

Final Report

40th Street Green Shared Lane Evaluation



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PREFACE FOR THE NOVEMBER 2, 2017 MEETING OF THE CALIFORNIA TRAFFIC CONTROL DEVICES COMMITTEE

This report documents the City of Oakland's experimentation with a continuous band of green color on the pavement in conjunction with shared roadway bicycle markings (sharrows). The experimentation was conducted under the auspices of the Federal Highway Administration (FHWA) and the California Traffic Control Devices Committee (CTCDC) as per the requirements of the Manual on Uniform Traffic Control Devices (MUTCD) and the California MUTCD.

The experiment purpose was to promote: (a) safe and legal lane positioning by cyclists; and (b) safe and legal passing by motorists on a multi-lane urban roadway with frequent cyclists and no bike lanes. Based on a phased before/after study, this report documents key findings that include the following:

- Super sharrows resulted in cyclists riding further from parked cars ("outside of the door zone").
- Standard sharrows shifted motorists from the right travel lane to the left travel lane.
- The average passing distance for motorists overtaking cyclists did not change, but the presence of standard sharrows and super sharrows created more variability in that passing distance.
- Super sharrows did not have a negative operational effect on auto operations, auto speeds, or transit speeds, and there was no effect on reported collisions.

Based on the report's key findings, we have the following recommendations:

- We do not propose a specific change to the California MUTCD. We suggest that the CTCDC monitor FHWA's rulemaking based on the results of related experiments across the United States.
- We intend to keep the project as constructed until rulemaking is completed, or until the street is scheduled for pavement resurfacing.
- Reserve solid green color for dedicated bicycle space (e.g., bike lanes). Use skip green in bike lane conflict zones (e.g., Detail 39A) and sharrows with green backing in shared travel lanes.
- Consider standardizing a door zone striping treatment (parking edge line stripe with cross-hatching or parking Ts) that may be used in conjunction with sharrows.

Overall we recommend providing dedicated space for bicyclists on collector and arterial roadways. Where bike lanes are not feasible, shared lane treatments may be needed where alternative routes are not available. These shared lanes should be marked in a bold but pragmatic manner. The marking design should communicate that bicyclists are welcome on the road, while recognizing that a majority of bicyclists is unlikely to "take the lane" on urban arterials and collectors.

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INTRODUCTION & PROBLEM STATEMENT

In 2013 the City of Oakland, California implemented a continuous band of green color on the pavement in conjunction with shared roadway bicycle markings (sharrows) as an experimental traffic control device. The purpose of the experiment was to improve traffic operations on a multi-lane urban roadway frequented by cyclists. The request to experiment was approved by the Federal Highway Administration and the California Traffic Control Devices Committee as per the requirements of the Manual on Uniform Traffic Control Devices (MUTCD, Section 1A.10) and the California MUTCD.

The City of Oakland conducted the experiment on 40th Street between Adeline and Webster Streets in proximity of the MacArthur BART Transit Station and Transit Village development. MacArthur BART, a heavy rail station operated by the Bay Area Rapid Transit District, is amongst the busiest San Francisco Bay Area BART stations for cyclists. The station entrance is on 40th Street, a four-lane urban arterial with two travel lanes each way, a raised median with turn pockets at intersections, and parallel parking on both sides of the street. Average daily traffic was approximately 16,000 vehicles and there are seven traffic signals on the one-mile segment of roadway. Adjoining land uses are a mixture of multi-unit residential, single-family homes, and commercial.

The experiment purpose was to promote: (a) safe and legal lane positioning by cyclists; and (b) safe and legal passing by motorists on a multi-lane urban roadway with frequent cyclists and no bike lanes. Such roadways are prone to the following operational issues. First, cyclists ride too close to vehicles parked parallel along the street, exposing themselves to collisions with opening car doors. Second, overtaking motorists pass cyclists by “squeezing by,” encroaching on the adjoining travel lane, creating conflicts with other motorists, and providing insufficient width for cyclists to operate safely. Third, cyclists controlling the right-hand lane in a safe and legal manner are subject to intimidation by overtaking motorists. The experiment sought to improve upon the standard treatments currently available: sharrows, parking edge line stripes or parking Ts to help delineate the door zone, and bicycle-related signage.

The experiment included a phased before/after study with three rounds of data collection:

- (1) Baseline condition: previously installed bicycle guide signs; no bikeway striping;
- (2) Sharrows, parking edge line stripes, and “Bicycles May Use Full Lane” signs; and



- (3) Above plus five-foot wide green band centered in the right travel lane.

Pneumatic tubes and video cameras collected data on cyclist volumes, vehicle volumes and speeds, vehicle lane utilization, cyclist lane positioning, motorist lane positioning, and motorist passing behavior. The green band was created by applying a colored epoxy to the surface of the roadway (StreetBondCL in Shamrock Green) at a cost of approximately \$100,000 per centerline mile. The effects of the green band (or “super sharrow”) on user behavior were isolated and compared to no bikeway striping and to standard sharrows using statistical analysis. The key findings are as follows:

- **Super sharrows resulted in cyclists riding further from parked cars (“outside of the door zone”).** The shift was statistically significant compared to the baseline condition and to the standard sharrows condition. Standard sharrows had a small positive effect on cyclist positioning but the shift in bicyclists riding outside of the door zone was not statistically significant. In comparison, super sharrows had a greater effect with and without overtaking motorists that was statistically significant, increasing the percentage of bicyclists operating outside of the door zone from 5% (baseline) to 39% (super sharrows) in free flow conditions and 0% (baseline) to 19% (super sharrows) during overtaking events.
- **Standard sharrows shifted motorists from the right travel lane to the left travel lane.** Statistically significant compared to the baseline condition, two-thirds of motorists used the right lane under the baseline conditions and under the standard sharrows condition less than one-half of motorists used the right lane. The addition of the green band did not shift additional motorists from the right travel lane to the left lane.
- **The passing distance for motorists overtaking cyclists did not change in a statistically significant manner.** The average passing distance remained the same between baseline and with standard sharrows and increased slightly with super sharrows. The percentage of motorists leaving three or more feet decreased over the three phases, which was statistically significant between the baseline and super sharrow conditions. While super sharrows encourage cyclists to ride further from parked cars, the treatment may not affect the passing behavior of some motorists, resulting in some passing events where there is less space between the motorist and the cyclist. This indicates both that the average passing distance is unaffected by the treatments and that the variability in passing distance increases with the treatments, with some autos passing much further and other autos passing more closely with the treatments than without.
- **Super sharrows and standard sharrows did not affect the number of cyclists who pass motorists on the right at red lights.** At signalized intersections, cyclists continued to “jump the queue,” overtaking waiting motorists by passing on the right. The treatments were not effective in reducing the possibility of right hook collisions at



signalized intersections by encouraging cyclists to “take the lane” and queue with motorists. The number of observations was limited and no conclusion can be drawn for cyclists arriving at traffic signals on green lights.

While the experiment did not include a user survey, the City of Oakland received extensive informal feedback on the project. Cyclists were largely positive, describing the super sharrows as empowering and legitimizing their use of the roadway. The highly visible treatment created a situation in which there could be no doubt amongst motorists and cyclists that cyclists are legitimate users of the travel lane. Cyclists who were critical of the treatment generally expressed a desire for separation from motorists, either with conventional bike lanes or cycle tracks. Motorists and residents were generally sympathetic to the goal of improving conditions for cyclists. Isolated complaints fell into three categories: that cyclists should ride somewhere else; that the treatment was a waste of money; and that the treatment was unsightly.

The key findings of the quantitative analysis plus anecdotal observations and user feedback suggest the following implications. An assertive shared lane treatment like super sharrows can improve conditions for cyclists on multi-lane urban roadways where bike lanes are not feasible. Specifically, the super sharrows shifted cyclists away from the door zone and such treatments communicate forcefully that cyclists are legitimate users of the shared travel lane. These benefits were achieved with no documented negative effects on operations or safety. Future research should evaluate the relative merits of a “take the lane” design approach – directing cyclists to the center of the travel lane – versus an “avoid the door zone” design approach – directing cyclists to ride only as far left as necessary to avoid the door zone.

PROBLEM STATEMENT

On multi-lane urban arterials and collectors that are too narrow for bicycle lanes, bicyclists often ride in the “door zone”: the area immediately adjacent to curbside parallel parking into which car doors open. Overtaking motorists often pass such bicyclists without changing lanes, encroaching into the adjoining travel lane, and providing insufficient width for the bicyclist to operate safely.

The California Vehicle Code requires bicyclists to “ride as close as practicable to the right-hand curb or edge of the roadway” (CVC 21202(a)). Exceptions to this requirement include roadways with “a substandard width lane” defined as “a lane that is too narrow for a bicycle and a vehicle to travel safely side by side within the lane” (CVC 21202(a)(3)). This exception is the basis for the “Bicycles May Use Full Lane” sign (R4-11) that is included in the MUTCD.



In the City of Oakland, the majority of urban arterials and collectors have lane widths that are too narrow for a bicycle and vehicle to operate side by side in a safe manner. Oakland's design approach provides a minimum of 23' for side-by-side lane sharing where curbside parallel parking is allowed: 9.5' parking lane and door zone, 3.5' bicyclist operating space, 3' passing space for overtaking motorists, 6' width of a large passenger car, and 1' buffer to the travel lane line. Where this width is available, the City is in the process of adding bicycle lanes as per a citywide analysis of roadway widths completed for the City of Oakland's Bicycle Master Plan (2007). Where traffic volumes allow, the City is reducing the number of travel lanes to create space for bicycle lanes.

In multi-lane roadways, CVC 21654(a) requires slow moving vehicles to operate "in the right-hand lane for traffic or as close as practicable to the right-hand edge or curb." Exceptions to CVC 21202(a) allow a bicyclist to use the full extent of the right-hand lane if that lane is too narrow for a bicycle and vehicle to travel safely side by side. Thus the safe and legal behavior for the bicyclist is to "control" the travel lane, riding clear of the door zone with overtaking motorists deliberately changing lanes to pass safely. A minority of bicyclists operates in this manner because the cultural expectation is that bicyclists should "get out of the way" of overtaking motorists. Incidents include motorists honking, yelling, driving aggressively, and physically assaulting bicyclists who were using the travel lane in a manner that inconvenienced motorists.¹

Traffic operations on multi-lane urban streets frequented by bicyclists are thus prone to the following operational issues:

- (1) Bicyclists ride too close to vehicles parked parallel along the street, exposing themselves to collisions with opening car doors.
- (2) Overtaking motorists pass bicyclists by "squeezing by," encroaching on the adjoining travel lane, creating conflicts with other motorists, and providing insufficient width for bicyclists to operate safely.
- (3) Bicyclists controlling the right-hand lane in a safe and legal manner are subject to intimidation by overtaking motorists.

Existing traffic control devices do not provide sufficient guidance to roadway users on the safe and legal travel path for bicyclists in shared lane situations. Currently, the City's design options include sharrows, parking edge line stripes or parking Ts to help delineate the door zone, and bicycle-

¹ Peter G. Furth, Daniel M. Dulaski, Dan Bergenthal, and Shannon Brown. "More Than Sharrows: Lane-Within-A-Lane Bicycle Priority Treatments in Three U.S. Cities." Transportation Research Board Annual Meeting, 2011.



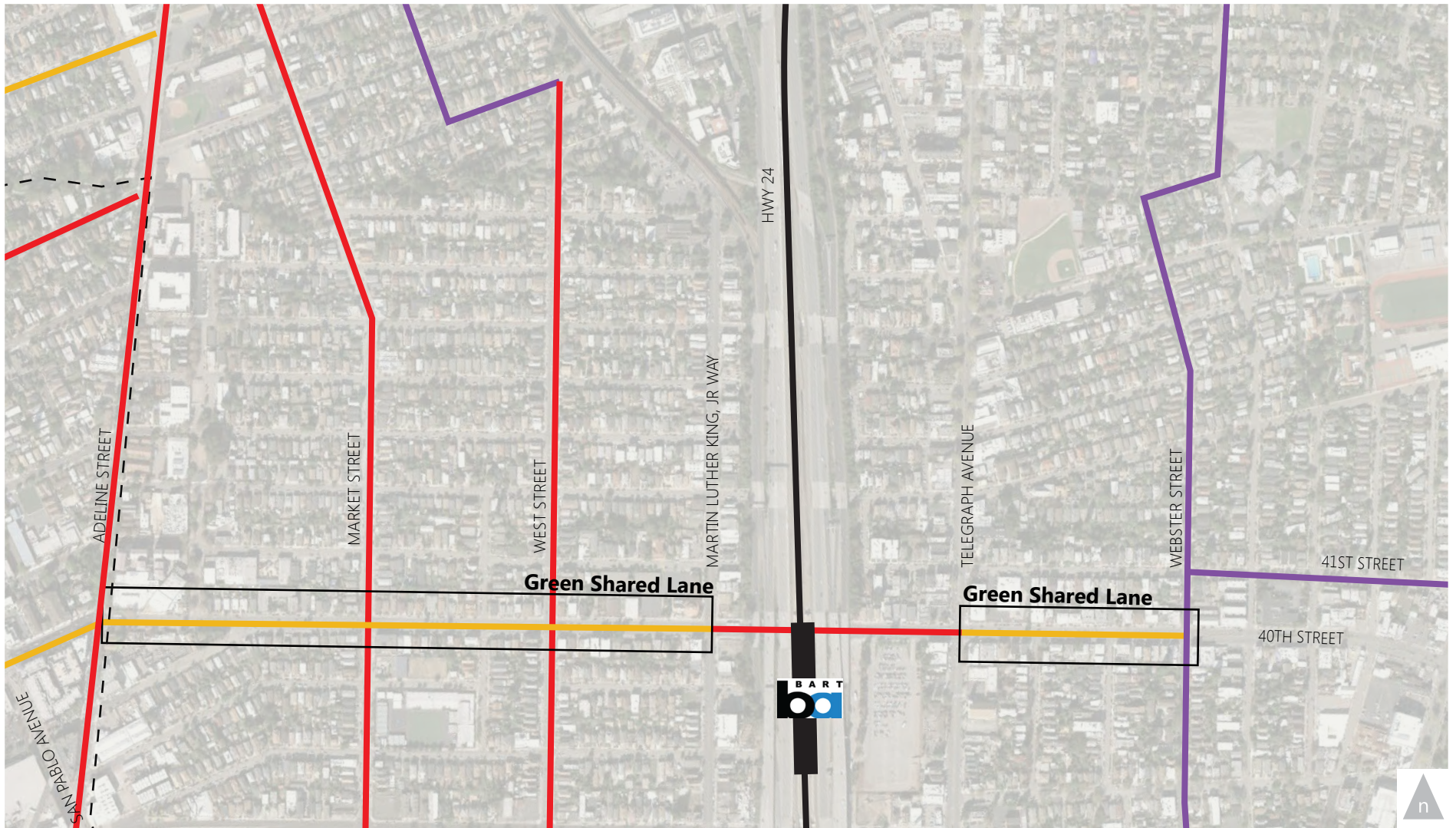
related signage. These treatments are in place on other multi-lane roadways in Oakland but, based on user feedback, they have been insufficient in addressing the operational issues noted above.

The City sought to address these operational issues by experimenting with roadway delineation for shared lane situations that may promote: (a) safe and legal lane positioning by bicyclists; and (b) safe and legal passing by motorists.

