

Evaluation of Rural Intersection Treatments

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16. Abstract <p>Because crashes at rural intersections frequently result from failure to yield, agencies attempt to find countermeasures that encourage drivers to stop and yield appropriately. In this research, two promising low-cost rural intersection countermeasures were selected and evaluated for their impact on safety: post-mounted beacons and retroreflective strips on stop sign posts. The post-mounted beacons were set to activate only when an approaching vehicle's speed surpassed a predetermined threshold.</p> <p>High-crash rural stop-controlled intersections were identified using in-house crash and roadway data and then filtered for suitability via site visits. The retroreflective strips were installed on stop signs at 14 intersections on both minor street approaches. The post-mounted beacons were installed on stop signs at 10 approaches at 6 intersections. Driver behavior was used to assess the countermeasures. Because the post-mounted beacon was expected to noticeably impact driver behavior while the retroreflective strips were not, driver behavior data were only collected at locations where post-mounted beacons were installed. Video data were collected using trailer-mounted cameras at all 10 approaches where post-mounted beacons were installed 1 month before and 1 month after installation. For 6 of the 10 approaches, data were also collected 12 months after installation. Several driver behavior metrics, including type of stop, stopping position, braking point, and number of times braking, were reduced for a random sample of vehicles for each approach in each evaluation period and were compared before and after installation.</p> <p>Overall, the post-mounted beacon had an overwhelmingly positive safety benefit, as measured by several changes in driver behavior. Most approaches where the countermeasure was installed experienced increases in the number of drivers making full stops, braking within 450 to 500 ft of the intersection, stopping at or before the stop bar, and braking only once. Ideally, these improvements in driver behavior will result in reduced crashes at the study intersections. Because the retroreflective strips were not evaluated, the researchers propose to conduct a crash analysis when at least three years have elapsed after installation.</p>			
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EXECUTIVE SUMMARY

Background and Objectives

Crashes at rural intersections are frequently a result of failure to yield. As a result, agencies attempt to find countermeasures that encourage drivers to stop and yield appropriately. A number of countermeasures have been utilized to reduce crashes and improve intersection safety. However, some treatments have been shown to have mixed results, while for others only limited information about effectiveness is available. Because even low-cost treatments require some maintenance, it is important for agencies to have good information about the effectiveness of the various treatments before investments are made.

The objective of this research was to select promising low-cost rural intersection countermeasures and evaluate their impact on improving safety. The research team, in conjunction with the technical advisory committee, selected two low-cost countermeasures: post-mounted beacons and retroreflective strips on stop sign posts. The post-mounted beacon included a radar so that the system could be set to only activate when an approaching vehicle's speed surpassed a predetermined threshold. This threshold was based on whether a vehicle would be likely to stop.

Site and Countermeasure Selection

High-crash intersections on rural minor street stop-controlled intersections were identified using in-house crash and roadway data and then filtered for suitability via site visits. The retroreflective strips were installed on stop signs on both approaches of the minor street at 14 intersections. Beacons were installed on stop signs at 10 approaches at 6 intersections.

The ideal metric for evaluating the safety impacts of a countermeasure is to evaluate crashes before and after installation. However, this requires several years of data after installation of the countermeasure, which was beyond the timeframe of this project. As a result, only driver behavior could be evaluated in the short term to assess the impacts of the countermeasures in this study.

Because the stop sign beacon only activates for vehicles traveling over a certain speed threshold, the countermeasure was expected to have a noticeable impact on stopping point, type of stop, and other similar characteristics. While the retroreflective strip increases sign conspicuity and ideally alerts a driver to the presence of the stop sign, it was not expected to impact driver behavior in a measurable way similar to the stop sign beacon. As a result, driver behavior data were only collected at locations where stop sign beacons were installed, and driver behavior, such as type of stop, was monitored before and after installation of the beacons.

Data Collection

Because it is difficult to conduct a crash analysis in the short term, measures of effectiveness focused on unsafe driver behaviors. Portable data collection trailers with speed sensors and cameras were used for the data collection. The trailers were placed upstream of the intersection, which allowed the cameras to monitor vehicles as they approached the intersection. A trailer was placed at each approach with a post-mounted beacon.

A variety of driver behavior metrics, including type of stop, stopping position, point at which vehicles first began braking, and number of times braking, were reduced for a random sample of vehicles for each approach during three evaluation periods: before, 1 month after, and 12 months after installation. The trailers were deployed for a full week at each data collection period. Beacons were installed much earlier at several sites than at other sites, so the 1-month after data included measurements at 10 intersection approaches and the 12-month after data included measurements at 6 intersection approaches. Driver behavior metrics were compared before and after installation.

Results and Summary

Results are summarized for each measure of effectiveness in the following sections. Results by individual intersection are provided in Chapter 5.

Type of Stop

The type of stop was reported as “full stop,” “slow rolling,” “fast rolling,” or “non-stop.” In summary, 8 of the 10 approaches where a stop sign beacon was installed experienced an increase in the number of vehicles coming to a full stop, with an average increase of 10.8% at 1 month after installation. The percentage of vehicles that did not stop decreased at 4 of the 10 intersections. At 5 approaches, there were no vehicles reported as not stopping in either the before or 1-month after periods, and as a result no change was observed. At one approach, an increase of 0.7% in vehicles not stopping was reported.

At 12 months after installation, 4 of the 6 approaches where data were available experienced increases in the number of vehicles coming to a full stop, with an average increase of 11.3%. Two sites experienced decreases in the percentage of vehicles coming to a full stop (15.9% and 20.1%).

Point of Initial Braking

Earlier braking is an indicator that vehicles are preparing to stop, and this behavior was analyzed to determine whether vehicles are stopping earlier based on the installation of the post-mounted beacon. The point at which drivers initially began to brake was recorded and evaluated. Distance was aggregated into the following bins:

- 450 to 500 ft
- 350 to 400 ft
- Less than or equal to 300 ft

Stopping sight distance was calculated based on an approach speed of 55 to 60 mph using a standard deceleration value. Depending on the assumed coefficient of friction, stopping distance ranged from 300 to 350 ft. It was assumed that braking at 350 ft or more represented normal braking and braking at a distance of less than 350 ft would result in harder braking. Although harder braking does not pose a safety risk in and of itself, it was assumed that drivers who began braking sooner were more likely to be aware of the upcoming intersection.

Six of the 10 approaches where a stop sign beacon was placed experienced increases in the number of vehicles that stopped between 450 and 500 ft of the approach stop bar. An average increase of 10.3% was found at 1 month. Four of the approaches experienced a decrease in the percentage of vehicles stopping between 450 and 500 ft, with an average decrease of 21.1%.

At 12 months, 5 of the 6 approaches evaluated experienced increases in the percentage of vehicles first braking at 450 to 500 ft upstream of the intersection, with an average increase of 8.4%, while one approach experienced a decrease (-9.6%).

Mixed results were found for the change in the percent of vehicles that first began braking within 300 ft of the intersection for the 1-month after period. with 5 of the 10 approaches experiencing a decrease and 5 experiencing an increase. At 12 months, 4 of the 6 approaches experienced a decrease in the percentage of vehicles stopping within 300 ft. Two of the 6 experienced an increase.

It was expected that vehicles would overall begin braking sooner when the beacon was present. Overall, the majority of approaches in the 1-month and 12-month after periods experienced an increase in vehicles that began braking early (450 to 500 ft) and a decrease in vehicles that first began braking within 300 ft of the intersection.

Stopping Location

The stopping location for each vehicle was also recorded to determine whether the post-mounted beacons impacted the location where drivers stopped. Stop location was initially coded as before, at, or after the intersection approach stop bar or as a non-stop when the vehicle did not clearly stop at any point. Data were aggregated to just two conditions that the team felt were the most meaningful:

- At: includes vehicles that stopped at or before the approach stop bar
- After: includes vehicles that stopped after the approach stop bar or did not stop

It was assumed that drivers who came to a stop before the stop bar were better prepared to assess and scan on-coming traffic and react if needed. As a result, an improvement in the percentage of drivers stopping at or before the stop bar was treated as a positive safety benefit.

At 1-month after installation of the flashing beacon, eight of the 10 approaches where data were collected experienced an increase in the percentage of vehicles stopping at or before the intersection approach stop bar at 1 month after installation of the flashing beacon. The average increase was 6.3%. At the west approach of the intersection in Johnson County, all vehicles stopped at or before the stop bar before installation, and this trend continued at the 1-month and 12-month after periods. As a result, no change was noted at this location. The percentage of vehicles stopping at or before the stop bar decreased at the south approach of the Clay County intersection (20.4%).

At 12 months, 5 of the 6 approaches where data were recorded experienced an increase in the percentage of vehicles stopping at or before the stop bar. The average increase was 6.6%. No change was noted at the west approach of the Johnson County intersection and an increase was noted at the north approach of the Benton County intersection (12.5%).

Overall, driver stopping locations were more compliant after installation of the flashing beacons.

Number of Times Braking

The number of times the brake lights were activated for each vehicle was also extracted from the field video. It is not known whether the frequency of braking behavior impacts safety. However, the premise for collecting this information is that drivers who brake multiple times may not be prepared for the upcoming intersection. As a result, the number of times vehicles only had one braking event was compared to the number of times vehicles had multiple braking events. At 1 month after installation of the stop sign beacons, 6 of the 10 approaches experienced an increase in the number of vehicles that only stopped once (average increase of 12.6%). Four of the 10 approaches experienced a decrease in the percentage of vehicles that only had one braking event.

At 12 months after installation, all six approaches experienced an increase in the percentage of vehicles that braked only once, with an average increase of 21.0%.

Overall, the number of vehicles braking a single time increased at the majority of the intersection approaches at 1 month after installation, and all approaches where data were collected at 12 months after installation experienced an increase in the number of vehicles braking only once. As a result, it can be inferred that the presence of the beacons had a positive impact on braking behavior.

