Effects of Bicycle Boxes on Bicyclist and Motorist Behavior at Intersections

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Executive Summary

While Austin has a sizeable network of bicycle lanes, traditional bicycle facilities at intersections are often inadequate and can lead to unsafe interactions between motorists and bicyclists. One potential tool to alleviate this problem is the bicycle box. This device is intended to improve the predictability of bicyclist stopping position at an intersection by allowing bicyclists utilizing a bicycle lane to position themselves in front of motorists waiting at a red light. A bicyclist in this position is more visible to motorists and therefore less likely to be hit by a right-turning motorist. Typically, a “No Right Turn on Red” sign is installed at a bicycle box intersection to further prevent bicyclist-motorist collisions.

The primary goal of this study was to determine what effect, if any, bicycle boxes have on bicyclist and motorist safety. Data of bicyclist and motorist behavior was collected under three conditions: while no bicycle box existed, after bicycle box markings were installed at the intersection, and after a chartreuse color was added to the bicycle box and the approaching bicycle lane. For this study, safety was defined along the following lines: (1) The bicyclist used the bicycle lane to approach the intersection, (2) the bicyclist used the bicycle box after installation, (3) motorists did not encroach on the stop line or bicycle box, (4) the bicyclist departed the intersection before the motorist and (5) the bicyclist did not make an illegal movement, such as running a red light. Bicycle boxes were installed on Shoal Creek Boulevard at Anderson Lane and on Speedway at 38th Street. These sites were chosen due to the high volume of bicyclists along these routes.

Bicyclists at Shoal Creek Boulevard and Anderson Lane took a more predictable position at the intersection and were more likely to depart the intersection first after the bicycle box was installed. Bicyclists were also more likely to approach the intersection in the bicycle lane after the colored bicycle box was installed. Motorist stopping behavior improved after the bicycle box markings were installed as indicated by the decrease in the proportion of motorists who encroached beyond the stop line and into the bicycle box. The percentage of motorists that encroached on the bicycle lane remained unchanged through the three phases of bicycle box installation. The installation of the “No Right Turn on Red” sign did not discourage motorists from turning right on red.

The addition of the bicycle box on Speedway at 38th Street resulted in many improvements to bicyclist and motorist behavior and interaction. In general, bicyclists’ behavior tended to become more predictable, resulting in safer interactions at the intersection. After bicycle box markings were installed and the color added, 26% of bicyclists maneuvered into or in front of the bicycle box. After each phase of the installation, the proportion of bicyclists who used the bicycle lane to approach the intersection instead of riding in the full lane increased substantially, as did the proportion of bicyclists who departed the intersection first. The addition of the color to the bicycle box also encouraged bicyclists to stop in the colored area in front of motorists. Lastly, a decrease in motorist encroachment on the bicycle lane and bicycle box showed that motorist behavior improved as well.

Given these results, colored bicycle boxes are recommended at intersections where there is a high volume of bicyclists and the volume of motorists turning right on red is not high. Using chartreuse thermoplastic to color the bicycle box is recommended because it tended to make bicyclists’ movements more predictable, but it is not crucial. Applying color to the bicycle box increases costs rather substantially, but had little effect on the percentage of bicyclists that used the bicycle box. The bicycle box markings alone have proven to be an effective method of improving safety of bicyclists and motorists at intersections at a much lower cost.

Background

Since Austin's bicycle program was re-established in 1992, the city has seen a growth in bicycle facilities leading to a significantly improved bicycle network. Unlike many other cities, bicycle routes in Austin were selected by identifying routes already used for bicycle commuting. This procedure, along with a focus on network connectivity is at least partially responsible for the increase in the percentage of adults commuting to work by bicycle. Douma and Cleaveland (2008) documented a statistically significant increase in bicycle mode share in Austin from 1990 (0.87%) to 2000 (1.19%) in Census block groups with new bicycle routes developed during that period. During that time period, the journey-to-work bicycle mode share for Austin increased significantly from 0.76% to 0.95%. The University of Texas, the largest university in Austin with approximately 68,000 students, faculty and staff members, estimates 5-7% of all trips to campus are made by bicycle (BMA, 2007).

While the proportion of commuting trips made by bicycle appears to be increasing, it remains small. Surveys studying the factors affecting bicycling demand show safety to be a major concern. In a survey of bicyclists in Texas, 69% of respondents stated they feel bicycling is "somewhat dangerous" or "very dangerous" from the standpoint of traffic crashes (Sener et al., 2009). A recent survey in Portland, Oregon showed that positive perceptions of the availability of bicycle facilities are associated with more bicycling and a desire to bicycle more often (Dill and Voros, 2007). One common type of collision between motorists and bicyclists is a right-hook collision, where a motorist makes a right turn into a through moving bicyclist. To avoid this type of collision, the American Association of State Highway and Transportation Officials (AASHTO) recommends transitioning bicycle lanes from the curb to the left of the right turn lane. However, this is not feasible for use in intersections where there is not a dedicated right turn lane for turning vehicles. For these situations, the City of Austin in conjuction with The University of Texas at Austin's Center for Transportation Research proposed to study the effectiveness of bicycle box markings at reducing the risk of right-hook collisions by moving bicyclists in front of motorists waiting at a red light, instead of waiting to the right of motorists.

Several cities in the U.S. have implemented bicycle boxes, Eugene (Oregon) conducted a study of bicycle boxes several years ago, and a preliminary report from Portland (Oregon) showed that bicycle boxes improved perceptions of safety on the part of both bicyclists and motorists. In Tucson (Arizona) a colored bicycle box was installed to help bicyclists at the University of Arizona campus cross from the north side of an intersection (where there is a bicycle lane) to the south side of the intersection where a bicycle lane does not begin for 200 feet. In Phoenix (Arizona), a bicycle box is used to help bicyclists transition from a bicycle lane on the right side of the street, to a bicycle lane on the right side of the street on the downstream side of the intersection. Researchers in Eugene videotaped bicyclists traveling through an intersection before and after the placement of a bicycle box designed to assist bicyclists for a similar purpose. Twenty-two percent of bicyclists used the bicycle box for the intended purpose. Motorists, however, frequently encroached into the bicycle box. New York City installed a bicycle box in at least one location where bicyclists are traveling on a bicycle lane on the left side of a one-way street and risk left-hook collisions by left-turning vehicles. Columbus (Ohio) is adding bicycle boxes to key intersections along a popular bicycle route. Advanced stop boxes serve the same purpose as bicycle boxes and have been implemented more frequently in Europe. Studies in the UK suggest a minimum reservoir depth of four meters based on studies suggesting the bicyclists felt unsafe at depths of three meters or less. Deeper boxes, however, are hypothesized to increase the rate of motorist encroachment.

Bicycle Box Detail

The dimensions of the bicycle box are shown in Figure 1. The bicycle box consists of a 24-inch advanced stop bar and an eight foot deep box (based on bicycle box measurements in Eugene, Oregon) containing a bicycle symbol. Before bicycle box installation, both intersections studied in Austin had the motorist stop line set back 4.5 feet from the crosswalk (measurement taken between the painted lines). After bicycle box installation, this distance increased to between 8 and 8.5 feet. “Wait Here” is painted on the roadway to instruct motorists to wait at the stop bar. The cost of the "Wait Here" symbol is $267.66. Cold thermoplastic material was purchased at $4.46 per square foot and was used for the box and approaching bicycle lane. As recommended by the National Committee on Uniform Traffic Control Devices (NCUTCD), a chartreuse (or strong yellow green) color was used. The material is embedded with corundum for traction. In addition, bicycle symbols were installed at the beginning of the green thermoplastic and in the middle of the bicycle box. Each symbol costs $98.21. Given these numbers, an eight foot deep bicycle box in a ten foot wide lane costs $1596.92 in materials.