LOCATION OF PROPOSED EXPERIMENT

The City of Oakland's Bicycle Master Plan, part of the Oakland General Plan, calls for the installation of bikeways to improve access to major transit stations. One of the busiest stations is MacArthur BART, located in North Oakland and operated by the Bay Area Rapid Transit District. As of 2008, 8.2% of BART patrons accessed the station by bicycle despite there being no bikeways serving the station. The station had the fourth largest number of bicyclists accessing the station out of the 43 BART stations in the San Francisco Bay Area. The primary station entrance is on 40th Street, a four-lane urban arterial with two travel lanes in each direction, a 16-foot raised median with turn pockets at the intersections, and parallel parking lanes on both sides of the street. Average daily traffic is approximately 16,000 vehicles and there are seven traffic signals on this 1.0 mile segment of roadway. **Figure 1** is a context map showing the location of the experiment and Oakland's bikeway network in the vicinity of MacArthur BART.

The City made multiple prior efforts to develop a bikeway in the 40th Street corridor to serve MacArthur BART. In 2006 and 2008, the City completed two studies on the removal of travel lanes and the installation of bicycle lanes. The City did not implement the "road diet" option because of (1) concerns from the public transit agency – Alameda-Contra Costa Transit District (AC Transit) – regarding delays to bus operations; and (2) future year traffic forecasts whereby the road diet would create significant and unavoidable impacts to motor vehicle delay under the California Environmental Quality Act. The City then studied the feasibility of maintaining the four travel lanes and adding bicycle lanes by narrowing the raised medians. This proposal was opposed by neighborhood groups who, over the duration of the City's studies, adopted and landscaped the medians. Given these constraints, the City sought an additional design treatment to improve the positive effects of sharrows in delineating the safe and legal path of travel for bicyclists.



LEGEND

- | | | | |
|---------------------------------------|-------------------------------|--|------------------------|
| — | Class II Bicycle Lanes | | Location of Green Band |
| — | Class III Bicycle Routes | - - | City Limit |
| — | Class IIIB Bicycle Boulevards | | |

Figure 1



40th Street Green Shared Lane Location and Adjacent Bicycle Network



DESCRIPTION AND USE OF THE PROPOSED TRAFFIC CONTROL DEVICE

Green Shared Lane Treatment

In September 2013, the City installed a five-foot wide band of green color, applied to the surface of the pavement, and centered in the outside travel lane. The green band extends the length of the shared lane condition in the project area, excluding intersections and crosswalks. The use of green in the shared lane context is currently not approved under the federal MUTCD Interim Approval for green pavement, which only allows the use of green in bicycle lanes and their extensions through conflict zones. The objective of this experimental traffic control device is to provide continuous guidance in delineating the safe and legal path of travel for bicyclists. It was installed in conjunction with the following standard (MUTCD-approved) traffic control devices:

- Sharrows spaced at intervals of approximately 135 to 200 feet with a minimum of two sharrows in each direction on each block;
- Parking edge line stripes (Detail 27B) delineating the right edge of the outside travel lane along the length of the project, excluding intersections, crosswalks, and bus stops; and
- "Bicycles May Use Full Lane" (R4-11) signs on the far-side of each intersection with a collector or arterial roadway (6 intersections total).

Figure 2 presents photographs from each phase of the study. **Figures 3 and 4** present a conceptual section and striping plan for the experimental treatment as it was installed on 0.8 miles of 40th Street from Adeline Street to Martin Luther King, Jr Way and from Telegraph Avenue to Webster Street. No change was made to the connecting 0.2 miles of 40th Street from Martin Luther King, Jr Way to Telegraph Avenue. Bicycle lanes were installed along this segment at the MacArthur BART station entrance (and under State Highway 24) as part of a streetscape project in 2009. The width for the bike lanes was created by narrowing the median. Bicycle Route Signs (D11-1) were installed along the length of the corridor in May 2010 and remained throughout the experiment.

Phase 1 Baseline Conditions



- Designated bicycle route with D11-1 signs
- Baseline condition prior to May 2013

Phase 2 MUTCD-Approved Treatments



- Designated bicycle route with D11-1 signs
- Sharrows centered in #2 travel lane
- Edgeline stripe (Detail 27B)
- "Bicycle May Use Full Lane" (R4-11) signs
- Condition between June and August 2013

Phase 3 Green Shared Lane



- Designated bicycle route with D11-1 signs
- Sharrows centered in #2 travel lane
- Edgeline stripe (Detail 27B)
- "Bicycle May Use Full Lane" (R4-11) signs
- Five foot experimental green band centered in #2 travel lane with sharrows on top ("green shared lane" or "super sharrow")
- Condition between September 2013 and present



Figure 2

Photos of Phased Improvements

Phase 3 Green Shared Lane Concept Section and Plan

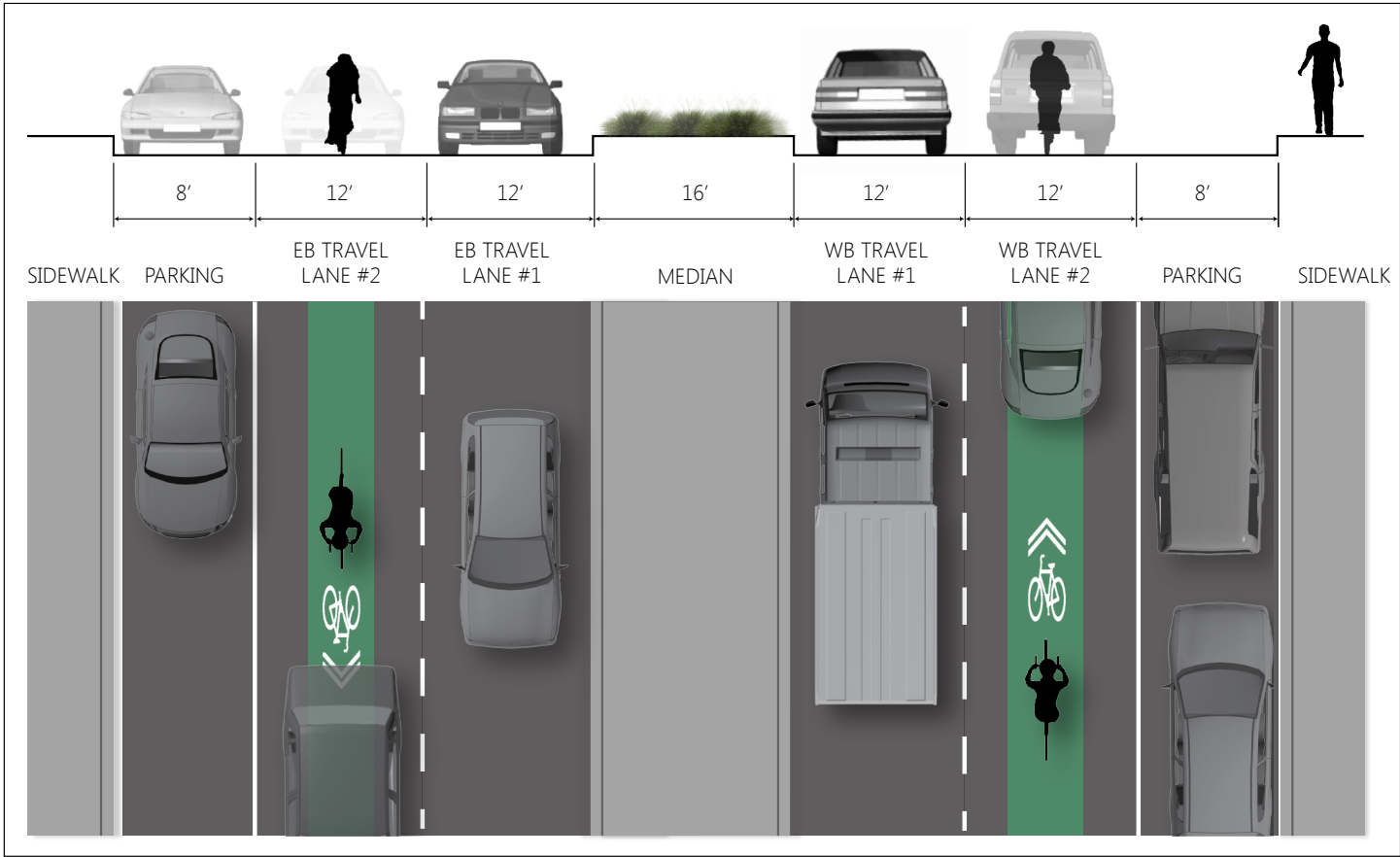


Figure 3
Phase 3 Green Shared Lane Concept Section and Plan

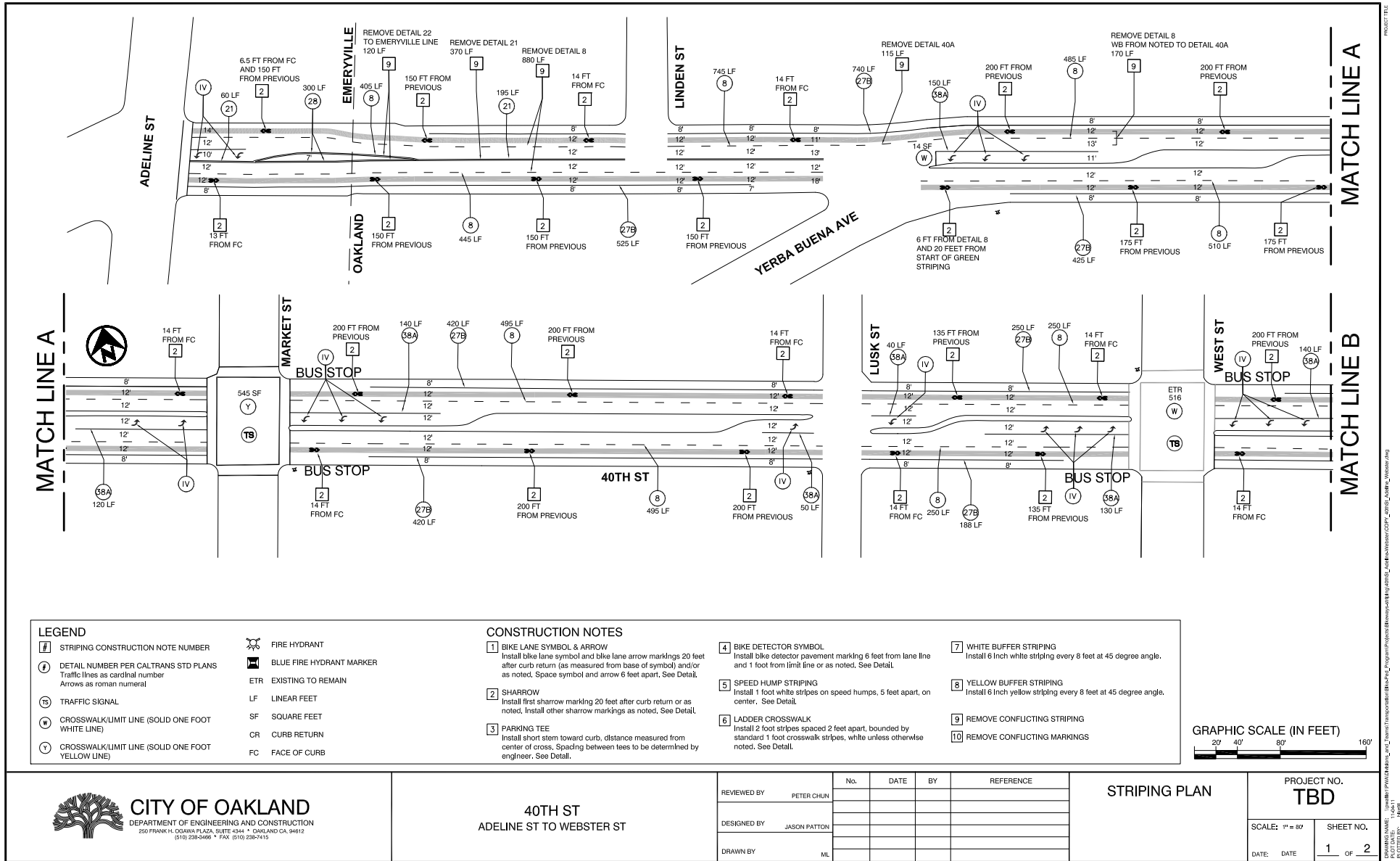


Figure 4a
Phase 3 Green Shared Lane Striping Plan - Sheet 1

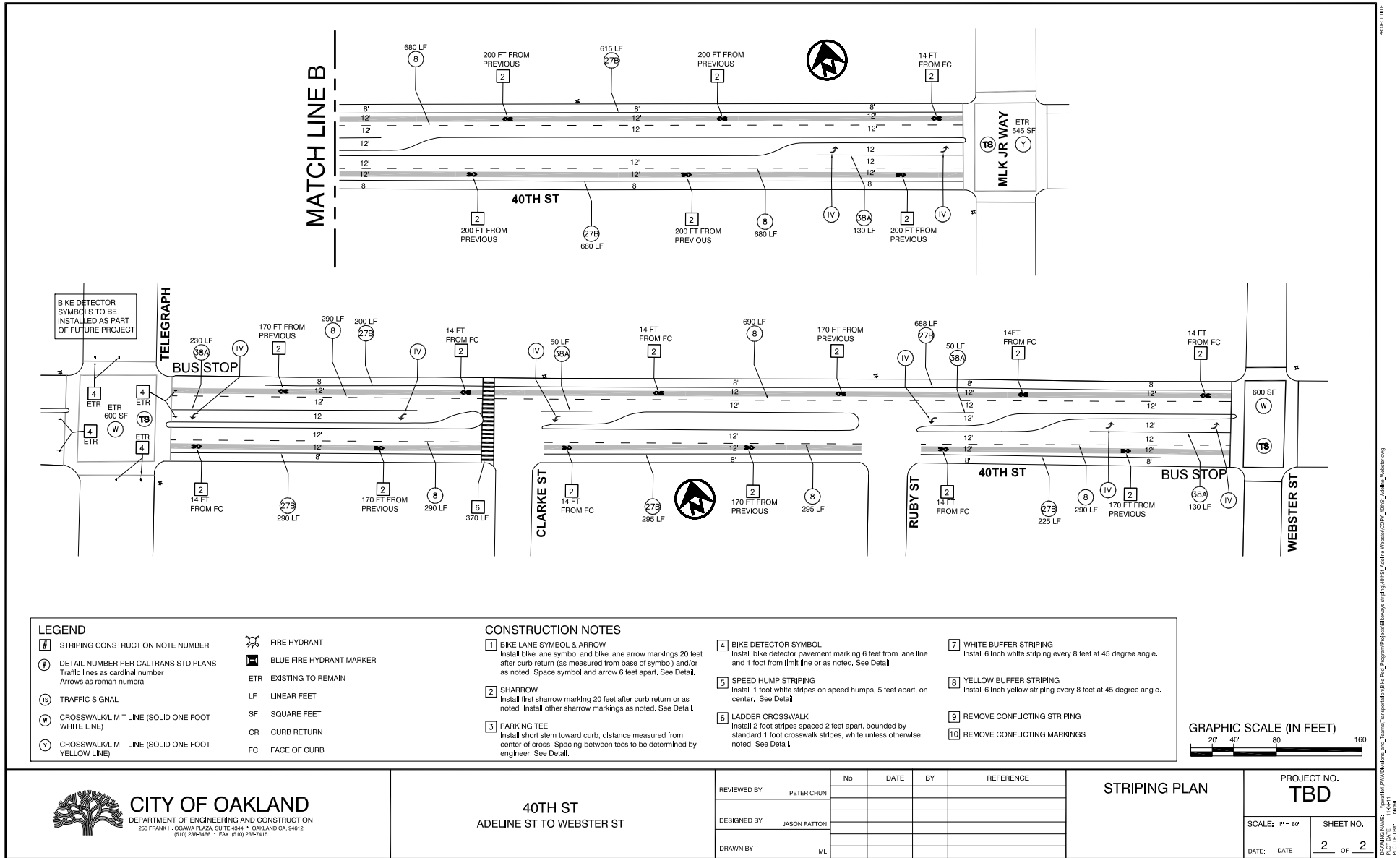


Figure 4b
Phase 3 Green Shared Lane Striping Plan - Sheet 2



The five-foot width of the green band was chosen in order to: (1) match established practice on bicycle operating and facility widths; (2) align with the center of the travel lane over a range of urban lane widths; and (3) ensure a prominent visual presence. The five-foot (60") green band is comparable to the width of sharrows (39"), bike lane symbols (40"), AASHTO's minimum width to operate a bicycle (40"), and bike lane widths (≥ 60 "). In particular, the sharrow at 39" in width and the green band at 60" in width allows 10.5" of green on either side of the sharrow. This overlap improves the visibility of the sharrow and creates a consistent appearance for the green band. A five-foot band is located in the effective center of a travel lane and remains clear of the door zone over the range of typical urban lane widths: 17 feet to 20+ feet (measured from face of curb to lane line). In communicating the bicyclists' path of travel, a five-foot green band is thus narrow enough to center in the lane, remain clear of the door zone, and be visually prominent.