Discussion

The addition of a speed-activated flashing red beacon at the approach stop sign was found to positively impact driver behavior in terms of the following:

- Stopping behavior, including the number of vehicles coming to a full stop at the intersection as well as the number of vehicles stopping at or before the stop bar
- Intersection awareness, including the number of drivers who first began braking within 450 to 500 feet as well as the number of drivers only braking once

Ideally, these improvements in driver behavior will result in reduced crashes at the study intersections. The cost of each stop sign beacon was approximately \$3,000, and they require regular maintenance. Overall, they were found to be a reasonably low-cost countermeasure. There were some concerns from participating agencies that having the beacon only activate at a set speed threshold rather than continuously may be confusing to drivers. However, studies of other dynamic countermeasures that only present a message to drivers who are speeding have been widely used and have been shown to be very effective (Hallmark et al. 2015, Zineddin et al. 2015, Fitzsimmons et al. 2007).

The addition of retroreflective strips on stop sign posts was not evaluated because they were installed on a large number of stop signs and collection of data was not feasible given project resources. The intent is therefore to conduct a crash analysis when at least three years have elapsed after installation of the countermeasure.

1. BACKGROUND

1.1 Scope of Problem

In Iowa, intersection crashes account for 30% of severe crashes, with 40 % of those crashes occurring in rural areas. Rural intersection crashes are frequently a result of drivers failing to yield right of way. Failure to yield may be due to speeding, which can result in failure to react in time, or may be due to a failure to recognize the presence of the intersection or traffic control due to sight distance issues or driver inattention. Retting et al. (2003) investigated crashes at stop-controlled intersections in four cities and found that stop sign violations accounted for about 70% of crashes.

Both older and younger drivers have been attributed responsibility in failure to yield crashes at intersections. Retting et al. (2003) report that younger drivers (< 18) and older driver (65+) were more likely to be at fault at stop-controlled intersections. Massie et al. (1993) created a collision typology to assess crash types and investigated 50 crashes involving failure to yield. They found that older drivers were more likely to stop first and then pull out and collide with another vehicle while younger drivers were more likely not to stop.

Intersection characteristics such as sight distance, skew angle, presence of horizontal or vertical curvature, presence of a median, or lighting have also been correlated to failure to yield and intersection crash risk (Harwood et al. 1995, Burchett and Maze 2006).

1.2 Objectives

Crashes at rural intersections are frequently a result of failure to yield. As a result, agencies attempt to find countermeasures that encourage drivers to stop and yield appropriately. A number of countermeasures have been utilized to reduce crashes and improve intersection safety. However, some treatments have been shown to have mixed results, while for others only limited information about effectiveness is available. Because even low-cost treatments require some maintenance, it is important for agencies to have good information about the effectiveness of the various treatments before investments are made.

The objective of this research was to select one or two promising low-cost rural intersection countermeasures and evaluate their impact on improving safety. The research team selected high-crash intersections and then evaluated the effectiveness of treatments installed at those intersections. Because it is difficult to conduct a crash analysis in the short term, measures of effectiveness focused on unsafe driver behaviors.

1.3 Selection of Countermeasures

Team first identified several potential countermeasures, as described in the following sections. Next, they met with the project's technical advisory committee (TAC), as described in Section 1.4, and selected final countermeasures. The objective was to evaluate lower cost

countermeasures that were appropriate for rural high-speed roadways. As a result, more expensive alternatives such as intersection realignment, roundabouts, channelization, intersection collision warning systems, and alternative intersection designs (i.e. J-turn, reduced conflict) were not assessed. Additionally, countermeasures that would typically be used within a city or village, such as a traffic signal, were not considered.

Overhead Beacons

Overhead flashing beacons have been widely used to warn drivers that an upcoming intersection is present. Overhead beacons also remind drivers of who has the right of way (see Figure 1-1). In general, overhead beacons have shown mixed results.



Shutterstock

Figure 1-1. Overhead flashing beacon

Several studies have found overhead beacons to be effective. Brewer and Fitzpatrick (2004) found a 43% reduction in crashes after installation. Stackhouse and Cassidy (1996) analyzed crash data at eight rural intersections in Minnesota for three years before and after overhead beacons were installed. All were four-way intersections with stop control on the minor approaches. A simple crash analysis indicated a 39% reduction in crashes. Murphy and Hummer (2007) developed crash reduction factors for overhead flashing beacons at 34 four-leg two-way stop-controlled rural intersections in North Carolina.

Results from an empirical Bayes analysis of overhead beacons that considered traffic increases showed a 12% decrease in total crashes, a 9% decrease in injury crashes, a 40% decrease in severe injury crashes, a 9% decrease in frontal impact crashes, and a 26% reduction in “ran stop sign” crashes.

Srinivasan et al. (2008) conducted an empirical Bayes analysis on standard overhead beacons, beacons mounted on stop signs, and actuated beacons in North Carolina and South Carolina. They conducted a before and after analysis that included control sites. All types of beacons were combined in one analysis (90 test sites). The authors found a 13.3% reduction in angle crashes and a 10.2% reduction in injury crashes and found a 12% reduction in crashes. They further evaluated sites with stop sign-mounted beacons and found a 58.2% reduction in angle crashes. However only five sites were represented. They also further evaluated standard overhead beacons (84 sites) and found an 11.9% reduction in angle crashes.

Several other studies have found little change in crashes. Pant et.al. (2007) compared crashes at 13 rural intersections with beacons and 13 stop-controlled intersections with no beacons in Ohio. They found that vehicular speeds in the major directions of traffic were reduced at intersections with beacons, especially at intersections with inadequate stopping sight distance. However, the beacons were found to have little effect on reducing stop sign violations or crashes. Hammer et al. (1987) evaluated 14 intersections with yellow-red beacons and 10 intersections with red-red beacons in California. The study reported a reduction in right-angle accidents at all four-leg intersections regardless of type of flasher, but results were not statistically significant. Fatal accidents were not significantly reduced when a flashing beacon was installed.

Although some studies have indicated the effectiveness of overhead beacons, some concerns have been raised about whether drivers understand the flashing yellow/red lights. Stackhouse and Cassidy (1996) conducted a driver opinion survey (of 144 drivers) on the installation of overhead beacons. Approximately one-half of older drivers (65+) and 42% of younger drivers (18 to 35 years old) stated some confusion about intersection beacons. A yellow indication normally indicates a clearance interval, which may be confusing to drivers

Overhead beacons also require overhead wiring and a power source, which make them difficult to install in some settings. Additionally, they incur on-going operating costs for electricity. Additionally, because overhead flashing beacons are continuously activated, regular drivers may become acclimated to their presence and begin to ignore them.

Use of Additional Retroreflective Material on Stop Sign Posts

Some agencies have begun adding an additional strip of retroreflective material to stop sign posts to increase their conspicuity (see Figure 1-2).



Neal Hawkins, Institute for Transportation

Figure 1-2. Additional reflective material on stop sign post

Only one study evaluated the addition of this treatment to a stop sign post. A 100% reduction in crashes was found, but only one intersection was evaluated (Fitzpatrick et al. 2011).

As a result of this lack of studies, very little information is available about the effectiveness of this countermeasure.

LED Stop Signs

The addition of LEDs embedded in the stop sign face is another strategy that has been used by agencies to increase the conspicuity of the stop sign, as shown in Figure 1-3.



Davis et al. 2014

Figure 1-3. Use of LEDs around stop sign face

The Federal Highway Administration (FHWA) (2009) summarized information about use of embedded LEDs in signs. The agency indicated that the LED units increase sign conspicuity and enhance visibility and recognition of regulatory and warning signs, particularly under low-light or low-visibility conditions.

Davis et al. (2014) evaluated the impact of flashing LED stop signs at 15 locations in Minnesota and at 240 intersections where no treatment was installed. The sites were through-stop-controlled intersections on undivided major roads. Controls sites were along trunk highways within 20 miles of a treated intersection. The author conducted a hierarchical Bayes observational before-and-after study and found a 41.5% decrease in right-angle crashes at intersections where the treatment was installed (confidence interval: 0 to 70.8%).

Davis et al. (2014) also recorded driver stopping behavior at one intersection before and after installation of an LED stop sign. Results indicated that when opposing traffic was present, drivers were significantly more likely to engage in a full stop. But no change was observed when no opposing traffic was present.

Another study reported a 29% reduction in vehicles not fully stopping and a 53% reduction in vehicles moving through the intersection without slowing after LED stop signs were installed (FHWA 2009). Arnold and Lantz (2007) evaluated a T-intersection in Virginia where a flashing LED stop sign face was installed. They found that average speeds decreased by 1 to 3 mph after

installation of the signs and that the speed decreases were greater during the nighttime. They also evaluated stop sign compliance but noted that their results were inconclusive.

As noted, a few studies have shown the LED treatment to be promising. However, each sign costs \$2,000 to \$4,000 depending on whether radar activation is used, and the signs require more maintenance than a regular stop sign. As a result, more information about the effectiveness of the countermeasure would be helpful for agencies before they invest in this type of treatment.

Stop Sign-Mounted Beacons

Standard stop sign beacons are usually mounted on a stop sign (Figure 1-4). In some cases, there may also be a warning beacon upstream.



Srinivasan et al. 2008

Figure 1-4. Beacon on a stop sign

Srinivasan et al. (2008) conducted an empirical Bayes analysis on standard stop sign-mounted beacons and flashing overhead beacons in North Carolina and South Carolina. The following CMFs were reported, but these included both countermeasures:

- 0.95 for all crashes
- 0.90 for injury crashes
- 0.42 to 0.88 for angle crashes

Brewer and Fitzpatrick (2004) investigated various treatments for rural highways and intersections. They found that a flashing beacon mounted on a “stop ahead” sign for a single intersection reduced crashes from 0.06 to 0.03 crashes/month based on a comparison of the crash data three years before and three years after installation.

As noted, some evidence is available that suggests flashing beacons are effective, but the results are based on just a few intersections. Additionally, the treatment costs \$1,500 or more per installation. As a result, more information is necessary about the effectiveness of the treatment.