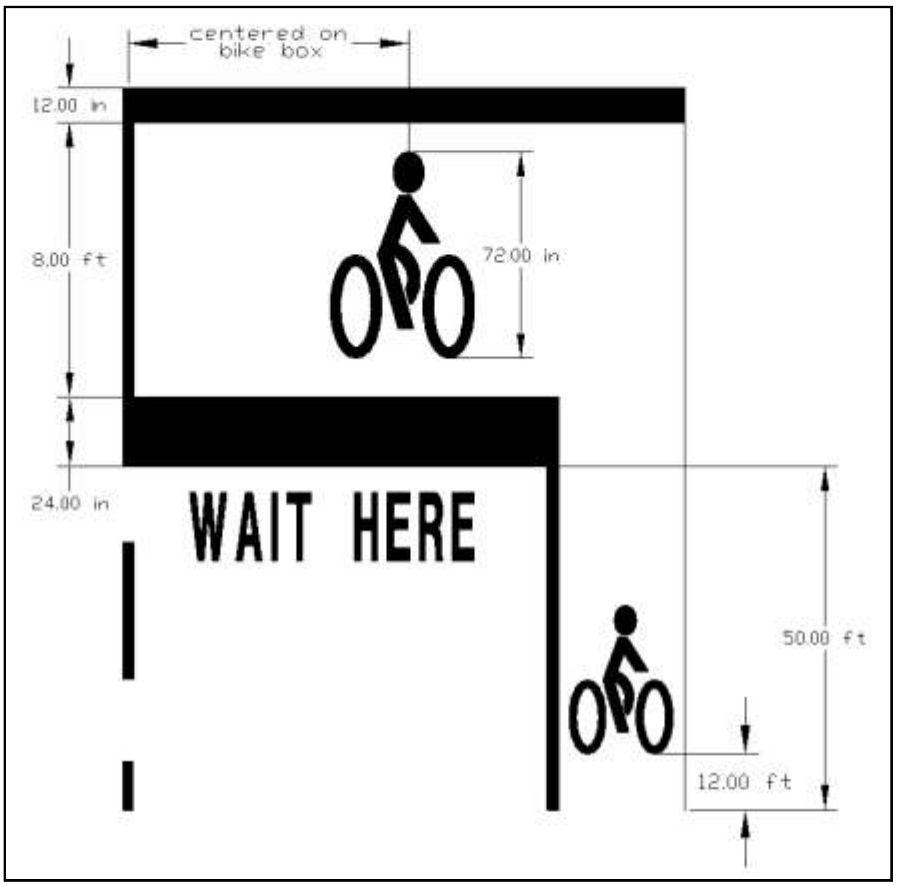

Figure 1. Dimensions of bicycle box

Additionally, "No Right Turn on Red" signs were installed when the color was added to the bicycle boxes in attempts to prevent motorists from encroaching on the bicycle box and to further prevent right-hooks, where a right turning motorist sideswipes a bicyclist traveling straight through the intersection. The "No Right Turn on Red" sign installed at Speedway and at 38th Street is shown in Figure 2.

Figure 2. The "No Right Turn On Red" sign installed at 38th Street

Site Descriptions

Bicycle Box applications were installed on two multi-lane facilities in Austin. Speedway is a very common commuter route for students of The University of Texas at Austin and bicycle boxes were installed on both sides of the intersection at 38th Street. On Shoal Creek Boulevard, another popular bicycle route, a bicycle box was installed on the southbound side of the intersection.

Shoal Creek Boulevard at Anderson Lane

Shoal Creek Boulevard in Austin experiences heavy bicycle traffic heading north and south. However, heading south on Shoal Creek Boulevard from Anderson Lane, there is a gap in the bicycle lane as the road narrows. After crossing the intersection, bicyclists are forced to share the lane with motorists because of the absence of a bicycle facility. The researchers hypothesized that the geometry of this intersection is ideal for a bicycle box because if bicyclists enter the intersection from the bicycle lane rather than from the bicycle box, they will be entering unsafe conditions when they reach the downstream side of the intersection where the lane narrows and a bicycle lane does not exist. The cross street, Anderson Lane is a busy four lane roadway with several commercial shopping centers. It is not a bicycle friendly roadway so most bicycle movements through this intersection are through movements northbound or southbound. The posted speed limit on Shoal Creek Boulevard is 35 mph and the observed traffic volume was 450 vehicles per hour (vph) in the PM peak hours and 350 vph in the AM peak hours.

A bicycle box was installed on Shoal Creek Boulevard heading south to alert motorists of the presence of bicycles at the intersection and give bicyclists the right-of-way as they transition from the bicycle lane to the stretch of roadway where the bicycle lane ends briefly. Figure 3 shows the colored bicycle box and Figure 4 shows a map of the intersection and the location of the bicycle box.

Figure 3. The bicycle box on Shoal Creek Boulevard at Anderson Lane

Figure 4. The intersection of Shoal Creek Boulevard and Anderson Lane

Speedway at 38th Street

Speedway is primarily a one lane street that runs north-south through The University of Texas and connects the Hyde Park area with campus. Bicycle lanes in both directions make this facility attractive to many students living north of campus. Bicycle boxes were installed on both sides of Speedway at 38th Street to alert motorists to the presence of bicycles at the intersection and give them the right-of-way. The researchers hypothesized that bicyclists would be less likely to use the bicycle box at this location because the bicycle lane continues on the downstream side of the intersection. Data was collected on northbound Speedway during afternoon hours as students departed the university. A map of the intersection and the location of the bicycle boxes is shown in Figure 5. The posted speed limit is 25 mph and the observed hourly traffic volumes ranged from 150 vph to 250 vph in the afternoon.

Figure 5. The intersection of Speedway and 38th Street

Experimental Design

To measure and evaluate bicyclist and motorist behavior, video footage of traffic movements at each site was collected. The experiment included three phases. Phase 1 involved videotaping each location under existing facility conditions. Phase 2 was the installation of bicycle box markings at each location and videotaping the experimental conditions. The bicycle box at this time will often be referred to as “skeleton bicycle box”. Phase 3 was surveillance of the bicycle box and approaching bicycle lane after it was painted chaurtrese with the bordering white lines and all markings kept intact. Video was recorded between 2:00 PM and 7:00 PM at both sites, while Shoal Creek Boulevard was also observed between 6:00 AM and 10:00 AM. All data incorporated into the analysis was observed during daylight hours. Video was played back on flat panel monitors where researchers answered binary (yes or no) questions for each bicyclist observed.

The primary goal of this study was to determine what effect, if any, bicycle boxes have on bicycle and motorist interaction at intersections. Therefore, data was collected while no bicycle box existed, after the skeleton bicycle box was installed (no color), and after the color was added. This allowed researchers to explore the effectiveness of the colored bicycle box versus the skeleton bicycle box and pre-existing conditions. For this study, safety was defined along the following lines: (1) The bicyclist uses the bicycle lane to approach the intersection, (2) the bicyclist uses the bicycle box after installation, (3) the motorist does not encroach on the stop line or bicycle box, (4) the bicyclist departs the intersection before the motorist and (5) the bicyclist does not make an avoidance maneuver or illegal movement.

To evaluate safety as defined above, several measures of bicyclist behavior and bicyclist-motorist interaction were recorded. Although no single measurement can comprehensively measure bicyclist and motorist safety, the improvement of several safety indicators can contribute to the conclusion that safety is indeed improved. Among the measurements taken were the approach method of bicyclist, phase of stoplight, stopping position of the bicyclist and motorist (when present), the departing maneuver of the bicyclist (turning movement, if any, and if the bicyclist entered the intersection before a motorist), any avoidance maneuvers or illegal actions of bicyclists, and any conflicts between motorists and bicyclists.

Tests of statistical significance were conducted to determine if there were any notable differences between the three conditions: no bicycle box, skeleton bicycle box, and colored bicycle box. All proportions and means were compared using a two-sided test of equality, where the null hypothesis was that no change occurred and the alternative hypothesis that behavior changed. While a campaign to alert the public to the presence of and proper use of the bicycle box was not conducted for the this experiment, City of Austin citizens were involved in the proposal’s development. Bicyclists were surveyed for their preferences for experimental locations, an opportunity for citizen comment was provided when the Austin City Council voted to fund this project, and the proposal was presented to the City’s Bicycle Advisory Committee, where further comments from citizens were noted.

Terminology

The following terms are used throughout this paper to characterize the actions of bicyclists and motorists at the various study sites.

- **Event** (or observation) - An event was recorded every time a bicyclist traveled through the intersection, regardless if the rider had an opportunity to use the bicycle box. Therefore, bicycles riding through the intersection with and without stopping were recorded to keep an accurate count of the facility's use.

- **Bicyclist stopping position** (recorded when a bicyclist makes a complete stop at the intersection)
  - **In bicycle box** - Before the installation of the bicycle box, "in bicycle box" was recorded when the bicyclist stopped where a bicycle box would be installed. When the bicycle box was installed and the color was added, "in bicycle box" was recorded when the bicyclist stopped in the existing bicycle box.
  - **In bicycle lane** - For all phases, "in bicycle lane" was recorded when a bicyclist stopped in or in front of the bicycle lane area to the right of the bicycle box.
  - **Before stop line** - Before the installation of the bicycle box, "before stop line" was recorded when a bicyclist did not encroach the stop line or pedestrian crosswalk. Since the bicycle box abuts the crosswalk when installed, "before stop line" was recorded when a bicyclist stayed behind the white lines marking the crosswalk.

- **Motorist encroachment** (recorded only when a motorist was present as a bicyclist approached the intersection)
  - **Stop line** - Before the bicycle box was installed, a motorist encroached when the front two wheels of the vehicle were on or over the designated stop line. After the bicycle box was installed, stop line motorist encroachment was recorded when the motorist's front two wheels were touching any part of the bicycle box, including the bordering white lines.
  - **Bicycle lane** - For all phases, bicycle lane motorist encroachment was recorded when a motorist was occupying any part of the bicycle lane area.

- **In queue** (or in full lane) - A bicyclist waits behind motorists in the traffic lane or at the front of the traffic lane if no motorists are present.

- **Illegal** - A bicyclist acted illegally when any traffic laws were broken. The most common illegal movement was bicyclists running the red light at Speedway and 38th Street.

- **Avoidance Maneuver** – An avoidance maneuver was recorded whenever a bicyclist rode outside of the lane (e.g. rode on the sidewalk or used a driveway instead of using the bicycle lane).