Intent of Green Pavement in Shared Lanes

The green band was intended to delineate the bicyclists' path of travel in a shared lane condition. It was not intended to denote a zone for the preferential or exclusive use of bicyclists. To date the various uses of green color pavement on bikeways have this underlying commonality: to indicate the bicyclists' path of travel to motorists and bicyclists. The green color is used to enhance the delineation established by standard traffic control devices: bike lane stripes and sharrow markings. Standard lane lines and markings allocate the roadway width for established purposes while the green color indicates where to expect bicyclists.

BACKGROUND/LITERATURE REVIEW

To date, four other cities installed continuous bands of green color pavement with sharrows: Salt Lake City (200 South); Long Beach (2nd Street); Minneapolis (Hennepin Avenue and Bryant Avenue South); and Edina, MN (Valley View Road and West 70th Street/Metro Boulevard). Three additional experiments are closely related: Philadelphia's sharrows on rectangular patches of green color pavement ("greenback sharrows") on South 59th Street; Los Angeles' experiment with greenback sharrows²; and Brookline, MA's sharrows flanked by dashed white lines on Longwood Avenue. The projects with sharrows and green color pavement share the following characteristics:

- Locations where bicycle lanes are infeasible due to insufficient width.

² This project was approved by the California Traffic Control Devices Committee (CTCDC) but not by the Federal Highway Administration (FHWA).



- Sharrows typically centered on the effective width of the outside travel lane;
- Continuous green bands of four to six feet in width, underneath the sharrows and also centered on the effective lane width of the outside travel lane; and
- Signs communicating shared lane messages (e.g., “bikes may use full lane,” “share the road,” and experimental alternatives).

The projects in Salt Lake City, Long Beach, and Minneapolis (Hennepin Avenue) were implemented on four-lane urban arterials. **Table A-1 (Appendix A)** summarizes the specific characteristics and evaluation methodologies for these six experiments.

Across the available evaluation studies, the enhanced shared lane was found to shift a substantial percentage of bicyclists away from the door zone (or curb) and closer to the center of the lane. The changes in lateral positioning on enhanced shared lanes were more pronounced than those found in separate studies of sharrows without the green color pavement (or other enhancements); however, previous studies of enhanced shared lanes were not phased and therefore did not specifically isolate the effects of the green color pavement (or other enhancements). The green shared lane experiments in Long Beach and Minneapolis (Hennepin Avenue) both documented corresponding decreases in auto-bicycle collision rates.

Table A-2 (Appendix A) summarizes the findings of the four completed projects and identifies outstanding issues that were addressed by the City of Oakland’s experiment:

- Comparative effects of sharrows versus sharrows plus the green band;
- Changes in passing distance between overtaking motorists and bicyclists;
- Changes in auto lane utilization; and
- Effects on transit (including passing distance, leap-frogging, and delay).

METHODOLOGY

EXPERIMENT DESIGN

A phased before/after study was designed to evaluate the effectiveness of the experimental treatment and to monitor safety. The implementation phases were as follows:

- (1) Baseline condition: bicycle guide signs (D11-1); no bikeway striping (prior to May 2013);



- (2) Sharrows, parking edge line stripes (Detail 27B), and “Bicycles May Use Full Lane” (R4-11) signs (June to August 2013); and
- (3) Above plus five-foot wide green band (September 2013 to present).

The study was deliberately phased to use standard, currently-approved MUTCD traffic control devices first and then add the experimental device. The green band was introduced last in order to compare its efficacy with the standard and simpler treatments. Each phase remained in place for a minimum of four weeks to allow for behavior to normalize.

RESEARCH QUESTIONS AND DATA COLLECTION PLAN

To address gaps in the existing literature, the evaluation study and data collection plan were designed to address the following research questions:

- A. Are bicyclist volumes increasing on 40th Street? If so, is this a shift from parallel streets or an overall increase?
- B. Does the green band result in bicyclists riding further from parked cars?
- C. Does the green band result in motorists giving bicyclists more room when passing mid-block?
- D. Does the green band result in motorists giving bicyclists more room when passing at intersections?
- E. Does the green band result in changes to lane utilization?
- F. Do auto speeds change in either lane with the green band in place?
- G. Are motorists safely able to change lanes to pass bicyclists?
- H. What is the collision history for motorists and bicyclists without and with the green band installed?
- I. How do bus drivers navigate the outside travel lane mid-block with the green band in place?
- J. How do bus drivers navigate the outside travel lane at intersections with the green band in place?

Table 1 presents the research questions and the data collected to answer them. Data collection occurred in the final week of each phase. With scheduling constraints due to construction of the project and holidays, this allowed for four weeks during Phase 2 and six weeks during Phase 3 for motorist and bicyclist behavior to adjust to the newly introduced treatments.

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For each phase, the study collected two weekdays and two weekend days of video data between 12:00PM and 8:00PM. Data collection periods were chosen to exclude holidays and inclement weather. For this evaluation report, only the weekday PM peak (4:00-6:00PM) period and weekend afternoon (12:00-2:00PM) peak period were analyzed. In addition, seven days of bicycle and auto volume counts plus auto and bus speeds were collected. Bicycle tube counts were also collected on 42nd Street and MacArthur Boulevard, which are parallel routes to the north and south of 40th Street, respectively.

The collision analysis was completed for the entire corridor, comparing one year of before data to one year of after data using Oakland Police Department and California Highway Patrol collision reports. For all other measures, data were collected for both directions of travel between Market Street and West Street, the mid-section of the corridor.

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Table 1: Data Interpretation Methodology and Statistical Analysis

Evaluation Questions	Variables	Coding Methodology	Analytical Method
A. Are bicyclist volumes increasing on 40 th Street? If so, shifting from parallel streets or overall increase?	<ul style="list-style-type: none"> Bicycle volumes on 40th Street, 42nd Street, and MacArthur Boulevard 	-	Percentage change between phases
B. Does the green band result in bicyclists riding further from parked cars?	<ul style="list-style-type: none"> Mid-block lateral positioning of bicyclists and parked cars relative to lane line ² Instances of sidewalk riding Instances of wrong-way riding 	<ul style="list-style-type: none"> Distance in feet between bicyclists and edge of curb¹ Notation of bicyclists riding on the sidewalk 	<i>t</i> -test to determine whether change in mid-block positioning is statistically significant
	<ul style="list-style-type: none"> Intersection lateral positioning^{2,3} 	<ul style="list-style-type: none"> Distance in feet between bicyclists and edge of curb¹ 	<i>t</i> -test to determine whether change in intersection positioning is statistically significant
C. Does the green band result in motorists giving bicyclists more room when passing mid-block?	<ul style="list-style-type: none"> Mid-block lateral positioning of bicyclists and autos 	<ul style="list-style-type: none"> Distance in feet between inside edge of auto to bicyclist ¹ 	<i>t</i> -test to determine whether change in passing difference is statistically significant
D. Does the green band result in motorists giving bicyclists more room when passing at intersections?	<ul style="list-style-type: none"> Intersection lateral positioning of bicyclists and autos, distinguishing between left- and right-side passing 	<ul style="list-style-type: none"> Distance in feet between inside edge of auto to bicyclist ¹ Whether or not bicyclist arrived first 	<i>t</i> -test to determine whether change in passing difference is statistically significant
E. Does the green band result in changes to lane utilization?	<ul style="list-style-type: none"> Vehicle volume by lane 	-	Percentage change in lane 1 and lane 2 lane utilization between three phases



Table 1: Data Interpretation Methodology and Statistical Analysis

Evaluation Questions	Variables	Coding Methodology	Analytical Method
F. Do auto speeds change in either lane when the green band is in place?	<ul style="list-style-type: none"> 85th percentile speed by lane 	-	Percentage change in lane 1 and lane 2 speeds between three phases
G. Are motorists safely able to change lanes to pass bicyclists?	<ul style="list-style-type: none"> Assessment of motorist ability to "safely change lanes to pass" 	<ul style="list-style-type: none"> "No Car Immediately Adjacent" "No Opportunity to Pass" (Gap < 50') "Car Immediately Adjacent" 	Percentage change in ability to safely change lanes to pass between three phases
H. What is the collision history for motorists and bicyclists without and with the green band installed?	<ul style="list-style-type: none"> Bicycle-auto collision reports from Oakland Police Department (OPD) 	-	Number of reported collisions
I. How do bus drivers navigate the outside travel lane mid-block with the green band in place?	<ul style="list-style-type: none"> Mid-block lateral positioning of bicyclists and buses 	-	Qualitative observations
J. How do bus drivers navigate the outside travel lane at intersections with the green band in place?	<ul style="list-style-type: none"> Intersection lateral positioning of bicyclists and buses relative to curb face 	-	Qualitative observations

Notes

1. Data was recorded in half-foot increments.
2. The data collection methodology measured positioning relative to the lane line due to limited visibility of curb line in video and the variation in parked cars spacing relative to face of curb. Data analysis reports distance from face of curb to understand positioning of bicyclists relative to the door zone and allow direct comparison to other studies.
3. Only through bicyclists were analyzed, as right-turning bicyclists were assumed to position different at the intersection.



VIDEO INTERPRETATION

Vehicle and bicycle volumes and auto speeds were received in Microsoft Excel format. For the experiment Fehr & Peers developed a methodology, using a constructed, perspectival grid, to measure bicycle and vehicle positioning from the video data. Previous studies measured lateral positioning through physical markings in the roadway. In order to avoid the possibility that physical markings affect bicyclist and vehicle positioning in the roadway, a post-processing approach was chosen.



Screen captures of quality of video data prior to processing.

Adobe software and known roadway and striping dimensions were used to construct a perspectival grid overlaid onto the video at half foot increments. Half foot increments were chosen in order to provide precision while also acknowledging the limitations of the media to provide more specific measurements. To facilitate video interpretation, half foot zones were drawn and centered on each half foot increment. Each event within that zone was recorded according to the band it was centered on. For example, if a bicyclist was positioned between 10.25 and 10.75 feet away from the curb, they would be recorded as traveling 10.5 feet from the curb.

Screen captures of quality of video with measured ½ foot zones.





FINDINGS

EFFECTS ON BICYCLE VOLUMES

Analysis Methodologies

Evaluation Question A posed the following question, “Are bicyclist volumes increasing on 40th Street? If so, shifting from parallel streets or overall increase?” The purpose of these questions is to establish whether the applied treatments attracted more bicyclists to ride the corridor and what, if any, affect that had on parallel bikeway volumes. Two methods were used to assess bicycle volumes. The first utilized peak period counts collected through the City of Oakland’s citywide program to identify changes at the 40th Street/West Street intersection before and after the super sharrow treatment. The second method analyzed average daily bicycle volumes between Phase 1 and Phase 3 to examine changes in 40th Street and the two parallel bikeways: MacArthur Boulevard and 42nd Street.

Assessing Changes in Volume through Peak Period Counts

The changes in bicycle volumes across the three phases of the experiment used peak period intersection bicycle volume counts on typical weekdays between 4:00-6:00PM. These data are collected annually at specific intersections by the City of Oakland. Calculation of a background growth rate is presented and is applied to measure the change in bicycle volumes on 40th Street at West Street between 2012 and 2014 attributable to sharrow and super sharrow treatments.

Identification of Background Growth

Bicycle volumes have increased in Oakland over the course of the phased experiment. To account for background growth in cycling that is attributable to larger trends in biking rather than the introduction of new bicycle facilities on 40th Street, a background growth rate for bicycling in the North Oakland area was calculated. Three intersections in the North Oakland area were studied to identify trends in bicycle volumes between 2012 and 2014:

- 55th Street/Market Street
- Cavour Street/Shafter Avenue
- Broadway/27th Street



2012 and 2014 volumes at each of the three intersections and the percent change in bicyclists are presented in **Table 2**. The change in volumes ranged between a 38 percent increase and 46 percent increase, which indicates an average background growth rate for North Oakland of 41 percent.

Table 2: Background Growth in North Oakland Bicycle Volumes				
Volumes	55th Street/ Market Street	Cavour Street/ Shafter Avenue	Broadway/ 27th Street	Total
Fall 2012	88	125	341	554
Fall 2014	121	183	477	781
Percent Change	38%	46%	40%	41%

Source: City of Oakland, Fehr & Peers, 2012-2014.

Results

Changes in volumes attributable to Phase 3 treatments are presented in **Table 3**. A high and low range for bicycle volume increases between Phase 1 and Phase 3 of the experiment are presented to account for fluctuations in the baseline data. Data collected in 2011 indicated 87 peak period bicyclists and data from Fall 2012 indicated 80 bicyclists during the peak period (4-6PM) on 40th Street at West Street. The low value was calculated with the 2012 data, and the high value was calculated with 2011 data to account for potential fluctuations in bicycle volumes.

Between Phase 1 and Phase 3, peak period bicycle volumes on 40th Street (eastbound and westbound) at West Street increased to 138 bicyclists during the peak period. Using the 41% background growth factor derived in Table 1, between 113 and 123 bicyclists might be expected on 40th Street in 2014 with no change in bicycle facility type. Even with background growth factored out, an increase of 15 to 25 peak period bicyclists was observed, indicating an 18 to 31% increase in bicyclists on the corridor attributable to the super sharrow treatment.



Table 3: Changes in Weekday Peak Period (4-6PM) Bicycle Volumes on 40th Street at West Street between Phases 1 and 3

Range of Volume Change ¹	"Before" (Phase 1) – Designated Bicycle Route Only – Peak Period Volume ²	"After" (Phase 3) – Super Sharrow Treatment ³ – Peak Period Volume	Percent Change	40 th Street Estimated Volumes due to Background Growth ⁴	Volume Change between Phases 1 & 3	
					Growth in Bicyclists	Percent Change in Bicyclists
High Value	80	138	73%	113	25	31%
Low Value	87		59%	123	15	18%

1. Low and high estimates are presented, as the 2011 data indicate 87 total bicyclists and the 2012 data indicated 80 total bicyclists during the peak period.

