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# Evaluation of Driver Behavior in Response to Stop Sign Beacons

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## Abstract

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. Stop sign beacons are one such low-cost measure. This paper discusses results of research which evaluated stop sign beacons. Stop sign beacons were installed at 10 stop-controlled approaches in the US state of Iowa. The beacons were set to activate only when an approaching driver was traveling over a set speed threshold which was set based on whether a driver would be able to stop. Video data were collected before, at 1-month, and at 12-month after installation. Type of stop (*i.e.*, rolling, no-stop), stop location in reference to the stop bar, and location of initial brake application were reduced from the video data. The percentage of drivers who began braking before or after 350 feet were compared. This threshold indicates the point at which drivers would need to engage in hard braking based on approach speed and stopping sight distance. At one month, 6 of the 9 intersections experienced an increase in the percentage of vehicles braking at 350 feet or before. At 12-month, drivers at more than half of the approaches were braking sooner than the before period. Results also indicate stopping behavior improved after installation of the beacons. Most of the approaches (70%) showed an increase in the percentage of drivers who came to a full stop at 1-month compared to the period before installation. At 12-month, 71% of approaches showed an increase in drivers who came to a complete stop. Similar results were found for stopping location. Around 80% of approaches experienced an increase in the percentage of vehicle that stopped at or before the stop bar at the 1-month period after installation and 86% of approaches had an increase at 12-month.

**Keywords**

Stop-Sign Mounted Beacons, Safety Analysis, Stopping Behavior, Rural Intersection, Countermeasures

# 1. Introduction

## 1.1. Background

Rural intersections account for around 30% of crashes in rural areas and 6% of all fatal crashes [1], representing a significant but poorly understood safety problem. Inappropriate gap selection has been found to be a major contributing cause of crashes at rural intersections. For example, inappropriate gap selection accounts for 56% of right-angle crashes at rural Minnesota thru-stop intersections [2] [3]. Right-angle collisions, the result of drivers selecting a gap that is too small or failing to observe traffic control, account for between 36% to 50% of crashes at intersections on high-speed divided highways, while such collisions account for only 28% of crashes at intersections on other types of roads [4].

Drivers failing to stop on the minor approach account for 25% of right-angle crashes [3]. Retting *et al.* [5] found that when a crash occurs at a stop sign, those where drivers failed to stop were more likely to result in injuries than crashes where drivers stopped. Characteristics correlated to failure to yield right of way include age [6] [7], speeding, vision obstruction, and inattention/distraction [8]. Speed is a particular issue in rural settings due to long distances between intersections or towns which may lead to drivers not paying attention when they approach rural intersections [9].

To enhance rural intersection safety, various countermeasures have been used at approaches of stop-controlled intersections. These include double stop signs, traverse rumble strips, overhead flashing beacons, on-pavement marking, lighting, stop sign beacons, LED lights embedded in STOP signs, and Intersection Conflict Warning Systems.

Overhead flashing beacons have been widely used to warn approaching drivers of either the need to stop (Flashing RED) on stop-controlled approaches or as a warning (Flashing YELLOW) for uncontrolled approaches. They have generally shown to be effective with reductions in crashes up to 43% reported [10] [11] [12] [13]. However, some concerns have been raised about whether drivers understand the flashing yellow/red lights. For instance, a yellow indication normally indicates a clearance interval, which may be confusing to drivers. Stackhouse and Cassidy [11] conducted a driver opinion survey (n = 144 drivers) about overhead beacons. Approximately one-half of older drivers (65+) and 42% of younger drivers (18 to 35 years old) stated some confusion about what the beacon meant. Additionally, because overhead flashing beacons are continuously activated, regular drivers may become acclimated to their presence and begin to ignore them. As a result, many agencies are replacing existing overhead beacons with stop sign mounted beacons. An assessment of the effectiveness of stop sign beacons was therefore the focus of this study.

Although stop sign beacons are increasingly being used as a safety countermeasure, only a few studies have evaluated their effectiveness. Srinivasan *et al.* [13] conducted a before and after empirical Bayes analysis of stop sign mounted beacons in North Carolina and South Carolina. They found a 58.2% reduction in angle crashes. However only five sites were represented. Brewer and Fitzpatrick [10] 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. Goswamy *et al.* [14] conducted a cross-sectional analysis to assess the impact of stop-sign mounted beacons at rural intersections in Iowa (USA). A total of 40 treatment and 40 control intersections were included in the analysis. Negative binomial models for different injury combinations for nighttime and daytime crashes were developed. Presence of stop-sign mounted beacons was associated with a 5% - 54% reduction in nighttime crashes. Injury nighttime crashes decreased by 54% and total nighttime crashes reduced by 18%. A cross-sectional analysis was utilized since installation dates could not be confirmed in order to conduct a before and after analysis.