Results

The following section describes the results of the study. Although many pieces of information were collected about bicyclist and motorist behavior, the shifts in bicyclist and motorist stopping position proved to be the most revealing and are studied in detail below. In the following figures, bicycle box and bicycle lane are referred to as 'bike box' and 'bike lane', respectively. Detailed information about bicycle counts (organized by day of the week and hour of the day) can be found in Appendix A. P-values for significance tests on all comparisons can be found in Appendix B. Table 1 shows the number of observations gathered from each of the two study sites.

Table 1. Total number of events for each condition at the two study sites

Site	No bicycle Box	Skeleton bicycle Box	Colored bicycle Box
Shoal Creek Boulevard	257	81	111
Speedway	182	150	170

Shoal Creek Boulevard at Anderson Lane

Figure 6 shows the changes in bicyclist behavior before the bicycle box existed, after the skeleton bicycle box was installed, and after the chartreuse color was added. The percentage of bicyclists who approached the intersection in the bicycle lane remained about the same after the bicycle box skeleton was installed. However, after the color was added to the bicycle box the percentage of bicyclists who approached the intersection using the bicycle lane significantly increased from 77% to 93% ($p = 0.001$). This may suggest that the colored lane leading to the bicycle box encourages bicyclists to approach in the bicycle lane rather than the full lane.

The proportion of bicyclists that stopped before the stop line increased significantly after each phase of bicycle box installation as shown in Figure 6. This suggests that the bicycle box skeleton and added color were successful in encouraging bicyclists to stay behind the stop line within the bike box area. The percentage of bicyclists that departed first at the intersection also steadily increased after each phase of installation. This increase proved to be more significant from the before condition to the skeleton bicycle box condition than from the skeleton bicycle box condition to the implementation of color ($p < 0.001$ versus $p = 0.267$). This could indicate that the presence of the bicycle box causes motorists to be more aware of the presence of bicyclists and are letting them depart first. However, the higher percentage of bicyclists departing first may simply be attributed to the fact that the motorist stop bar is advanced four feet further from the intersection when the bicycle box is in place than under the original conditions. Even though bicyclists are stopping further back from the intersection (because they are encroaching on the crosswalk less frequently), right-turning and through-movement motorists are stopping even further back (behind the advanced stop line) and are often allowing the bicyclists to pull into the intersection first.

The percentage of bicyclists that waited in the queue increased after the first phase of installation but without significance ($p = 0.286$). After the second phase of installation, the percentage of bicyclists who waited in the queue decreased. This change borders on significance ($p = 0.103$). Researchers discovered that bicyclists waited in the queue more often when it is dark so only daytime events were considered for the “Waits in the queue of motorists” variable. Incidences where a bicyclist made an avoidance maneuver increased after the bicycle box skeleton was installed (p = 0.132). However, no instances of avoidance occurred after the color was added indicating that color may make bicyclists more comfortable with stopping at the intersection rather than on a sidewalk. While only data observed during daylight hours was incorporated into the analysis, it is interesting to note that bicyclists riding at night were observed to stop in the motor vehicle lane significantly more frequently perhaps to increase their visibility to oncoming motorists.

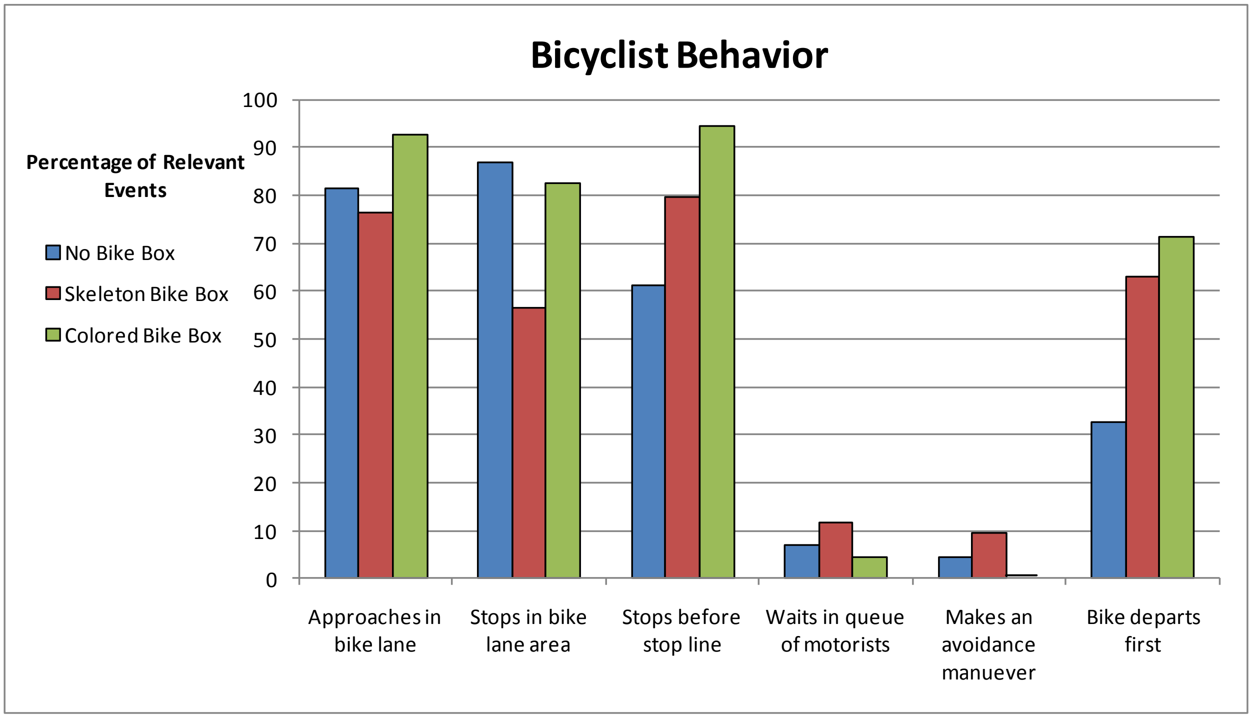

Figure 6. Bicyclist behavior on Shoal Creek Boulevard and Anderson Lane

"No Right Turn on Red" signs were installed at the same time color was added to the bicycle box skeleton. Despite the presence of the sign, there was an extremely high rate of illegal right turns on red. Of right-turning vehicles at the front of the queue at a red light about 79% turned right illegally. Some bicyclists may have been discouraged from using the bicycle box due to the heavy right turning traffic onto Anderson Lane. In several instances bicyclists that stopped in the bicycle box were observed shifting their position to allow motorists to make the illegal right turns on red.

Motorist stopping behavior is shown in Figure 7. The percentage of motorists that encroached on the stop line decreased after the bicycle box skeleton was installed. However, this change did not prove to be significant (p = 0.167). After the color was added the percentage of motorists encroaching on the stop line significantly increased to approximately 41%, a value comparable to the Phase 1 condition value of 37% (p = 0.099). One hypothesis for why this occurred is that motorists were inclined to initially comply with the new site design, but as it became clear that the percent of time when a bicyclist was in the box was low, they began to ignore the advanced stop line. The incidence of encroachment on the bicycle lane remained mostly constant over the different phases of implementation.

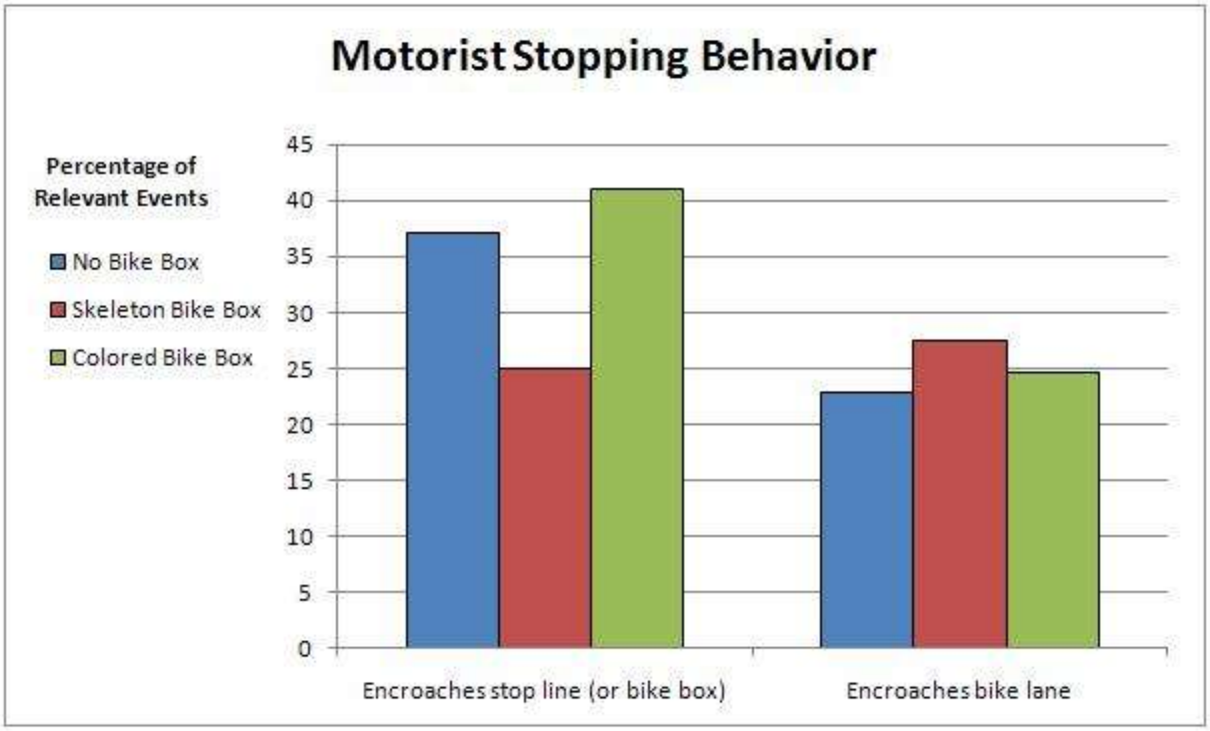

Figure 7. Motorist stopping position when a bicyclist is present at Shoal Creek Boulevard and Anderson Lane

