists riding over the sharrow in the outbound (downhill) direction.

Figure 15. Photo. Bicyclist riding next to the sharrow in the inbound (uphill) direction.

In the before period, 98 percent of the bicyclists rode proximate to the curb (approximately 3 to 4 ft from the spacing data results to follow), and 2 percent rode near the center of the lane. In the after period, 99 percent of the bicyclists rode proximate to the curb, and 1 percent rode near the center of the lane. The differences were not significant. In the before period, 2 percent of the bicyclists were considered to have taken the lane (i.e., rode near the center of the lane in such a position where motor vehicles would most likely have to change lanes in order to pass), and in the after period, 1 percent of the bicyclists were considered to have taken the lane. The differences were not significant. Neither of these variables was affected by direction of travel.

Interactions Between Bicycles and Motor Vehicles

Table 19 shows the distributions of avoidance maneuvers and conflicts by period. In the before period, 81 percent of the bicycle/motor vehicle interactions resulted in avoidance maneuvers, and there were no conflicts. In the after period, 71 percent of the bicycle/motor vehicle interactions resulted in avoidance maneuvers, and there were no conflicts. The "None" category (no avoidance maneuvers or conflicts) increased from 19 percent in the before period to 29 percent in the after period. The differences were statistically significant ($p < 0.001$). These changes were consistent by direction of travel.

Table 19. Avoidance maneuvers, Chapel Hill, NC.

Interaction	Before Period	After Period	Total
Avoidance maneuver	419 (80.7)[1]	297 (70.7)	716 (76.3)
None	100 (19.3)	123 (29.3)	223 (23.8)
Total	519 (55.3)[2]	420 (44.7)	939 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Table 20 shows the number of times bicyclists and motorists yielded (changed direction or speed to give way to the other) in the before and after periods while interacting with each other. Bicyclists yielded only once in the before period and none in the after period. Motorist yielding decreased from 4 percent in the before period to 3 percent in the after period. Neither party yielded in 95 percent of the interactions in the before period and in 97 percent in the after period. Removing the single instance of bicyclist yielding indicated that the differences were not statistically significant ($p = 0.2034$). There were more instances of motorist yielding in the downhill direction, but there were no significant differences by direction.

Table 20. Bicyclist and motorist yielding behavior, Chapel Hill, NC.

Yielding Behavior	Before Period	After Period	Total
Bicyclist	1 (0.2)[1]	0 (0.0)	1 (0.1)
Motorist	23 (4.4)	12 (2.9)	35 3.7)
Neither	495 (95.4)	408 (97.1)	903 (96.2)
Total	519 (55.3)[2]	420 (55.3)	939 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Bicyclists rarely made any changes in riding behavior when interacting with motor vehicles. When riding in the downhill direction, bicyclists generally traveled at a reasonably fast speed and tracked in a consistent position in the roadway. In the uphill direction, the grade was such that many on-street bicyclists rode about 2 ft from the curb (just outside the drainage grate). Perhaps they did this to give them more space from overtaking motorists when they were traveling slowly. Thus, in virtually all interactions with motorists, bicyclists were coded as “kept moving safely.” There were no differences between the before or after periods or the direction of travel.

Table 21 shows the full distribution of motorist responses during their interaction with bicyclists by period. Motorists completely changed lanes in 18 percent of the interactions in the before period and 17 percent in the after period. Motorists had slight direction changes in 58 percent of the interactions in the before period and 51 percent in the after period. Motorists had no changes in 20 percent of the interactions in the before period and 29 percent in the after period. Motorists slowed in 4 percent of the interactions in the before period and 3 percent in the after period. The differences between the before and after periods were statistically significant ($p < 0.0110$).

Table 21. Motorist responses during interactions with bicyclists, Chapel Hill, NC.

Motorist Response	Before Period	After Period	Total
Changed lanes	94 (18.1)[1]	71 (16.9)	165 (17.6)
Slight direction change	299 (57.6)	214 (51.0)	513 (54.6)
Brakes	0 (0.0)	1 (0.2)	1 (0.1)
Slows	23 (4.4)	12 (2.9)	35 (3.7)
No change	103 (19.9)	122 (29.1)	225 (24.0)
Total	519 (55.3)[2]	420 (44.7)	939 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Examining this variable further by direction of travel showed significant differences ($p = 0.0350$) for the uphill direction as follows:

- Motorists changing lanes decreased from 20 to 14 percent.
- Motorists making slight direction changes (slight lateral movement) decreased from 57 to 56 percent.
- Motorists making no changes increased from 21 to 30 percent.
- Motorists slowing down decreased from 2 to 1 percent.

The differences from the before to the after period for the downhill direction were also statistically significant ($p = 0.0365$) as follows:

- Motorists changing lanes increased from 17 to 22 percent.
- Motorists making slight direction changes decreased from 58 to 44 percent.
- Motorists making no changes increased from 19 to 28 percent.
- Motorists slowing down remained unchanged at 6 percent.

There were occasions in these bicycle/motor vehicle interactions where a subsequent interaction occurred. All of these interactions involved a motorist in an adjacent lane reacting to a motor vehicle in the act of passing a bicycle encroaching, or tending to encroach, into the adjacent lane. There were 15 of these events in the before period and 3 in the after period. All but two of these were in the downhill direction. During these events, the motorist in the adjacent lane tended to slow down or make a direction change. These counts are likely conservative in that the videotape perspective did not always provide a clear view of interactions in adjacent lanes.

Spacing Measures

Bicycle to Curb

Table 22 shows the results from the analysis of the distance between bicycles and curbs when motor vehicles were not present. Overall, bicyclists rode closer to the curb after the sharrow was implemented. The reduction in spacing between the bicycle and curb was the highest in the downhill direction, with a decrease of 4.6 inches (from 47.1 to 42.5 inches), and this reduction was statistically significant ($p = 0.049$). This may reflect the large proportion of bicyclists who tracked over the sharrows. The reduction in spacing between the bicycle and the curb was 2.9 inches (from 35.2 to 32.3 inches) in the uphill direction.

When the percentage of bicyclists within 30 inches of the curb was examined, the combined uphill and downhill directions experienced a small and insignificant decrease in percentage in the after period that was due to an uneven number of values by direction. In the downhill direction, the percentage increased from 13 to 15 percent, and in the uphill direction, the percentage increased from 47 to 51 percent. None of these changes were statistically significant. In the uphill direction, the percentage riding within 24 inches of the curb, and thus within the spacing of the drain grates, decreased from 27 to 24 percent, while the proportion riding within 24 inches of the curb in the downhill direction increased from 4 to 5 percent (not shown in table and no significance tests). When the percentage within 40 inches was investigated, all three values experienced an increase, but only the percentage increase in the uphill direction approached statistical significance ($p = 0.057$). These results confirm the videotape coding that showed a lower percentage of bicyclists riding over the sharrow in the uphill direction.

Bicycle to Passing Motor Vehicle

Table 23 shows the results from the analysis of the average distance between bicycles and passing motor vehicles. The combined directions showed a small decrease in passing distance. However, after the introduction of the sharrow, the distance between bicycles and motor vehicles decreased 7 inches in the downhill direction, and the difference was significant ($p = 0.012$). There was no significant change in the uphill direction. The percentage within 50 inches showed only small and insignificant differences. The percentage within 60 inches increased from 8 to about 18 percent in the downhill direction in the after period. Again, there was essentially no difference in the uphill direction.

Table 22. Distance between bicycle and curb (motor vehicle not present), Chapel Hill, NC.