1.4 Treatment Selection

The original project goal was to select two or three rural intersection treatments to install at two or three intersections each. Driver behavior would be recorded and compared at each intersection before and after installation. Identified potential treatments were summarized in Section 1.3 and include the following:

- Overhead flashing beacon
- Additional strip of retroreflective material on stop sign post
- LED stop sign
- Stop sign-mounted flashing beacon

Advance stop sign rumble strips are already widely used in Iowa. Their effectiveness is not well established, but it was determined that because they are so widespread, preference should be given to countermeasures that are not commonly used. Additionally, concerns have been raised about whether drivers understand the overhead flashing beacon, and in some cases these beacons are being removed in Iowa. As a result, it was decided that this treatment would not be included in this study.

Flashing beacons and LED stop signs were identified in the proposal for this project as the treatments that were the most likely to be evaluated. The research team met with the TAC, which was made up of state and county representatives. Many of the TAC members were not in favor of the LED treatment. Although it was agreed that it may be useful in a few isolated situations, they were concerned that a pilot study may encourage others to more unilaterally apply the treatment. There were also concerns that the LED stop sign would be attractive to the public, who may begin requesting its widespread use due to its perceived safety effectiveness. As a result, it was decided that the study would not include the LED stop sign.

The team and TAC discussed alternative countermeasures. It was decided that the additional reflective strip on the stop sign post was a reasonable countermeasure that was not likely to be overused. Additionally, the stop sign-mounted beacon that could be selectively activated only for vehicles not likely to stop was selected.

Initially, funds were allocated to treat three to five intersections with each countermeasure and to collect data after one month for both countermeasures. Beacons were installed at 7 approaches at

4 intersections. The retroreflective strips were also slated for installation at 14 intersections. Once the beacons were installed and the retroreflective strips purchased, the team reviewed the budget. Because the retroreflective strip on the stop sign post was cheaper than had been budgeted, it was decided that there were sufficient funds to install three additional stop sign beacons. It was also decided, as noted in Chapter 4, to only collect data at the beacon locations because the retroreflective strips were not expected to have a significantly measurable impact on observable driver behavior. As a result, it was decided to utilize the remaining resources to collect data at 12 months after installation for beacons installed in 2016.

2. SITE SELECTION

The focus of the project was rural two-way stop-controlled intersections at the intersection of two-lane roadways and rural four-lane divided highways with two-lane stop-control at the intersection. Treatment locations were identified using the following methodology.

A database of intersections in Iowa was previously developed by the Iowa Department of Transportation (DOT) in conjunction with the Institute for Transportation at Iowa State University. The following information was available in the intersection database and was used to query rural stop-controlled intersections:

- Number of approaches
- Signing by approach
- Presence and type of medians
- Presence and type of lighting
- Roadway surface type
- Channelization

The database was overlain with crash data from 2010 to 2014 (five years), and the total number of intersection crashes was extracted for each intersection. Intersections were sorted by number of crashes, and any intersection with 9 or more crashes was flagged. This resulted in a list of 60 potential locations. The team then used aerial imagery and Google Street View to inventory other characteristics that were not available in the intersection database. These included the following:

- Advance stop line rumble strips
- Overhead beacons
- Stop sign beacons
- Advance signing
- Type of pavement markings
- Roadway surface type
- Presence of lighting

The initial list of potential intersections was further reviewed and prioritized based on the following:

- Number of crashes or crash rate
- Presence of other countermeasures (ideally, the fewer existing countermeasures the better)
- Intersection configuration (unusual configurations may not be used if they are significantly atypical)
- Location (all other things being equal, closer locations facilitate data collection)
- Volume (it may difficult to collect data at locations with low traffic volumes)

Locations were also screened for their suitability for the application of stop sign treatments. Locations with stop sign beacons or overhead flashing beacons were removed from further consideration because they already have a prominent countermeasure that may confound further analysis. Several locations turned out to have a traffic signal or were located in an urbanized area and were also removed. Several other locations had adverse geometry (i.e., significant skew) or a railroad crossing near the intersection and were also removed.

A total of 23 intersections remained after the screening process. The team then solicited location information and suitability advice from the TAC and other stakeholders. This feedback resulted in minor location changes due to recent intersection countermeasure treatments that the team was unaware of or due to preference from local agencies that were more familiar with the location characteristics.

Site visits were made prior to the final selection of the sites to collect any relevant variables not available through other means. This also ensured that the proposed treatments could be installed.

The objective of the study was to apply two different stop sign countermeasures. Project funds were available for installation of stop sign beacons at 6 locations and additional reflective treatment on stop sign poles at 14 locations. Each treatment is described in more detail below.

Table 2-1 shows intersection characteristics and installation dates for the 14 intersections where the additional reflective strip treatment was placed. Intersection configuration, speed limit, and installation data are also provided.

Table 2-1. Intersections receiving additional reflective strips on stop signs

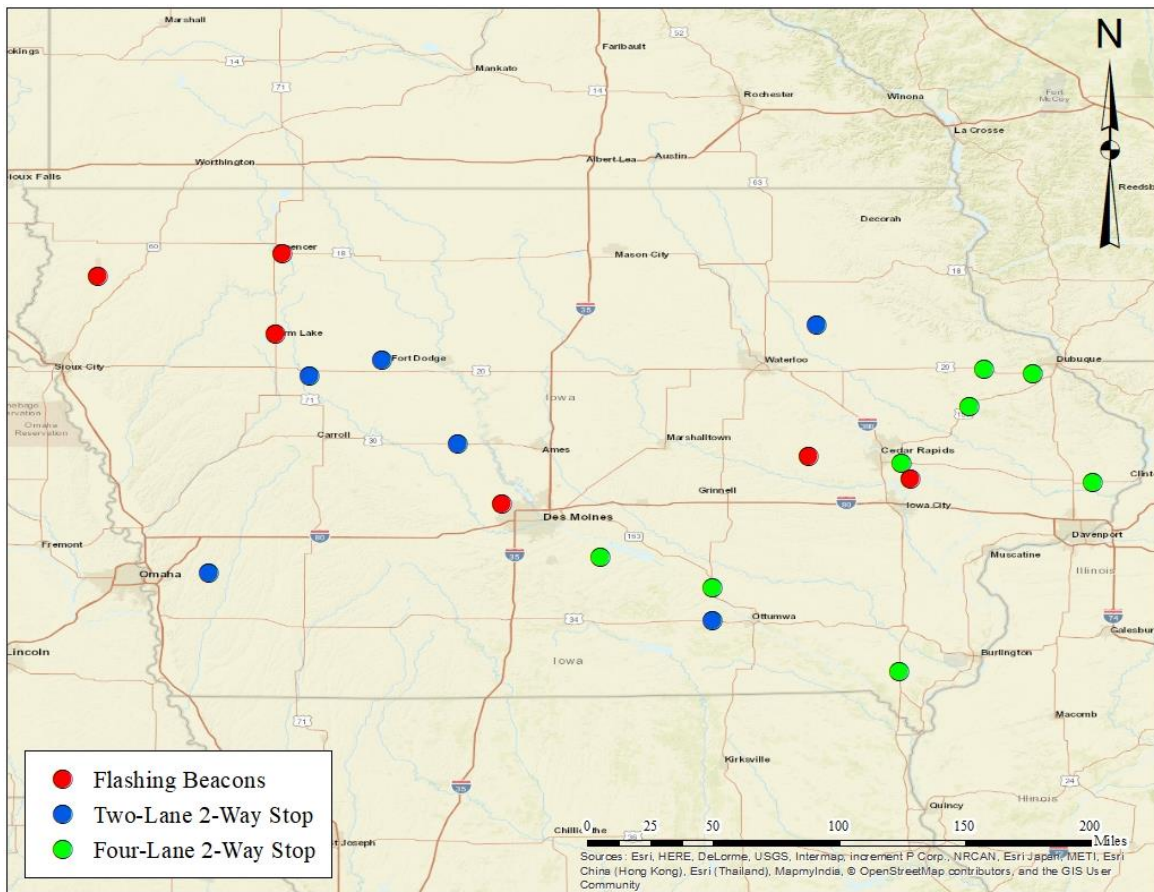
Configuration (speed limit in mph)	County	Coordinates	Installation Date
two-lane/two-lane 55/55	Washington	41.3808, -91.7155	10/5/2017
two-lane/two-lane 55/55	Fayette	42.714934, -92.038	10/5/2017
two-lane/two-lane 55/55	Monroe	41.016247, -92.639	10/5/2017
two-lane/two-lane 45/30	Calhoun	42.517, -94.54	10/5/2017
two-lane/two-lane 55/55	Pottawattamie	41.289, -95.537	10/5/2017
two-lane/two-lane 55/55	Sac	42.421, -94.954	10/5/2017
four-lane divided/two-lane 65/55	Clinton	41.815338, -90.451	10/6/2017
four-lane divided/two-lane 65/55	Dubuque	42.439922, -90.800	10/6/2017
four-lane divided/two-lane 65/55	Dubuque	42.466315, -91.077	10/6/2017
four-lane divided/two-lane 55/55	Lee	40.726023, -91.563	10/6/2017
four-lane divided/two-lane 54/40	Linn	41.925920, -91.555	10/6/2017
four-lane divided/two-lane 65/55	Jones	42.25, -91.161	10/6/2017
four-lane divided/two-lane 65/55	Mahaska	41.2050, -92.6401	10/6/2017
four-lane divided/two-lane 55/55	Marion	41.384, -93.28	10/6/2017

Table 2-2 shows the intersections selected for the stop sign beacons. All intersections had a 55 mph speed limit on both the major and minor approaches.

Table 2-2. Intersections receiving stop sign beacons

Configuration	Intersection	County	Coordinates	Installation Date
two-lane/two-lane	West approach of US 75 and 450th St	Sioux	42.997, -96.175	9/24/2017
two-lane/two-lane	East and west approach of 590th St and 130th Ave	Buena Vista	42.662, -95.152	9/24/2017
two-lane/two-lane	North and south approach of Lincoln Hwy & 21st Ave	Benton	41.963, -92.085	10/21/2016
two-lane/two-lane	West approach of Hwy 1 and 140th St	Johnson	41.831, -91.498	10/21/2016
two-lane/two-lane	North and south approach of 360th St and M-50	Clay	43.1262, -95.1125	10/6/2016
two-lane/two-lane	North and south approach of 240th St and W Ave	Dallas	41.688, -93.852	10/6/2016

The locations of these intersections are shown in Figure 2-1.