2. Intersection turning movement count data from September 11, 2012, provided by the City of Oakland.

3. 2014 data collected represents volumes one full year after the installation of the super sharrow treatment. Intersection turning movement count data from September 11, 2014, provided by the City of Oakland.

4. The background growth rate is assumed to be 41%, as presented in Table 1.

Source: City of Oakland, Fehr & Peers, 2011-2014

Assessing Changes in Volume through Average Daily Bicycle Counts

Pneumatic tubes calibrated to detect bicyclists were used to collect 24-hour bicycle volumes counts during each phase of the study. Tubes were placed on MacArthur Boulevard, 40th Street, and 42nd Street so that changes in volumes on the three parallel bikeways could be measured across phases.

Table 4 presents the changes in bicycle volumes by corridor. Note that the table presents the average of Tuesday, Wednesday, and Thursday data only. This is due to a labor strike by BART employees that occurred during the first four days of Phase 3 data collection. During the strike, the BART rail system was closed, resulting in abnormally low traffic volumes around the MacArthur BART station. Additionally, equipment malfunctioning occurred with the westbound pneumatic tubes on 40th Street during Phase 3, so only eastbound data are reported.

The data indicate that bicyclist volumes increased by 29 percent on 40th Street between Phase 1 and Phase 3. A small increase is observed between Phase 1 and Phase 2. That may be attributable to fluctuations in bicycle volumes or a slight increase in volumes associated with the Phase 2 sharrow treatment.



The increase in volumes on 40th Street corresponds to a decrease in bicycle volumes on the two parallel bikeways, MacArthur Boulevard and 42nd Street. However, the corresponding decrease accounts for a little less than half of the increase in ridership on 40th Street. It appears that about half of the 29 percent growth in ridership on 40th Street may be due to shifts from other corridors or new bicycle ridership associated with the Phase 3 super sharrow treatment. This roughly corresponds to the range of growth estimated in Table 3.

Table 4: Change in Bicycle Volumes on 40th Street and Parallel Bikeways between Phases 1 and 3

Corridor	Phase 1	Phase 2	Phase 3	Change between Phases 1 & 3
40th Street	628	640	811	+183 (29%)
MacArthur Boulevard	355	344	278	-77 (22%)
42nd Street	283	288	272	-11 (4%)

Source: City of Oakland, Fehr & Peers, 2012-2014.

EFFECTS ON BICYCLE LATERAL POSITIONING MID-BLOCK

Analysis Methodology

Evaluation Question B posed the following question, “Does the green band result in bicyclists riding further from parked cars?” The purpose of this question was to analyze whether the applied treatments encouraged bicyclists to ride closer to the center of the lane or fully take the lane and to shift positioning to outside the door zone. The benefit of riding outside the door zone is that bicyclists would have a reduced risk of hitting a door opened by someone in a parked car. To evaluate this question, bicyclist lateral positioning was evaluated under two conditions: 1) bicycle free flow (no vehicle present), 2) vehicle interaction (vehicle either tailing or passing cyclist). For the purpose of this study, a vehicle interaction is defined as either (1) an auto that does not pass a bicyclist and continues to travel behind the bicyclist (whether or not an opportunity was available) or (2) an automobile that overtakes and passes a bicyclist. For each bicyclist, the distance between the curb and the center of the front wheel of the bicycle was recorded. Lateral positioning was evaluated both based on distance from the curb in half-foot increments, and organized by zone of



travel (“in the door zone” versus “in or near the green band”).³ Since it was expected that the presence of parked cars would influence bike positioning, the data were also separated by whether a car was parked to the right of the cyclist when the measurement was taken.

Bicyclist distance from the curb was compared between weekday and weekend; however, for the most part, the cycling distance from the curb was not statistically different between weekday riders and weekend riders. The one exception is during Phase 3 when vehicles are present and cars are parked, where the results show that cyclists were riding further from the curb during weekends than during weekdays. Therefore, for the following analysis, unless otherwise noted, weekend and weekday data are aggregated together, which creates a larger sample size.

To determine whether the shift in lateral positioning was statistically significant between each subsequent phase, t-test analysis was performed based on the bicyclist distance from the curb in half-feet. Chi-square tests were performed to evaluate whether there was a statistically significant shift in the percent of bicyclists cycling in the green zone.

Results: Bicyclist Positioning with Vehicles Parked

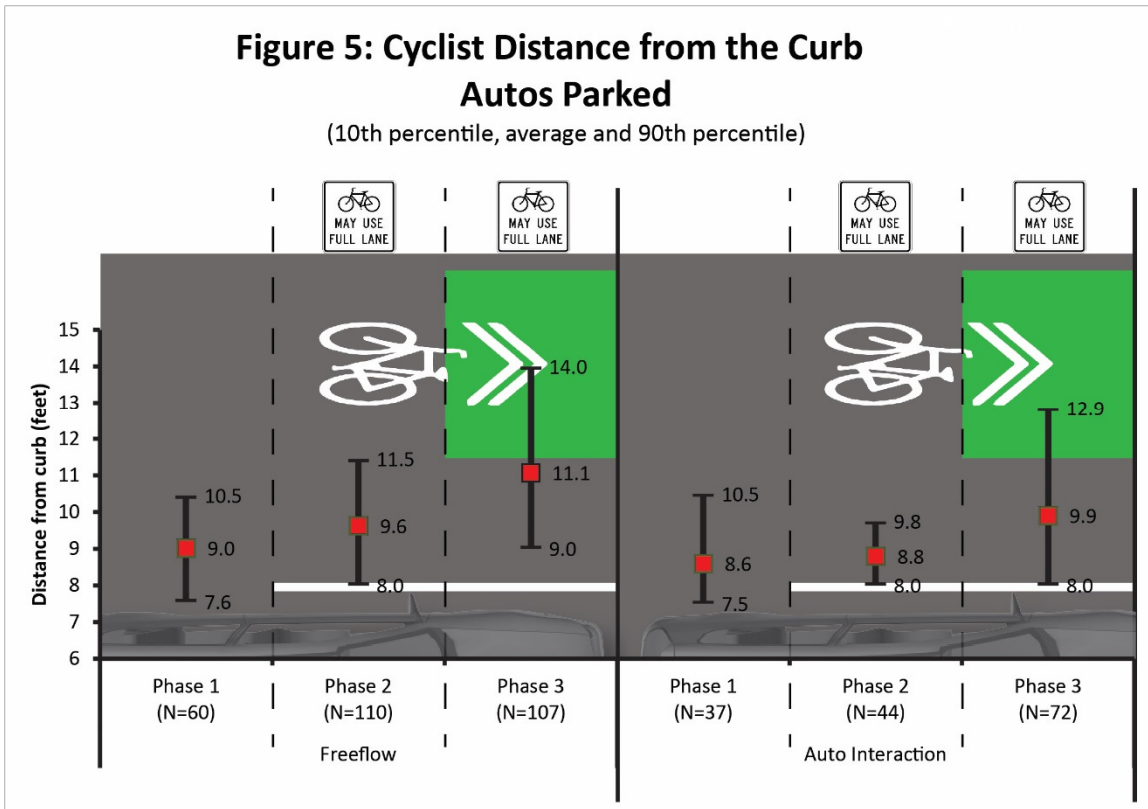
Numeric Distance from Curb

Question B Key Findings –with Parked Cars, Numeric Distance from Curb:

- (1) The average lateral bicycle free-flow positioning increased by 2.1 feet, from 9.0 to 11.1 between Phases 1 and 3, and the shift was found to be statistically significant. The average lateral bicycle free-flow positioning increase by 0.6 feet, from 9.0 to 9.6 feet, between Phases 1 and 2, and the shift was found to be statistically significant,
- (2) During overtaking events, the average lateral bicycle positioning increased by 1.3 feet, from 8.6 to 9.9 feet between Phases 1 and 3, and the shift was found to be statistically significant.

Figure 5 summarizes the bicyclist distance from the curb for each condition during each of the three phases when cars were parked. The red boxes indicate the average bicyclist distance from the curb for each category. The lines, or “whiskers,” indicate the 10th to the 90th percentile values for bicyclist lateral positioning (the percentile is the value below which a given percentage of observations within a group fall). As the figure demonstrates, the average bicyclist distance from

³ The door zone was assumed to be 8.5-11 feet from the curb as measured to the center of the bicyclist. Positioning greater than 11 feet is considered to be the “green zone” which is in the green band or directly adjacent to it and therefore outside of the door zone.



the curb increased between each subsequent phase for bicyclists under both free flow conditions and conditions in which a vehicle was present, but the range of values varied greatly. Under both conditions the range of values varied more during Phase 3 than during Phases 1 or 2. This is consistent with previous findings on the effectiveness of sharrows.⁴

The t-test results are summarized in **Table 5**. Between each subsequent phase, the increase in the bicyclist distance from the curb during free flow conditions was found to be significant. This indicates that compared to the base condition with bicycle accommodation, both the presence of all MUTCD-approved treatments (Phase 2) and the presence of green pavement (Phase 3) increased the cyclist distance from the curb when no cars were present. The longer whiskers during Phase 3 indicate that there is more variation in bicyclist behavior during Phase 3; while the average distance from the curb increased significantly, some bicyclists still rode close to the curb, and others rode

⁴ For example, in the San Francisco Shared Lane Marking Evaluation (2004), bicyclists shifted an additional eight inches away from parked cars with the presence of sharrows as compared to the baseline condition, which was a statistically significant finding. This is comparable to the statistically significant approximately seven inches, on average, observed in this study.



further from the curb than before the treatments were installed. This may indicate a varied response to the super sharrow amongst bicyclists. Likely this reflects (1) some bicyclists understanding that the green band is where they should ride and (2) varying degrees of bicyclist comfort with taking the lane. The variability in positioning and the statistically significant increase in average distance from the curb with the Phase 3 green pavement indicate that the treatment achieved the goal of encouraging bicyclists to take the lane.

Table 5: Bike Distance from Curb t-test¹ Results – Vehicles Parked

Condition	Phases	p-value ² (2-tailed)	Significant?
Free Flow	<i>Between Phase 1 and Phase 2</i>	0.02	Yes
	<i>Between Phase 2 and Phase 3</i>	< 0.001	Yes
	<i>Between Phase 1 and Phase 3</i>	< 0.001	Yes
Vehicle Present	<i>Between Phase 1 and Phase 2</i>	0.30	No
	<i>Between Phase 2 and Phase 3</i>	< 0.001	Yes
	<i>Between Phase 1 and Phase 3</i>	< 0.001	Yes

1. A t-test is a statistical examination of two population means. A two-sample t-test examines whether two samples are different.
2. The p-value is the probability of obtaining a test statistic result at least as extreme as the one that was actually observed, assuming that the null hypothesis of no difference between the phases is true. The smaller the p-value, the more confidence that of statistical significance.

Cyclist distance from the curb while a vehicle was present did not change significantly between Phases 1 and 2. Between Phases 2 and 3 and between Phases 1 and 3, when vehicles were present, the increased bicyclist distance from the curb was significant. This indicates that, when vehicles are present, the super sharrow markings encourage cyclists to shift their positioning, cycling further from the curb than both the base scenario and the scenario with standard sharrows. However sharrows alone did not encourage a significant shift in cyclist distance from the curb over the base case when vehicles were present.



Distance from Curb by Zone of Travel

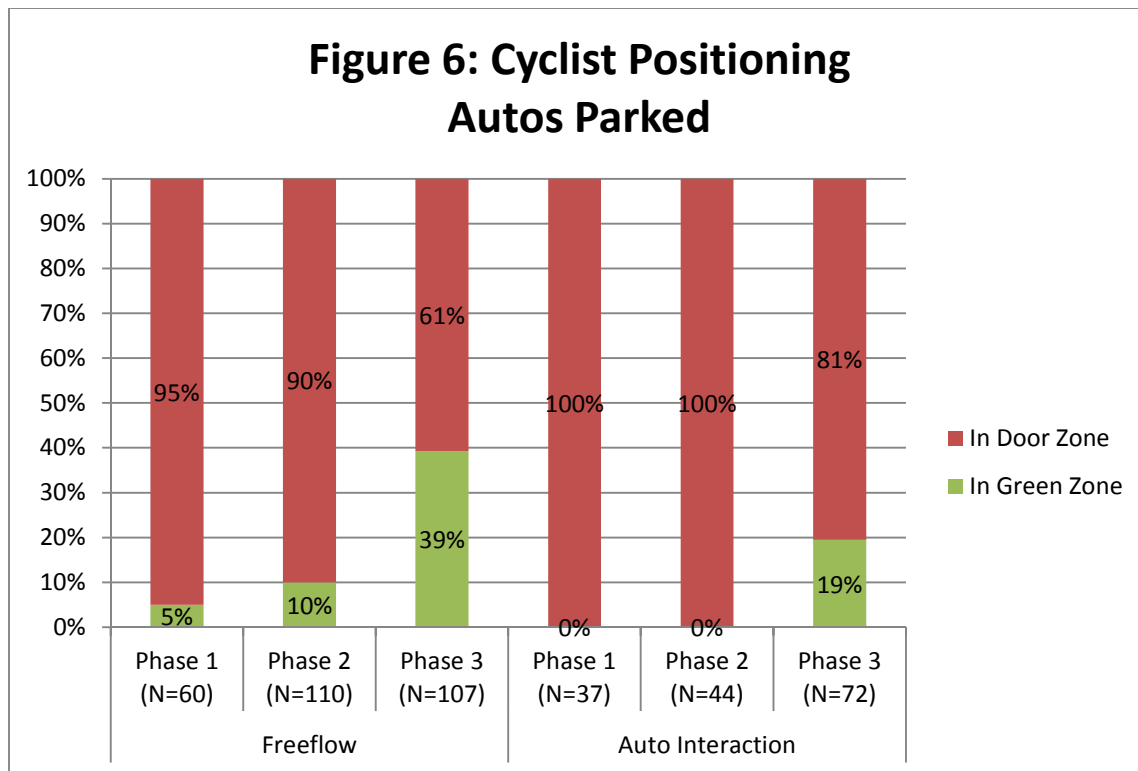
Question B Key Findings – with Parked Cars, Zone of Travel:

- (1) During bicyclist free flow, the percentage of cyclists riding in the green zone increased from 5% to 39% between Phases 1 and 3 and from 5% to 10% between Phases 2 and 3. These shifts are statistically significant.
- (2) During overtaking events, the percentage of bicyclists riding in the green zone increased from 0% to 19% between Phases 1 and 3, and the shift is statistically significant. Between Phases 1 and 2, all overtaking events in the presence of parked cars occurred in the door zone.

The results were also analyzed based on zone of travel. **Figure 6** summarizes the percent of bicyclists riding within each of the following zones, during each of the three phases and under both conditions studied, when vehicles are parked:

- Door Zone (8.5-11 feet from curb)
- In or Near Green Band, "Green Zone" (>11 feet from curb)

The distances refer to the location of the bicyclists' front wheel with respect to the roadway's curb. These results were analyzed to determine whether the percent of bicyclists riding outside of the door zone (e.g. to the left of the door zone, either to the right of the green band, in the green band or to the left of the green band) increased between the subsequent phases.