Direction	Analysis of Average Spacing: Average Spacing (inches)		Analysis of Average Spacing: Results of ANOVA Test		Analysis of the Percentage Within 30 inches: Percent		Analysis of the Percentage Within 30 inches: Results of Chi-Square Test		Analysis of the Percentage Within 40 inches: Percent		Analysis of the Percentage Within 40 inches: Results of Chi-Square Test		Number of Observations	
	Before	After	F(df1,df2)	*p*-Value	Before	After	Chi-Square	*p*-Value	Before	After	Chi-Square	*p*-Value	Before	After
Downhill and uphill	40.1	37.7	1.94(1,344)	0.165	32.9	31.9	0.04	0.850	60.0	65.4	1.09	0.297	155	191
Downhill	47.1	42.5	3.95(1,162)	0.049	12.5	15.0	0.20	0.653	37.5	46.0	1.15	0.283	64	100
Uphill	35.2	32.3	1.43(1,180)	0.233	47.3	50.5	0.20	0.656	75.8	86.8	3.62	0.057	91	91

Note: df indicates degree of freedom.

Table 23. Distance between bicycle and passing motor vehicle, Chapel Hill, NC.

Direction	Analysis of Average Spacing: Average Spacing (inches)		Analysis of Average Spacing: Results of ANOVA Test		Analysis of the Percentage Within 50 inches: Percent		Analysis of the Percentage Within 50 inches: Results of Chi-Square Test		Analysis of the Percentage Within 60 inches: Percent		Analysis of the Percentage Within 60 inches: Results of Chi-Square Test		Number of Observations	
	Before	After	F(df1,df2)	*p*-Value	Before	After	Chi-Square	*p*-Value	Before	After	Chi-Square	*p*-Value	Before	After
Downhill and uphill	82.3	79.4	2.33(1,393)	0.128	2.0	2.6	0.00	0.975	9.5	13.8	1.81	0.178	200	195
Downhill	84.7	77.7	6.48(1,193)	0.012	2.0	5.3	0.70	0.401	8.0	17.9	4.27	0.039	100	95
Uphill	80.0	81.1	0.19(1,198)	0.661	2.0	0.0	0.51	0.477	11.0	10.0	0.05	0.818	100	100

Note: df indicates degree of freedom.

Motor Vehicle in Travel Lane to Curb

Table 24 shows the results from the analysis of the distance of a motor vehicle in the travel lane and the curb. This distance increased about 7 inches when both directions were combined ($p < 0.001$). The more prominent increase was 8.3 inches in the uphill direction ($p < 0.001$). There was an increase of approximately 5 inches in the downhill direction ($p = 0.017$). The percentages within 50 and 60 inches were also significantly lower in the after period. The effect was most pronounced in the uphill direction. Figure 16 shows a typical view for the uphill direction.

Figure 16. Photo. Motor vehicle position in the uphill direction after the sharrow.

Table 24. Distance between motor vehicles in the travel lane and the curb, Chapel Hill, NC.

Direction	Analysis of Average Spacing				Analysis of the Percentage Within 50 inches				Analysis of the Percentage Within 60 inches				Number of Observations	
	Average Spacing (inches)		Results of ANOVA Test		Percent		Results of Chi-Square Test		Percent		Results of Chi-Square Test			
	Before	After	F(df1,df2)	*p*-Value	Before	After	Chi-Square	*p*-Value	Before	After	Chi-Square	*p*-Value	Before	After
Downhill and uphill	70.5	77.0	19.25(1,398)	<0.001	9.5	2.0	9.04	0.003	30.0	13.0	17.12	<0.001	200	200
Downhill	76.6	81.3	5.83(1,198)	0.017	3.0	0.0	1.35	0.245	14.0	9.0	1.23	0.268	100	100
Uphill	64.4	72.7	17.57(1,198)	<0.001	16.0	4.0	6.72	0.010	46.0	17.0	19.49	<0.001	100	100

Note: df indicates degree of freedom.

Analysis of Bicycle Riding on the Sidewalk

A possible effect of the sharrow is to shift bicyclists' riding on the sidewalk to riding on the roadway. In this corridor, sidewalk riding is particularly dangerous due to the large number of driveways (see figure 17).

Figure 17. Photo. Bicyclist interaction with motor vehicle at driveway.

Before the sharrow was installed, observations of bicyclists riding on sidewalks were made on seven different days in July and August 2008, with four morning observation periods and three afternoon observation periods. Bicyclists on both sides of the corridor were observed. After period observations were made on eight different days from September to November 2008 shortly after sharrow installation and on four additional days from October to November 2009 for a total of four morning and eight afternoon observation periods.

Table 25 shows that out of 290 observations for the entire study 33.8 percent of observed bicyclists were riding on the sidewalk while 66.2 percent were riding on the roadway in a travel lane. Most bicyclists, 90.3 percent, were observed to ride in the correct direction of traffic, while 9.7 percent rode against traffic. Of the 28 bicyclists riding against traffic, only 2 were observed to be in a travel lane at the time, and the remainder were on the sidewalk. Bicyclists are allowed to ride on the sidewalks along this corridor. There is at least one regulatory sign and markings posted on the shared walkway in some areas prohibiting wrong-direction riding, but they have not been well-maintained and seem to be largely ignored. The researchers were not aware that this prohibition had been enforced.

Table 25. Bicyclist position and direction observations for entire study period, Chapel Hill, NC.

Wrong Way	Number of Observations and Bicycle Position	Sidewalk		
		No	Yes	Total
No	Number of observations	190	72	262
	Percentage within wrong way	72.5	27.5	100.0
	Percentage within sidewalk	99.0	73.5	90.3[1]
Yes	Number of observations	2	26	28
	Percentage within wrong way	7.1	92.9	100.0
	Percentage within sidewalk	0.7	26.5	9.7
Total	Number of observations	192	98	290
	Percentage of total	66.2	33.8	100.0

[1] Row percent of total.

From the sample of observed bicyclists, 43 percent were riding on the sidewalk before the sharrows were installed compared with 23 percent who were riding on the sidewalk after sharrow installation (see table 26). A chi-square test of independence suggests that the sharrows had a significant influence on where bicyclists chose to ride. The difference in proportions was significant (chi-square or Cochran's test of conditional independence = 12.495, df1, $p < 0.001$)

Table 26. Sidewalk riding before and after sharrow installation (both directions), Chapel Hill, NC.

On Sidewalk	Before Period	After Period	Total
No	90 (57.0)[1]	97 (77.0)	187 (65.8)
Yes	68 (43.0)	29 (23.0)	97 (34.2)
Total	158 (55.6)[2]	126 (44.4)	284 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

While the number of downhill observations was equal, there were 35 percent less uphill observations in the after period than in the before period, Since there were an unequal number of observations and unequal proportions of sidewalk riders by direction, further analysis controlled for direction of travel. It was necessary to ensure that any apparent shifts in sidewalk and wrong-way riding were not associated only with this potential confounder.

Researchers examined whether there was an effect of travel direction on the risk factors of bicycle sidewalk and wrong-way riding. The percentages (before and after combined) and the proportions of riders in different locations (on the sidewalk versus street) are shown below. Riding with or against traffic were both significantly different than expected depending on whether the bicyclists were riding uphill or downhill.

Overall, before and after bicycle riding directions and positions were as follows:

Downhill (total number of observations, *n* = 166):

- In street in correct direction with traffic: *n* = 125 (75.3 percent).
- In street in wrong direction against traffic: *n* = 1 (0.6 percent).
- On sidewalk in correct direction with traffic: *n* = 36 (21.7 percent).
- On sidewalk in wrong direction against traffic, *n* = 4 (2.4 percent).

Uphill (total *n* = 124):

- In street in correct direction with traffic: *n* = 65 (52.4 percent).
- In street in wrong direction against traffic: *n* = 1 (0.8 percent).
- On sidewalk, in correct direction with traffic: *n* = 36 (29.0 percent).
- On sidewalk in wrong direction against traffic: *n* = 22 (17.7 percent).

Researchers analyzed the effects on sidewalk riding before and after sharrow installation within the direction of travel. Table 27 shows sidewalk bicyclists in the uphill and downhill directions for the before and after periods .