Figure 8 shows the percentage of bicyclists that stopped in each location at Shoal Creek Boulevard and Anderson Lane before and after color was added to the bicycle box. Only events when a bicyclist had the opportunity to access the bicycle box are shown. A bicyclist had the opportunity to access the bicycle box when a motorist did not encroach on the bicycle lane or stop line and there was no additional bicyclist blocking the bicycle box. This figure supports the assertion that the color in the bicycle box encourages bicyclists to stay within the bicycle box area. The percentage of bicyclists in this area increased while the percentage of bicyclists in the queue and beyond the stop line decreased. Ultimately, not taking into account the bicyclists who avoid, the percentage of bicyclists who stopped behind the stop line in the bicycle box area increased from about 52% to 92%. This increase proved to be significant ($p < 0.001$).

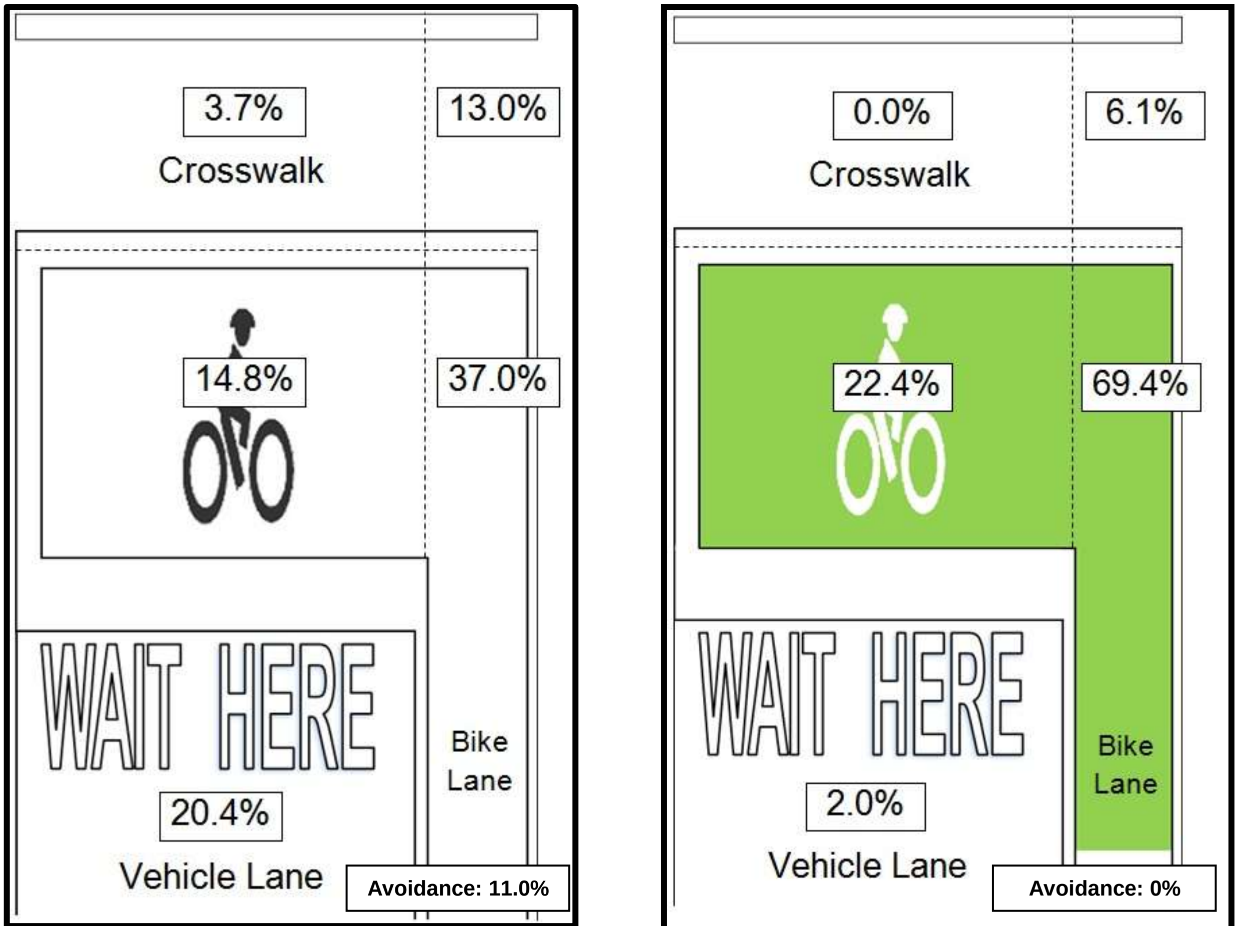

Figure 8. Bicyclist stopping position by percentage on Shoal Creek Boulevard before and after color is added to the bicycle box

Speedway at 38th Street

Figure 9 shows changes in bicyclist behavior before any bicycle box existed, after the skeleton bicycle box was installed, and after the chartreuse color was added. There was a steady increase in the number of bicyclists that use the bicycle lane on their approach to the intersection. This fact combined with the significant decrease in the percentage of bicyclists that waited in a queue of motorists ($p=0.007$) and the increase in the percentage of bicyclists that stopped before the stop line ($p=0.015$) after the skeleton bicycle box was installed suggests that bicyclists used the facilities at the intersection more appropriately and predictably. Also, a significant increase in the percentage of bicyclists that stopped in the bicycle lane area was observed when the skeleton bicycle box was installed ($p=0.001$). Stopping in the bicycle lane area is a viable, safe option for the bicyclist. Due to the advanced stop bar the bicyclist is still positioned in front of the motorist and can be clearly seen. Since the bicycle lane continues on the other side of the intersection, bicyclists at this location might find it unnecessary to maneuver into the bicycle box area away from their straight line path.The problem that resulted from bicyclists stopping in the bicycle lane area was that it hindered following bicyclists from entering the bicycle box. Often a queue of bicyclists would develop in the bicycle lane causing the bicyclists further back in the queue to be at a greater risk of being right-hooked. Lastly, a significant decrease in the percentage of avoidance maneuvers ($p<0.001$) was observed when the skeleton bicycle box was installed, although this percentage did increase slightly after the color was added (p=0.008). In general, the addition of the bicycle box and color led to safer and more predictable bicyclist actions.