### 1.2. Need for Research and Objectives

As noted above, many agencies are moving towards use of stop sign beacons rather than overhead beacons to reduce crashes at rural intersections. Additionally stop sign beacons are widely used to address intersections where failure to yield is problematic. Some evidence is available that suggests stop sign beacons are effective, but the results are based on just a few intersections. Although considered a low-cost countermeasure, the treatment costs up to $3000 (USD) or more per installation. Although low cost, the countermeasures still require maintenance and as a result it is important for agencies to have reliable information about their effectiveness before investments are made. Additionally, most stop sign mounted beacons flash continuously which provides the same information to all drivers and may become less effective over time once drivers acclimate. As a result, more information is necessary about the effectiveness of the treatment when the beacons are set to activate at a particular speed threshold.

The main objective of this study was to evaluate the effectiveness of stop sign beacons. The study in particular focused on stop sign beacons which were set to activate only when a driver was traveling over a set speed threshold and was unlikely to stop as shown in **Figure 1**.


**Figure 1.** Flashing beacon installation.

This study evaluated stop sign mounted beacons at 10 rural intersection approaches in Iowa. Due to the short study time frame (<3 years) of the study and scope of the study, a before and after crash analysis could not be conducted. Additionally, collection of data sufficient to conduct a robust analysis [15] was beyond the scope of the project. Surrogate measures were used to assess effectiveness. These included gap acceptance, stopping behavior, and braking behavior.

## 2. Site Selection and Installation

The study was conducted in Iowa which is a state located in the Midwest section of the United States. The Iowa Department of Transportation (DOT) maintains an intersection database which was overlain with crash data for a 5-year period and rural intersections with minor street control which had experienced 9 or more crashes were further investigated. Intersection characteristics, such as surface type, number of approaches, etc. were collected using aerial imagery and Google Street view. Locations with more than 4 approaches were excluded as were locations with other countermeasures (*i.e.*, transverse rumble strips, overhead beacons) and locations with unusual configurations (*i.e.*, significant skew). Locations with lower volumes were further discarded since it would have been difficult to collect data with low traffic volumes. Locations were also screened for their suitability for the application of stop sign treatments. Further only paved approaches were included. 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. A list of intersections that met the screening criteria was developed and the team contacted the corresponding agency (*i.e.*, county) to determine their interest in participating.

Final locations and characteristics are shown in Table 1. Resources were available to install 10 stop sign beacons. As shown, ten approaches at six intersections were selected for installation of the stop sign beacons. Beacons were installed at both stop controlled approaches at 4 of the intersections while they were installed at only one approach for 2 other intersections. In these cases, the remaining stop-controlled approach was not paved or that approach was not conducive to installation of a beacon.

Stop sign beacons were purchased from TAPCO. Many stop sign beacons continuously flash. There is some thought that regular drivers may become acclimated to a beacon that is continuously flashing thus rendering the countermeasure less effective. The particular configuration evaluated included radar so 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 targets vehicles that are not likely to stop, similar to a dynamic speed feedback sign, rather than targeting all vehicles.

An example of a sign installation is shown in Figure 1 above. The radar detected speeds approximately 350 to 400 feet before the stop sign. When a vehicle's speed was greater than 40 miles per hour from an approaching distance of 350 feet, the beacon was set to 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. Data Collection and Reduction

### 3.1. Data Collection

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

**Table 1.** Intersections receiving stop sign beacons.

| Configuration | Intersection | County | Installation Date |
|---|---|---|---|
| two-lane/two-lane | West approach of US 75 and 450th St | Sioux | 9/24/2017 |
| two-lane/two-lane | East and west approach of 590th St and 130th Ave | Buena Vista | 9/24/2017 |
| two-lane/two-lane | North and south approach of Lincoln Hwy & 21st Ave | Benton | 10/21/2016 |
| two-lane/two-lane | West approach of Hwy 1 and 140th St | Johnson | 10/21/2016 |
| two-lane/two-lane | North and south approach of 360th St and M-50 | Clay | 10/6/2016 |
| two-lane/two-lane | North and south approach of 240th St and W Ave | Dallas | 10/6/2016 |

installation of the countermeasure, which was beyond the timeframe and scope of this project. As a result, only surrogate measures of safety, such as stopping behavior, were evaluated.

Portable data collection trailers with speed sensors and cameras were used for data collection. A trailer array was set up at each approach where beacons were installed, as shown in **Figure 2**. This ensured coverage of some portion of the upstream approach as well as the intersection. 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 resulted in making 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.

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

**Figure 2.** Video view of intersection.

located in the video frame and marked so that they were clearly visible to the data reductionists.