Table 27. Sidewalk riding before and after sharrow within travel direction, Chapel Hill, NC.

Direction	On Sidewalk	Before Period	After Period	Total
Downhill/ outbound	No	51 (61.4)[1]	75 (90.4)	126 (75.9)
	Yes	32 (38.6)	8 (9.6)	40 (24.1)
	Total	83 (50.0)	83 (50.0)	166 (100.0)
Uphill/ inbound	No	39 (52.0)	27 (55.1)	66 (52.9)
	Yes	36 (48.0)	22 (44.9)	58 (47.1)
	Total	75 (60.5)[2]	49 (39.5)	121 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

The overall difference in the proportions of sidewalk riding versus on-street riding was due to a significant decrease in the proportion of bicyclists riding on the sidewalk in the downhill direction from 39 percent in the before period to less than 10 percent in the after period. In the uphill direction, the proportion riding on the sidewalk declined from 48 to 45 percent following sharrow implementation, but the change was not statistically significant. (The most recent observations in 2009 showed even lower percentages riding on the sidewalk than in the after period as a whole, but the number of observations was small.)

The difference in proportions in the downhill direction was significant (chi-square = 18.971, $p = 0.000$). The difference in proportions in the uphill direction was not significant (chi-square = 0.115, df1, $p = 0.854$). (Cochran's test of conditional independence = 11.151, df1, $p = 0.001$.)

While all but two cases or 93 percent of wrong-way bicyclist riding occurred on sidewalks, it is conceivable that wrong-way riding could also have been affected by the sharrow treatment (e.g., if the directional arrows somehow influenced those riding on adjacent sidewalks to avoid wrong-direction riding). Table 28 illustrates overall results for wrong-direction riding in the before and after periods. The difference in proportions was not significant (chi-square or Cochran's test of conditional independence = 0.649, df1, $p = 0.420$).

Table 28. Wrong-way riding before and after sharrow installation (both directions), Chapel Hill, NC.

Wrong Way	Before	After	Total
No	141 (89.2)[1]	121 (91.7)	262 (90.3)
Yes	17 (10.8)	11 (8.3)	28 (9.7)
Total	158 (54.5)[2]	126 (45.5)	284 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Wrong-way bicycle riding occurred 8 percent of the time in the after period compared to 11 percent in the before period, but the differences were not significant. Thus, the null hypothesis that there is no association or effect of the sharrow on the proportions of wrong-way riding overall cannot be rejected.

Proportions of wrong-direction bicycling by the inbound versus outbound direction were also examined to ascertain whether there were differences in effect by direction. Table 29 shows that the number of wrong-direction bicyclists in both periods was small in the downhill direction. In the uphill direction, the proportion of wrong-direction riding was essentially the same for both periods, around 19–20 percent. Thus, the sharrows were not associated with a reduction in wrong-direction riding that occurred predominantly on the east sidewalk and uphill (results confirmed by Fisher's exact test).

Table 29. Wrong-way riding within travel direction, Chapel Hill, NC.

Direction	Wrong Way	Before Period	After Period	Total
Downhill/ Outbound	No	80 (96.4)[2]	81 (97.6)	161 (97.0)
	Yes	3 (3.6)	2 (2.4)	4 (3.0)
	Total	83 (50.9)[1]	80 (49.1)	163 (100.0)
Uphill/ Inbound	No	61 (81.3)[2]	37 (80.4)	98 (81.0)
	Yes	14 (18.7)	9 (19.6)	23 (19.0)
	Total	75 (62.0)[1]	46 (38.0)	121 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Analysis of Speed Data

Analyses of speed data were conducted from the before and after periods at two sharrow implementation locations (test sites) and at two locations along the same corridor where sharrows were not implemented (comparison sites). Data were collected at the same sites and directions in the before and after periods and at the same morning or afternoon time periods for each site. Although the sites did not match perfectly in terms of before-implementation speeds or geometric characteristics, comparison sites were used to control for unexpected time-related trends and for seasonality since before data were all collected in late winter (February to March 2008), and after data were collected in September 2009, which was nearly 1 year after sharrow implementation. Speeds were measured with laser radar for approximately 100 free-flowing vehicles (vehicles that were not part of a platoon or closely following other vehicles) at each location and study period except near Weaver Dairy Road, where two before period and one after period speed studies were conducted (see table 30).

Table 30. Results of laser speed studies (mi/h) before and after sharrow implementation, Chapel Hill, NC.

Type of Site	Street Locations	Period	Mean	*n*	Standard Deviation	Median	Minimum	Maximum
Sharrow sites	Hillsborough	Before	41.63	101	3.939	41.00	34	54
		After	42.29	105	4.028	43.00	32	51
		Total	41.97	206	3.988	42.00	32	54
	Longview	Before	41.82	98	5.010	41.00	30	61
		After	39.76	108	3.884	40.00	32	48
		Total	40.74	206	4.562	40.00	30	61
Comparison sites	Weaver Dairy	Before	43.41	205	4.551	43.00	34	55
		After	42.62	106	3.907	42.00	33	53
		Total	43.14	311	4.352	43.00	33	55
	Estes	Before	42.14	99	4.753	42.00	31	58
		After	44.24	103	4.541	44.00	34	56
		Total	43.21	202	4.753	43.00	31	58
Total		Before	42.50	503	4.624	42.00	30	61
		After	42.20	422	4.386	42.00	32	56
		Total	42.36	925	4.517	42.00	30	61

The Weaver Dairy comparison site had a raised median and bicycle lanes, while the Estes site was geometrically more similar to the sharrow implementation locations with a two-way center turn lane and wide outside lane configuration in one direction and a paved shoulder in the other. Although both comparison sites had higher initial speeds, the Estes site mean and median speeds were more similar to the sharrow implementation locations in the before period.

As the results from table 30 suggest, the speeds did not change by a large amount from the before to the after period. A univariate analysis of variance of speed was conducted to determine whether a significant speed reduction corresponding to the sharrow implementation occurred. Two models were examined: one included data from both comparable locations and the second included data only from the most similar location. The models incorporated an intercept term and dummy variables to indicate whether the location was a test location or a non-test location and for before and after periods. The interaction term of test location by before versus after periods is the primary term used to detect whether there was a significant change from the before to the after period for the sharrow locations versus the comparison groups.

There was a slight reduction of less than 1 mi/h in the locations where the sharrow was implemented and a slight overall increase of less than 1 mi/h at nonsharrow sites (see table 31). The reduction was not significant at the 95 percent confidence level when tested against both comparison sites (results shown in table 31). The reduction was significant at the 95 percent confidence level when compared with only the closer, more similar site (results not shown). The 0.7-mi/h reduction was attributable to a reduction at one location/direction (see Longview results in table 30), since mean speeds increased at the other site/direction.

Table 31. Comparison of before and after speeds (mi/h) at sharrow and comparison sites, Chapel Hill, NC.

Test	Period	Mean	Change in Mean	95 Percent Confidence Interval	Standard Deviation	*n*
Sharrow	Before	41.72	-0.72	41.108, 42.339	4.488	199
	After	41.00		40.410, 41.599	4.144	213
Comparison	Before	43.00	+0.42	42.502, 43.498	4.649	304
	After	43.42		42.821, 44.022	4.298	209
Total	Before	42.50	-0.16	41.97, 42.76	4.624	503
	After	42.20		41.79, 42.64	4.386	422

F-statistic = 3.733.
p = 0.054 for interaction of sharrow location by before/after periods.

