TECH**BRIEF**

Safety Evaluations of Innovative Intersection Designs for Pedestrians and Bicyclists

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This document is a technical summary of the Federal Highway Administration report *Safety Evaluations of Innovative Intersection Designs for Pedestrians and Bicyclists* (FHWA-HRT-23-033).

INTRODUCTION

Traffic professionals are exploring innovative intersection designs to determine if they can successfully accommodate multimodal transportation by reducing conflicts between moving vehicles and vulnerable road users or by lowering the impact force (reducing the vehicle speed and changing the collision angle in the event of a collision).

The objective of this Federal Highway Administration (FHWA) project was to investigate the operational and safety improvements of innovative intersection retrofitting designs that benefit pedestrians and bicyclists while maintaining a reasonable service to motor vehicles. The project included summarizing previous research efforts, developing three design types, identifying potential study sites (both before-after and comparison-existing pairs), and collecting operational behaviors of the users.

These types of intersections have several names, including innovative intersection, protected intersection, dedicated intersection, Dutch intersection, and Dutch-style junction. The term protected intersection is used in the text of this document.

SITE IDENTIFICATION

With the goal of conducting 15 before-after evaluations representing a total of 30 site periods (15 sites multiplied by 2 periods, before and after), a key component of the study was to identify the study site before the treatment had been installed so that before data could be collected. The research study was also bound by a fixed end date, so the installation of the treatment had to occur in sufficient time to permit adequate time to collect the after data, to conduct the analysis, and to complete the required study documentation before the end date of the contract. With these restrictions, six study sites were identified where both before data and after data could be collected within the contract limits. These 6 sites represented 12 site periods, resulting in a need of 18 additional site periods. The remaining intersections to be selected either already had the treatment (14 intersections) or served as a comparison to nearby sites with existing treatments (4 intersections). Table 1 lists the sites included in this project, including 6 before-after sites (for 12 site periods), 4 comparison sites (i.e., untreated intersections), and

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12 existing (or treated) intersections. In most cases, the intersection traffic control was a traffic signal, only 4 of the 24 intersections had an all-way stop sign for traffic control. All but one of the intersections had four legs.

The posted speed limit (PSL) on the approaches was generally 25–40 mph with a few at 20 mph or 45 mph. Table 2 provides the data collection dates for each site period along with the street names for the intersection.

Table 1. Study sites selected for project.

SITE	CONDITION	CONTROL	PSL-NB (MPH)	PSL-SB (MPH)	PSL-EB (MPH)	PSL-WB (MPH)
CA–BER–01	Existing	Signal	25	25	25	25
CA–FRE–01	Existing	Signal	25	30[b]	35[b]	35
CA–FRE–02	Existing	Signal	30	30	35	35
CA–FRE–03	Existing	Signal	25	25	35	35
CA–FRE–04	Existing	Signal	25[a]	25[a]	25	25
CA–FRE–05	Compare	Signal	35	35	30	30
CA–FRE–05	Existing	Signal	35	35	35	30
CA–FRE–06	Existing	Signal	35	NA[c]	40	45
CA–FRE–07	Compare	Signal	35	NA[c]	40	45
CA–FRE–07	Existing	Signal	40	40	NA[c]	45
CA–FRE–09	Existing	Signal	25[a]	25	40	40
CA–FRE–11	Before-after	Signal	35	40	35	35
CA–FRE–12	Before-after	Signal	35	40	35	35
DC–WAS–01	Before-after	All-way stop	25[a]	25	25[a]	25[a]
DC–WAS–02	Before-after	All-way stop	25[a]	25	25[a]	25[a]
DC–WAS–03	Before-after	Signal	25[a]	25[a]	25	25[a]
MD–SSP–01	Existing	Signal	25	30	25	30
MD–SSP–02	Before-after	Signal	25[a]	25[a]	25	25[a]
TX–AUS–16	Compare	Signal	35	35	35[d]	35[d]

Table 1. Study sites selected for project. (Continued)

SITE	CONDITION	CONTROL	PSL-NB (MPH)	PSL-SB (MPH)	PSL-EB (MPH)	PSL-WB (MPH)
TX–AUS–16	Existing	Signal	40[b]	40[b]	40	35
TX–CST–01	Existing	All-way stop	25	NA[c]	30	20
UT–SLC–01	Compare	Signal	25	25[a]	20	20
UT–SLC–01	Existing	Signal	25	25	20	20
UT–SLC–03	Existing	All-way stop	30	25	25	25

[a]Assumed speed limit based on local conditions because a speed limit sign was not identified near the intersection.
[b]Approach also had a 25-mph school speed limit.
[c]No speed limit as approach was either a driveway or not present.
[d]Approach also had a 20-mph school speed limit.