### 3.2. Data Reduction

Once data were collected for each intersection, a sampling of events, each of which consists of one driver negotiating the intersection from the minor approach where the stop sign beacon was installed, was manually reduced. Data reduction elements include:

- Type of vehicle
- Location of first brake activation (within 100-foot intervals)
- Presence of vehicle on opposing or perpendicular approach
- Turning movement
- Type of stop (full, slow rolling, fast-rolling, no-stop)
- Beacon status (whether beacon activated for particular driver for after period)
- Stop location (before the stop bar, after the stop bar, or right at the stop bar are the options coded

A random sample of vehicles were selected and coded for each time period. 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.

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.

Stopping location was also coded. 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.

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.

## 4. Analysis and Results

The following section shows the results for each of the measures of effectiveness used to evaluate the beacons. Section 4.1 summarizes results for initial braking. Section 4.2 discusses results for type of stop. Section 4.3 reviews stopping location.

The analyses present results comparing 1-month after installation to the before period and results at 12-month after installation to the before period. It should be noted that on some cases, 12-month after data were not available as noted in Section 2. 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%. Statistical significance was determined using a test of proportions.

### 4.1. Point of Initial Braking

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. Stopping sight distance was calculated based on an approach speed of 55 to 60 mph using a standard deceleration value of 11.2 ft/sec$^2$. Depending on the assumed coefficient of friction, stopping distance ranged from 300 to 350 ft. Stopping sight distance is given by:

$$SSD = Vt + V^2 / [2g/a]$$

where:

$SSD$ = stopping sight distance

$V$ = speed

$t$ = perception/reaction time

$a$ = deceleration rate

$g$ = gravity

It was assumed that braking at 350 ft or more (as measured from the intersection stop bar) 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.

The changes in percent of vehicles that began braking 350 or more feet before the intersection are presented in **Table 2**. Statistical significance was evaluated using a test of proportions. As noted, at six of the ten approaches, the percent of vehicles that began braking more than 350 feet upstream of the stop sign increased at the 1-month after interval. The percent decrease was calculated by diving number of vehicles braking before 350 feet by all vehicles. The change was a simple arithmetic difference. For instance, the difference between 1-month and before at the Benton North site was 94 - 90 (4%). The increases ranged from 3%

**Table 2.** Point of initial braking.

| | Before % | 1-Mon % | 1-Mon Change | 12-Mon % | 12-Mon Change |
|---|---|---|---|---|---|
| Benton N | 94% | 90% | −4%* | 82% | −12%* |
| Benton S | 26% | 83% | 57%* | 65% | 39%* |
| Buena Vista E | 71% | 89% | 18%* | | |
| Buena Vista W | 85% | 97% | 12%* | | |
| Clay S | 97% | 63% | −34%* | 92% | −5% |
| Clay N | 92% | 99% | 6%* | | |
| Dallas N | 90% | 77% | −13%* | 93% | 2% |
| Dallas S | 94% | 97% | 3% | 99% | 5%* |
| Johnson | 91% | 71% | −20%* | 92% | 1% |
| Sioux W | 78% | 90% | 12% | 52% | −26%* |

*statistically significant at the 95% level of significance.

to 57%. At four of the approaches the percentage of vehicles braking more than 350 feet upstream decreased (5% to 20%). Data were only available for 7 approaches for the 12-month after period with 4 experiencing increases in the percent of vehicles braking for the first time 350 or more feet upstream (1% to 39%). Decreases were noted for 3 approaches (5% to 26%).

### 4.2. Type of Stop

Type of stop was reported as "full stop", "slow rolling", "fast rolling", or "non-stop". Due to low sample size, fast rolling and no-stop were combined. As a result, results are shown for full stop, rolling stop, and fast/no-stop are presented in Table 3. For simplicity, changes are discussed only for full stop. The percentage of vehicles stopping was calculated by dividing by the number of vehicles coming to a full stop divided by the total number of vehicles observed.

In summary, 8 of the 10 approaches experienced an increase in the number of vehicles coming to a full stop at the 1-month after period. Five approaches had increases from 2% to 9%. The Clay North approach had an increase in the percentage of vehicles stopping of 15% while the percentage of full stops at Buena Vista West approach increased by 33%. Two approaches had decreases in the percentage of vehicles coming to a full stop. Clay South had a 34% decrease while Dallas South had 24% decrease in full stops.

At 12 months after installation, all 5 approaches where data were available experienced increases in the number of vehicles coming to a full stop, with one site experiencing a 20% increase. One site (Benton County north) experienced a decrease of 16% in the percentage of vehicles coming to a full stop and Dallas North had a decrease of 20%.