SUMMARY

Results from the data analysis of bicycles interacting with motor vehicles in the after period as compared to the before period are highlighted as follows:

- There was no difference in the percentage of motorists following or passing bicyclists (about 92 percent passing for both the before and after periods).
- The percentage of motorists who made no movement to change lanes when overtaking a bicyclist increased from 24 to 32 percent.
- The percentage of safe overtaking movements by motorists (approached and passed the bicyclist without difficulty) increased slightly from 94 to 96 percent, and the percentage of overtaking movements considered unsafe decreased from 3 to 0.7 percent.
- A total of 91 percent of bicyclists rode over the sharrow, distributed as 97 percent in the downhill direction and 88 percent in the uphill direction.
- There was no difference in the proportion of bicyclists riding near the curb (approximately 98 percent) or taking the lane (approximately 2 percent).
- The percentage of avoidance maneuvers decreased from 81 to 71 percent.
- The percentage of motor vehicles staying in the lane when following bicycles increased from 20 to 29 percent.
- There was no change in the percentage of bicyclists or motorists who yielded (neither user yielded 96 percent of the time).

- The percentage of motorists who made slight lateral direction changes decreased from 58 to 51 percent with more effect in the downhill direction, which decreased from 58 to 44 percent.

- The percentage of motorists who changed lanes decreased from 20 to 14 percent in the uphill direction and increased from 17 to 22 percent in the downhill direction.

Results from the spacing analysis in the absence of motor vehicles included the following:

- Bicyclists rode closer to the curb after the sharrow by about 2.5 inches, a decrease from 40.1 to 37.7 inches. The effect was more pronounced downhill (4.6 inches closer) versus uphill (2.9 inches closer). As in the Cambridge, MA, experiment, this probably is a reflection of a high percentage of bicyclists tracking over the sharrow.

- There were slight increases in the percentage of bicyclists riding within 30 and 40 inches of the curb. Within 30 inches, the increase was from 12.5 to 15 percent in the downhill direction and from 47 to 50.5 percent in the uphill direction.

Results for when motor vehicles passed bicyclists in the after period were as follows:

- There was a small decrease in the passing distance overall from 82 to 79 inches. In the downhill direction, the motor vehicles passed 7 inches closer to bicycles (from 84.7 to 77.7 inches). In the uphill direction, there was very little change (from 80.0 to 81.1 inches).

- The percentage of passing motor vehicles within 50 inches showed only small and insignificant differences (from 2.0 to 2.6 percent).

Results for when the distance of motor vehicles from the curb in the absence of bicycles was examined in the after period were as follows:

- The spacing increased 8.3 inches (from 64.4 to 72.7 inches) in the uphill direction, almost 5 inches in the downhill direction (from 76.6 to 81.3 inches), and 7 inches overall (from 70.5 to 77.0 inches).

- The percentages of motor vehicle right front tires within 50 and 60 inches of the curb were also significantly lower in the after period. The effect was most pronounced in the uphill direction with reductions from 16 to 4 percent within 50 inches and from 46 to 17 percent within 60 inches.

- Sidewalk riding significantly decreased from 43 percent in the before period to 23 percent in the after period. In the downhill direction, the reduction was from 39 to 10 percent. There was no significant change in the uphill direction.

- Wrong-way riding by bicyclists occurred 11 percent of the time in the before period and 8 percent of the time in the after period, and the change was not statistically significant.

Results from the motor vehicle speed data showed a slight reduction of less than 1 mi/h in the locations where the sharrow was implemented and a slight overall increase of less than 1 mi/h in the nonsharrow sites. Thus, the sharrows may have had a slight influence on motorist speeds, although it is debatable whether this is practically significant.

By examining the findings listed above, it is evident that the percent grade of the roadway had an effect on a variety of the outcomes. The downgrade resulted in bicyclists traveling closer to the speed of motor vehicles and riding in a location somewhat further from the curb. The uphill grade resulted in slower moving bicyclists riding closer to the curb and an increase in passing motor vehicles.

In the downhill direction, more motorists changed lanes completely (an increase from 17 to 21 percent) or remained in position and tracked in the outside lane (an increase from 26 to 34 percent) when overtaking bicyclists in the after period. The proportion of motorists making slight directional shifts decreased from 58 to 44 percent. A lower percentage of motorists changed lanes completely in the uphill direction (a decrease from 19 to 14 percent). The percentage of motorists staying in the lane behind bicyclists increased from 23 to 30 percent, and the percentage moving partway decreased slightly from 58 to 56 percent.

Mean bicyclist position (in the absence of motor vehicles) shifted toward the curb by about 5 inches in the downhill direction and by about 3 inches in the uphill direction. The grade of the street seemed to make a difference in bicyclist positioning. About 97 percent of bicyclists rode over the sharrow in the downhill direction compared to 88 percent in the uphill direction. The mean spacing to the curb in the downhill direction is almost identical to the distance of the center of the sharrow from the curb. Going uphill, there was a tendency for bicyclists to ride closer to the curb, with about 20 percent riding within 24 inches of the curb in the after period. The latter result suggests that these bicyclists would need to shift around the drain grates as they climbed the hill, a factor that could influence interactions with overtaking motorists; however, there was little indication of this being a factor when interactions were coded, probably because motorists were, on average, tracking further from the curb.

Although bicyclists overall rode closer to the curb, the motorist lateral passing distance (using only those motorists at least partly in the adjacent lane) to bicyclists decreased by 7 inches in the downhill direction but remained essentially the same with an increase of 1 inch in the uphill direction. This is a function of changes in motorist tracking and maneuvering near bicyclists in the after period. The difference by direction is probably due to the smaller decrease in proportion of motorists shifting partway to the adjacent lane and the closer positioning of bicyclists to the curb in the uphill direction. Thus, bicyclists may have been passed more frequently by motor vehicles remaining in the outside lane in the uphill direction but were passed at a similar spacing as before, whereas motorists may have passed bicyclists less frequently (in the same lane) in the downhill direction but passed somewhat more closely when doing so.

The percentage of bicyclists riding on the sidewalk decreased from 39 percent to less than 10 percent in the downhill direction but did not change appreciably in the uphill direction (45 to 48 percent from the before period to the after period). The shift of more bicyclists riding on the roadway as well as the placement of the sharrow could have contributed to the overall bicyclist shift toward the curb, with perhaps less experienced bicyclists being less likely to ride further out. Bicyclists riding uphill tended to ride more frequently near or within the drain grate area, and there was little shift in this tendency from the before period to the after period. Likewise, the proportion of riders traveling on the sidewalk in the uphill direction did not change significantly.

Thus, results suggest that the sharrows provided some possible enhancement to the safety of bicyclists in several ways. Sharrow installation increased the percentage of bicyclists who rode on the roadway, which would place the bicyclists in a more expected position with respect to motor vehicles entering and exiting the corridor. The sharrows also enhanced recognition of riding space for bicyclists. Motorists drove 7 inches farther from the curb overall after the sharrows, and there was a decrease in the proportion of motorists driving within 50 inches of the curb in both directions (3 percent change downhill and 12 percent change uphill). However, due to shifts in the observed percentage of motorists shifting laterally (excluding those changing lanes entirely), motorists passed bicyclists 3 inches closer on average in the after period and 7 inches closer in the downhill direction. Again, this measure excludes motor vehicles that changed lanes completely, which increased somewhat in the after period. These results may indicate a smoother operating traffic stream, particularly from a motor vehicle perspective, with more motorists feeling comfortable passing bicyclists within the outside lane if they did not opt to change lanes completely. However, the comfort level of bicyclists being passed may have decreased as a result of this. Data are not available on bicyclists' perceptions of the passing distance used by motorists to verify this conjecture. As noted, only about 5 percent of motorists passed within 50 inches of bicyclists downhill, where bicyclists were about 10 inches further from the curb on average when compared to the uphill direction. No motorists were observed passing within 50 inches in the uphill direction.

Operations and safety appear to have improved in the downhill direction. The impact for bicyclists commuting uphill along this corridor is less clear, because they tended to travel closer to the curb. The result of this would be less operating space when interacting with motor vehicles. On the other hand, motorists traveling uphill tended to travel further from the curb after sharrow placement, which would increase operating space for bicyclists.

