ODOT Library
555 13th Street NE
Salem, OR 97301
(503) 986-3280
laura.e.wilt@odot.state.or.us

LITERATURE REVIEW
Flashing LED Stop Signs

February, 2023

Much research has been done to reduce the number of crashes at stop-controlled intersections. These intersections see substantially fewer crashes than signalized intersections, but overall, more fatalities occur at the stop-controlled intersections (Bryer, 2011). In the US, approximately 8,000 intersection and intersection-related fatalities occurred in 2015 alone, accounting for around 24% of all traffic-related deaths across the country. Unsignalized intersections were responsible for more than 70% of the intersection and intersection-related deaths between 2010 and 2014 (Medina, Gibbons 2020).

The most common type of crash occurring at stop-controlled intersections is a 2-vehicle right angle crash between a vehicle on the stop approach and a vehicle on the through approach (Bryer, 2011). These accidents are generally caused by vehicles running a stop sign or pulling out without a safe gap in the oncoming traffic (Arnold, Lantz 2007, Davis, Hourdes, Xiong 2014). These actions can be unintentional, due to improper perception of the sign, or they can be deliberate violations with drivers intentionally not complying with the traffic control command (Foomain, Alecsandru, Awasthi 2015). In Minnesota, police reports were analyzed for 768 right-angle crashes at stop-controlled intersections in 1998, 1999, and the first half of 2000. This revealed that most of the crashes occurred during daylight hours; 435 (57%) involved a vehicle that had stopped at the stop sign, and then pulled out, while 204 (26%) involved vehicles that ran through the stop sign. Another 129 (17%) could not be identified relative to the vehicle actions. The right-angle crashes at stop-controlled intersections accounted for 71% of Minnesota traffic fatalities during this period (Harder, Bloomfield, Chihak 2003).

One safety approach that has been investigated are flashing LED stop signs. These are regular octagonal stop signs with flashing light emitting diodes (LED) outlining the edge of the sign. Not only do these signs grab a driver's attention, but they are also visible from a greater distance – typically 1 km, or 2/3 of a mile, when no sight obstructions exist (Foomani, Alecsandru, & Awasthi 2015) By increasing the conspicuity of the stop sign, the hope is that violations and related crashes at stop-controlled intersections will be reduced (Davis, Hourdos, Xiong 2014). While this has been shown to be effective at mitigating safety concerns, particularly at through-stop intersections, researchers have had difficulty giving a precise estimate of safety benefits in terms of Crash Modification Factors (CMF), given the wide confidence intervals of the studies (Arnold, Lantz, 2007).

Arnold, Lantz 2007

Early research in the early 2000s led to LED flashing stop signs being included in the Manual of Uniform Traffic Control Devices (MUTCD). The guidelines there include the following:

> "Except as provided in Paragraphs 11 and 12 [which includes paddle signs held by flaggers in work Zones], neither individual LEDs nor groups of LEDs shall be placed within the background area of a sign.
>
> If used, the LEDs shall have a maximum diameter of 1/4 inch and shall be the following colors based on the type of sign:
> A. White or red, if used with STOP or YIELD signs.
> B. White, if used with regulatory signs other than STOP or YIELD signs.
> If flashed, all LED units shall flash simultaneously at a rate of more than 50 and less than 60 times per minute. 10 The uniformity of the sign design shall be maintained without any decrease in visibility, legibility, or driver comprehension during either daytime or nighttime conditions."

A 2003 research project out of Texas evaluated a few different applications to increase the conspicuity of warning and regulatory signs (Gates, Carlson & Hawkins 2004). The study established Measures of Effectiveness (MOEs) to determine the value of safety measures at stop-controlled intersections. These included:

- Speeds approaching intersection (mean)
- Decelerations approaching intersection (rate exceeding 10 ft/s2)
- Speed variance
- Stopping compliance. Stopping compliance was divided into four categories established by ITE:
    - Full stop (complete cessation of movement)
    - Rolling stop (≤ 3 mph)
    - Blow-through (≥ 4 mph)
    - Stopped by conflicting traffic (these vehicles were omitted from the analysis since their actions were considered involuntary.