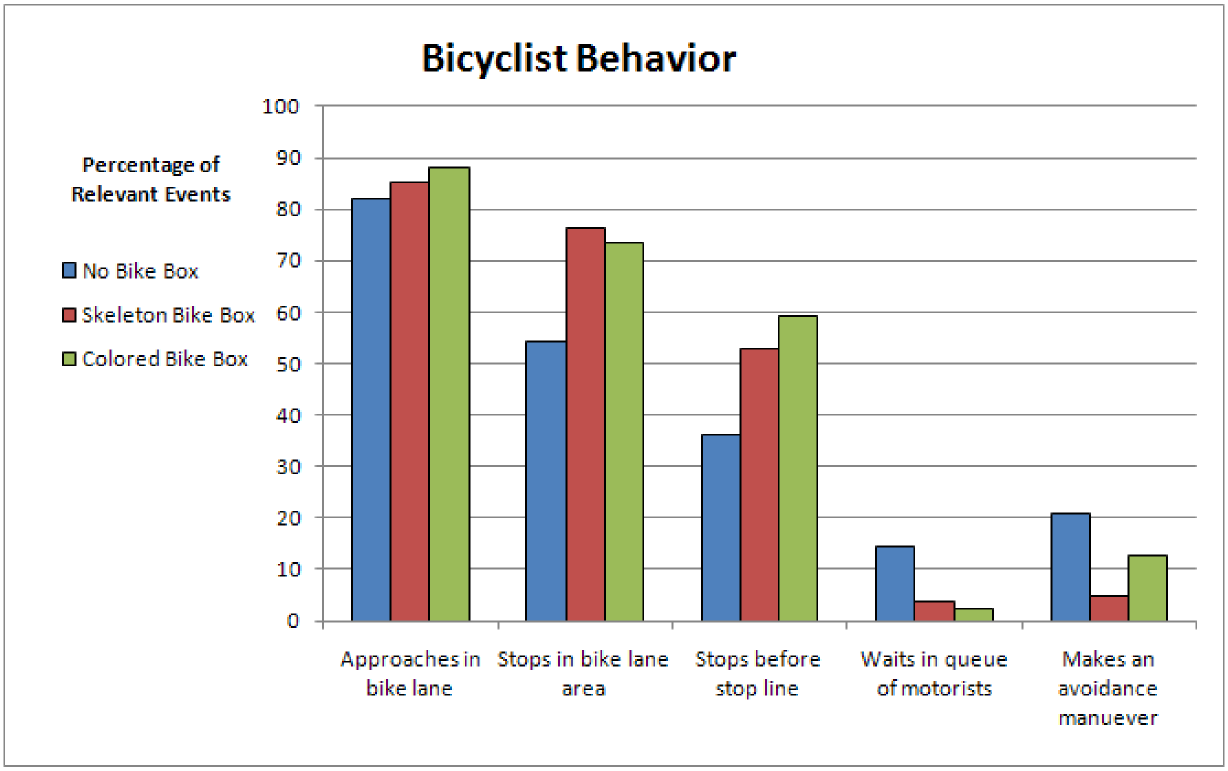

Figure 9. Bicyclist behavior on Speedway and 38th Street

Safety was also quantified by how the bicyclist and motorist depart the intersection. Figure 10 shows an increase in the percentage of bicyclists that depart the intersection before a motorist after each stage of implementation (p=0.224), which may suggest that motorists are more aware of the presence of a bicyclist at the intersection and therefore more likely to yield to them when the light turns green. Unfortunately, a significant increase in the percentage of bicyclists that ran a red light was observed (p<0.001), which could be due to the higher percentage of bicyclists positioning themselves in front of motorists.

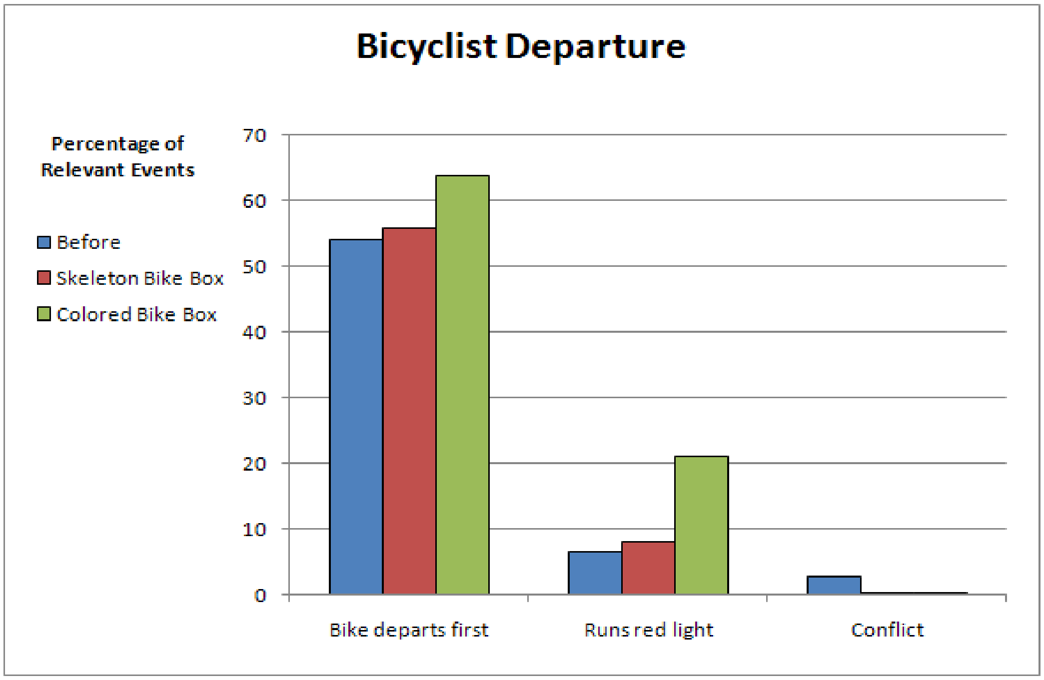

Figure 10. Bicyclist departure movements on Speedway and 38th Street

Additionally, motorist stopping position was recorded and is shown in Figure 11. Considerably more motorists encroach on their stop line after the skeleton bicycle box was installed ($p<0.001$), which could be due to motorists being unaware of the intention of the bicycle box. After the color was added, a significant change in the percentage of motorists stopped behind the bicycle box in the appropriate place was observed ($p=0.002$). The motorist encroachment results showed a trend opposite to that found on Shoal Creek. More research is needed to study this issue. Another positive result of the bicycle box was the decrease in the percentage of motorists that encroach on the bicycle lane after the installation of the skeleton bicycle box ($p=0.003$), which allows for bicyclists to safely bypass a queue of motorists and access the bicycle box. The small increase in motorists encroaching the bicycle lane after color was added ($p=0.058$) could be partially attributed to some motorists exiting a driveway located just before the intersection. The majority of bicycle lane encroachment observed during the pre-bicycle box phase was done by motorists approaching the intersection on Speedway, not exiting the driveway. Lastly, the percentage of motorists making an illegal right turn on red was recorded. Contrary to Shoal Creek Boulevard, only 5.3% of motorists made an illegal right turn after the bicycle box and the “No Right Turn On Red” sign was installed at this location. Also, the bicycle volume on this facility was much higher than on Shoal Creek Boulevard (20-60 bicyclists per hour as opposed to 0-30 bicyclists per hour). This could contribute to the more desirable motorist behavior at Speedway than at Shoal Creek Boulevard. Since motorists are more likely to encounter a bicyclist along Speedway, they may be more cognizant of a bicycle facility as well as the bicyclist itself. The low percentage of illegal right turns combined with the high volume of bicyclists make this site well suited for a bicycle box.

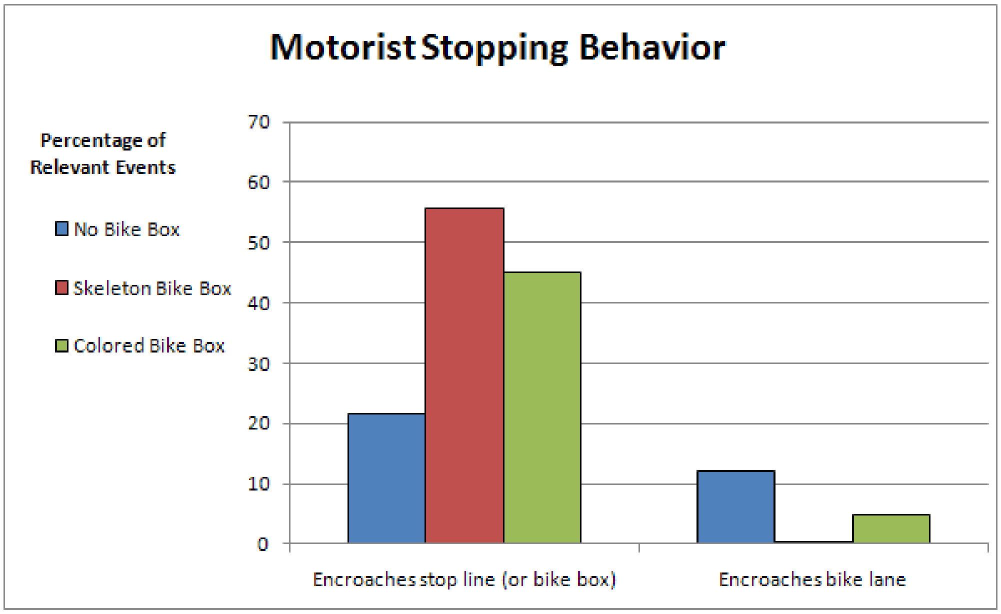

Figure 11. Motorist stopping position when a bicyclist is present at Speedway and 38th Street

Figure 12 shows the percentage of bicyclists stopped in each location at Speedway and 38th Street before and after color was added to the bicycle box. Only events when a bicyclist was given the opportunity to access the bicycle box are shown. A bicyclist had the opportunity to access the bicycle box when a motorist did not encroach on the bicycle lane or stop line and there was no additional bicyclist blocking the bicycle box. After the chartreuse was added, bicyclists stayed within the colored area 13% more often, indicating a positive reaction to the color. A higher percentage of bicyclists began using the bicycle box correctly and did not encroached on the crosswalk (p=0.329). Although the most significant decrease in bicyclists waiting in the queue occurred after the installation of the skeleton bicycle box (p=0.007), the addition of the color further encouraged bicyclists to bypass the queue and access the bicycle box (p=0.516). Overall, only 25% of bicyclists stopped in or in front of the bicycle box when the skeleton was installed and 26.1% used the bicycle box after color was added. An ideal use of the bicycle box on southbound Speedway is shown below in Figure 13. One hypothesis of why the percentage of bicyclists using the bicycle box itself is low is the continued bicycle lane on the downstream side of the intersection. Since nearly all bicyclists were traveling straight through the intersection, it is likely that bicyclists did not see the need to maneuver into the bicycle box and were comfortable waiting in the bicycle lane area.