CHAPTER 6. SEATTLE, WA, EXPERIMENT

INTRODUCTION

Seattle, WA, is in the process of placing sharrows as approved in the bicycle plan adopted in fall 2007. Based on this plan, the city is expected to have up to 100 mi of streets with sharrows in a variety of situations. Some streets have the sharrows on both sides of the street, including sharrows to prevent dooring from parked vehicles. The city was interested in experimenting with placing sharrows in the center of the lane on a downhill portion (3.6 percent grade) of Fremont Street, a popular street for bicycle commuters. Fremont Street is a two-lane street with parking on both sides, a speed limit of 30 mi/h, and approximately 10,000 vehicles per day (see figure 18). The distance from the curb to the centerline was 20 ft on both sides. Sharrows had previously been installed at the traditional 11-ft spacing from the curb on a four-lane section of the street with parking on both sides for approximately 2,000 ft prior to this downhill section.

Figure 18. Photo. Fremont Street in the before condition.

The remainder of the street change was to shift the center line of the street and to place a 5-ft bicycle lane on the uphill portion of the street (right side of figure 18). Parking would remain on both sides of the street. Since bicycles travel close to the same speed as motor vehicles on the downgrade (left side of figure 18), the hypothesis was that placing the sharrow in the center of the lane would potentially encourage bicyclists to take the lane, removing them from the door zone.

The cross section changes are shown in figure 19. In after period 1, the bike lane including a parking stripe was added, and the center line of the street was shifted approximately 2.5 ft to the left. In after period 2, the sharrows were installed 12.25 ft from the curb and spaced 100 to 200 ft (varied due to intersecting side streets) over approximately 1,000 ft between N 46th and N 42nd streets. The city also added a parking stripe along the downhill side, although this was not part of the original experiment. Parking turnover is infrequent on the street in the early morning hours when the data were collected. No public educational information was provided regarding sharrow placement.

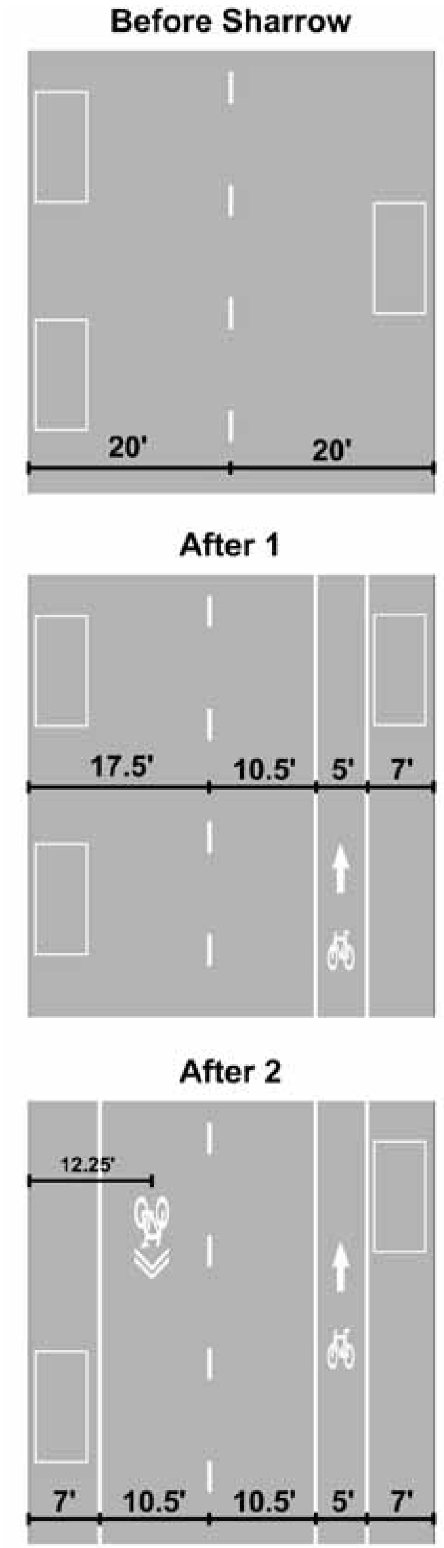


Figure 19. Illustration. Cross section view of Fremont Street before and after sharrow installation.

DATA COLLECTION AND REDUCTION

Local data collectors videotaped bicyclists riding along Fremont Street during three time periods: (1) from June to August 2008 before any changes were made to the street, (2) from September to November 2008 after moving the centerline 2.5 ft to the left and placing the bicycle lane in the uphill direction (see figure 19, After 1), and (3) from June to July 2009 after sharrow installation in the downhill direction. Downhill traffic was videotaped at a midblock location south of N 46th Street. Videotaping was performed on weekdays when it was not raining during early morning commute times. After the videotaping was complete, SigmaScan® was used to examine images from the videotapes to determine the spacing measures of interest.(13) Approximately 150–200 images were obtained for the downhill direction for the three conditions. The categories of images were as follows: (1) bicycle to parked vehicle without being affected by a following motor vehicle and (2) passing motor vehicle to parked motor vehicle with no bicycles present. It was rare for motor vehicles to pass bicycles on this downhill section; thus, the distance between bicycles and passing motor vehicles was not obtained. The videotapes were also used to code other variables pertaining to the interactions of bicycles and motor vehicles.

RESULTS

The results pertain to a number of variables and are derived from the spacing images extracted from the videotapes as well as from the coding of the bicycle and motor vehicle interactions. Weather was a factor in the data collection, and less time was spent collecting data during after period 1. However, approximately 130–240 images were extracted for each of the three phases for a total of 411 images. When coding the interactions between bicycles and motor vehicles, researchers obtained 153 observations in the before period, 108 in after period 1, and 150 in after period 2. Totals in the subsequent tables deviating from these numbers represent missing values. Chi-square tests were used to compare the distributions.

Bicyclist Data

Table 32 shows the gender of bicyclists by period. Overall, 77 percent of the bicyclists were male, and 23 percent were female. There were no differences by period. Helmet use was 99 to 100 percent in each period.

Table 32. Gender of bicyclists, Seattle, WA.

Gender	Before Period	After Period 1	After Period 2	Total
Male	118 (77.1)[1]	83 (76.9)	115 (76.7)	316 (76.9)
Female	35 (22.9)	25 (23.2)	35 (23.3)	95 (23.1)
Total	153 (37.2)[2]	108 (26.3)	150 (36.5)	411 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Motor Vehicle Data

Table 33 shows the proximity of motor vehicles to bicycles. Overall, 62 percent of motor vehicles were following bicycles, 35 percent were passing, and 3 percent were involved in another movement (e.g., a parked motor vehicle event). The differences were not statistically significant.

Table 33. Motor vehicle proximity to bicycles, Seattle, WA.

Proximity	Before Period	After Period 1	After Period 2	Total
Following	85 (55.6)[1]	75 (69.4)	95 (63.3)	255 (62.0)
Passing	61 (39.9)[1]	31 (28.7)	52 (34.7)	144 (35.0)
Other	7 (4.6)[1]	2 (1.9)	3 (2.0)	12 (2.9)
Total	153 (37.2)[2]	108 (26.3)	150 (36.5)	411 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Table 34 shows whether motor vehicles changed lanes when overtaking bicycles. Overall, less than 1 percent of motor vehicles completely changed lanes, 30 percent moved partway into the next lane, 67 percent stayed in the lane behind the bicycle (no movement), and 3 percent were involved in a parked vehicle event ("Not applicable"). Comparing "Moved partway" versus "No movement" for a valid chi-square test showed that the differences were not statistically significant.

Table 34. Motor vehicle changed lanes, Seattle, WA.

Method	Before Period	After Period 1	After Period 2	Total
Changed lanes	0 (0.0)[1]	0 (0.0)	2 (1.3)	2 (0.5)
Moved partway	40 (26.1)	33 (30.6)	49 (32.7)	122 (29.7)
No movement	105 (68.6)	73 (67.6)	97 (64.7)	275 (66.9)
Not applicable	8 (5.2)	2 (1.9)	2 (1.3)	12 (2.9)
Total	153 (37.2)[2]	108 (26.3)	150 (36.5)	411 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Overall, 97 percent of motor vehicle overtaking events were considered to be performed safely. The differences were not statistically significant.