The chi-square results are summarized in **Table 6**. Between each subsequent phase, the increase in the percent of bicyclists riding in the green zone during free flow conditions increased. This increase was only found to be significant between Phases 2 and 3 (MUTCD approved treatments and green pavement plus MUTCD-approved treatments, respectively) and between Phases 1 and 3 (no bicycle treatment and green pavement plus MUTCD-approved treatments, respectively). This indicates that both the average cycling distance from the curb and the percentage of cyclists riding outside of the door zone increased with the green band in Phase 3. Although the MUTCD-approved treatments alone provided a statistically significant increase in bicyclist distance from the curb, the increase in the percent of cyclists riding outside of the door zone compared to base conditions was not statistically significant.

The percent of bicyclists riding in the green zone while vehicles are present was zero in both Phases 1 and 2. However, this percent increased and was significant between Phases 2 and 3 and between Phases 1 and 3. This indicates that the percent of cyclists riding outside of the door zone increased significantly with the implementation of the green band plus MUTCD-approved treatments, even when vehicles were present.



Table 6: Percent of Bicyclists Riding in Green Zone Chi-Square¹ Results – Vehicles Parked

Condition	Phases	Chi-Square	p-value ²	Significant?
Free Flow	<i>Between Phase 1 and Phase 2</i>	1.28	0.257	No
	<i>Between Phase 2 and Phase 3</i>	25.14	<0.001	Yes
	<i>Between Phase 1 and Phase 3</i>	22.91	<0.001	Yes
Vehicle Present	<i>Between Phase 1 and Phase 2</i>	NA	NA	No
	<i>Between Phase 2 and Phase 3</i>	9.73	0.002	Yes
	<i>Between Phase 1 and Phase 3</i>	8.25	0.004	Yes

1. A Chi-square test is a statistical test commonly used for testing independence and goodness of fit.
2. The p-value is the probability of obtaining a test statistic result at least as extreme as the one that was actually observed, assuming that the null hypothesis of no difference between the phases is true. The smaller the p-value, the more confidence that there was a statistically significant increase in the percent of bicyclists riding in the green zone.

Results –No Vehicles Parked

Question B Key Findings –No Parked Cars:

- (1) With no autos parked, bicyclists appear to exhibit weaving behavior where space allowed them to ride in the parking lane.
- (2) Average distance from the curb was 8.8 (free flow) and 8.4 (auto interaction) during Phase 3, increased minimally between Phases 1 and 3, and did not increase between Phases 2 and 3, when autos were passing or tailing bicyclists. During bicycle free flow conditions, the difference between Phases 1 and 2 and Phases 1 and 3 were significant.
- (3) Sample size for this analysis was limited due to the highly utilized parking.

The same analysis was performed when no cars were parked to the right of the cyclist, as shown in **Table 7**. For the purpose of this analysis “no parking” is defined as either one or more unoccupied parking spaces or a break in parking as a result of a driveway or bus stop. Video data only captured the no parking condition during the weekday; as such, no weekend data are available. The average, 10th percentile and 90th percentile values for cyclist distance from the curb for each phase and condition are shown in **Figure 7**. Between Phases 1 and 2 and between Phases 1 and 3 under free



flow conditions, cyclist distance from the curb increased significantly on weekdays when no cars were parked. However, between other conditions and phases no statistically significant shift was found. This indicates that, even when no cars are parked, under free flow conditions both sharrows and super sharrows result in cyclists riding further from the curb than under base conditions. However, the shift was comparable with standard sharrows and super sharrows. Furthermore, variability in bicyclist distance from the curb is greatest with super sharrows. When autos are interacting with bicyclists, there is no statistically significant shift in bicyclist position with the sharrows or super sharrows. This indicates that when no cars are parked and vehicles are tailing or passing, cyclists tend to ride in, or close to, the parking lane rather than taking the lane. However, the sample size for this analysis was very small; a larger sample size could help to confirm these results.

Figure 7: Cyclist Distance from the Curb
No Autos Parked

(10th percentile, average and 90th percentile)

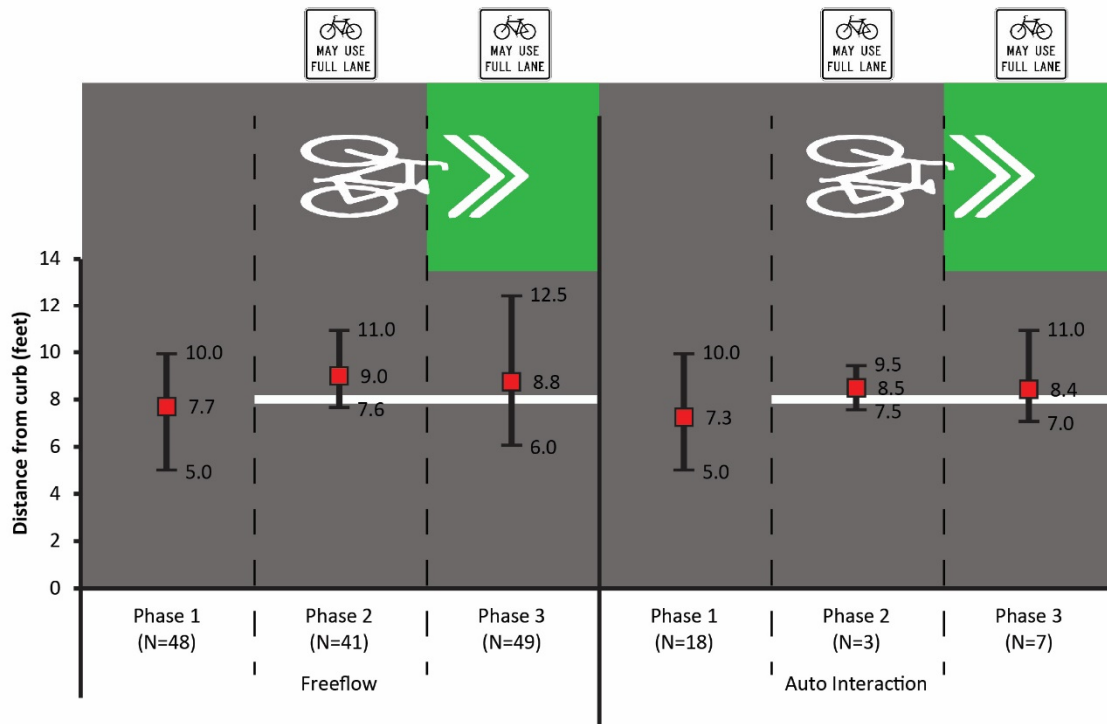




Table 7: Bike Distance from Curb t-test¹ Results – Weekday, No Vehicles Parked

Condition	Phases	p-value ² (2-tailed)	Significant?
Free Flow	<i>Between Phase 1 and Phase 2</i>	< 0.001	Yes
	<i>Between Phase 2 and Phase 3</i>	0.55	No
	<i>Between Phase 1 and Phase 3</i>	0.02	Yes
Vehicle Present	<i>Between Phase 1 and Phase 2</i>	0.24	No
	<i>Between Phase 2 and Phase 3</i>	0.94	No
	<i>Between Phase 1 and Phase 3</i>	0.13	No

1. A t-test is a statistical examination of two population means. A two-sample t-test examines whether two samples are different.
2. The p-value is the probability of obtaining a test statistic result at least as extreme as the one that was actually observed, assuming that the null hypothesis of no difference between the phases is true. The smaller the p-value, the more confidence that there was a statistically significant increase in the bicyclist distance from the curb.

EFFECTS ON PASSING DISTANCE

Analysis Methodology

Evaluation Question C posed the following question: “Does the green band result in motorists giving bicyclists more room when passing mid-block?” The purpose of this question was to analyze whether the applied treatments encouraged motorists to change lanes to pass and thereby give bicyclists more space. For each vehicle-bicyclist interaction, the distance between the center of the front wheel of the bicycle and the inner edge of the vehicle was recorded. The distance between the center of the front wheel of the cyclist and the edge of the cyclist was assumed to be 1 foot⁵.

⁵ Average width of a bicycle is typically about 2 feet (Minnesota DOT Bikeway Facility Design Guide <http://www.dot.state.mn.us/bike/pdfs/manual/Chapter3.pdf>). As a result, half of that distance is subtracted (1 foot) to measure the distance between the edge of the bicyclist and the edge of the passing automobile.



Vehicle passing was evaluated both based on distance between vehicle and bicycle in feet, and based on passing zone (passing with more than three feet versus less than three feet⁶).

In order to determine whether the shift in passing distance was statistically significant between each subsequent phase, t-test analysis was performed based on the distance between the vehicle and bicyclist in feet. Additionally, chi-square tests were performed to evaluate whether there was a statistically significant shift in percent of vehicles passing at a safe distance (more than three feet).

Results

Question C Key Findings – with Parked Cars:

(1) Average passing distance was over 4 feet in all three phases and though the average passing distance increased in the third phase, this increase was not found to be significant.

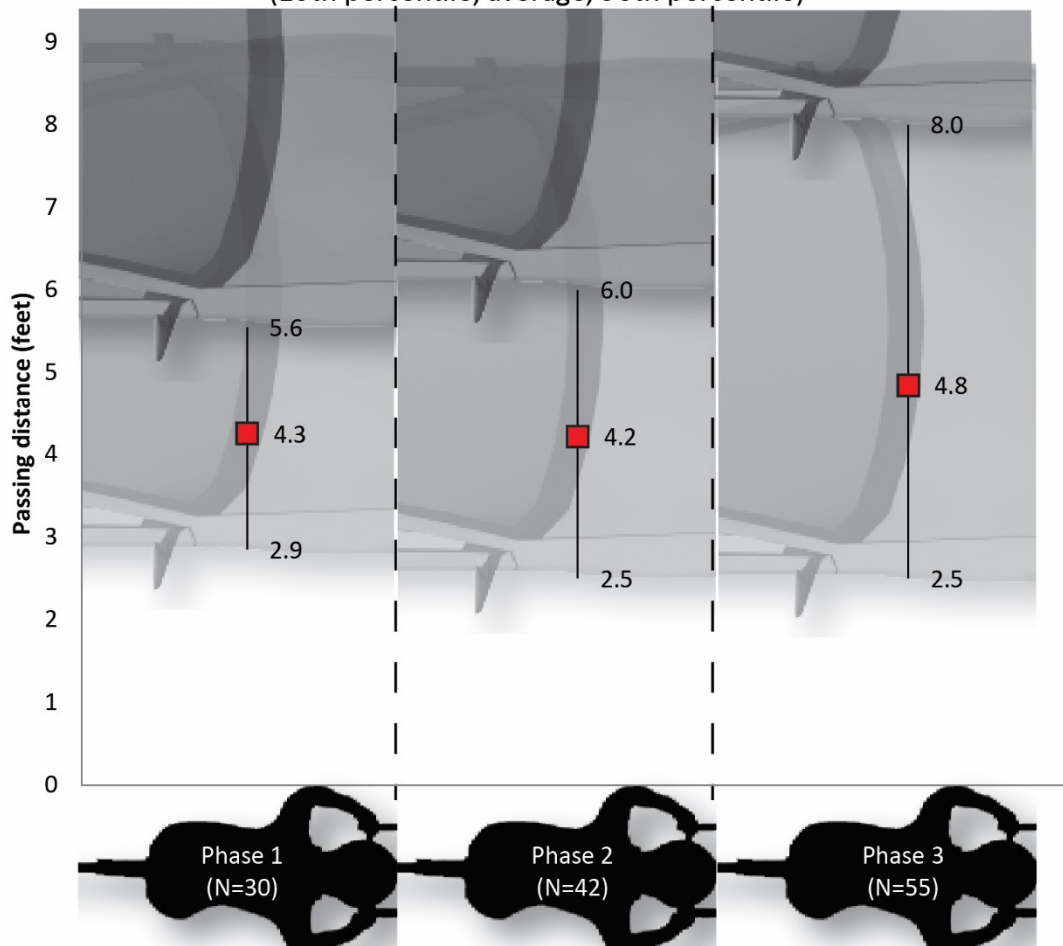
Passing distance between vehicles and cyclists during each phase is summarized in **Figure 8**. The average passing distance remained the same between Phases 1 and 2 and increased slightly in Phase 3. The variation in passing distance increased between each subsequent phase. This indicates that while some vehicles gave bicyclists more room while passing, other vehicles passed at a closer distance during Phases 2 and 3. This may be because bicyclists were riding further from the curb, vehicles had less room to pass within the lane, and therefore passed at a closer distance in order to stay within the lane of travel.

⁶ A three foot passing distance was used, as Assembly Bill 1371 will require motorists to give bicyclists three feet of passing distance in the State of California. The law took effect in September 2014.



**Figure 8:
Auto-Cyclist Passing Distance**

(10th percentile, average, 90th percentile)



The *t*-test results are summarized in **Table 8**. Although the average passing distance increased slightly in Phase 3, this increase was not found to be statistically significant; the increase was within the margin of error. It should be noted that the travel lane plus parking lane is 20 feet in width. When bicyclists are operating in or near the door zone, passenger vehicles typically have sufficient room to pass cyclists within the travel lane while still giving at least three feet of passing distance.



Table 8: Vehicle-Bicycle Passing Distance *t*-test¹ Results

Condition	Phases	p-value ² (2-tailed)	Significant?
Vehicle Present	<i>Between Phase 1 and Phase 2</i>	0.89	No
	<i>Between Phase 2 and Phase 3</i>	0.14	No
	<i>Between Phase 1 and Phase 3</i>	0.22	No

1. A *t*-test is a statistical examination of two population means. A two-sample *t*-test examines whether two samples are different.
2. The p-value is the probability of obtaining a test statistic result at least as extreme as the one that was actually observed, assuming that the null hypothesis of no difference between the phases is true. The smaller the p-value, the more confident we can be that there was a statistically significant shift in vehicle-bike passing distance between the two phases identified.

Figure 9 shows a breakdown of the vehicle passing events observed during each phase between vehicles passing a bicyclist within three feet and those passing with more than three feet. The chi-square test results are summarized in **Table 9**. No significant shift in the percent of vehicles passing with more than three feet was seen between Phase 1 and Phase 2, however the difference between Phase 1 and Phase 3 was found to be significant. This suggests that, with super sharrows, auto passing distance is more variable. Although the average passing distance remains fairly constant between the three phases, during Phase 3 a larger percent of autos are passing bicyclists with less than three feet of passing distance.