NB = northbound; SB = southbound; EB = eastbound; WB = westbound; NA = not applicable; CA = California; BER = Berkeley; FRE = Fremont; DC = District of Columbia; WAS = Washington; MD = Maryland; SSP = Silver Springs; TX = Texas; AUS = Austin; CST = College Station; UT = Utah; SLC = Salt Lake City.

Table 2. Dates data collected at each study site.

SITE–PERIOD	INTERSECTION	DATA COLLECTION DATE
CA–BER–01–Exi	Alameda and Hopkins	8/31/21
CA–FRE–01–Exi	Walnut Ave and Galluadet Dr	9/1/21
CA–FRE–02–Exi	Walnut Ave and Guardino Dr	8/30/21
CA–FRE–03–Exi	Walnut Ave and Civic Center Dr	8/23/21
CA–FRE–04–Exi	Civic Center Dr and Bart Way	8/27/21
CA–FRE–05–Com	Walnut Ave and Fremont	8/24/21
CA–FRE–05–Exi	Walnut Ave and Paseo Padre Pkwy	8/25/21
CA–FRE–06–Exi	Cushing Pkwy and Northport Loop W	8/18/21
CA–FRE–07–Com	Cushing Pkwy and Fremont Blvd	8/19/21
CA–FRE–07–Exi	Cushing Pkwy and Northport Loop E	8/17/21
CA–FRE–09–Exi	Grimmer and Wisdom Way	11/21/21

Table 2. Dates data collected at each study site. (Continued)

SITE–PERIOD	INTERSECTION	DATA COLLECTION DATE
CA–FRE–11–Aft	Fremont Blvd and Mowry Ave	11/22/21
CA–FRE–11–Bef	Fremont Blvd and Mowry Ave	12/15/20
CA–FRE–12–Aft	Fremont Blvd and Stevenson	11/20/21
CA–FRE–12–Bef	Fremont Blvd and Stevenson	12/15/20
DC–WAS–01–Aft	1st St SE/Potomac Ave and L	10/13/21
DC–WAS–01–Bef	1st St SE/Potomac Ave and L	10/13/20
DC–WAS–02–Aft	1st St SE/Potomac Ave and K	10/13/21
DC–WAS–02–Bef	1st St SE/Potomac Ave and K	10/14/20
DC–WAS–03–Aft	K St NE/NW and 5th	10/12/21
DC–WAS–03–Bef	K St NE/NW and 5th	10/15/20
MD–SSP–01–Exi	Spring St and 2nd Ave	12/10/20
MD–SSP–02–Aft	Fenton & Cameron	6/7/22
MD–SSP–02–Bef	Fenton & Cameron	12/10/20
TX–AUS–16–Com	Escarpment Blvd and Davis	6/21/21
TX–AUS–16–Exi	Escarpment Blvd and La Crosse Ave	6/21/21
TX–CST–01–Exi	Bizzell and Ross	1/26/22
UT–SLC–01–Com	Temple and Broadway	11/18/21
UT–SLC–01–Exi	Broadway (also known as 300 South) and 200 West	11/17/21
UT–SLC–03–Exi	700 South and 300 East	11/19/21

CA = California; BER = Berkeley; FRE = Fremont; DC = District of Columbia; WAS = Washington; MD = Maryland; SSP = Silver Springs; TX = Texas; AUS = Austin; CST = College Station; UT = Utah; SLC = Salt Lake City; Aft = after; Bef = before; Exi = existing; Com = comparison.