Bicycle Data

In after period 2, 15 percent of bicyclists rode over the sharrow, while 85 percent did not. Figure 20 shows the typical position of a bicyclist riding downhill. The travel lanes were narrowed to 10.5 ft wide in after period 2. The horizontal lines on the street are grids used as calibrators for the determination of spacing data. There was no evidence that the grids had any effect on bicycle position.

Figure 20. Photo. Typical position of bicyclist after sharrow installation.

Table 35 shows the bicycle riding position. In the before period, 73 percent rode proximate to parked vehicles (i.e., usually within 2 to 3 ft). This decreased to 49 percent in after period 1 as more bicyclists moved toward the center of the lane with the narrower travel lane. In after period 2, with the sharrows in place, 75 percent of the bicyclists rode proximate to parked vehicles. The differences were statistically significant ($p < 0.0001$).

Table 35. Bicycle riding position, Seattle, WA.

Bicycle Riding Position	Before Period	After Period 1	After Period 2	Total
Near parked vehicle	111 (72.6)[1]	53 (49.1)	113 (75.3)	277 (67.4)
Near center of lane	42 (27.5)	55 (50.9)	37 (24.7)	134 (32.6)
Total	153 (37.2)[2]	108 (26.3)	150 (36.5)	411 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Similar results are found in table 36, showing whether bicyclists took the lane. In the before period, 28 percent of the bicyclists were considered to have taken the lane. The percentage increased to 51 percent in after period 1 and decreased to 27 percent in after period 2. The differences were statistically significant ($p < 0.0002$).

Table 36. Bicyclist took lane, Seattle, WA.

Bicyclist Took Lane	Before Period	After Period 1	After Period 2	Total
No	110 (72.3)[1]	53 (49.1)	110 (73.3)	273 (66.4)
Yes	42 (27.6)	55 (50.9)	40 (26.7)	137 (33.3)
Total	152 (37.1)[2]	108 (26.3)	150 (36.6)	410 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Table 37 shows the distribution of parked motor vehicle events . As parking turnover was low on Fremont Street during commute time, these events were infrequent, with slightly more occurrences in the before period than in both after periods. Comparing "None" to the other events, the differences were not statistically significant. Figure 21 shows a possible dooring event in the before period if the bicyclist had been riding in the door zone.

Table 37. Parked motor vehicle events, Seattle, WA.

Event	Before Period	After Period 1	After Period 2	Total
Existing open door	2 (1.3)[1]	1 (0.9)	0 (0.0)	3 (0.7)
Pulling in or out	3 (2.0)	1 (0.9)	1 (0.7)	5 (1.2)
Possible dooring	2 (1.3)	0 (0.0)	0 (0.0)	2 (0.5)
None	146 (95.4)	106 (98.2)	149 (99.3)	401 (97.6)
Total	153 (37.2)[2]	108 (26.3)	150 (36.5)	411 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Figure 21. Photo. Potential dooring in before period.

Interactions Between Bicycles and Motor Vehicles

Table 38 shows the distribution of avoidance maneuvers. The results show that there were no conflicts. Across all periods, 38 percent of bicycle/motor vehicle interactions resulted in avoidance maneuvers (change in speed or direction to avoid the other party). The differences were not statistically significant.

Table 38. Avoidance maneuvers, Seattle, WA.

Interaction	Before Period	After Period 1	After Period 2	Total
Avoidance maneuver	61 (39.9)[1]	41 (38.0)	54 (36.0)	156 (38.0)
None	92 (60.1)	67 (62.0)	96 (64.0)	255 (62.0)
Total	153 (37.2)[2]	108 (26.3)	150 (36.5)	411 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Table 39 shows the number of times bicyclists and motorists yielded in the before and after periods while interacting with each other. Bicyclist yielding (changed direction or speed to give way to a motor vehicle) was infrequent and decreased across all periods. Motorist yielding (changed direction or speed to give way to a bicycle) was also infrequent and decreased across the periods. The differences were statistically significant (p = 0.0487).

Table 39. Yielding behavior of bicyclists and motorists, Seattle, WA.

Yielding Behavior	Before Period	After Period 1	After Period 2	Total
Bicyclist	5 (3.3)[1]	3 (2.8)	1 (0.7)	9 (2.2)
Motorist	20 (13.1)	7 (6.5)	8 (5.3)	35 (8.5)
Neither	128 (83.7)	98 (90.7)	141 (94.0)	367 (89.3)
Total	153 (37.2)[2]	108 (26.3)	150 (36.5)	411 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Table 40 shows the full distribution of bicyclist responses during their interaction with motorists. Bicyclists were able to continue riding safely 92 percent of the time in the before period, 84 percent in after period 1, and 98 percent in after period 2. Slight direction changes occurred 8 percent of the time in the before period, 16 percent in after period 1, and 1 percent in after period 2. Comparing the "Kept moving safely" category with the "Slight direction change" category resulted in statistically significant differences ($p < 0.0001$). The major chi-square contribution resulted from more slight direction changes than expected in after period 1 and less slight direction changes than expected in after period 2. This would be associated with more bicyclists taking the lane when the lane width was first narrowed to install the bicycle lane in after period 1.

Table 40. Bicyclist responses during interactions with motor vehicles, Seattle, WA.

Bicyclist Response	Before Period	After Period 1	After Period 2	Total
Kept moving safely	140 (91.5)[1]	91 (84.3)	147 (98.0)	378 (92.0)
Slowed, stopped pedaling	0 (0.0)	0 (0.0)	1 (0.7)	1 (0.2)
Slight direction change	12 (7.8)	17 (15.7)	2 (1.3)	31 (7.5)
Braked	1 (0.7)	0 (0.0)	0 (0.0)	1 (0.2)
Total	153 (37.2)[2]	108 (26.3)	150 (36.5)	411 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Table 41 shows the full distribution of motorist responses during their interaction with bicyclists. Motorists had slight direction changes in 28 percent of the interactions across all periods, had no changes in 64 percent, and slowed in 6 percent. Comparing these three rows showed no statistically significant differences in the distributions.

Table 41. Motorist responses during interactions with bicyclists, Seattle, WA.

Motorist Response	Before Period	After Period 1	After Period 2	Total
Changed lanes	0 (0.0)[1]	0 (0.0)	2 (1.3)	2 (0.5)
Slight direction change	40 (26.1)	32 (29.6)	44 (29.3)	116 (28.2)
Braked	2 (1.3)	1 (0.9)	1 (0.7)	4 (1.0)
Full Stop	2 (1.3)	0 (0.0)	1 (0.7)	3 (0.7)
Slowed	11 (7.2)	6 (5.6)	7 (4.7)	24 (5.8)
No change	98 (64.1)	69 (63.9)	95 (63.3)	262 (63.8)
Total	153 (37.2)[2]	108 (26.3)	150 (36.5)	411 (100.0)

[1] Column percent.
[2] Row percent.
Note: Frequencies are shown with percentages in parentheses.

Spacing Measures

Table 42 shows the results of the analysis of the average spacing between bicycles and parked motor vehicles (without an influential moving motor vehicle present) and the analysis of the average spacing between motor vehicles in the travel lane and parked vehicles during the before period, after period 1, and after period 2. The average spacing between bicycles and parked vehicles did not change very much across the periods. The slight increase from the before period to after period 1 is likely associated with more bicyclists moving toward the center of the lane after the centerline was shifted and the lane narrowed to accommodate the bicycle lane addition in the uphill direction. The slight decline in spacing in after period 2 was likely associated with 15 percent of the bicyclists riding over the sharrows in this area. With low parking turnover during the morning commute, the bicyclists seemed comfortable riding somewhat proximate to the parked motor vehicles. As would be expected, the average spacing between passing motor vehicles and parked motor vehicles decreased dramatically due to the change in the roadway configuration.