Green dots = two-way stops on four-lane divided roadways; Blue dots = two-way stops on undivided two-lane roadways; Red dots = flashing beacons

Figure 2-1. Location of treatment sites

3. DESCRIPTION OF TREATMENT AND INSTALLATION

Once final sites were selected, the team followed up with the corresponding agencies to confirm their participation. The installation process varied depending on the type of installment and is described in the section below.

3.1 Speed-Activated Stop Sign Beacons

Stop sign beacons were purchased from TAPCO. The particular configuration used in this study was purchased because it included a radar and the system could be set to only activate when an approaching vehicle's speed was over a predetermined threshold. This threshold was based on whether a vehicle would be likely to stop.

This configuration was selected to contrast actuated versus continuous beacon operation at rural intersections. The objective was to target vehicles that are not likely to stop, similar to a dynamic speed feedback sign, rather than to target all vehicles.

Formal authorization was requested before installation of the flashing beacons by submitting an application for approval of the traffic control to the Iowa DOT state traffic engineer. The application describes the details of the project and the operation of the control to be installed. A separate agreement had to be acquired for each intersection being treated.

Once approval was received, the team scheduled the installation of each beacon with the corresponding agency. Because installation was a rather involved process, assistance from the district technicians was necessary. The team coordinated with the district sign crew to meet with the team at the site location. Some locations were more challenging than others due to the varying conditions of the existing sign control at the intersections.

Typically, the sign crew removed the existing telespar pole and replace it with a longer pole to accommodate the beacon, radar, operation box, and solar panel. All items were installed on the same post positioned facing the lane of approaching traffic. An example of a sign installation is shown in Figure 3-1.



Raju Thapa, Institute for Transportation

Figure 3-1. Flashing beacon installation

After installation, the beacon was configured to flash when vehicles were approaching over a set threshold. The radar detected speeds approximately 350 to 400 ft before the stop sign. When a vehicle's speed was greater than 40 miles per hour from an approaching distance of 350 ft, the beacon would activate. When activated, the beacon flashed at a standard flashing rate for 9 seconds, allowing the driver to register and respond to the intersection ahead. The threshold of 40 mph was used based on calculations of normal stopping distance.

3.2 Retroreflective Strips on Stop Sign Posts

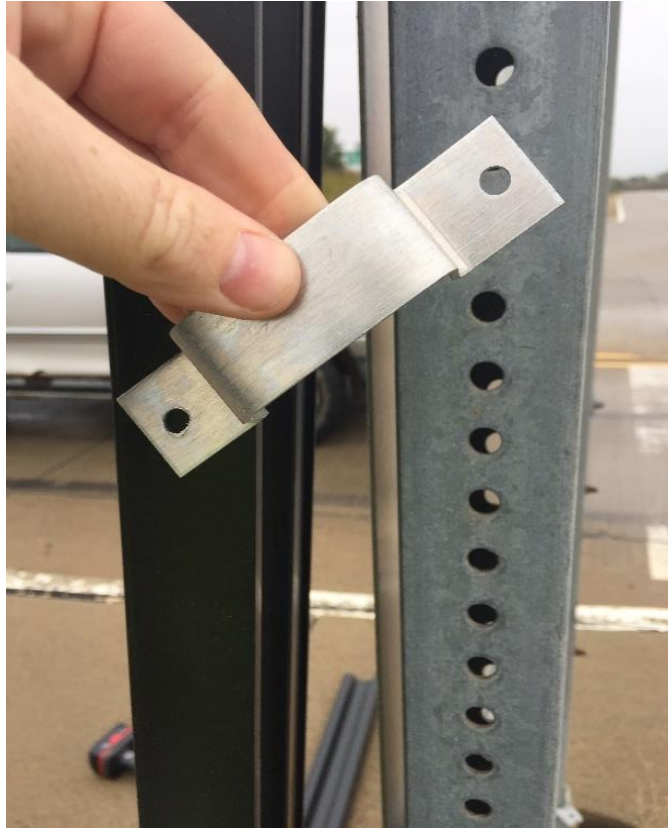
Retroreflective strips were added to the stop sign posts at selected intersection approaches. Sign posts and sign configurations varied. Most of the approaches along two-way/two-way roadways had a single wooden or single telespar post with a stop sign. At the approaches on four-lane divided highways, double telespar posts were present, and additional signs were placed along with the stop sign, as shown in Figure 3-2. This presented challenges because installation techniques had to vary due to differences in post configurations and sign placements.



Theresa Litteral, Institute for Transportation

Figure 3-2. Reflective strip installation at four-lane divided highways

The team also had to adapt due to inconsistencies between the design constraints of the retroreflective strips supplied by the manufacturer and the post sizes at each intersection. For telspar posts, the retroreflective strips were mounted by first drilling holes through the center of the strips and then attaching the strips to the posts with bolts, as shown in Figure 3-3.



Theresa Litteral, Institute for Transportation

Figure 3-3. Retroreflective strip installation on regular telspar posts

Several telspar posts were smaller than the standard post size. In this case, additional brackets were used, as shown in Figure 3-4.



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Figure 3-4. Retroreflective strip placement on smaller telespar post

When a single wooden post was present, the manufacturer-supplied brackets were used to install the strips (see Figure 3-5).



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Figure 3-5. Retroreflective strip installation on wooden post

There were additional challenges with installing the strips. In some cases, additional signs were present on the sign post that significantly shortened the distance between the sign and the top of the ground (see Figure 3-2).

In several cases, the strip could still be installed but was shortened to accommodate the additional signs. In at least one case, an attempt was made to affix the strip over the bottom existing signs, but ultimately it was determined that the countermeasure would not stay in place and the strip was removed (see Figure 3-6).



Theresa Litteral, Institute for Transportation

Figure 3-6. Installation not possible due to sign and spacing constraints

An view of the retroreflective countermeasure at night is shown in Figure 3-7.



Theresa Litteral, Institute for Transportation

Figure 3-7. Nighttime view of retroreflective strip

4. DATA COLLECTION AND REDUCTION

The ideal metric for the evaluation of safety impacts is an evaluation of crashes before and after installation. However, this requires several years of data after installation of the countermeasure, which was beyond the timeframe of this project. As a result, only driver behavior in the short term could be evaluated to assess the impacts of the countermeasures. Because the stop sign beacon only activates for vehicles traveling over a certain speed threshold, the countermeasure was expected to have a noticeable impact on stopping point, type of stop, and other characteristics. While the retroreflective strip increases sign conspicuity and ideally alerts a driver to the presence of the stop sign, it was not expected to impact driver behavior in a measurable way similar to the stop sign beacon. As a result, driver behavior data were only collected at locations where stop sign beacons were installed, and driver behavior, such as type of stop, was monitored before and after installation.

4.1 Data Collection

Portable data collection trailers with speed sensors and cameras were used for the data collection. A trailer array was set up at each approach where beacons were installed, as shown in Figure 4-1. This ensured coverage of some portion of the upstream approach as well as the intersection.



Institute for Transportation

Figure 4-1. Video data collection array

Figure 4-2 illustrates a schematic of the data collection setup.

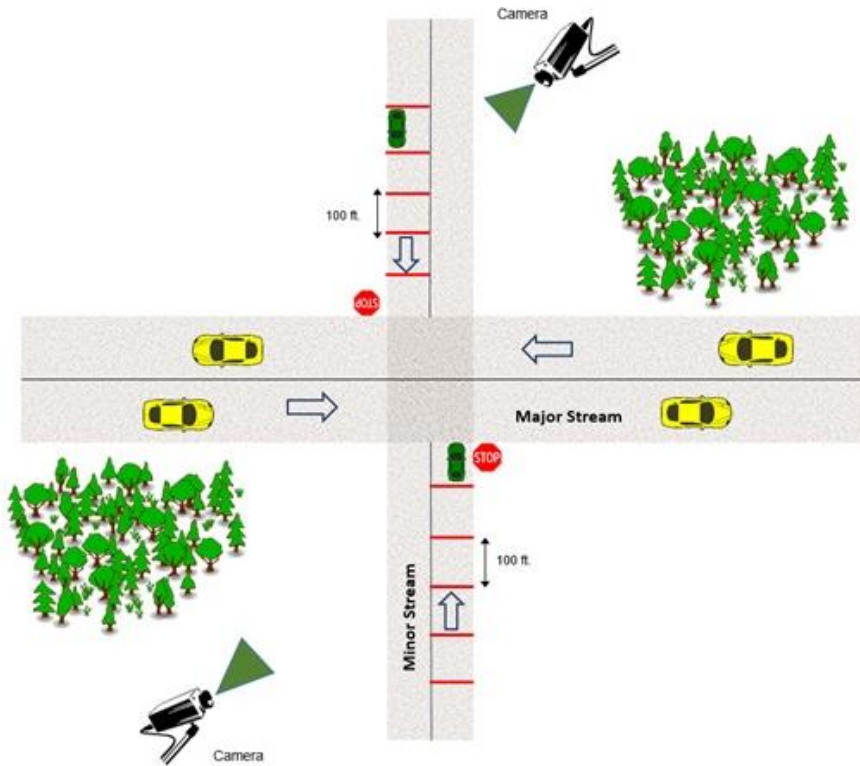


Figure 4-2. Video data collection setup

Video data were collected approximately one month before installation at all approaches where the flashing beacons were to be installed. Data were also collected at all 10 approaches around one month after installation of the stop sign beacons.

Beacons were installed at the Benton, Johnson, Clay and Dallas County intersections in 2016. For those intersections, data were also collected 12 months after installation, except for Clay County north. The intersection configuration at the Clay County north approach was characterized by a significant grade, which made it difficult to orient the cameras properly. Additionally, there were several issues with the beacon at that location. As a result, data were collected at 12 months after installation for the south approach at the Clay County intersection but not for the north approach. Because beacons were installed at the Buena Vista and Sioux County intersections in 2017, there was not sufficient time to collect data 12 months after installation. As a result, data were collected at only 6 intersection approaches for the 12-month after period.

Once the video data collection trailers were placed in the field, data were collected continuously for around one week during each period.