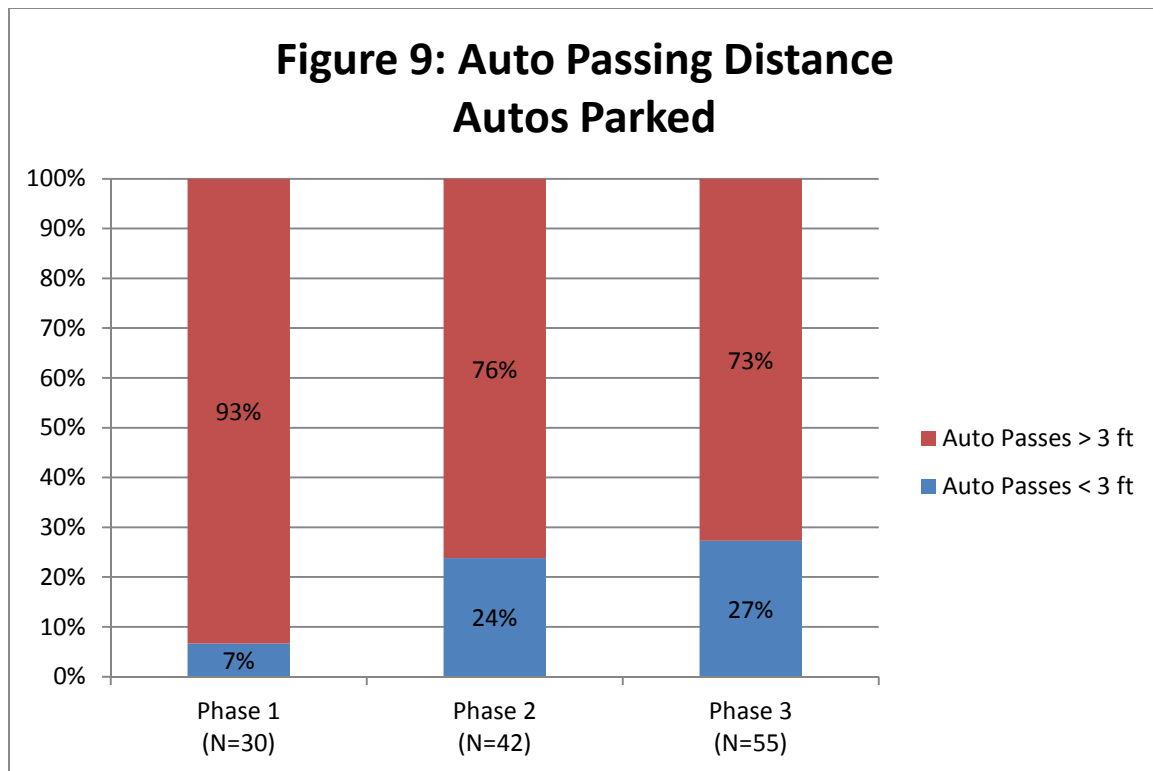


Table 9: Vehicle Passing Distance Chi-Square¹ Results – Vehicles Parked

Condition	Phases	Chi-Square	p-value ²	Significant?
Vehicle Present	<i>Between Phase 1 and Phase 2</i>	3.70	0.05	No
	<i>Between Phase 2 and Phase 3</i>	0.15	0.70	No
	<i>Between Phase 1 and Phase 3</i>	5.15	0.02	Yes

1. A Chi-square test is a statistical test commonly used for testing independence and goodness of fit.
2. The p-value is the probability of obtaining a test statistic result at least as extreme as the one that was actually observed, assuming that the null hypothesis of no difference between the phases is true. The smaller the p-value, the more confidence that there was a statistically significant increase in the percent of autos passing with more than 3 feet.



EFFECTS ON BICYCLE LATERAL POSITIONING AT INTERSECTIONS

Analysis Methodology

Evaluation Question D posed the following question: “Does the green band result in motorists giving bicyclists more room when passing at intersections?” Cyclist position at the intersection was observed to determine whether cyclists were more likely to take the lane through the intersection or shift to the right. Bicyclist position at the intersection was broken into two categories: 1) “bike takes the lane” meaning the bicyclist controlled the lane, remaining in or near the center of the lane and queued behind cars if any were present, or 2) “bike shades right” meaning the bicyclist traveled to the right side of the lane, closer to the curb, before stopping or entering the intersection. Bicyclists arriving at a red light versus a green light were analyzed separately since behavior may change when bicyclists are required to stop. Bicyclists were also separated by whether they arrived at the intersection when no cars were present, versus arriving when vehicles were already present at the intersection.

Results

Question D Key Findings:

(1) With a limited sample size, anecdotal observations indicate that when autos were queued at the intersection, bicyclists typically shaded right. When cars were not queued, bicyclists typically took the lane during Phases 1 and 3.

Based on a limited number of observations, if a cyclist arrived to an intersection during a green light and no vehicles were present, the cyclist typically took the lane. If a vehicle was present at the intersection, the cyclist typically traveled to the right of the vehicle. Similarly, based on a limited number of observations, if a cyclist arrived to the intersection during a red light and no vehicles were present, the cyclist typically took the lane during Phases 1 and 3. Most cyclists arriving at an intersection during a red light when a vehicle was present cycled to the right of the waiting vehicle. These results are summarized in **Figure 10** and **Figure 11**. Based on the limited number of data points an increase did not occur in the percentage of cyclists taking the lane during each subsequent phase.



Figure 10: Bike Positioning at Intersection when Arriving at a Green Light

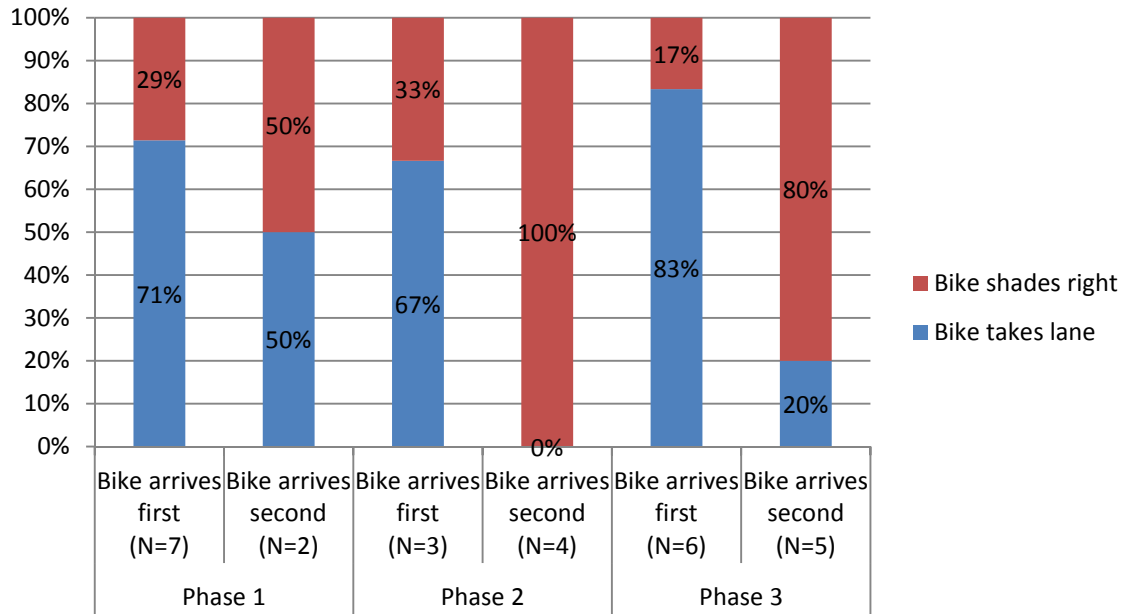
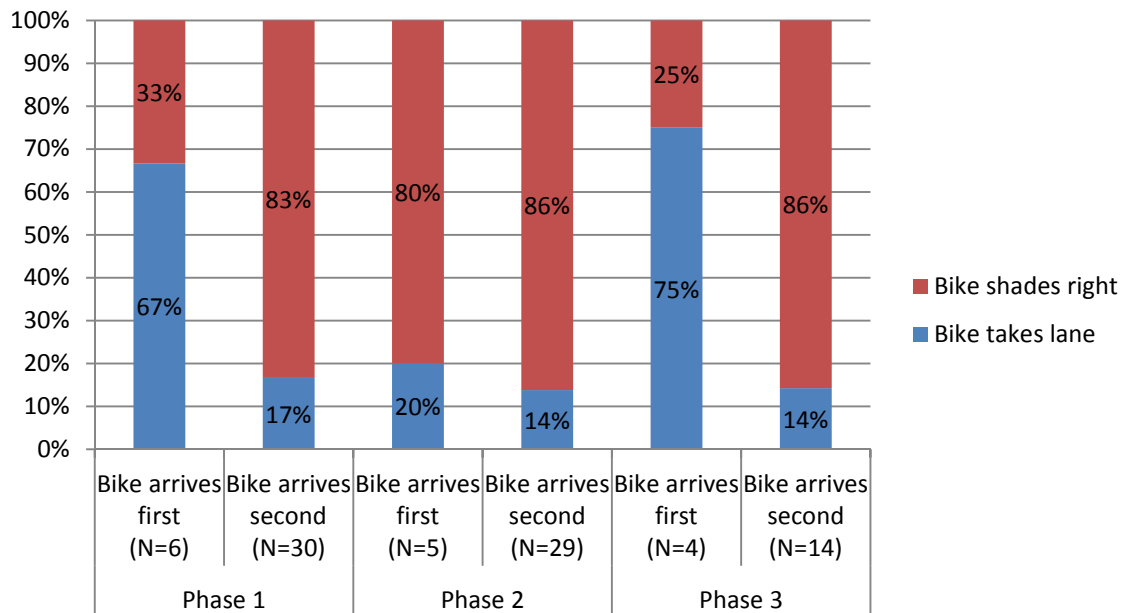


Figure 11: Bike Positioning at Intersection when Arriving at a Red Light





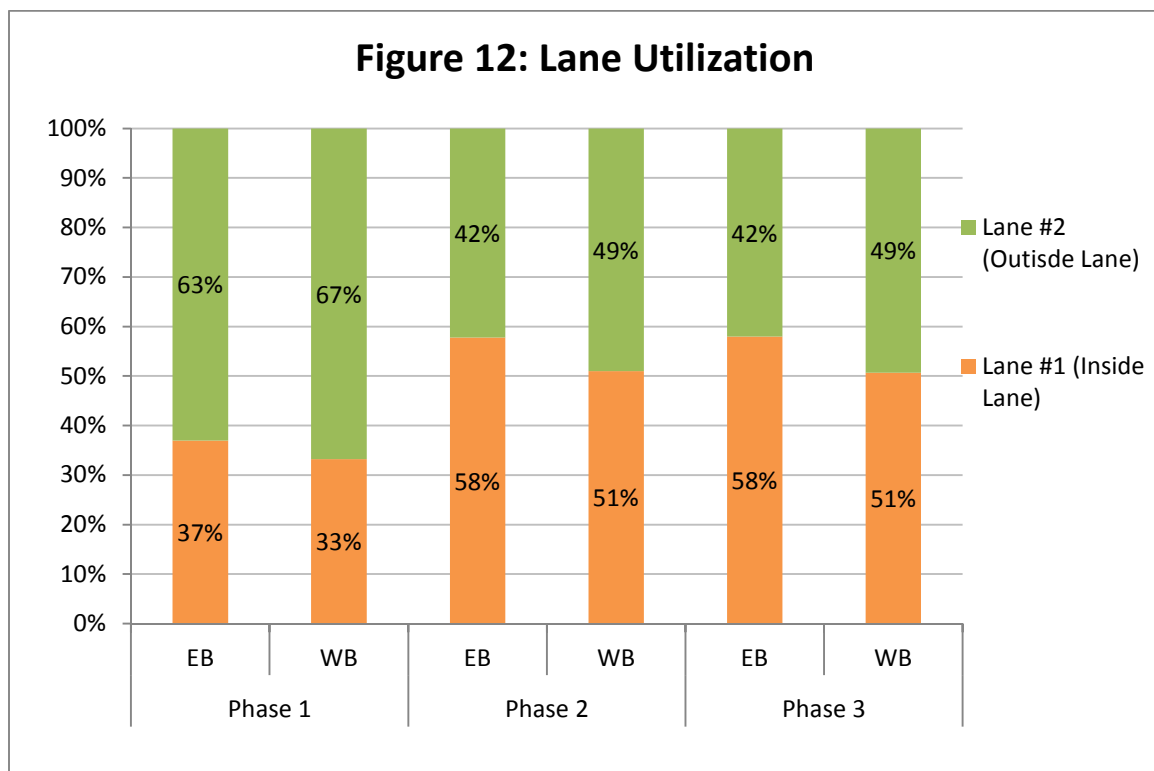
EFFECTS ON LANE UTILIZATION

Analysis Methodology

Evaluation Question E posed the following question: “Does the green band result in changes to lane utilization?” In order to measure lane utilization, 24-hour vehicle tube counts were conducted for each lane and in each direction for a full week during each phase. The purpose was to measure whether utilization between the two lanes shifted after implementation of the treatments.

Results

The lane utilization results are summarized in **Figure 12**. Lane #2, the outside lane, is where the treatments were applied. As seen in the chart, utilization of Lane #2 decreased between Phases 1 and 2. In other words, more vehicles shifted to the inside lane after the implementation of the sharrows. This can have a positive impact on bicyclists using the outside lane because it reduces the number of bicycle-vehicle interactions in the lane. Lane utilization between the two lanes remained the same between Phases 2 and 3 indicating that the implementation of super sharrows may have no impact on lane utilization beyond what would be seen with sharrows alone.





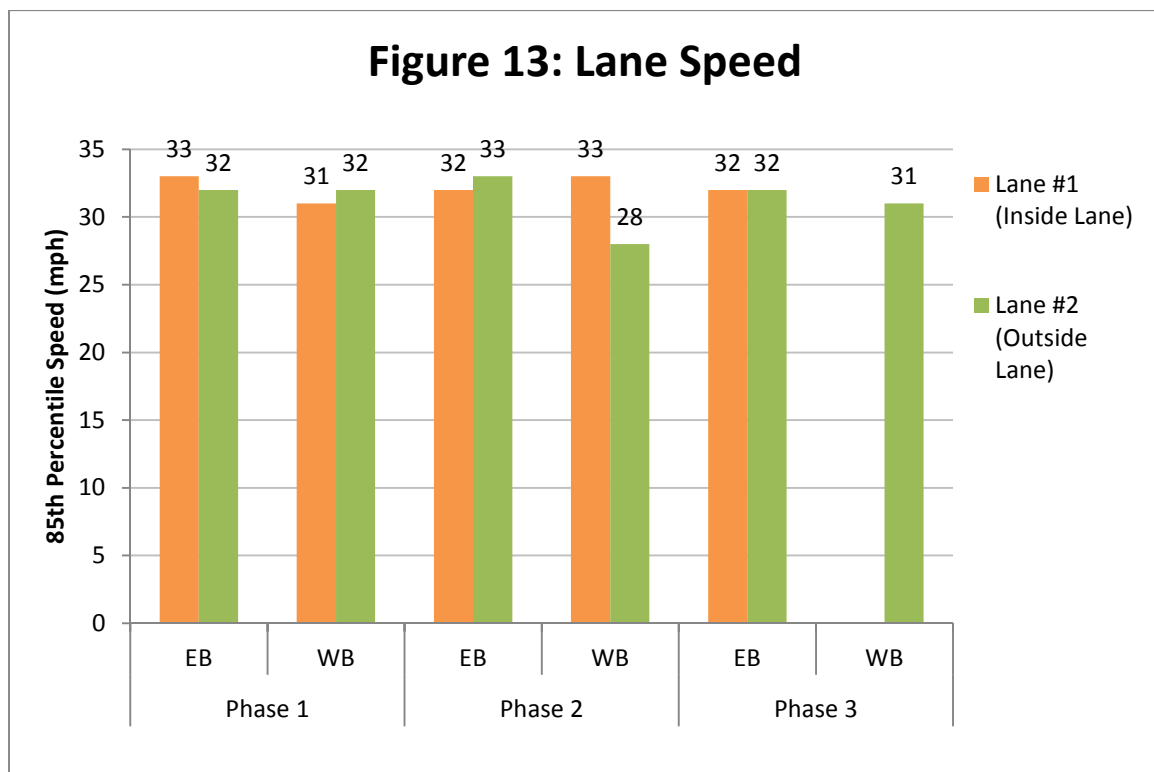
EFFECTS ON VEHICLE SPEEDS

Analysis Methodology

Evaluation Question F posed the following question: “Do auto speeds change in either lane when the green band is in place?” The tube counts were also used to measure average speed in each of the lanes, by direction.