Table 42. Analysis of average spacing data, Seattle, WA.

Measure	Average Spacing (inches)			Results of ANOVA Test		Number of Observations		
	Before Period	After Period 1	After Period 2	F(df1,df2)	*p*-Value	Before Period	After Period 1	After Period 2
Bicycle to parked vehicle	45.82	47.48	44.50	1.53(2,531)	0.217	240	145	149
Motor vehicle to parked vehicle	69.78	51.38	51.96	243.22(2,484)	<0.001	198	131	158

Note: df indicates degrees of freedom.

Table 43 shows the results obtained when the distribution of spacing between bicycles and parked motor vehicles was compared in the before and after periods. The percentage of spacing values within 30 inches (within the door zone) increased from about 6 percent in the before period to about 12 percent in the two after periods. Chi-square tests indicated that the change in this distribution was marginally significant ($p = 0.054$). The percentage of spacing values within 40 inches also seems to have increased slightly in the two after periods, but this change was not statistically significant.

Table 43. Distribution of the percentage of spacing between bicycles and parked vehicles, Seattle, WA.

Percentage	Before Period	After1 Period	After2 Period	Chi-Square	*p*-Value
Within 30 inches	5.8	11.7	12.2	5.86	0.054
Within 40 inches	36.3	38.6	43.6	2.11	0.348

SUMMARY

Data analysis results from bicycles interacting with motor vehicles across all periods are as follows:

- There was no change in the percentage of motorists following (62 percent) and passing (35 percent) bicyclists.
- There was no change in whether a motorist changed lanes when overtaking a bicyclist. When motorists passed bicyclists, 30 percent of them tended to move partway to the opposing lane.
- There was no difference in the safety of the manner in which motorists were following and passing bicyclists. Overall, 97 percent of the movements were performed safely.
- A total of 15 percent of the bicyclists rode over the sharrow during after period 2.
- A significantly higher percentage of bicyclists were shifting toward the center of the lane and taking the lane during after period 1 when the travel lane was narrowed to accommodate

the addition of the bike lane in the uphill direction (from 28 percent in the before period to 51 percent in after period 1) .

- There were few bicycle/parked motor vehicle events, as parking turnover was low during morning commute time.
- There was no difference in the percentage of avoidance maneuvers (38 percent overall) across periods.
- The percentage of bicyclists who yielded (changed direction or speed to give way to a motor vehicle) decreased from slightly more than 3 percent in the before period to slightly less than 3 percent in after period 1 and to less than 1 percent in after period 2.
- The percentage of motorists who yielded (changed direction or speed to give way to a bicycle) decreased from 13 percent in the before period to 6.5 percent in after period 1 and to 5 percent in after period 2.
- The percentage of bicyclists who kept moving safely (basically no change in speed or direction) decreased from 92 percent in the before period to 84 percent in after period 1 and increased to 98 percent in after period 2.
- The percentage of bicyclists who made slight direction changes increased from 8 percent in the before period to 16 percent in after period 1 and decreased to 1 percent in after period 2.
- There were no differences in motorist responses to bicyclists across all periods. Overall, motorists made no changes in 64 percent of the interactions.

Results from the spacing analysis in the absence of a following motor vehicle included the following:

- The average spacing between bicycles and parked vehicles did not change much across the periods. The spacing values were 45.8 inches in the before period, 47.5 inches in after period 1, and 44.5 inches in after period 2.
- The percentage of spacing values within 30 inches (within the door zone) increased from about 6 percent in the before period to about 12 percent in the two after periods, which was a marginally significant increase.
- The percentage of spacing values within 40 inches was 36 percent in the before period, 39 percent in after period 1, and 44 percent in after period 2. The changes were not significant.

Results for the distance of motor vehicles in the travel lane from parked motor vehicles in the after period were as follows:

- The average spacing between motor vehicles in the travel lane and parked motor vehicles decreased about 18 inches due to the change in the roadway configuration (the lane had been narrowed by 2.5 ft).

This sharrow experiment in Seattle, WA, was intended to encourage bicyclists to ride in the center of the lane in a downhill situation on a narrow street. The results do not show an effect directly attributable to the sharrow itself because only 15 percent of the bicyclists rode over the sharrow. However, the percentage of bicyclists riding in the center of the lane increased from 27 percent in the before period to 51 percent in after period 1 after the effective lane width had been narrowed by about 2.5 ft in the shift of the centerline to accommodate the addition of the uphill bike lane. Surprisingly, the percentage of bicyclists riding in the center of the lane in after period 2, after the sharrows were installed, reverted to 25 percent. Coupled with this is the lack of change in spacing between bicycles and parked motor vehicles across all three periods. In addition, the percentage of bicyclists riding within 30 inches of parked vehicles increased from about 6 percent in the before period to about 12 percent for both after periods.

Conversely, the average spacing between bicycles and parked vehicles was about 15 inches outside of the door zone, and the percentage actually riding within the door zone was quite small for all three phases. All of the videotape data were collected during the early morning commute time, and the bicyclists riding the street appeared to be aware that the probability of a door opening or a motor vehicle pulling into or out of a parking space would be low. In addition, the videotapes show motorists yielding to trailing bicyclists when pulling into a parking space or turning right and looking in the side mirror once parked to see whether a bicyclist was coming before opening the door.

From the videotapes, the impression was that the bicyclists were mainly experienced commuters. The typical location of the bicyclists in the street was outside of the door zone but not quite in the center of the roadway. Many rode close to the outside edge of the sharrow in after period 2. It is apparent that they were aware of following motor vehicles and that they were ready to move to the center of the roadway if necessary to prevent being squeezed next to parked vehicles. This was especially noticeable once the downhill lane had been narrowed in after period 1.

It is possible that the narrowing of the lane in the downhill direction in after period 1 had more of an effect than the subsequent sharrow placement on the interactions of bicyclists and motorists. In the before period, motorists may have been more inclined to pass a bicyclist if the opportunity was present. As a result, more motorists appeared to be driving faster and then had to slow for bicyclists. This led to more motorist yielding (reducing speed or changing direction) during the before period. Once the downhill lane was narrowed, the percentage of both bicyclists and motorists who yielded to the other decreased both in after period 1 and then slightly more in after period 2. The same was true for the percentage of bicyclists who kept riding safely. The value decreased from 92 percent in the before period to 84 percent during after period 1 and increased to 98 percent in after period 2. Similarly, the percentage of bicyclists who made slight direction changes (e.g., moved to the left) increased from 8 percent in the before period to 16 percent in after period 1 and decreased to 1 percent in after period 2. Thus, the flow of bicycles and motor vehicles was smoother in after period 2.

Sharrows had been placed along a four-lane portion of Fremont Street for approximately 2,000 ft prior to the downhill section. The placement was the recommended 11-ft spacing from the curb to prevent dooring by parked motor vehicles. It is possible that the nominal position of bicyclists was thus attained prior to the downhill section of Fremont Street and that the placement of the sharrow in the center of the street was unexpected. In addition, no public education was provided with the introduction of the sharrows on the downhill section. Although insufficient for truly representative comparison data, it would have been useful to have gathered videotape data at an upstream location to ascertain the spacing of bicyclists from parked motor vehicles on the section of the street prior to the steep downgrade.

It would seem that sharrows used in downhill situations such as this one would work by having bicyclists track over the marking and more readily ride in the center of the lane. For whatever reasons, that effect was not achieved for this application in Seattle, WA. This may have been due to the fact that experienced bicyclists were already staying out of the door zone in the before period, coupled with the realization that they could control the lane without actually being in the middle of the lane. Having experienced motorists who were used to driving with bicyclists in the travel lanes could also be a factor. It is recommended that additional trials with sharrows in the center of the lane should be evaluated in other locations.