**Table 3.** Changes in stopping behavior.

| | | Before | 1-Mon | 1-Mon Change | 12-Mon | 12-Mon Change |
|---|---|---|---|---|---|---|
| Benton North | full | 91% | 98% | 6%* | 75% | −16%* |
| | slow roll | 8% | 2% | −6% | 20% | 12% |
| | fast/no stop | 1% | 0% | 0% | 4% | 4%* |
| Benton South | full | 94% | 99% | 6%* | 98% | 4%* |
| | slow roll | 6% | 1% | −5% | 2% | −4% |
| | fast/no stop | 0% | 0% | 0% | 0% | 0% |
| BV East | full | 78% | 81% | 4% | NA | NA |
| | slow roll | 20% | 18% | −2% | NA | NA |
| | fast/no stop | 2% | 1% | −1% | NA | NA |
| Buena Vista West | full | 50% | 83% | 33%* | NA | NA |
| | slow roll | 35% | 17% | −18% | NA | NA |
| | fast/no stop | 15% | 0% | −15% | NA | NA |
| Clay South | full | 75% | 41% | −34%* | 96% | 20%* |
| | slow roll | 24% | 56% | 32% | 3% | −21% |
| | fast/no stop | 1% | 3% | 2% | 1% | 1% |
| Clay North | full | 84% | 99% | 15%* | NA | NA |
| | slow roll | 16% | 1% | −15% | NA | NA |
| | fast/no stop | 1% | 0% | −1%* | NA | NA |
| Dallas North | full | 78% | 80% | 2% | 58% | −20%* |
| | slow roll | 20% | 19% | −1% | 34% | 15% |
| | fast/no stop | 2% | 1% | −1% | 8% | 5% |
| Dallas S | full | 94% | 69% | −24%* | 98% | 5%* |
| | slow roll | 5% | 29% | 24% | 2% | −3% |
| | fast/no stop | 2% | 2% | 0% | 0% | −2% |
| Johnson | full | 84% | 97% | 13%* | 100% | 16% |
| | slow roll | 15% | 3% | −12% | 0% | −15% |
| | fast/no stop | 1% | 0% | −1% | 0% | −1% |
| Sioux West | full | 91% | 100% | 9% | 98% | 7%* |
| | slow roll | 6% | 0% | −6% | 1% | −5% |
| | fast/no stop | 2% | 0% | −2% | 1% | −2% |

## 4.3. 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 as described in Section 3.2. Data were aggregated to just two conditions that the team felt was 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.

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 91% before installation of the beacon to 95% at 1 month after installation (an increase of 4%). Conversely, the percentage that stopped after the stop bar decreased from 9% before installation to 5% at 1 month after installation (a decrease of 4%).

Table 4 shows the changes in the number of vehicles stopping at or before the stop bar for the 10 intersections where beacons were installed. At the one-month period after installation, eight approaches had an increase in the percent that stopped at or before the stop bar. These increases ranged from 4% to 10%. The Johnson West approach had 100% compliance in stopping at/before the stop bar before installation with no change at 1-month. One location (Clay South) had a decrease of 20% in the percent of vehicles stopping at or before the stop bar.

At the 12-month after interval, five of the six approaches where data were available had increases in the percent of vehicles stopping/at before the stop bar. The increases ranged from 2% to 12%. One location (Benton North) had a decrease in the number of vehicles stopping at/before the stop bar (12%).

**Table 4.** Change in vehicles stopping at or before stop bar.

| | Before | 1-mon | 1-Mon Change | 12-mon | 12-Mon Change |
|---|---|---|---|---|---|
| Benton N | 91% | 95% | 4%* | 78% | −12%* |
| Benton S | 94% | 100% | 6%* | 98% | 4% |
| Buena Vista E | 88% | 98% | 10%* | NA | NA |
| Buena Vista W | 96% | 99% | 4% | NA | NA |
| Clay S | 90% | 70% | −20%* | 99% | 9%* |
| Clay N | 92% | 100% | 8%* | NA | NA |
| Dallas N | 93% | 97% | 4% | 94% | 2% |
| Dallas S | 87% | 93% | 6% | 98% | 12%* |
| Johnson W | 100% | 100% | 0% | NA | NA |
| Sioux W | 90% | 100% | 10% | 99% | 9%* |

## 5. Conclusions

This study evaluated the impact of stop sign beacons on driver behavior. Stop sign beacons were installed at 10 stop-controlled approaches in the US state of Iowa. The stop sign beacon utilized 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 presented with the flashing beacon. The objective was to only target "problem" drivers because drivers may become habituated to countermeasures that they observe regularly.

Video data were collected before, at 1-month, and at 12-month after installation. Type of stop (*i.e.*, rolling, no-stop), stop location in reference to the stop bar, and location of initial brake application were reduced from the video data.

Overall, the stop sign-mounted beacons 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 at 350 feet or greater before the intersection
- Vehicles stopping at or before the stop bar

The cost of each stop sign beacon was approximately $3000, and they require regular maintenance. Overall, they were found to be a reasonably low-cost countermeasure.

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## Conflicts of Interest

The authors report there are no competing interests to declare.

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