To accurately record the distance from each vehicle to the flashing beacon, white lines were painted on the pavement at 100 ft increments upstream of the intersection, as shown in Figure 4-3.



Figure 4-3. White lines marked in the field

These markings were placed for a distance of 500 ft upstream of the intersection stop bar. These markings were used as a reference in the video to approximate the point at which drivers began applying their brakes. The lines were then located in the video frame and marked (see Figure 4-4) so that they were clearly visible to the data reductionists.



Figure 4-4. Marks placed in video frame to ensure distances are visible to data reductionists

4.2 Data Reduction

Once data were collected for each intersection, a sampling of minor approach events, each of which consists of one driver negotiating the intersection from the minor approach where the treatment was installed, was manually reduced.

Table 4-1 shows the variables that were reduced for each event. Data were not coded during the nighttime or during inclement weather due to visibility issues.

Table 4-1. Variables extracted from video

Data Reduced	Summary
First Time Vehicle Appears in Video	The time a car appears in the video frame
Brake activation Time	The time at which the brake is applied before arriving at the intersection
Brake Activation Distance	Lines placed on the road at 100-meter increments
Number in Queue	Indicates if there is a queue formed at the intersection as a vehicle slows down and, if so, how many cars
Following	Shows if the vehicle being coded is following another vehicle
Number of Time Braking	How many times a driver brakes in the 500-meter area leading up to the intersection
Vehicle Stopped at Opposing Minor Road	Indicates if a vehicle is stopped at an opposing minor road
Vehicle Visible	How many vehicles are seen moving perpendicular to the intersection as a car approaches the stop sign
Turning Movement	Indicates the turning movement of the car approaching the intersection
Type of Stop	Choices are a complete stop, slow rolling, fast rolling, and nonstop
Stop Location	Before the stop bar, after the stop bar, or right at the stop bar are the options coded
Conflict	A description of any conflict that is observed while coding the vehicles
Beacon Status and Time	Whether the beacon is activated based on the approaching speed and the time this beacon is illuminated

Data were initially coded for every vehicle. The process of coding is described below for each variable. Variables were manually reduced by data coders. The coders were all trained and their work reviewed periodically to ensure that coding was consistent from one coder to another. After completing two intersections (Benton County north and Clay County north), the team realized that the process was more resource intensive than expected. As a result, it was decided to code a sample of vehicles rather than code all vehicles. The sampling plan consisted of coding every fourth vehicle, which represented a random sample of available vehicles.

Type of Vehicle

The type of vehicle was recorded using the following designations:

- Motorcycles
- Passenger cars
- Minivans/SUVs
- Pickups: single-unit vehicles with an open back with two axles and four tires
- Buses
- Farm vehicles: any vehicles that cannot be classified into any other category and that are used on a farm
- Single-unit trucks: vehicles on a single frame, including trucks, camping and recreational vehicles, motor homes, etc., with two axles and dual rear wheels
- Multi-unit trucks: vehicles with five or fewer axles consisting of two or more units

First Appearance

A time stamp was recorded for the first time a vehicle appears in the video (see Figure 4-5). The time stamp was noted as soon as the front of the vehicle was visible in the video. This was reduced so that the vehicle could be easily found later if needed.



Figure 4-5. First appearance of vehicle in video frame

Brake Activation Time

The time when a driver first applied the brake to decelerate a vehicle was noted as “brake activation time.” This was determined by noting the activation of the brake lights for the vehicle. An example of brake activation is shown in Figure 4-6.



Figure 4-6. Brake activation

Brake Activation Distance

The approximate distance from the intersection approach stop bar where a vehicle began braking was noted as “brake activation distance.” This was noted by estimating the vehicle location based on the 100 ft markings and assuming the vehicle stopped at the stop bar. As a result, this distance indicates the distance between the initial braking and the subsequent stopping at the intersection. If a vehicle was approximately midway between the second and third set of markings, the distance was recorded as 250 ft. Because the distance was estimated, it can be assumed that the distance was accurate to approximately 50 ft. If the vehicle did not visibly apply its brakes within the video frame, braking distance was reported as N/A. However, for this study the majority of drivers applied their brakes.

Number in Queue

The number in queue indicated the position of the subject vehicle in the queue as it approached and stopped at the intersection. Number in queue thus also indicated the number of vehicles ahead of the subject vehicle. If no vehicles were ahead of the subject vehicle, number in queue was noted as 0.

Following

Whether the subject vehicle was following another vehicle was also recorded because the braking behavior of the following car may be influenced by the lead car. Following was a subjective measure.

Beacon Status

The status of the flashing beacon was noted for vehicles only in the after period because the beacons were not present in the before period. Beacon status was noted as “active” or “not

active.” When activated, it was assumed that the subject vehicle (or surrounding vehicles) was traveling over 40 mph at the trigger point 350 ft upstream. If the beacon was active at any point while the subject vehicle was present within the video frame (Figure 4-7), beacon status was marked as “active.” If the beacon was activated at some point after the vehicle entered the frame, status was also marked as active.



Figure 4-7. Activated beacon in Dallas County

Number of Times Braking

The “number of times braking” variable indicated how many times a driver applied the brake before the vehicle came to a complete stop at the intersection. In some cases, drivers applied the brake two or three times before reaching the stop bar. Although it is not clear whether this is a positive behavior, it may indicate that drivers are paying attention well before they reach the stop bar, as opposed to drivers who brake immediately before the stop bar.

Stopped at Opposing Minor Road

This variable indicated whether a vehicle was present at the stop bar of the opposing minor road approach. There was a sense that when an opposing vehicle was present, drivers may have been more likely to come to a full stop because they were more likely to perceive the potential for a conflict. This variable was a dummy variable, with 0 indicating no vehicles at the on-coming approach and 1 indicating that a vehicle was present. The subject vehicle was coded as present the moment it became visible in the video frame so that the influence of the car at the opposing minor approach on the braking of the subject car could be noted.

Number of Vehicles Visible

This variable indicated the number of vehicles on the major road that would have been visible to the subject vehicle. It was expected that the subject driver’s decision to brake and stop would be

affected by the presence of on-coming vehicles on the major approach. The number of vehicles on the major approach was counted from the time the subject vehicle was 500 ft upstream of the intersection stop bar until the time the subject vehicle reached the stop bar.

Turning Movement

Turning movement indicated the direction of intended travel for the subject vehicle (i.e., left, through, right).

Type of Stop

The type of stop is identified as the extent to which a vehicle complied with the stop control. Type of stop was coded using the following criteria:

- Complete stop: The vehicle comes to a complete stop at the stop bar (velocity = 0 for at least an identifiable fraction of a second).
- Slow rolling: Clear braking is evident as the vehicle slows down, but at no point does the vehicle make a complete stop.
- Fast rolling: The vehicle is moving at a fast pace as it approaches the stop sign and the brake light is visible to indicate that the brake has been applied, but at no point does the vehicle make a complete stop. If no brake light were visible, the type of stop would be coded as a non-stop.
- Non-stop: There was no noticeable effort to slow and the vehicle does not stop at the stop sign.

Stop Location

This variable indicates where the vehicle stopped at the intersection based on the location of the front tip of the vehicle. The following designations were used:

- Before: The subject vehicle stops well before the stop bar. The subject vehicle should be at least a foot from stop bar for the stop location to be classified as “before.”
- At: The subject vehicle stops exactly at the stop bar but does not cross the stop bar line.
- After: The subject vehicle stops after crossing the stop bar.

Conflict

A conflict was defined as a near-crash or evasive maneuvers at the intersection involving at least one minor street vehicle. Conflicts included actions such as significant slowing, brake application, or lane changes of major stream vehicles due to the movement of minor stream vehicles. A near-crash was an event where vehicles nearly collided or made significant evasive maneuvers to avoid a collision.

Unlike other metrics, where a subset of vehicles was sampled, all video data were reviewed to identify conflicts. As a result, all evasive maneuvers that occurred during the daytime data collection period were recorded. Figure 4-8 shows an example of an evasive maneuver.



Figure 4-8. Example of conflict

No crashes were observed at any of the locations when data collection was in progress. Additionally, very few conflicts were recorded during any of the analysis periods. As a result, conflicts were not further evaluated as a measure of effectiveness.

Weather

To ensure that weather was not a factor affecting driver behavior, no data were reduced that involved nighttime or snow or rain conditions. As a result, all recorded events occurred in daytime conditions with dry pavement.

5. ANALYSIS AND RESULTS

The following section will show the results for each of the measures of effectiveness. In some cases, 12-month after data were not extracted, as noted in Section 4.1. In most cases, data are presented for each approach because sample sizes and intersection characteristics differed among intersection approaches.

5.1 Type of Stop

As noted in Section 4.2, the type of stop was reported as “full stop,” “slow rolling,” “fast rolling,” or “non-stop.” Results are presented as simple arithmetical differences in percentages between the before and after periods. For example, if the percentage of full stops was 33.9% in the before period and 41.8% in 1-month after period, the difference would be indicated as an increase in full stops of 7.8%.

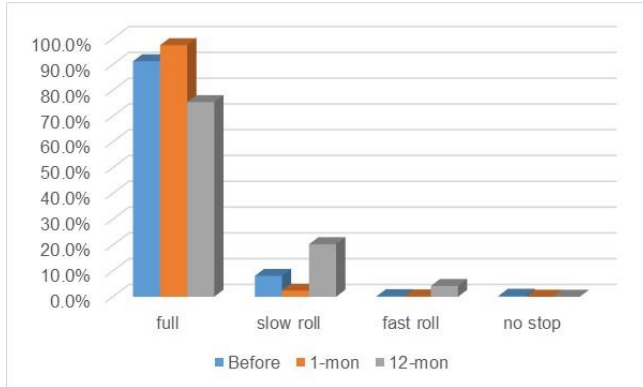
Summary of Results

In summary, 9 of the 10 approaches experienced an increase in the number of vehicles coming to a full stop, with an average increase of 13% at 1 month after installation. One approach experienced an increase of 26.2%. The percentage of vehicles that did not stop decreased at 5 of the 10 intersections. At 4 approaches, no vehicles were reported as not stopping in either the before or 1-month after periods; as a result, no change was observed. At one approach, an increase of 0.7% in vehicles not stopping was reported.