Results

Speed results are summarized in **Figure 13**. The 85th percentile speed did not change significantly between the three phases, even though vehicle volumes did increase in the inside lane between Phases 1 and 2. This indicates that the inside lane had capacity for more vehicles without impacting vehicle flow. Bicycle use of the outside lane did not lead to reductions in vehicle speeds.



*Note: no data were available for Lane #1 in the WB direction for Phase 3



EFFECTS ON ABILITY TO SAFELY CHANGE LANES TO PASS

Analysis Methodology

Evaluation Question G posed the following question: “Are motorists safely able to change lanes to pass bicyclists?” One concern with the installation of super sharrows was that vehicle volumes would shift from the outside to the inside lane, thus reducing gaps between vehicles in the inside lane and making it more difficult for vehicles to change lanes to pass cyclists. A gap of 50 feet or more was identified as a sufficient distance to allow a vehicle to change lanes to pass a cyclist. A gap of less than 50 feet was considered insufficient to allow vehicles to safely change lanes. A vehicle traveling adjacent to the cyclist in the inside lane would also preclude the opportunity for the vehicle to change lanes to pass a cyclist. All bicycle-vehicle interactions observed (these may include a vehicle passing a cyclist or tailing a cyclist) were broken into these three inside lane conditions and are summarized in **Figure 14**.

Results

Gaps of 50 feet or greater in the inside lane increased between Phases 1 and 2, and remained similar between Phases 2 and 3. Gaps of less than 50 feet remained similar between all phases. Presence of a vehicle adjacent to the cyclist decreased between Phases 1 and 2 and increased between Phases 2 and 3. Generally it does not appear that opportunities to change lanes to pass a cyclist are reduced between each subsequent phase. However, it was generally observed that vehicles did not change lanes to pass cyclists, but rather passed within the outside lane or slightly straddling the lane line.

Figure 15 summarizes the distance between the curb and the outer edge of the vehicle for vehicles passing cyclists within the lane. On average across all of the phases, vehicles pulled at least partially onto the lane line dividing the # 1 and #2 lanes when passing. During all phases there were instances of vehicles shifting to the inside lane to pass cyclists. The longer whiskers in Phases 2 and 3 indicate that vehicles pulled further into the inside lane to pass during those phases than during the base case. Each cyclist observation was categorized as one of the following:

- No Vehicle: the bicyclist was not tailed or passed by any vehicles
- Tailing Vehicle: the bicyclist was tailed, but not passed, by at least one vehicle
- Vehicle Passes within Lane: the bicyclist was passed by at least one vehicle within the lane
- Vehicle Changes Lanes to Pass: the bicyclist was passed by at least one vehicle which changed lanes to pass



Figure 14: Inside Lane Conditions while Autos Are Passing or Tailing Cyclists in Outside Lane

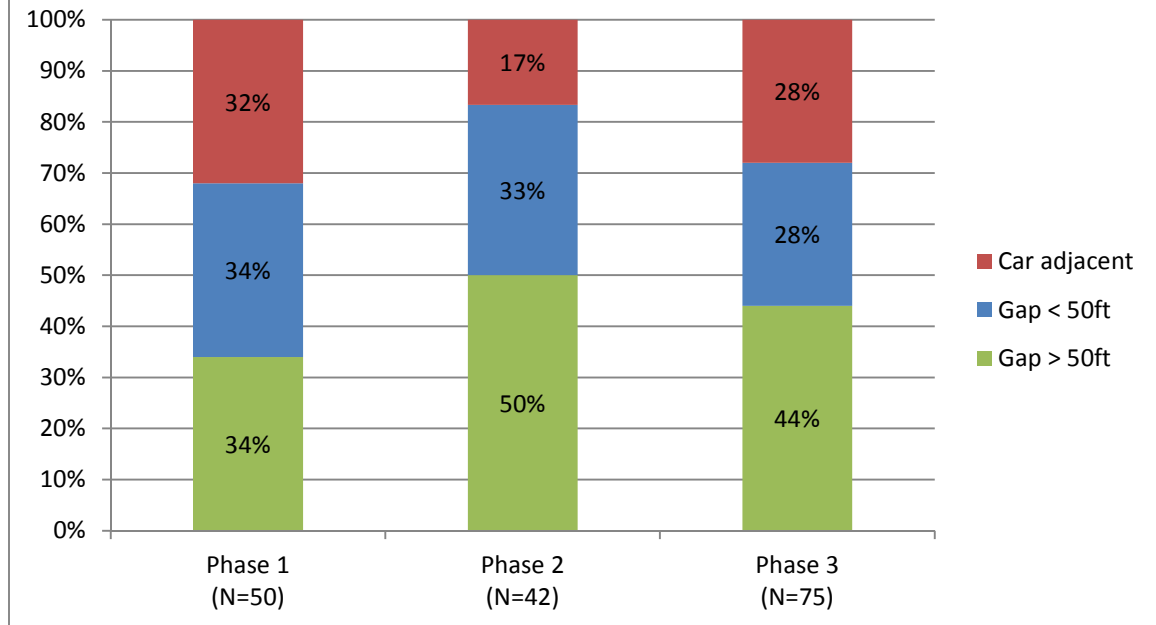
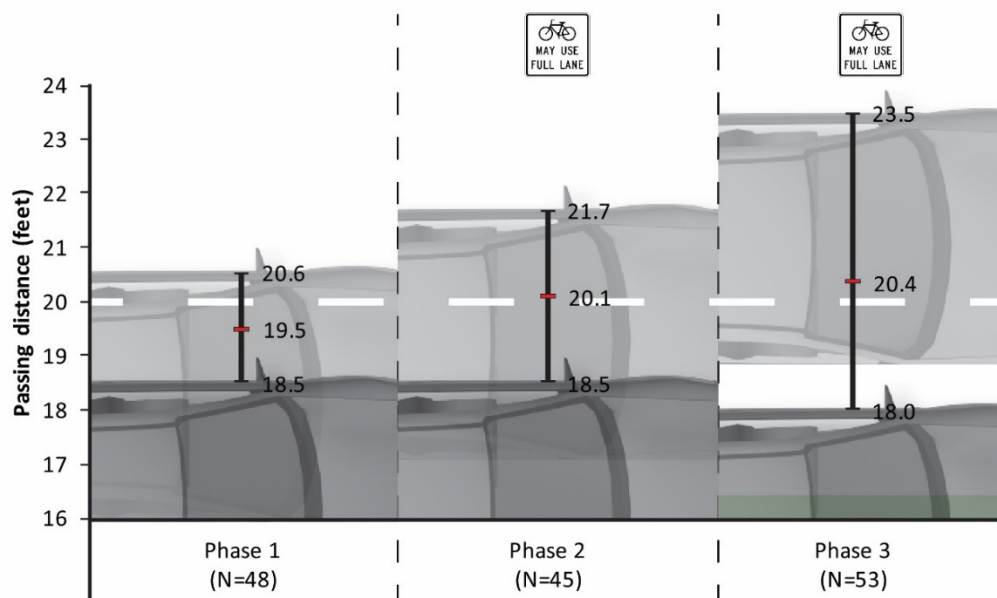


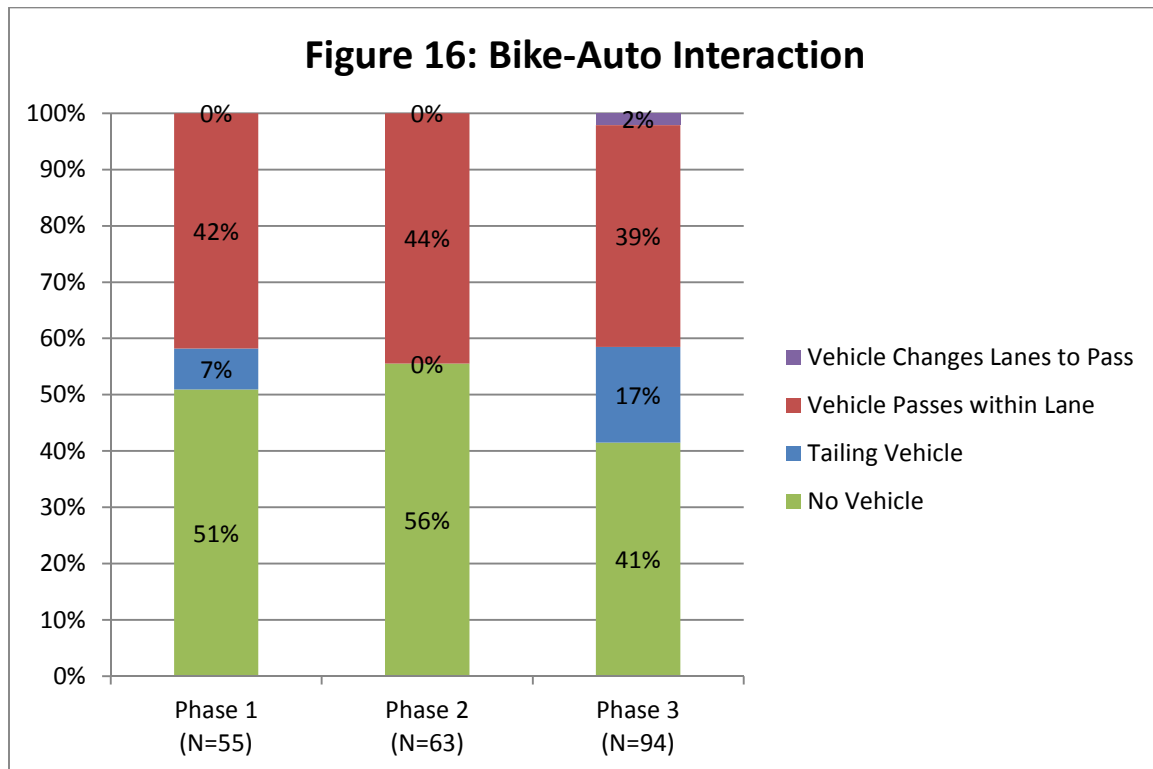
Figure 15: Distance between Curb and Outer Edge of Auto When Passing Cyclist within the Lane

(10th Percentile, Average, and 90th Percentile)





When more than one vehicle passed a bicyclist, each passing event was recorded as a separate event. **Figure 16** summarizes the above four categories for each unique bicyclist, in order to analyze the percent of bicyclists who encountered an interaction with a vehicle. The percent of bicyclists with no vehicle interaction decreased in Phase 3 while the percent of bicyclists being tailed by at least one vehicle increased.



EFFECTS ON CRASHES

Analysis Methodology

Evaluation Question H posed the following question: "What is the collision history for motorists and bicyclists without and with the green band installed?" Collision data in the study areas were accessed from the Statewide Integrated Traffic Records System (SWITRS), a California Highway Patrol (CHP) operated database which provides information gathered from a collision scene. Data for twelve months prior to Phase 1 – from May 1, 2012 to April 30, 2013 - and the twelve months following the installation of the Phase 3 super sharrows – from October 1, 2013 to September 30, 2014 - was used to understand effects to roadway safety.



Results

Collision data from SWITRS were reviewed for the twelve months prior to Phase 1 and for the twelve months after the installation of Phase 3. One bicycle collision was reported in the twelve months before Phase 1, and one was reported in the twelve months after installation of Phase 3 super sharrows. **Table 10** presents the collision data reported during the two study periods. With a limited sample size, no significant changes to safety can be measured. However, the collision activity is likely comparable between the before condition and the super sharrow condition.

Table 10: Reported Bicycle-Auto Collisions Before and After Super Sharrows¹		
Crash Type	Prior to Phase 1	After Phase 3
<i>Auto-Bicycle</i>	1	1

Source: Reported collisions in SWITRS between Adeline Street to MLK Jr Way and Telegraph to Webster Street in Oakland. Phase 1 is May 1, 2012 to April 30, 2013 and Phase 3 is October 1, 2013 to September 30, 2014.

In both phases, the reported collision occurred at the intersection of Telegraph Avenue and 40th Street. In both phases, there were bicycle lanes on the west side of the intersection and no striping treatments on Telegraph Avenue. In Phase 1, no specific vehicle code violation was reported and a violation category of “other improper driving” was reported. The bicyclist was found at fault and the collision resulted in a “complaint of pain.” In Phase 3, the primary collision factor violation was the bicyclist’s failure to stop at a red light (California Vehicle Code § 21453 (a)), and the collision resulted in a “complaint of pain.”

EFFECTS ON TRANSIT

Analysis Methodology

Evaluation Question I posed the following question: “How do bus drivers navigate the outside travel lane mid-block with the green band in place?” One concern was the impact of the installation of sharrows and super sharrows on corridor bus speeds. AC Transit⁷ Route 57 runs along 40th Street between San Pablo Avenue and Broadway with stops at Webster Street, West Street, and Market Street within the project area. AC Transit AVL (automatic vehicle location) data were analyzed during

⁷ Alameda-Contra Costa Transit District

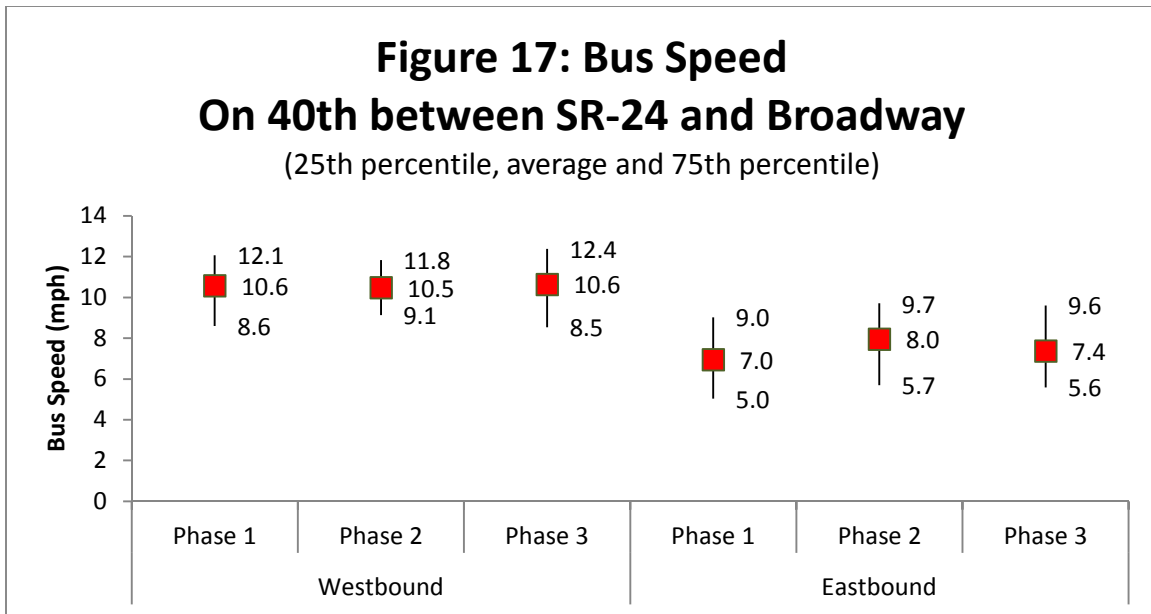


each phase to evaluate bus speeds within the corridor. A portion of AC Transit vehicles are equipped with AVL units which record bus GPS location and timestamp throughout the route. Two weeks' worth of weekday data were obtained per phase for analysis. AVL data for Line 57 was analyzed between Highway 24 (SR-24) and Broadway, on the eastern half of the project area. Data between Market and West Streets was not used, as the bus route ends just west of Market Street and bus speeds are difficult to analyze at this location due to layovers and bus turnaround time. The data were processed to calculate travel time and speed for each recorded bus run. These speed values include dwell time at stops and time stopped at intersections. Speeds presented below represent bus speed averaged over a day.