CHAPTER 7. CONCLUSIONS AND DISCUSSION

OVERVIEW

The use of shared lane markings continues to grow, and it is apparent that communities are looking to expand ways in which the markings can be used. The purpose of this study was to evaluate the impact of several uses of sharrows on operational and safety measures for bicyclists and motorists.

Sharrows were evaluated in three cities and with three different intentions. In Cambridge, MA, the markings were used 10 ft from the curb and next to parked motor vehicles to determine if the spacing for bicyclists next to parked motor vehicles and motor vehicles in the traffic stream could be increased. In Chapel Hill, NC, the markings were used along a corridor with wide outside lanes to determine if the spacing for bicyclists from the curb and from hazardous drainage grates could be improved as well as if motor vehicle spacing from the curb could be increased. In Seattle, WA, the markings were placed in the center of the street at a downhill portion to determine if bicyclists could be encouraged to take control of the lane. In addition, the operational interactions between bicycles and motor vehicles were studied.

The various hypotheses that were explored included the following:

- Sharrows may be useful to indicate a preferred path of travel and thereby improve bicyclist positioning relative to parked motor vehicles when riding in shared lanes with on-street parking.
- Sharrows may help improve spacing or operations when passing motor vehicles overtake bicyclists on streets with and without parking.
- Sharrows may improve bicyclist positioning relative to the curb or other hazards along the roadway edge, including unsafe drain grates or uneven pavement.
- Sharrows may be used in instances when a bicyclist needs to take the lane, such as on a section of steep downgrade where bicyclists need more operating space and there is insufficient width to provide a bicycle lane or shared lane, or on a narrow lane situation where bicyclists need to move away from the door zone or other hazards.
- Sharrows may reduce wrong-way and sidewalk riding, both of which are apparent risk factors for collisions.
- Sharrows may increase the distance of motor vehicles in the travel lane from parked motor vehicles or from the curb in the absence of bicyclists, thereby providing more operating space for bicyclists.

CAMBRIDGE, MA, RESULTS

In Cambridge, MA, there appeared to be safety effects associated with the installation of the sharrows 10 ft from the curb on Massachusetts Avenue, which is a busy street with frequent parking turnover. Some 94 percent of bicyclists rode over the sharrows. Operating space for bicyclists appeared to increase when motor vehicles were shifted 14 inches further away from parked motor vehicles in the absence of bicycles after placement of the markings. The distance from bicycles to parked motor vehicles in the presence of a following motor vehicle increased 4 inches after placement of the markings for the inbound direction but very little for the outbound direction. The percentage of bicycles riding within 40 inches of parked motor vehicles in the presence of a following motor vehicle also decreased, but the effect was again seen only in the inbound direction. It was unclear why there was an effect in one direction but not the other. There was little difference in the mean spacing distance when motor vehicles passed bicycles in the after period; however, the percentage of motor vehicles within 40 inches of bicycles decreased.

Examining a number of variables related to the operational interaction of bicycles and motor vehicles appeared to reflect more segregated flow with less lateral movement of bicycles and motor vehicles in the after period. The sharrows appeared to show no effect on free-flowing motor vehicle speeds or on the distance that motor vehicles were parked from the curb when front and rear distances were combined. However, in the outbound direction, the distance between the back tire and the curb increased by an average of almost 2.3 inches, and this increase was statistically significant ($p = 0.038$). This finding may be related to the lesser effect of the sharrows for the outbound direction.

CHAPEL HILL, NC, RESULTS

In Chapel Hill, NC, there were a variety of safety effects found after placement of the sharrows on a busy five-lane corridor with wide outside lanes and no parking. Similar to the results found in Cambridge, MA, the spacing of motor vehicles from the curb in the absence of bicycles increased about 7 inches in this wide-lane situation. The percentage of motor vehicles within 50 and 60 inches of the curb was also reduced. The combined effect should give bicyclists more operating space. The 3 to 4 percent grade on the street had an effect on various outcomes. The percentage of cyclists riding over the sharrows was 97 percent in the uphill direction and 88 percent in the downhill direction. There was a tendency for cyclists to ride closer to the curb uphill, which was possibly due to a large speed differential between the bicycles and passing motor vehicles. There was more of a tendency for bicyclists to ride further from the curb going downhill, but the overall change in mean spacing (both directions combined) was 2.5 inches closer to the curb in the after period. It is worth noting that the mean distance of bicycles from the curb in the downhill direction in the after period was almost identical to the distance of the center of the sharrow from the curb. Related to the above findings, motor vehicles decreased their passing distance to bicycles in the after period. This appeared to lead to a smoother flowing traffic stream as motorists felt comfortable in passing bicyclists within the lane. It should also reflect less motor vehicle-to-motor vehicle interactions as fewer motor vehicles move partway into adjacent lanes when overtaking bicyclists in the after period. Conversely, this may decrease the comfort level of bicyclists operating on the street.

Many bicycle/motor vehicle crashes on this corridor occur as bicyclists riding on the sidewalk cross driveways and intersections. After placement of the sharrows, the percentage of sidewalk riding decreased significantly, but most of the effect was for the downhill direction.

SEATTLE, WA, RESULTS

In Seattle, WA, sharrows were placed in the center of the lane on a downhill portion of a busy bicycle commuting street. The experiment had three stages, and the second involved the addition of a 5-ft bicycle lane to the uphill portion of the street in conjunction with shifting the center line of the street. The overall effect was to narrow the travel lanes. The sharrows were added in the third stage, and the effects were somewhat surprising. Placement of the sharrows in the center of the lane on the steep downhill portion of the street was intended to encourage bicyclists to ride in the center of the lane as well as to increase their space from parked motor vehicles. However, only 15 percent of the bicyclists rode over the sharrow, although many tracked near the sharrow. The percentage of bicyclists riding in the center of the lane increased from 27 percent in the before period to 51 percent in after period 1 after the effective lane width had been narrowed by about 2.5 ft in the shift of the centerline to accommodate the addition of the uphill bicycle lane. The percentage of bicyclists riding in the center of the lane after sharrow installation reverted to 25 percent.

Additionally, there was little change in the spacing between bicycles and parked motor vehicles across all three periods. The percentage of bicyclists riding within 30 inches of parked motor vehicles increased from about 6 percent in the before period to about 12 percent for both after periods. Conversely, the percentage of bicyclists actually riding within the door zone was small for all three phases, and the average spacing between bicycles and parked vehicles was about 15 inches outside of the door zone. This may be a reflection of experienced bicyclists realizing that they could control the lane without actually being in the middle of the lane.

In this experiment, the narrowing of the lane in the downhill direction in after period 1 may have had more of an effect on the interactions of bicyclists and motorists than the subsequent sharrow placement. A number of the variables associated with the interactions showed positive indications (e.g., less direction changes and yielding by both bicyclists and motorists) so that the overall flow on the street may be somewhat smoother.

Seattle, WA, is known as being a bicycle friendly city, and having experienced motorists who are used to driving with bicyclists in the travel lanes may play a role in these results. In the before period, experienced bicyclists were already staying out of the door zone, and their mean spacing from parked vehicles varied only slightly after sharrows were installed.

CONCLUSIONS

Sharrows can be used in a variety of situations, and it is assumed that increased use should increase motorist awareness of both bicycles in the traffic stream and the possibility of bicycles entering the traffic stream. Results indicate that sharrows increased operating space for bicyclists. Sharrows have reduced sidewalk riding not only in the current study but also in Gainesville, FL, as shown in a previous study.[(4)] Safety effects were apparent in variables related to the interactions between bicycles and motor vehicles. As communities continue to experiment with various uses of sharrows, it is recommended that researchers continue to create similar trials in other locations and traffic settings. Additionally, it is of utmost importance to evaluate and report those experiments so that more data can be examined to provide improved guidance to users.

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