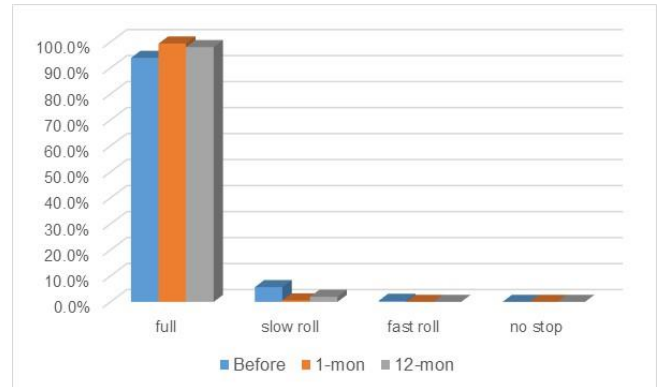
At 12 months after installation, all 6 approaches where data were available experienced increases in the number of vehicles coming to a full stop, with one site experiencing a 20.4% increase. One site (Benton County north) experienced a decrease of 15.9% in the percentage of vehicles coming to a full stop. Two intersections experienced decreases in the percentage of vehicles making a full stop (-1.2% and -0.4%, respectively). Five of the approaches had no instances of vehicles not stopping in both the before and 12-month after periods. As a result, no change was reported for these approaches.

Results by Individual Intersection

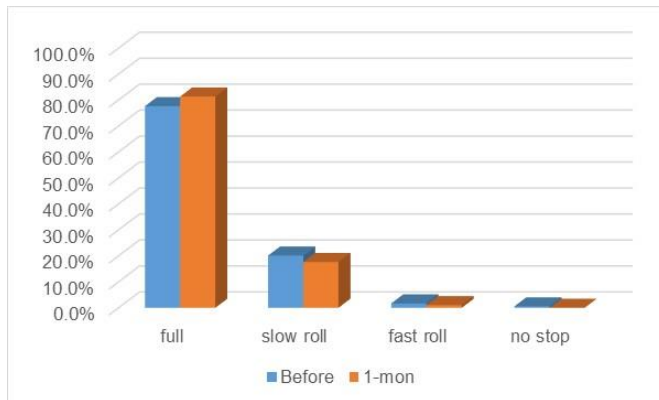
In this section, results are presented by individual intersection approach for the before, 1-month after, and 12-month after periods. Changes in type of stop for the north and south approaches of the intersection of Lincoln Highway and 21st Ave (Benton County) are shown in Figure 5-1.



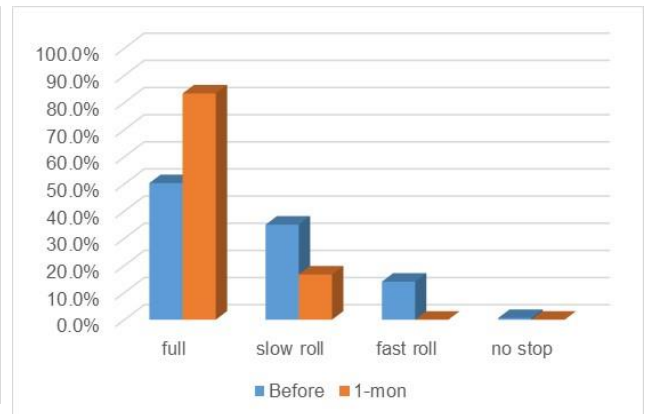
Benton North



Benton South



Buena Vista East



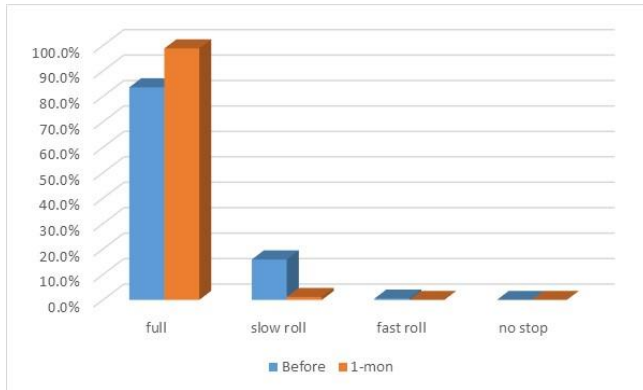
Buena Vista West

Figure 5-1. Changes in type of stop (Benton and Buena Vista Counties)

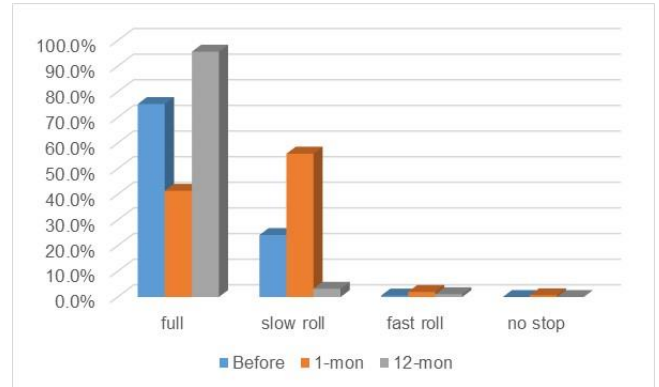
As Figure 5-1 shows, the percentage of vehicles coming to a full stop increased between the before and 1-month after periods at both Benton County locations, an increase of 6.2% for the north approach and 5.5% for the south approach. The percentage of vehicles that did not stop decreased from 0.4% to 0% for the north approach. At 12 months, the percentage of vehicles coming to a full stop increased by 4.2% for the south approach but decreased by 15.9% at the north approach. A decrease of 0.4% was observed in the number of non-stops for the north approach. At the south approach, no vehicles were recorded as engaging in a non-stop for any time period. As a result, no change was observed.

Changes in type of stop for the intersection of 130th Ave and 590th Street in Buena Vista County are also shown in Figure 5-1. The percentage of vehicles coming to a full stop increased by 3.7% at the east approach and 33.0% at the west approach at 1 month after installation. The percentage of vehicles that did not come to a stop decreased from 0.6% to 0% at both the east and west approaches. Data were not available for either approach at 12 months after installation.

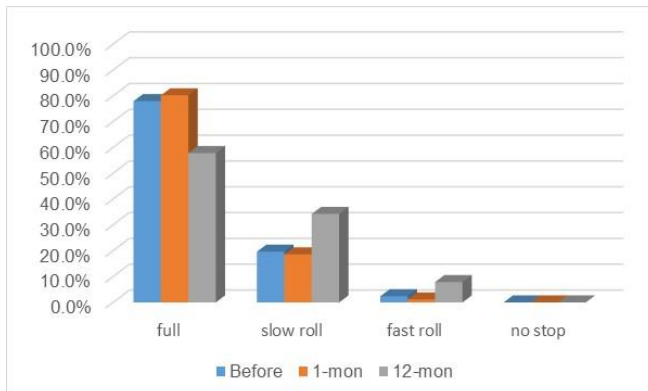
Results for the Clay and Dallas County approaches are shown in Figure 5-2.



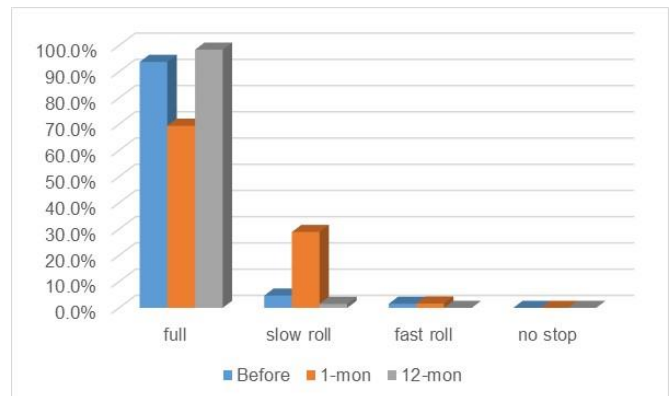
Clay North



Clay South



Dallas North



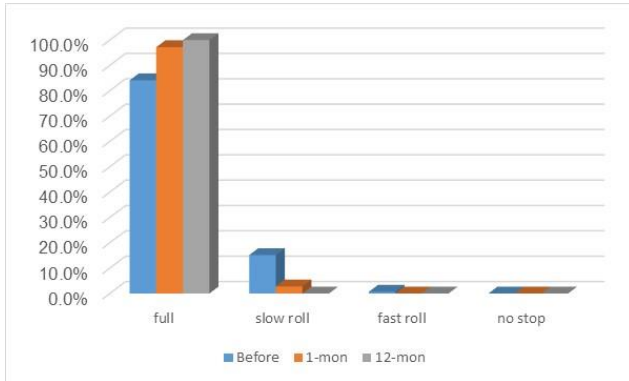
Dallas South

Figure 5-2. Changes in type of stop (Clay and Dallas Counties)

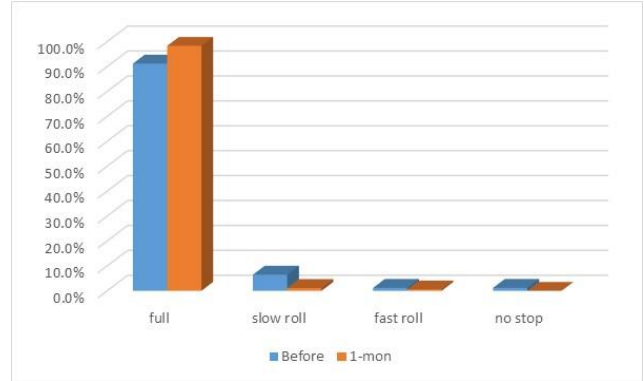
The north approach of intersection of W Ave and 240th Street (Dallas County) experienced an increase in the percentage of vehicles making a full stop (2.3%) at the 1-month after period but a decrease of 20.1% at the 12-month after period. The south approach experienced a decrease of 26.2% at the 1-month after period but an increase of 29.2% at the 12-month after period.

Neither of the Dallas County approaches experienced non-stops in the before period, and no change was observed for the 1-month or 12-month after periods.