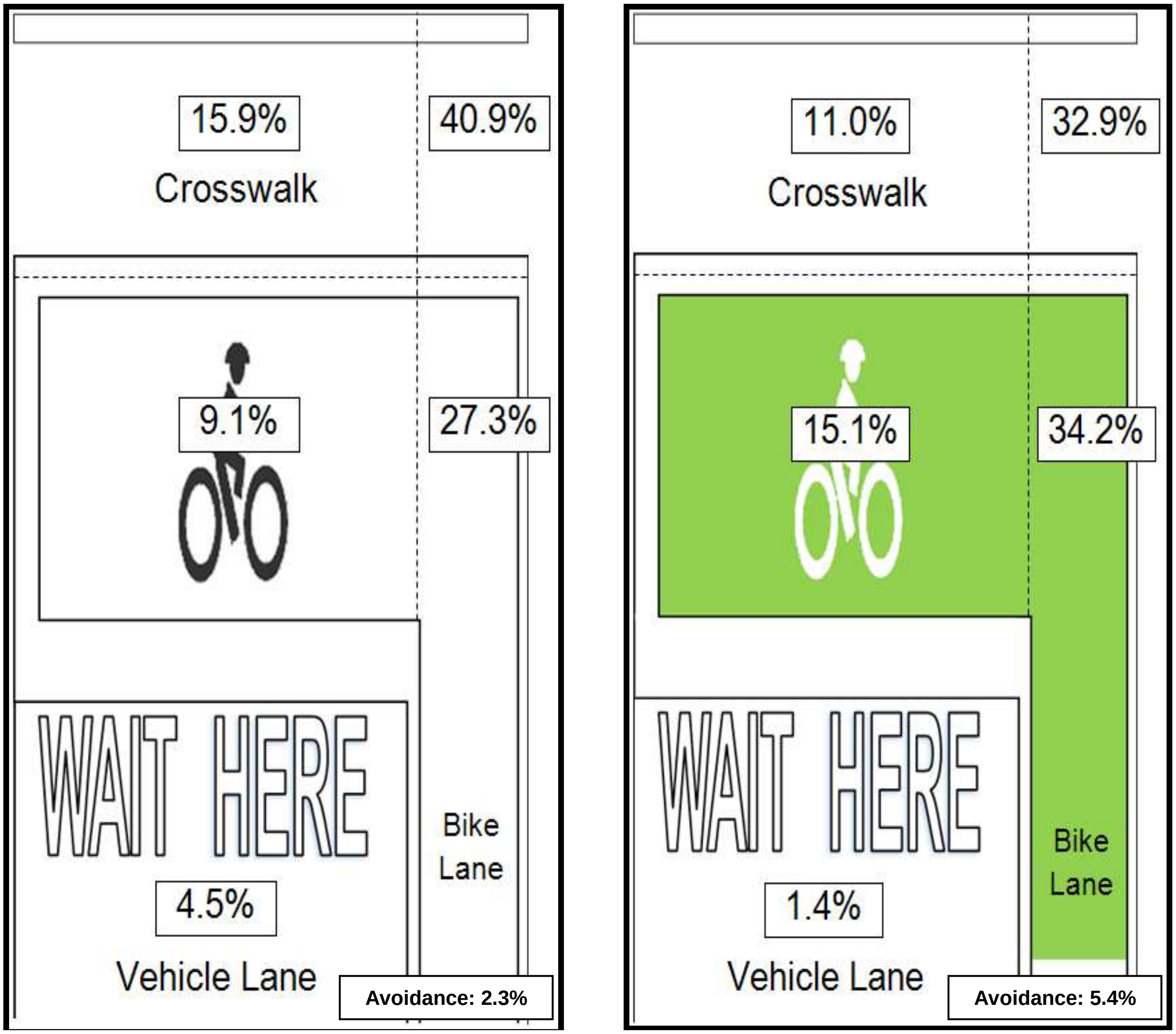

Figure 12. Bicyclist stopping position by percentage on Speedway before and after color is added to the bicycle box

Figure 13. Bicyclist using bicycle box on southbound Speedway at 38th Street

Conclusions and Recommendations

The results of this study show that bicycle boxes accompanied with “No Right Turn on Red” signs can improve the safety of bicyclists and motorists at intersections. At the two study sites, 15-25% of bicyclists use the bicycle box when the bicycle lane and bicycle box were not blocked by motorists or other bicyclists. The addition of the bicycle box allowed the bicyclist to take a much safer stopping position in front of motorists, resulting in a significant increase in the percentage of bicyclists that departed the intersection first. Although the addition of the color did not significantly affect the percentage of bicyclists that used the bicycle box, it does allow motorists to be more aware of the presence of a bicyclist; a higher percentage of bicyclists approach the intersection in the bicycle lane and stop within the colored area ahead of stopped motorists.

In several cases, positive changes in bicyclist behavior were observed at the intersection of Shoal Creek Boulevard and Anderson Lane. Despite positioning themselves further from the intersection, motorists were observed to give bicyclists the right-of-way more often with the presence of the bicycle box. Bicyclists riding at night tended to wait in the queue (or full lane) at the intersection more often than those during the day. After the color was added to the bicycle box, the percentage of bicyclists approaching the intersection in the bicycle lane increased suggesting that the presense of color influenced this behavior. The fact that the bicycle box on Shoal Creek Boulevard saw a slightly higher percentage of bicycle box usage may suggest that the geometrey of this intersection (absence of bicycle lane on the downstream side) is more ideal than that of Speedway and 38th. Shoal Creek Boulevard observed a high percentage of motorists that turned right on red illegally after the “No Right Turn on Red” signs were installed. Researchers observed bicyclists repositioning themselves at the intersection to allow motorists to turn right on red so it may be possible that the heavy right turning traffic discourages use of the bicycle box. In regards to motorist stopping behavior, the percentage of motorists that encroached on the stop line decreased significantly with the implementation of the skeleton bicycle box. However, after the addition of color this percentage returned to a value similar to that of the before condition. It is possible that this occurred because bicycle volumes were not very high at this location, so although motorists initially complied with the new device, they eventually ignored the advanced stop line. Overall, results indicate that the bicycle box resulted in safer conditions at the intersection.

At Speedway and 38th Street, the installation of the bicycle box proved to be effective in increasing safety. A decrease in the percentage of bicyclists that waited in a queue of motorists and an increase in the percentage of bicyclists departing first indicate that safety is indeed improved. Due to the existing bicycle lane on the downstream side of the intersection, it is possible that bicyclists did not maneuver into the bicycle box because they did not want to shift away from their straight line path. The percentage of bicyclists that ran a red light increased after the installation of the bicycle box. Although no conflicts or accidents were observed, this is an undesirable condition. Additionally, motorist behavior improved, which is evident by the decrease in bicycle lane encroachment and bicycle box encroachment after the color was added.

Given these results, the CTR research team recommends that bicycle boxes be installed at intersections where the majority of motorists do not turn right during a red phase and the volume of bicyclists is high. Of the intersections that meet this condition, priority should be given to intersections where the bicycle lane does not continue immediately after the intersection and to intersections where a safety hazard (e.g., a history of right-hook collisions) is evident. For locations where the bicycle lane does continue on the downstream side of the intersection, it may be sufficient to implement an advanced stop bar or to simply color the bicycle lane near the intersection to increase visibility. Further research into this configuration as well as other bicycle box configurations is necessary as most intersections have unique geometries.

The team recommends an educational campaign to inform bicyclists and motorists how to properly use the bicycle box. No educational efforts were conducted in any capacity in order to measure the true impact of the control device. Given the low percentage of bicyclists entering the bicycle box itself and the high rate of encroachment by motorists, educational outreach to both bicyclists and motorists will most likely further increase the device's effectiveness.

Further research is also needed to determine the appropriate sizing for the bicycle box. Feedback from the public indicates that eight feet is not large enough to comfortably maneuver into the box. However, previous research elsewhere has indicated that the rate of motorists encroaching into the box increases as the size of the box increases. Further, public feedback has suggested extending the bicycle box across multiple lanes to accommodate left-turning bicyclists. Although the sites observed in this study did not have high volumes of left-turning bicyclists, other intersections in the city often do, so additional research into extending the bicycle box into the left turn lane would have merit. The fact that more bicyclists wait in the full lane at night than during the day indicates that it may be worthwhile to further research differences in bicyclist riding behavior based on light conditions.

Finally, the team recommends installing color on bicycle boxes if available and financially viable. When color was added, bicyclists tended to follow and stay within the colored area. At Speedway and 38th Street, motorists encroached on the bicycle box less frequently when the color was added. Bicyclists were also given the right-of-way more often after installation of the skeleton bicycle box, and more often still after the application of color. If including the color is not an option, the team still recommends installing the skeleton bicycle box due to the positive results indicated by this study.