DATA COLLECTION

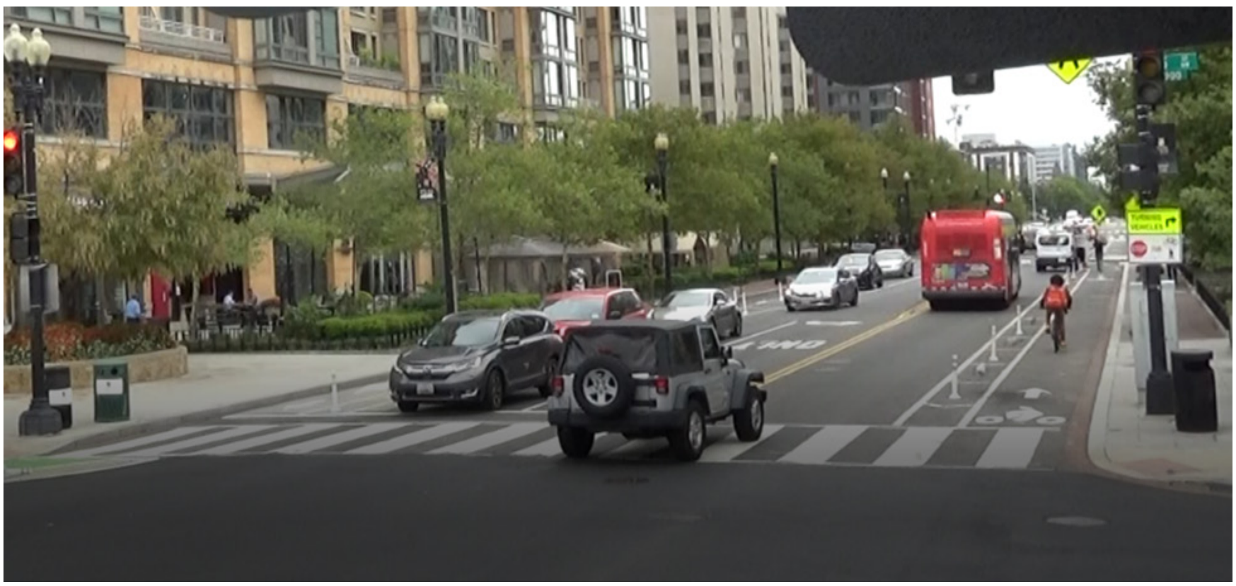
For each site period, data were collected using video obtained either from cameras installed on a pole or on a rooftop at the site, or from drones.

For the Washington, DC, sites, the research team installed four video cameras on streetlight poles on October 12 or October 13, 2020, to capture the before modifications condition. The installations occurred October 20 to 22, 2021, for the after condition. Each camera covered one crosswalk at the intersection. Figure 1 shows the video from one of the cameras.

For the College Station, TX, site, a camera used to monitor traffic conditions on campus was used to collect the video data. The video for MD–SSP–02 was a mix of drone video and video recorded from the top story of a parking garage. Figure 2 provides an example of the video view from the rooftop camera.

For the remaining study site, video data were collected using a drone-mounted video camera. The drone-enabled camera permitted all crosswalk data to be collected in one view. Figure 3 shows an example.

Figure 1. Photo. Example of video view for one of the cameras at DC–WAS–03–Aft (after).

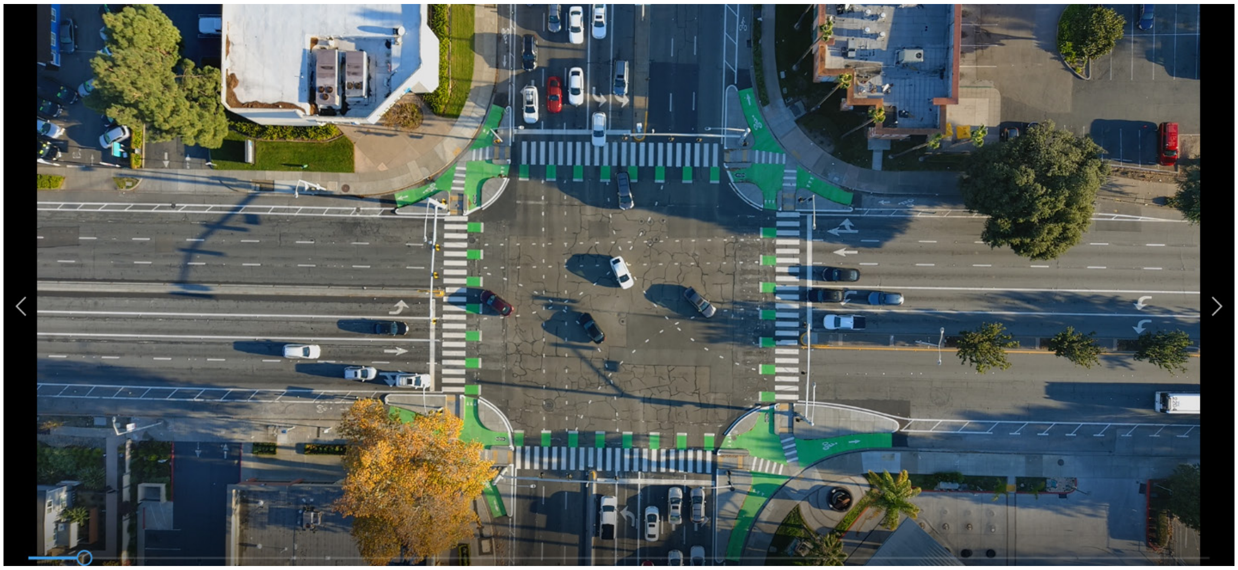


Source: FHWA.