Changes in type of stop for the west approach of the intersection of Hwy 1 and 140th St NE (Johnson County) and the west approach of the intersection of US 75 and 8th St SW (Sioux County) are shown in Figure 5-3.



Johnson West



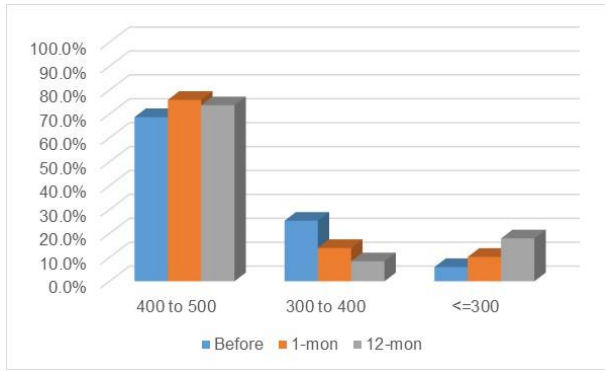
Sioux West

Figure 5-3. Changes in type of stop (Johnson and Sioux Counties)

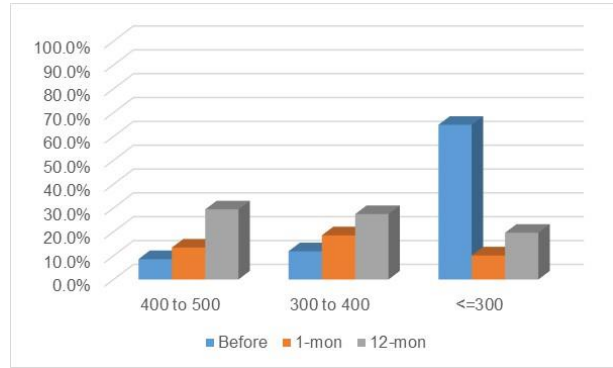
As Figure 5-3 shows, the percentage of vehicles coming to a full stop increased for the 1-month after period in both counties (13.1% and 7.1% for Johnson and Sioux Counties, respectively). The Johnson County site experienced a 15.9% increase in full stops for the 12-month after period. No vehicles were recorded as non-stops for Johnson County in the before period, and no change was noted in the after periods. At the Sioux County intersection, 1.2% of drivers did not stop in the before period, and no drivers were observed as not stopping in the after periods.

5.2 Point of Initial Braking

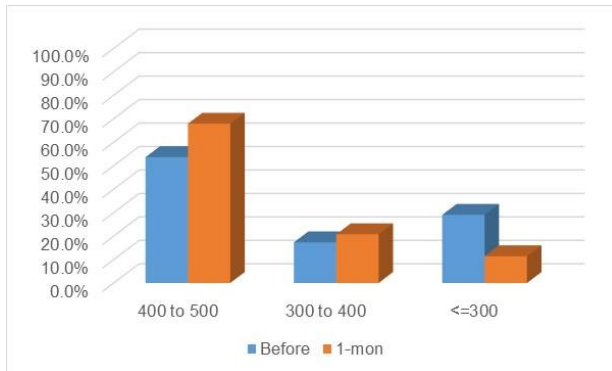
The point at which drivers initially began to brake was recorded, and results are provided in this section. Figures 5-4 to 5-6 show results by individual approaches, and information is provided as the percentage of vehicles that began braking within a specified distance.



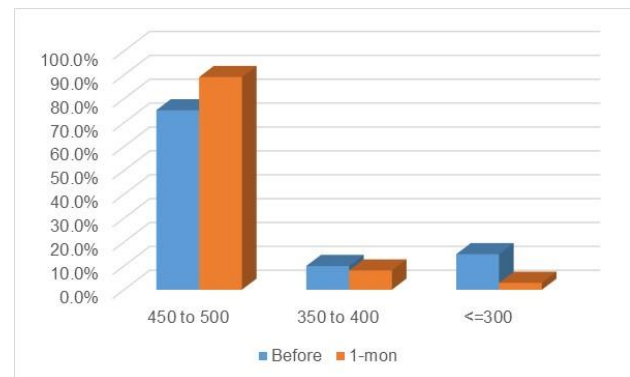
Benton North



Benton South

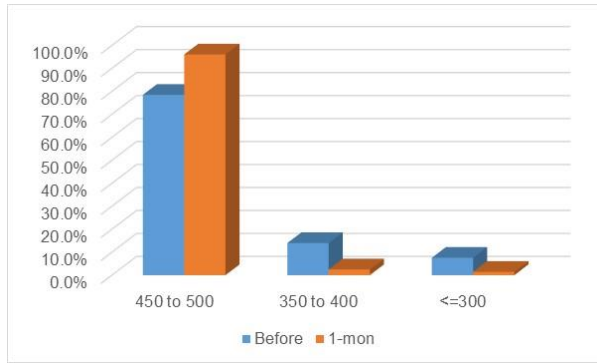


Buena Vista East

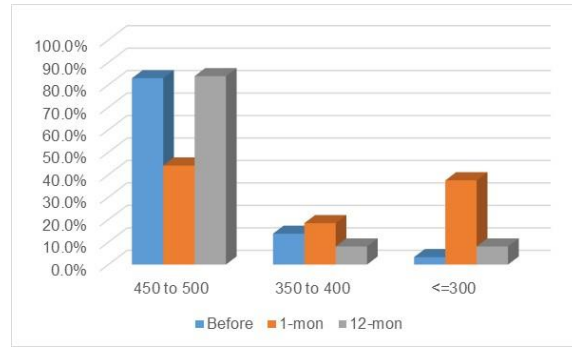


Buena Vista West

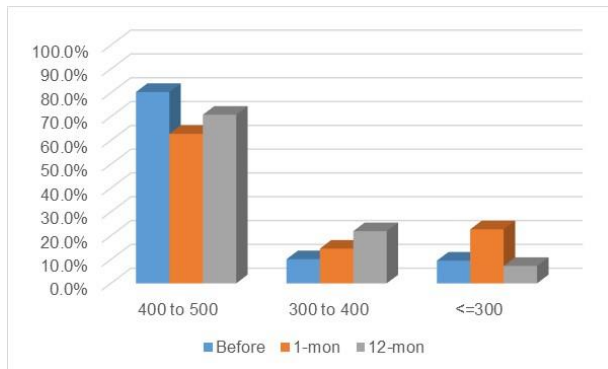
Figure 5-4. Changes in initial braking point (Benton and Buena Vista Counties)



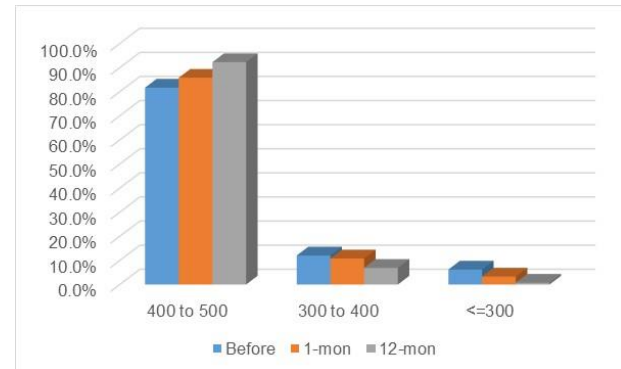
Clay North



Clay South

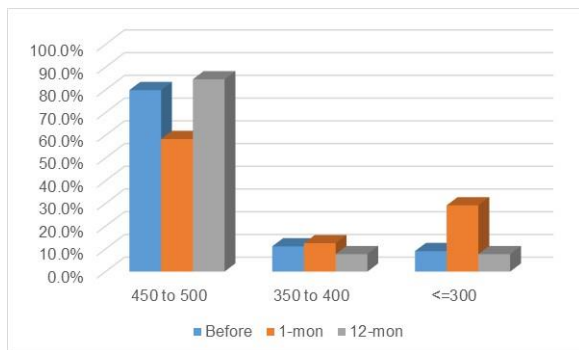


Dallas North

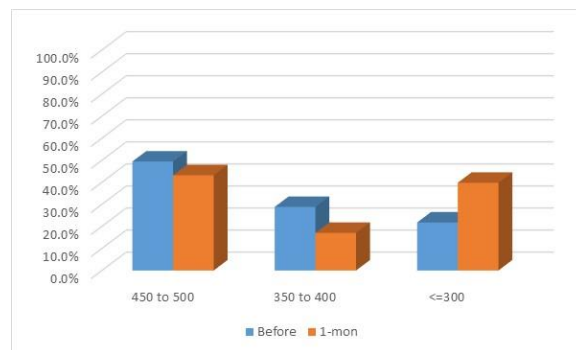


Dallas South

Figure 5-5. Changes in initial braking point (Clay and Dallas Counties)



Johnson West



Sioux West

Figure 5-6. Changes in type of stop (Johnson and Sioux Counties)

As noted in Chapter 4, the point of initial braking was the point at which drivers first applied their brakes. Distance was measured in 50 ft intervals from the intersection approach bar. In order to provide more a meaningful discussion, distance was aggregated into the following bins:

- 450 to 500 ft
- 350 to 400 ft
- Less than or equal to 300 ft

Stopping sight distance was calculated based on an approach speed of 55 to 60 mph using a standard deceleration value. Depending on the assumed coefficient of friction, stopping distance ranged from 300 to 350 ft. It was assumed that braking at 350 ft or more represented normal braking and that braking at a distance of less than 350 ft would result in harder braking. Although harder braking does not pose a safety risk in and of itself, it was assumed that drivers who began braking sooner were more likely to be aware of the upcoming intersection.

Summary of Results

Six of the 10 approaches where a stop sign beacon was installed experienced increases in the number of vehicles that initiated braking between 450 and 500 ft of the approach stop bar. An average increase of 10.3% was found at 1 month after installation. Four of the approaches experienced a decrease in the percentage of vehicles stopping between 450 and 500 ft, with an average decrease of 21.1%. At 12 months after installation, 5 of the 6 approaches evaluated experienced increases in the percentage of vehicles first braking at 450 to 500 ft upstream of the intersection, with an average increase of 8.4%, while one approach experienced a decrease (-9.6%).