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APPENDIX A: Bicycle Counts

Figure 14 and Figure 15 show the total number of bicyclists observed by hour of the day at Shoal Creek Boulevard and Speedway, respectively. Shoal Creek Boulevard experienced an increasing number of bicyclists as the afternoon progressed for all three phases. Based on the high number of bicyclists between 5:00 PM and 7:00 PM, Shoal Creek Boulevard is most likely a commuter route with about 10 bicyclists an hour. Bicycle volumes on Speedway also increased as the afternoon progressed, but had a slightly more constant trend. This could be due to its proximity to The University of Texas since students tend to have more flexible schedules than typical commuters. On average, about 10 bicyclists per hour and 30 bicyclists per hour traveled along Shoal Creek Boulevard and along Speedway, respectively.

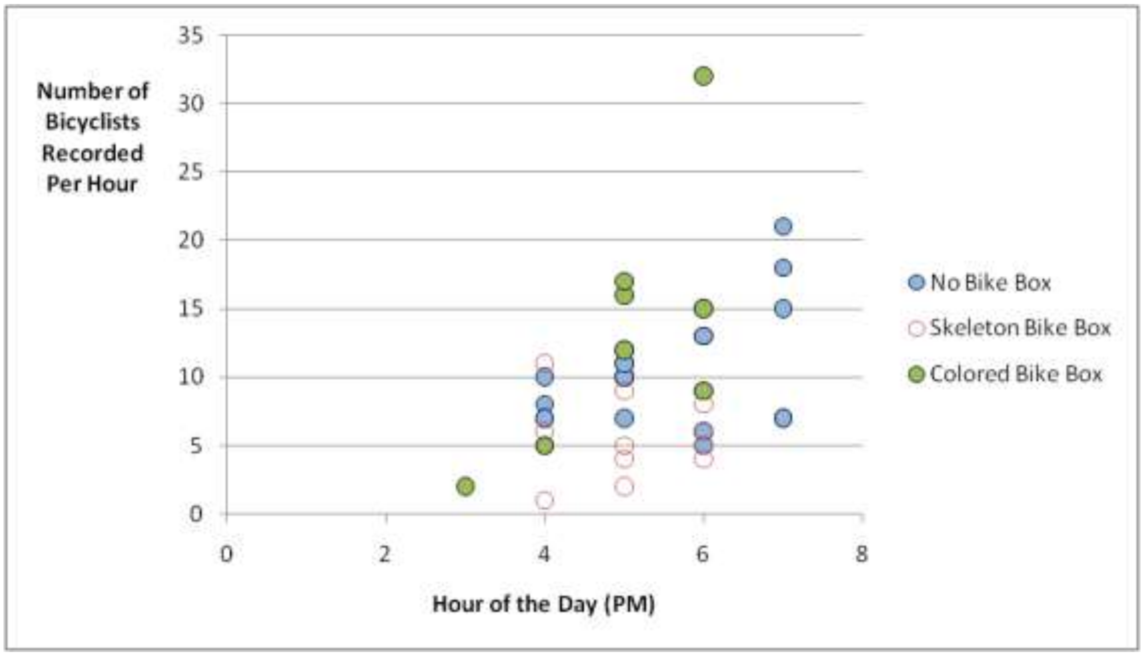

Figure 14. Number of bicyclists recorded each hour of the day on Shoal Creek Boulevard

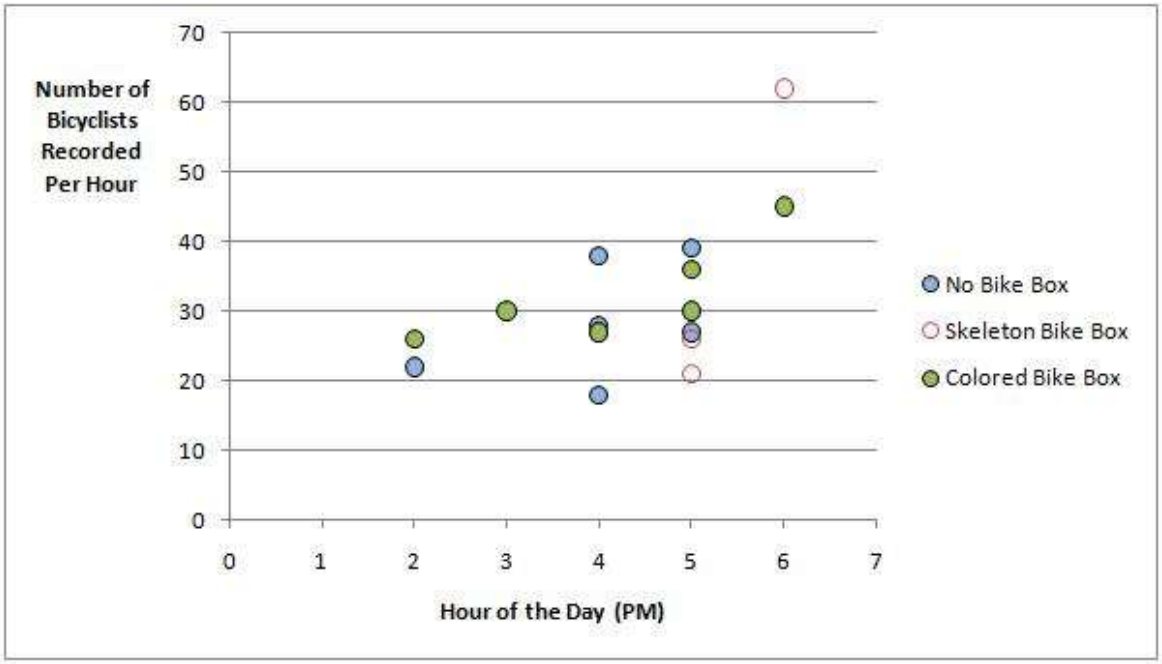

Figure 15. Number of bicyclists recorded each hour of the day on Speedway

Figure 16 and Figure 17 show the total number of bicyclists observed each day of the week at Shoal Creek Boulevard and Speedway, respectively. Both sites show a varying number of bicyclists for each day of the week. Bicycle volumes on Shoal Creek Boulevard were observed to range from five to 10 bicyclists per hour, while they range from 20 to 40 bicyclists per hour on Speedway over the course of the week.

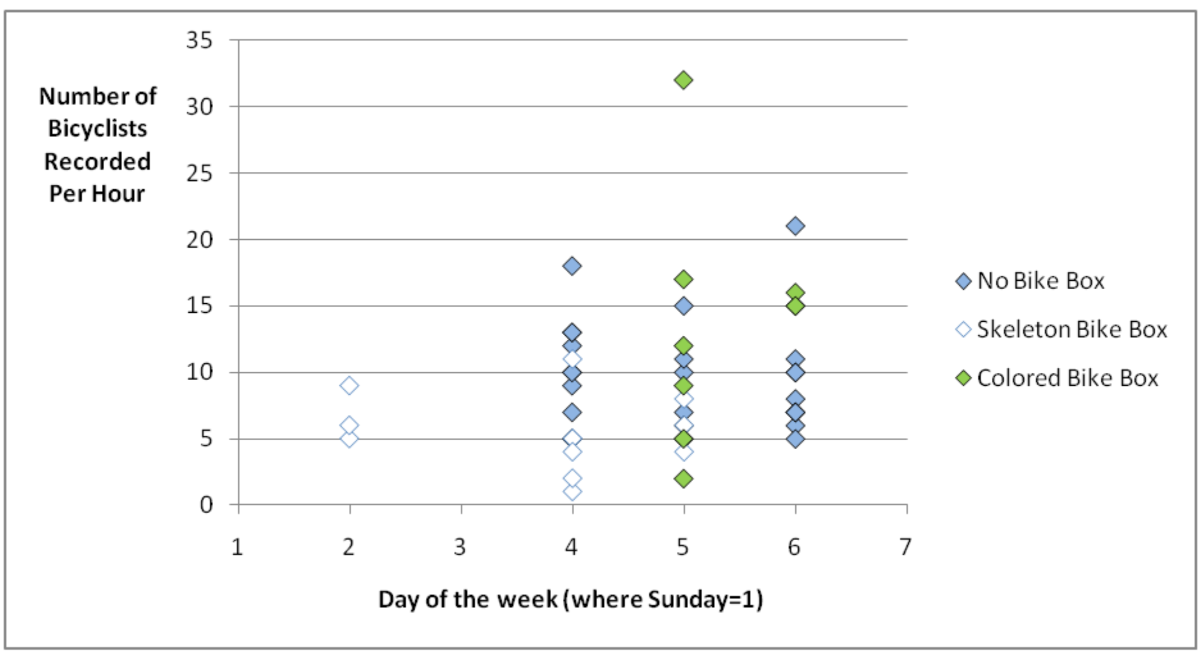

Figure 16. Number of bicyclists recorded each day of the week on Shoal Creek Boulevard