Figure 2. Photo. Example of view for rooftop camera at MD–SSP–02–Aft.

Source: FHWA.

Figure 3. Photo. Example of view from drone camera of CA–FRE–11–Aft.



Source: FHWA.

OBSERVATIONS

Because the accuracy of identifying vulnerable users using software to process the video was not sufficient, technicians watched the video and recorded user behaviors. Behaviors for 23,505 vulnerable users were recorded for the 30 site periods. The behaviors reviewed in this study included the following: change in volume; conflicts between vulnerable users and motorized vehicles; typical travel paths for the vulnerable users (including whether the bicyclists rode through pylons); waiting locations for the vulnerable users; and motorist right-turn behaviors, such as turning speed and driving on aprons or in bike queue areas.

Key Observations on User Behaviors (Other than Right-Turning Speed)

The key observations from this research effort included the following:

- Overall, pedestrians were more likely to interact with a vehicle (33 percent of the pedestrian crossings involved a vehicle) compared to bicyclists interacting with a vehicle (19 percent of bicyclist crossings).
- Drivers yielded to bicyclists and pedestrians more at the treated sites compared to the untreated sites. For bicyclist crossings, 38 percent of the crossings for treated sites compared to 34 percent for sites that were not treated involved a vehicle yielding to the bicyclist. In the majority of the bicyclist crossings (46 percent of the bicyclist crossings for treated and 46 percent for nontreated intersections), a vehicle was not involved. For pedestrian crossings, the comparison is 23 percent for treated sites compared to 16 percent for untreated sites.
- The treatment was designed to slow turning vehicles and provide drivers additional opportunity to see the crossing vulnerable user. The addition of the treatment at three of the before-after sites with traffic control signals resulted in more frequent yielding by drivers to pedestrians (41 percent in the before period to 47 percent in the after period).
- For the six before-after sites, the percentage of bicyclists riding from one bike lane to another bike lane increased from 13 percent to 52 percent, while the percent riding from one sidewalk to another sidewalk decreased from 21 percent to 12 percent. More of the bicyclists were in the space designed for their use after the treatment was installed.
- A greater proportion of the bicyclist's path through an intersection was separated from motorized vehicles with the presence of corner islands. At some sites, following the intended path resulted in longer travel time through the intersection, including having to slow to accommodate the bend out and bend in bicycle path that can be generated by the location of the corner island. With regard to sites with raised islands, the majority of the bicyclists (66 percent) did follow the marked path and went to the right of the corner islands. For those sites where the corner island was created using pylons, again, most of the bicyclists (58 percent) followed the marked path and went to the right of the corner island. A sizable number; however, rode through the pylons (19 percent).
- Bicyclists may have wanted to go in the opposite direction along a street and appear to have done so

at protected intersections by using the sidewalks and crosswalks rather than the bike lane and green marked waiting area.

- In some cases, bicyclists were leaving the bike lane and entering the sidewalk to use the pedestrian push button.
- The two intersections that converted the right-turn lane to the protected intersection treatment had similar trends. Most of the pedestrians who waited on the channelizing island in the before condition were now waiting in the pedestrian ramp area in the after condition. These pedestrians did not have to weave through the moving right-turning motorized vehicles to reach the refuge area where they waited before crossing the intersection.
- The inclusion of truck aprons could facilitate the turning of large vehicles while also encouraging smaller radius turns for right-turning vehicles.

Observations on Right-Turn Speed

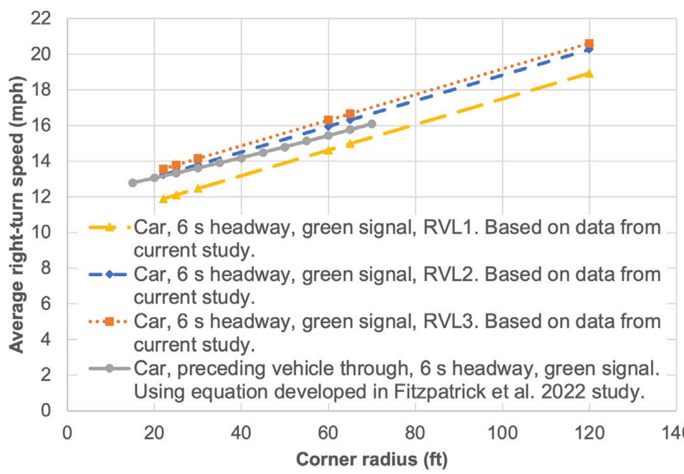
Right-turn speeds were gathered for two before-after California sites using computer analysis of the video. Speed and headway information were collected with a goal of having at least 30 right turning vehicles at each intersection corner for each period (before and after). On review of the data, the research team decided to remove vehicles that were not identified as being a car from the evaluation due to small sample sizes for the other vehicle categories.