Mixed results were found for the change in the percent of vehicles that first began braking within 300 ft of the intersection at 1 month after installation, with 5 of the 10 approaches experiencing a decrease (min = -2.9 and max = -54.8%) and 5 experiencing an increase (min = 4.2 and max = 34.2%). At 12 months after installation, 4 of the 6 intersections evaluated experienced a decrease in the percentage of vehicles stopping within 300 ft (min = -1.3% and max = -45.3%). Two of the 6 experienced an increase (min = 4.8% and max = 12.0%).

It was expected that vehicles would overall begin braking sooner when the beacon was present. Overall, the majority of approaches in the 1-month and 12-month after periods experienced an increase in vehicles that began braking early (450 to 500 ft) and a decrease in vehicles that first began braking within 300 ft of the intersection.

Results by Individual Intersection

Results are presented in Figures 5-4 to 5-6 by individual intersection approach for the periods before, 1 month after, and 12 months after installation.

At the Benton County north approach, the percentage of vehicles stopping within 450 to 500 ft of the intersection increased by 7.2% at 1 month and by 5.0% at 12 months after installation. At the south approach, the percentage increased by 4.8% at 1 month and by 20.8% at 12 months after installation.

The percentage of vehicles that first began braking within 300 ft of the intersection increased for Benton County north for both the 1-month and 12-month after periods (4.2% and 12.0%, respectively). The percentage significantly decreased for the Benton County south approach for both the 1-month and 12-month after periods (54.8% and 45.3%, respectively).

Similar results were found for both the east and west Buena Vista County approaches, with a 14.2% increase in the number of vehicles stopping between 450 and 500 ft at 1 month after installation for the east approach and a 13.9% increase for the west approach. The percentage of vehicles stopping within 300 ft decreased by 17.7% at 1 month after installation for the east approach and decreased by 12.0% for the west approach.

The Clay County north approach (see Figure 5-5) experienced a significant increase in the number of vehicles initially braking within the 450 to 500 ft range (17.6%) at 1 month after installation. The south approach experienced a decrease of 38.9% at 1 month after installation. However, at 12 months after installation the percentage of drivers braking within that distance increased slightly (by 0.9%) at the south approach. The percentage of drivers who initially began braking within 300 ft of the intersection declined for the north approach (-6.1%) at 1 month after installation, while this percentage increased for the south approach by 34.2% at 1 month and 4.8% at 12 months after installation.

The percentage of vehicles initially braking within 450 to 500 ft of the intersection decreased at the north approach of the Dallas County intersection by 17.6% and 9.6% for the 1-month and 12-month after periods, respectively. At the south approach, this percentage increased by 4.1% and 10.6% for the 1-month and 12-month after periods, respectively. Similarly, an increase in the percentage of vehicles initially braking within 300 ft of the intersection was noted for the north approach for the 1-month after period (13.2%), while a decrease was observed for the 12-month after period (-2.2%). At the south approach, decreases were noted for both the 1-month and 12-month after periods (-2.9 and -5.5%).

Changes in initial braking distance are shown in Figure 5-6 for the west approach of the Johnson County intersection and the west approach of the Sioux County intersection. As the figure shows, a mixed effect was observed in Johnson County, with a decrease in the percentage of vehicles stopping within 450 to 500 ft of the intersection at 1 month after installation (-21.5%) and an increase in this percentage at 12 months after installation (4.8%).

The percentage of vehicles initially braking between 450 and 500 ft of the intersection decreased at 1 month after installation (-6.2%) at the Sioux County intersection, while the number initially braking within 300 ft of the intersection increased (18.0%) in the same period.

5.3 Stopping Location

The point at which drivers stopped at the intersection approach was recorded. Stop location was initially coded as before, at, or after the intersection approach stop bar or as a non-stop when the vehicle did not clearly stop at any point. Data were aggregated to just two conditions that the team felt were the most meaningful:

- At: includes vehicles that stopped at or before the approach stop bar
- After: includes vehicles that stopped after the approach stop bar or did not stop

The percentage of vehicles that stopped after the stop bar is the inverse of the percentage that stopped before. For instance, at the Benton County north approach, the percentage of vehicles that stopped at the stop bar increased from 90.9% before installation of the beacon to 94.8% at 1 month after installation (an increase of 3.9%). Conversely, the percentage that stopped after the stop bar decreased from 9.1% before installation to 5.2% at 1 month after installation (a decrease of 3.9%).

It was assumed that drivers who came to a stop before the stop bar were better prepared to assess and scan on-coming traffic and react if needed. As a result, an improvement in the percentage of drivers stopping at or before the stop bar was treated as a positive safety benefit.

Only a summary of the results of stopping location is presented because presenting a table of changes in behavior is more concise than showing all information available. Table 5-1 shows the changes in the number of vehicles stopping at or before the stop bar for the 10 intersections where beacons were installed.

Table 5-1. Change in vehicles stopping at or before stop bar

	1 month after	12 months after
Benton County north	3.9%	-12.5%
Benton County south	5.6%	3.8%
Buena Vista County east	10.2%	NA
Buena Vista County west	3.9%	NA
Clay County south	-20.4%	9.4%
Clay County north	8.5%	NA
Dallas County north	3.7%	1.5%
Dallas County south	5.8%	11.7%
Johnson County west	0.0%	0.0%
Sioux County west	8.9%	NA

As Table 5-1 shows, 8 of the 10 approaches where data were collected experienced an increase in the percentage of vehicles stopping at or before the intersection approach stop bar at 1 month after installation of the flashing beacon. The average increase was 6.3% (min = 3.7% and max = 10.2%). At the west approach of the Johnson County intersection, all vehicles stopped at or before the stop bar before installation, and this trend continued at the 1-month and 12-month after periods. As a result, no change was noted for this approach. The percentage of vehicles stopping at or before the stop bar decreased at the south approach of the Clay County intersection in the 1-month after period (20.4%).

At 12 months after installation, 5 of the 6 approaches where data were recorded experienced an increase in the percentage of vehicles stopping at or before the stop bar. The average increase was 6.6%. No change was noted at the Johnson County west approach, and an increase was noted at the north approach of the Benton County intersection (12.5%).

Overall, it was felt that stop location improved in a positive manner, with most of the sites experiencing an increase in the percentage of vehicles stopping near the stop bar after installation.

5.4 Number of Times Braking

The number of times the brake lights were activated for each vehicle was also extracted. It is not known whether braking behavior impacts safety. However, the premise for collecting this information is that drivers who brake multiple times may not be prepared for the upcoming intersection. As a result, the number of times vehicles only had one braking event was compared to the number of times vehicles had multiple braking events. The difference in the percentage of vehicles braking once is shown in Table 5-2.

Table 5-2. Percentage of vehicles only braking once

	1 month after	12 months after
Benton County north	-24.1%	0.3%
Benton County south	5.2%	3.4%
Buena Vista County east	-14.2%	NA
Buena Vista County west	7.3%	NA
Clay County south	13.7%	51.7%
Clay County north	11.7%	NA
Dallas County north	25.5%	16.6%
Dallas County south	-26.2%	29.2%
Johnson County west	12.3%	24.8%
Sioux County west	-3.9%	NA

As Table 5-2 shows, at 1 month after installation 6 of the 10 approaches experienced an increase in the number of vehicles that only braked once, with an average increase of 12.6%. Four of the 10 experienced a decrease in the percentage of vehicles that only had one braking event.

At 12 months after installation, all six approaches where data were collected experienced an increase in the percentage of vehicles that braked only once, with an average increase of 21.0%.

Overall, the number of vehicles braking only once increased at the majority of the intersection approaches at 1 month after installation, and all approaches where data were collected at 12 months after installation experienced an increase in the number of vehicles braking only once. As a result, it can be inferred that the presence of the beacons had a positive impact on braking behavior.

6. CONCLUSIONS

Overall, the stop sign-mounted beacon had an overwhelmingly positive safety benefit, as measured by several changes in driver behavior. At the majority of approaches where the stop sign beacon was installed, an increase in the following was observed:

- Full stops
- Number of drivers who first began braking within 450 to 500 ft
- Vehicles stopping at or before the stop bar
- Number of vehicles only braking once

Ideally, these improvements in driver behavior will result in reduced crashes at the study intersections. The cost of each stop sign beacon was approximately \$3,000, and they require regular maintenance. Overall, they were found to be a reasonably low-cost countermeasure. There were some concerns from participating agencies that having the beacon only activate at a set speed threshold rather than continuously may be confusing to drivers. However, studies of other dynamic countermeasures that only present a message to drivers who are speeding have been widely used and have been shown to be very effective (Hallmark et al. 2015, Zineddin et al. 2015, Fitzsimmons et al. 2007).

The stop sign beacon differed from common beacon applications in that it was set to activate only when a vehicle was traveling 40 mph or more at a set point upstream of the intersection approach stop bar. In this situation, only those drivers who were less likely to stop were provided the flashing beacon. The objective was to only target “problem” drivers because drivers may become habituated to countermeasures that they observe regularly.

Overall it was felt that use of the targeted approach was effective. This type of system, however, does require a radar or other speed sensor, which adds an additional expense on top of the cost of the regular beacon setup. (The cost above includes the cost of the radar with the flashing beacon.)

The addition of retroreflective strips on stop sign posts is expected to increase sign conspicuity, particularly at night, which will ideally result in a reduction in crashes. However, reduction of nighttime video is challenging, and the countermeasure was not expected to have a measurable impact on driving behaviors such as braking point. As a result, video data were not collected at locations where this countermeasure was installed. The intent is therefore to conduct a crash analysis when at least three years have elapsed after installation of the countermeasure.

7. IMPLEMENTATION/TECHNOLOGY TRANSFER

The main venue for Iowa cities and counties to access the results of this research will be through updates to a current Synthesis of Safety-Related Research webpage. This webpage lists a number of countermeasures for rural intersections and provides a comprehensive resource. Integration of the results from this research will add Iowa-specific information about the treatments evaluated in this project so that agencies can apply the results.

Additionally, the research team will work with the Iowa Local Technical Assistance Program to disseminate the results to Iowa agencies.

The main benefit of this work is that the results are “shovel-ready.” Using the provided background and results, agencies can make a determination about their use of the stop sign beacon.

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