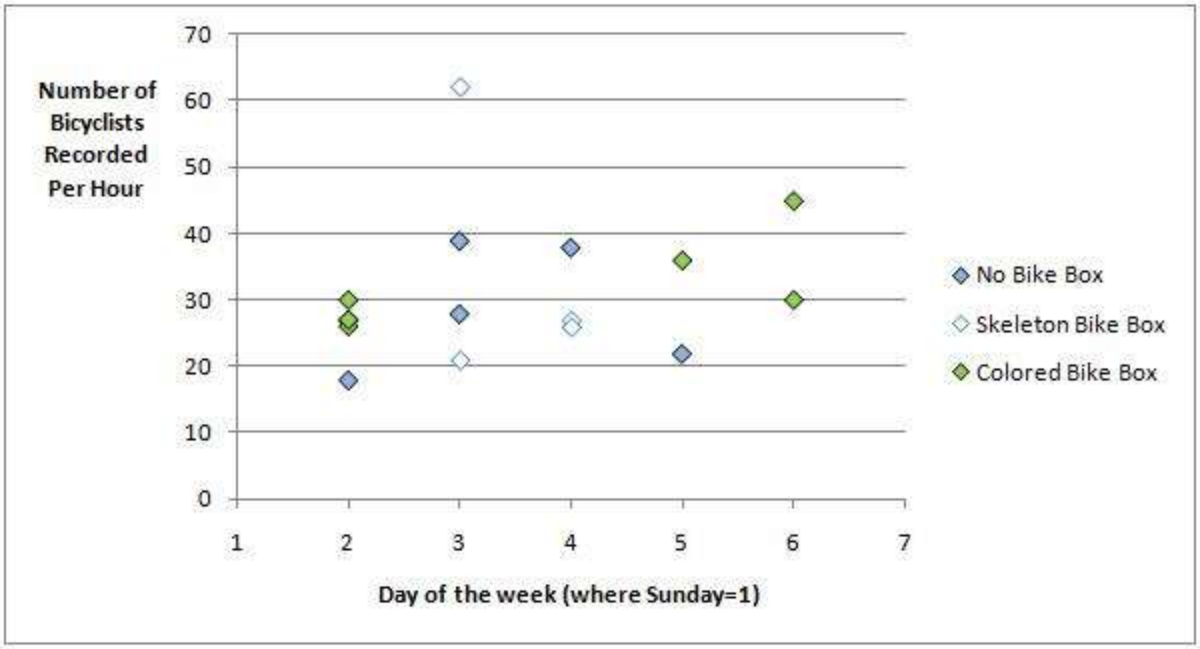

Figure 17. Number of bicyclists recorded each day of the week on Speedway

APPENDIX B: Thermoplastic Cost, Maintenance, and Upkeep

The colored thermoplastic, sharrows, and other thermoplastic forms were purchased from Flint Trading Inc (Thomasville, NC). Costs for these materials are provided in Table 2.

Table 2. Cost of thermoplastic units used in the studies

Item	Cost	Unit
Colored Thermoplastic	$4.46	SF
Sharrows	$126.30	EA
"WAIT HERE" Legend	$267.66	EA
Bicycle Symbol	$98.21	EA

Per manufacturer guidelines, the installation of the colored thermoplastic first required the application of an oil-based coating to the asphalt. The optimal installation of this initial layer would be an application to asphalt free of debris and sediment. The oil layer needed to dry (WC) before the colored thermoplastic could be laid out. Otherwise, the heat applied to the thermoplastic would cause the oil to burn through the material.

An installation error of the colored thermoplastic on Dean Keaton at the IH-35 exit ramp led to its quick deterioration. While waiting for the oil layer to dry, one of the crew members spilled a large amount of water onto the oil. This water eventually led to inadequate bonding between the pavement and the thermoplastic, which resulted in the thermoplastic breaking up (illustrated in Figure 18).

Also, the quality of pavement was a contributing factor to the quick deterioration of the colored thermoplastic, shown in Figure 18. In particular, the pavement on Speedway at 38th Street is cracked and uneven from the high volume of bus traffic. Clearing debris from the deep cracks of the application surface was nearly impossible; applying the oil-layer to these same cracks and the other surface flaws was also troublesome. The resultant colored thermoplastic was only tenuously bonded to the street surface at best.

Figure 18. Deteriorating thermoplastic on Dean Keeton Street at one of the I-35 exit ramps (breaking up in sheets)

Additionally, the colored thermoplastic on Speedway was discolored very quickly (see Figure 19). This discoloration is likely due to the heavy bus traffic on Speedway, where there is a peak hourly volume of over 15 buses/hour. This discoloration may have been compounded by the buses, wider than personal cars, driving in the colored lane. Another concern with the thermoplastic is shown in Figure 20. It is unclear whether the uneven application of thermoplastic shown in the photograph is the result of a misapplication, the rough nature of the street surface, or a deterioration problem.

Figure 19. Poor quality of road led to the deterioration of the thermoplastic bike boxes on Speedway

Figure 20. Thermoplastic thinning on the colored lane on San Jacinto Boulevard

Installing colored thermoplastic on new pavement would be the optimal situation. In the future, the City of Austin will most likely be applying a fresh asphalt surface (seal coat, microsurface, or overlay) before the installation of any proposed colored thermoplastic. A fresh street surface will provide a surface free of cracks and other defects, which could lead to erroneous installation and quick deterioration. These properties also lessen the importance of the oil layer in creating a bond between the pavement and thermoplastic.

All sharrows were installed on top of a painted black box in order to provide visual contrast. Additionally, all sharrows were installed in the outside travel lanes. The sharrows on Guadalupe, Lavaca, and 51st Streets were installed in the center of the outside travel lanes as described by Figure 21. Each sharrow was individually placed in order to keep the sharrow out of the typical wheel paths and to avoid driveways where entering and exiting vehicles would have more variable wheel paths. By placing the sharrows outside of wheel paths the integrity of the thermoplastic was maintained.

Figure 21. Central placement of sharrow resulted in thriving thermoplastic five months after installation.

The east-bound sharrows on Dean Keeton Street were installed in the center of the outside travel lanes (see Figure 22) in the same manner as the sharrows on Guadalupe, Lavaca, and 51st Streets. Like these other streets, centralizing the east-bound Dean Keeton Street sharrows helped to preserve the thermoplastic. Another reason these sharrows were installed in the center of the travel lane was to keep them out of the path of buses. Dean Keeton Street has an extremely high volume of bus traffic (peak hourly volume of 40 buses/hour) and there a number of bus stops requiring buses to enter and exit the outer travel lane as shown in Figure 22. Finally east-bound bicyclists are also able to reach faster speeds because of the downhill allowing bicyclists and cars to travel at similar speeds.

Figure 22. Central placement of sharrows on east-bound, downhill Dean Keeton Street

The west-bound sharrows on Dean Keeton differed from the other locations as these sharrows were aligned closer to the curb (see Figure 23). These sharrows were aligned closer to the curb for the following reasons: the outside travel lane on west-bound Dean Keeton was very large, there were no bus stops, the sharrows were only utilized to provide a bicycle facility to link two bicycle lanes, and west-bound bicyclists slow down to travel uphill.

Figure 23. Curb-justified placement of sharrows on west-bound, uphill Dean Keeton Street

APPENDIX C: P-values

Table 3 and Table 4 show the p-values for the comparisons made on Shoal Creek Boulevard and Speedway, respectively. Tests of statistical significance were used to determine if there were any significant differences between the different phases of bicycle box implementation including: no bicycle box, skeleton bicycle box, and colored bicycle box. All proportions and means were compared using a two-sided test of equality, where the null hypothesis was that no change occurred and the alternative hypothesis that behavior changed.

Table 3. P-values for comparisons of three stages for Shoal Creek Boulevard and Anderson Lane

Comparison		Bicycle Behavior					Motorist Behavior	
	Approaches in bike lane	Stops in bike lane area	Stops before stop line	Waits in queue of motorists	Makes an avoidance maneuver	Bike departs first	Encroaches stop line	Encroaches bike lane
No Bike Box vs. Skeleton Bike Box	0.343	<0.001	0.009	0.286	0.132	0.000	0.167	0.559
Skeleton Bike Box vs. Colored Bike Box	0.001	0.001	0.005	0.103	N/A	0.267	0.099	0.744
No Bike Box vs. Colored Bike Box	0.005	0.317	<0.001	0.376	N/A	<0.001	0.624	0.800

Table4. P-values for comparisons of the three stages for Speedway and 38th Street

Comparison		Bicyclist Behavior						Motorist Behavior	
	Approaches in bike lane	Stops in bike lane area	Stops before stop line	Waits in queue of motorists	Makes an avoidance maneuver	Bike departs first	Runs red light	Encroaches stop line	Encroaches bike lane
No Bike Box vs. Skeleton Bike Box	0.101	0.001	0.015	0.007	<0.001	0.847	0.624	<0.001	0.003
Skeleton Bike Box vs. Colored Bike Box	0.142	0.607	0.329	0.516	0.003	0.315	<0.001	0.190	0.058
No Bike Box vs. Colored Bike Box	0.002	0.002	<0.001	0.001	0.008	0.224	<0.001	0.002	0.110