The authors reported that the use of flashing LED stop signs reduced the occurrences of vehicles not fully stopping by 28.9%. This treatment was particularly effective for blow-through occurrences, reducing that rate by 52.9%. However, the study did not find a significant effect on vehicular speeds or deceleration on approaching the intersection (Gates, Carlson & Hawkins 2004).

Davis, Hourdos, & Xiong (2014) conducted both a statistical study and a field test. The statistical study compared the crash frequency following the installation of flashing LED lights at 15 intersections in Minnesota. The results showed a 41.5% reduction in crashes, but the fact that there were few crashes to use as a comparison made the confidence uncertain; however, researchers used the statistical data to develop tools to help engineers determine the most appropriate locations for flashing LED stop sign installation. The field test showed that drivers approaching intersections illuminated by flashing LED stop signs were more likely to stop when opposing traffic was present as opposed to the rate prior to the installation (10.6 clear stops for every clear nonstop after vs. 4.2 stops for every nonstop before). However, there was no appreciable change in behavior when no opposing traffic was discerned; approximately 4 drivers did not come to a complete stop for every one that did.

A Canadian study found a 27.8% reduction in the occurrence of vehicles not fully stopping at the intersection (blow-through and roll-through) after installation of flashing LED stop signs. On average, 75.6% of drivers came to a complete stop at these stop signs, greatly reducing the number of right-angle conflicts common at these intersections (Foomani, Alecsandru & Awasthi 2015). Stop sign compliance is noted in the following graphs:

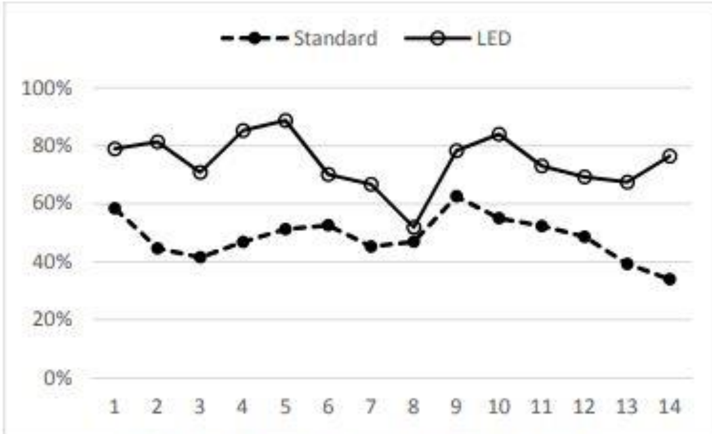


Figure 5 – Victoria Ave. West-bond approach STOP sign compliance ratio

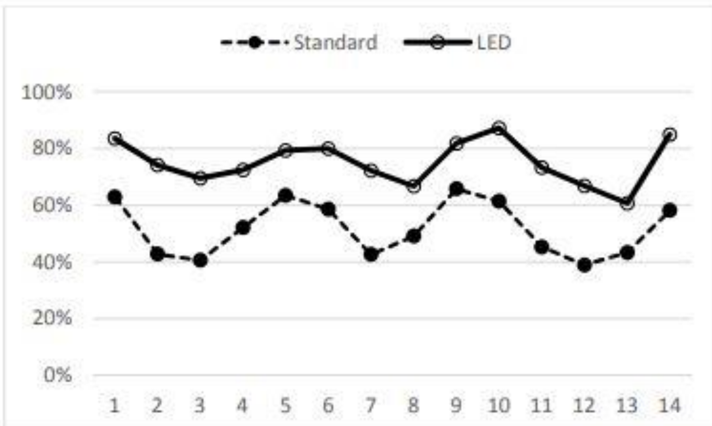


Figure 6 - Victoria Ave. East-bond approach STOP sign compliance ratio

Foomani, Alecsandru & Awasthi, 2015

Virginia traffic engineers in 2007 recommended a flashing LED stop sign for a T-intersection with a higher-than-average crash rate in Albemarle County (Arnold, Overton 2007). A before-and-after study used MOEs of the average speed of drivers approaching the intersection and compliance with a sign. Results showed a statistically significant reduction in speed of 1 to 3 mph, but the report pointed out that having a statistically significant result does not necessarily indicate a practically significant one. The researchers were not able to complete their data plan to evaluate compliance.