When drivers turn into a lane other than the one nearest to the curb, they are increasing their effective radius. The lane the vehicle turned into was considered during the analysis. Additional review of a sample of the data revealed that the signal indication for the right-turning vehicle was needed. The right-turning vehicles were included when their signal indication was green.

The research team conducted a regression analysis to determine how the corner speed was impacted by the vehicle headway, corner radius, and receiving lane. The study team added the independent factors of period, receiving lane, turning radius, and corner headways to the model. The model was done using only cars (no motorcycles or heavy vehicles) that had a green signal when they arrived at the intersection and turned into vehicle receiving lanes (vehicles that turned into parking lanes or bike lanes were eliminated).

Fitzpatrick et al. (2022) previously studied right-turn speeds at 31 urban intersections in Texas. The path (i.e., the receiving lane) followed by the vehicle during the turn was used to calculate the vehicle speed and was not included in the modeling efforts. Most of the vehicles turned into the nearest lane to the curb in that study. From those 31 Texas intersections, the variables that impact

Figure 4. Graph. Comparison of findings between this current study (lines with squares, diamonds, and triangles) and the Fitzpatrick et al. 2022 study (lines with circles).



Source: FHWA.

right-turn speeds included turning radii, vehicle type (car or trucks), signal indication at the time of arrival (yellow or green), whether the preceding vehicle was going straight or turning right, and vehicle headway.

Figure 4 compares the findings between this study and the Fitzpatrick et al. (2022) study. The range of radii included in the Fitzpatrick study was 15–70 ft, while the range of radii included in this evaluation was 22–120 ft. As shown in figure 4, the plot of the equation from both studies shows similar trends. The current study provided the opportunity to illustrate the difference in speeds between vehicles turning into different receiving lanes. The middle receiving lane (RVL2) and the outer side receiving lane (RVL3) had significantly higher turning speed values than the inner side receiving lane (RVL1).

This right-turn speed evaluation demonstrated that a protected intersection results in reduced turning speeds with the installation of smaller corner radii. The key observations with regard to right-turning speed are as follows:

- Right-turn speeds are higher at corners with a larger corner radius. The receiving lane for the right-turning vehicle also influences the right-turn speed, with drivers turning faster to the lane that is the furthest from the curb.
- Comparing the right-turn speeds before and after the installation of the protected intersection treatment at two California sites found the following conclusions:
  - With the decrease in corner radius from the before period to after period with the installation of the

protected intersection, the average right-turn speeds decreased. For example, a corner being changed from a 60-ft radius to a 25-ft radius is predicted to have about a 2.6 mph decrease in speed.

- In addition, the range of turning speeds in the period after the treatment was installed was smaller compared to the before period for most of the corners. In other words, the addition of the protected intersection treatment is also associated with fewer drivers turning at high right-turn speeds.

SUMMARY

Drivers yielded to bicyclists and pedestrians more at the treated sites compared to the sites that were not treated. Specifically, 38 percent of drivers yielded to bicyclists at treated crossings versus 34 percent at untreated crossings; 23 percent of drivers yielded to pedestrians at treated crossings versus 16 percent at untreated crossings.

The treatment is designed to slow turning vehicles and provide drivers additional opportunity to see the crossing vulnerable user. The addition of the treatment at three of the before-after sites with traffic control signals improved driver yielding from 41 percent in the before period to 47 percent in the after period.

For the two intersections that converted the right-turn lane to the protected intersection treatment, most of the pedestrians who waited on the corner island in the before condition were now waiting in the pedestrian ramp area in the after condition. These pedestrians did not have to weave through the moving right-turning motorized vehicles to reach the refuge area where they waited before crossing the intersection. Additionally, reducing the corner radius with the installation of the treatment decreased the speed of the right-turning vehicles. For example, a corner being changed from a 60-ft radius to a 25-ft radius is predicted to decrease right-turning speed by 2.6 mph. The inclusion of truck aprons can facilitate the turning of large vehicles while also encouraging smaller radius turns for right-turning vehicles.

REFERENCES

Fitzpatrick, K., R. Avelar, M. P. Pratt, S. Das, and D. Lord. 2022. *Crash Modification Factor for Corner Radius, Right-Turn Speed, and Prediction of Pedestrian Crashes at Signalized Intersections*. Report No. FHWA-HRT-21-105. Washington DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/safety/21105/index.cfm, last accessed December 6, 2022.

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