Anecdotally, transit vehicles that passed bicyclists on the corridor exhibited similar characteristics to automobiles overtaking bicyclists on the corridor. The video footage provided too few instances of buses overtaking bicyclists to allow for a quantitative analysis.

Results

The average, 25th percentile and 75th percentile speed values along the segment of 40th Street between SR-24 and Broadway of the bus run data collected during each of the three phases are summarized in **Figure 17**. The average speed in the westbound direction is higher than in the eastbound direction. This may be due to differences in the roadway network configuration, the number of passengers boarding and alighting at each stop, or that the segment is at the end of the line. Looking at each direction separately, there is no statistically significant change in bus speed between the three phases. Although the average bus speeds fluctuate slightly, these differences are within the expected margin of error. Additionally, the whiskers do not vary much between the three phases, suggesting that the variation in speeds also did not change between the three phases. This indicates that any changes related to the introduction of sharrows and super sharrows did not have a tangible impact on bus speeds within the corridor.





CONCLUSIONS

KEY FINDINGS

The effects of the green band (or “super sharrow”) on user behavior were isolated and compared to no bikeway striping and to standard sharrows using statistical analysis. The key findings are:

- **Super sharrows resulted in cyclists riding further from parked cars (“outside of the door zone”).** The shift was statistically significant compared to the baseline condition and to the standard sharrows condition. Standard sharrows had a small positive effect on cyclist positioning but the shift in bicyclists riding outside of the door zone was not statistically significant. In comparison, super sharrows had a greater effect with and without overtaking motorists that was statistically significant, increasing the percentage of bicyclists operating outside of the door zone from 5% (baseline) to 39% (super sharrows) in free flow conditions and 0% (baseline) to 19% (super sharrows) during overtaking events.
- **Standard sharrows shifted motorists from the right travel lane to the left travel lane.** Statistically significant compared the baseline condition, two-thirds of motorists used the right lane under the baseline conditions and under the standard sharrows condition, less than one-half of motorists used the right lane. The addition of the green band did not shift additional motorists from the right travel lane to the left lane.
- **The average passing distance for motorists overtaking cyclists did not change, but the presence of standard sharrows and super sharrows created more variability in that passing distance.** The average passing distance remained the same between baseline and with standard sharrows and increased slightly with super sharrows. The percentage of motorists leaving three or more feet decreased over the three phases, which was statistically significant between the baseline and super sharrow conditions. While super sharrows encourage cyclists to ride further from parked cars, the treatment may not affect the passing behavior of some motorists, resulting in passing events where there is less space between the motorist and the cyclist. This indicates both that the average passing distance is unaffected by the treatments and that the variability in passing distance increases with the treatments, with some autos passing much further and other autos passing more closely with the treatments than without.
- **Super sharrows and standard sharrows did not affect the number of cyclists who pass motorists on the right at red lights.** At signalized intersections, cyclists continued to “jump the queue,” overtaking waiting motorists by passing on the right. The treatments were not effective in reducing the possibility of right hook collisions at signalized intersections by encouraging cyclists to “take the lane” and queue with



motorists. The number of observations was limited and no conclusion can be drawn for cyclists arriving at traffic signals on green lights.

- **Super sharrows do not have a negative operational effect on either auto operations, auto speeds, or transit speeds.** Speed data for autos and transit, respectively, show no change in speeds between the three project phases.
- **Additional study should consider whether the role of parking utilization is as pronounced with a large sample size.** If found to be a key factor, parking utilization could be considered a criterion for future applications of super sharrows.
- **No effect on reported collisions.** Reported collision records indicated no changes in the number of bicycle-auto collisions with the super sharrow treatment.
- **A modest increase in bicycle volumes was observed.** When controlling for background growth in Oakland, modest increases in bicycle volumes on 40th Street were observed. There was also a decrease in volumes on parallel bikeways.

IMPLICATIONS FOR THE MUTCD

With the super sharrows, the majority of bicyclists continued to ride inside the door zone and many autos continue to pass fully or partially within the lane. These implications are qualified by the fact that cyclists road further away from parked cars and more motorists chose to use the left travel lane, thereby reducing the number of motorists overtaking cyclists in the right travel lane. These outcomes suggest two contrasting design approaches to shared travel lanes:

- “take the lane” design approach – directing cyclists to the center of the travel lane; or
- “avoid the door zone” design approach – directing cyclists to ride only as far left as necessary to avoid the door zone.

The 40th Street experiment was based on the “take the lane” design approach. In the context of urban arterial roadways, the results suggest an “avoid the door zone” approach may be more pragmatic about cyclist positioning. Such an approach may avoid the ideological baggage of “taking the lane” and thereby be less antagonistic to motorists. An “avoid the door zone” design could be constructed at lower cost by reducing the extent of green pavement.

“Take the Lane” versus “Avoid the Door Zone”

In the “take the lane” design approach to 40th Street, the sharrows and green band were centered at 14 feet from face of curb in the center of a 12-foot travel lane adjoining an 8 feet parking lane. In an “avoid the door zone” approach, the 20 feet of roadway width could be allocated as a 7-foot



parking lane, a 3 feet door zone buffer, and a 10-foot travel lane. The door zone buffer could be delineated with two parallel lines at either edge with cross-hatching in between. Sharrows would be placed at 12 feet from face of curb to be clear of the door zone buffer but at the right side of the travel lane. In the “take the lane” approach, cyclists are directed to ride at 14’ from face of curb. In the “avoid the door zone” approach, cyclists are directed to ride at 12’ from face of curb. Based on the results on the 40th Street experiment, it is plausible that an “avoid the door zone” experiment could provide comparable benefits by encouraging cyclists to ride further from parked cars and shifting motorists from the right travel lane to the left travel lane.

The “avoid the door zone” design approach may be more pragmatic about how far into the travel lane a majority of cyclists are willing to ride. Depending on lane widths, a cyclist does not necessarily need to “take the lane” to avoid the door zone. By being more pragmatic, an “avoid the door zone” approach may avoid some of the ideological baggage that has a tendency to polarize cyclists and motorists into us-versus-them debates. An “avoid the door zone” approach could be designed with standard treatments and thereby avoid the MUTCD’s formal experimentation process. Construction costs would also be lower given that standard white striping is significantly less expensive than green pavement treatments. However, informal feedback suggests that cyclists particularly liked the use of green pavement for the 40th Street project. Potentially an “avoid the door zone” approach could include green-backed sharrows with relatively tight spacing, providing the visual effect of green pavement without having a continuous green band. Based on the 40th Street results, an “avoid the door zone” design approach could have benefits that should be evaluated and compared to the benefits of super sharrows.



APPENDIX A: ADDITIONAL LITERATURE REVIEW



Table A-1: Characteristics of Similar Experiments

Location	Design	Signage	Adjacent Bicycle Network	Project Characteristics	Methodology
Second Street Long Beach, CA	<ul style="list-style-type: none"> 6' green band centered on effective lane width with sharrows Mixed flow lanes Continuous 	Modified "Share the Road" signs	Connects to Class II and III segments of Downtown bicycle network	<ul style="list-style-type: none"> 4-lane commercial arterial with on-street parallel parking 1,200 bicyclists over 3-day count 12-foot outside travel lane 	<ul style="list-style-type: none"> Before and after crash history Before and after general bicyclist position in roadway (sidewalk, door zone, green strip, travel lane) Anecdotal observations on transit bus interaction
South 200 Salt Lake City, UT	<ul style="list-style-type: none"> 4' green band 3' from curb face with sharrows Mixed flow lanes Continuous 	None identified	Connects Class II bike lanes through two-block long constrained area	<ul style="list-style-type: none"> 4-lane commercial arterial with no on-street parking Carries 20,000 vehicles and 200 bicyclists per day 12-foot outside travel lane 	<ul style="list-style-type: none"> Analysis of bicycle positioning for 3 days before and 3 days after striping, including on-street and sidewalk riding Anecdotal observation of motorists' use of shared lane Data collection on crashes after shared lane installed.
Hennepin Avenue Minneapolis, MN	<ul style="list-style-type: none"> 4' green band, 3.5' from curb with sharrows Bus/Bicycle/Right-Turn lanes Continuous 	"Bus Bikes & Right Turns" and "Share the Road" signs plus variable overhead signs	Key cross town spine route connecting multiple facilities	<ul style="list-style-type: none"> 4-lane commercial arterial with no on-street parking Carries 20,000 vehicles and 1,000 bicyclists per day and 20 to 30 buses per peak hour. Outside travel lane varies from 13.5 to 18 feet across the corridor. 	<ul style="list-style-type: none"> Measured bicyclist, motor vehicle, and bus positioning at 3 points along the green shared lane using hatch marks and compared against a control location on Hennepin Avenue with Class II bicycle lanes Survey-based analysis of motorist and bicyclist education on positioning in the shared lane Before and after reported crash history Before and after reported bicycle volumes.



Table A-1: Characteristics of Similar Experiments

Location	Design	Signage	Adjacent Bicycle Network	Project Characteristics	Methodology
Bryant Avenue South Minneapolis, MN	<ul style="list-style-type: none"> • 4' green band with sharrows centered on effective lane width • Mixed flow lane • Discontinuous: 100' green strip every 100' 	"Bikes May Use Full Lane" signs	Connects two segments of Class III bike boulevard	<ul style="list-style-type: none"> • 2-lane residential collector • 20-foot outside lane including parallel parking 	No evaluation study completed to date
Longwood Avenue Brookline, MA	<ul style="list-style-type: none"> • "Bicycle Priority Lane" • 2 dotted 4" lines with sharrows • Outside edge of priority lane line marked 10.33' from curb • Discontinuous: 80' gaps in between modules 	None identified	East-west connection between commercial centers	<ul style="list-style-type: none"> • 2-lane residential collector with on-street parking • Carries 8,000 vehicles • 20-foot outside travel lane including parallel parking, plus eastbound bicycle lane only. 	<ul style="list-style-type: none"> • Phased installation of bicycle priority lane: (1) striped outside dashed priority lane lines; (2) marked shared use lane markings 6 months later; • Analysis of bicycle positioning based on chalked hatch lines only when parking lane was unoccupied for 75 feet or less. (3 days of data for dashed priority lane lines, 3 day for dashed priority lane lines and shared use pavement markings) • Survey data of bicyclist and motorist understanding of treatment
S 59th St Philadelphia, PA	<ul style="list-style-type: none"> • Rectangular patch of green pavement with sharrow • Discontinuous 	Not implemented	On-street connection to regional multi-use path	<ul style="list-style-type: none"> • 2-lane residential collector with on-street parking • 20-foot outside lane including parallel parking 	Project was implemented in 2013 but evaluation not yet available—Goal of the project is to provide wayfinding to multi-use path



Table A-2: Outcomes of Similar Experiments

Location	Key Findings/Measures of Effectiveness	Factors Not Addressed in Evaluation Study
Second Street Long Beach, CA	<ul style="list-style-type: none"> • Doubling of bicycle usage over year of existence • After installation, the majority of cyclists positioned in the green band • Sidewalk riding decreased by 20% • Bicyclists familiar with standard sharrows noted that the additional emphasis resulting from the green pavement appears to be creating a heightened awareness by the motorists of bicycle usage in the lane • Special share the road signage was added approximately 2 months after the striping to enhance bicyclist understanding but only spot observations were made of effects • Crash experience involving bicyclists is largely unchanged, while the crash rate per bicyclist is reduced from pre-project levels • Crash rate not involving bicyclists was higher than in the previous year but does not appear to be related to the installation of the green band 	<ul style="list-style-type: none"> • Analysis of passing distance/separation when motorists overtake bicyclists • Effect of green shared lane and increased presence of bicyclists on transit operations, where bus transit exists • Number of motorists shifting to the inside lane • Comparative analysis of sharrows versus the complete shared-green lane package of treatments
200 South Salt Lake City, UT¹	<ul style="list-style-type: none"> • Before installation, 31% of cyclists (83% of in-road riders) rode 0 to 4 feet from the curb; after installation, only 3% of bicyclists (8% of in-road riders) traveled between 0 and 4 feet to the curb, with the remaining riders shifting to elsewhere the right lane, including on the green band • 46% of bicyclists continued to use the sidewalk both before and after the shared lane installation 	<ul style="list-style-type: none"> • Analysis of passing distance when motorists overtake bicyclists • Comparative analysis of sharrows versus the complete shared-green lane package of treatments • Analysis of any increase in bicycle ridership • Effect of oversized sidewalks in relation to sidewalk riding • Effect of green shared lane on transit operations

40th Street Green Shared Lane Evaluation

April 2017



Hennepin Avenue Minneapolis, MN

- Most bicyclists (79-93%) use the green band
- On the 13.5-foot travel lane, vehicles typically positioned themselves 4.4-feet from the curb on average, with approximately half the vehicle on the green band; vehicles traveled to the left of the green band in the 18-foot lane.
- Buses positioned on top of the green band
- Measured data on motor vehicles passing bicyclists and bicyclists passing stopped buses was inconclusive due to small sample size
- Bicycle volumes decreased though this was attributed to new or improved facilities on parallel corridors
- Reported bicycle crash rates decreased from 1.03% to 0.4%, and survey results indicated that 1/3 of bicyclists felt safer with the green band
- Survey results indicated that motorists think vehicles should position to the left of the green band; however, the graphic on the survey and the actual lane width may sway that understanding

- Analysis of passing distance/separation when motorists overtake bicyclists
- Effect of green shared lane and increased presence of bicyclists on transit operations
- Comparative analysis of shared-use pavement arrows versus the complete shared-green lane package of treatments

Longwood Avenue Brookline, MA

- Before, bicyclists positioned 10.4 feet from the curb, which increased to 11.1 feet 5 weeks after the installation of the bicycle priority lane, both with and without the presence of passing cars
- Of surveyed motorists, 50% the markings had made them more considerate of how they passed cyclists, and only 21% of motorists noticed the markings but were 70% confident that the markings indicated a preferred zone for bicycling

- Analysis of passing distance/separation when motorists overtake bicyclists
- Analysis of increase in bicycle ridership
- Comparative analysis of shared-use pavement arrows versus the complete bicycle priority lane package of treatments

1. Additional study information requested from Dan Bergenthal, Salt Lake City Transportation



Table A-3. Experiment Citations

Project	Citation
2nd Street Long Beach, CA	<ul style="list-style-type: none"> Experimental Authorization No. 9-113 Green & Shared Lane Markings and Bikes in Lane Symbol Sign on 2nd Street between Livingston Avenue and Bay Shore Drive in the City of Long Beach, California. City of Long Beach Department of Public Works. Progress Report (USDOT file HOTO-1). December, 2009.
Hennepin Ave. Minneapolis, MN	<ul style="list-style-type: none"> Hennepin Avenue Shared Green Lane Study, City of Minneapolis Department of Public Works Traffic and Parking Services Division. August, 2011.
200 South Salt Lake City, UT	<ul style="list-style-type: none"> More Than Sharrows: Lane Within A Lane Bicycle 2 Priority Treatments in Three U.S. Cities. Peter Furth et al. Transportation Research Board. July, 2010.
Longwood Ave. Brookline, MA	<ul style="list-style-type: none"> More Than Sharrows: Lane Within A Lane Bicycle 2 Priority Treatments in Three U.S. Cities. Peter Furth et al. Transportation Research Board. July, 2010.