While the Virginia study did not have very significant results following the installation of a flashing LED stop sign, the authors theorized that the fact that several alternate countermeasures were already in place at the intersection likely decreased the effectiveness of the LED sign (Arnold, Overton 2007). This highlights what all of the information on this topic stresses – that flashing LED stop signs are not appropriate for every situation and should only be used in particular locations for specific reasons. The advantage to these devices is their ability to capture drivers' attention when approaching an intersection, so overuse would diminish their effect;

they should remain an anomaly on the traffic scene (Forbes 2011). Also, there is the potential for decreasing the effectiveness of static stop signs through overuse of the LED-enhanced signs, as well as the possibility of distraction in some areas (Fitzpatrick, Chrysler et al. 2011).

Bryer (2011) suggested a set of criteria for consideration, including:

- Stop-controlled intersections with a history of higher-than-average crash rates
- Isolated high-speed stop-controlled intersections with significant sight distance limitations that cannot be easily mitigated or are too costly to correct.
- Isolated stop-controlled intersections on high-speed at-grade arterials that are at risk, or have a history of severe right-angle crashes

Brockman, Fertuck & Churko (2014) suggested that they be limited to intersections where there is a known problem with stop sign running and where other passive measures have failed to alert drivers to the stop sign. Other considerations include locations where a stop sign is not expected or where there are documented problems of failure to recognize an intersection (Fitzpatrick, Chrysler et al. 2011).

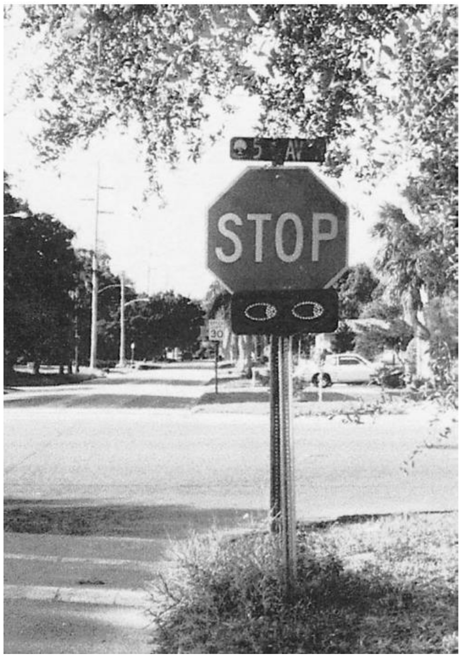
However, Forbes (2011) emphasized that, even with intersections that meet the criteria, flashing LED stop signs do not have to be the first consideration. These devices are only one of many tools that can be used to increase the conspicuity, and Forbes suggested employing the less expensive methods to see if the issue can be resolved with one of these. This approach can be repeated until the problem is successfully dealt with. The strategies he put forth:

- Increase the size of the sign
- Provide a more reflective sign sheeting
- Post an additional (left-side mounted) sign
- Add “STOP AHEAD” warning sign
- Add “STOP AHEAD” pavement markings
- Add transverse rumble strips
- Add a flashing beacon
- Embed LEDs in the border of the sign

Forbes also gave a decision ladder on using these methods. It was suggested that a flashing LED stop signs would not be appropriate if the intersection approached the criteria for installing a signal or roundabout (Bryer 2011).

While flashing LED stop signs allow drivers to perceive the intersection from a greater distance, this might not be advantageous if the distraction of the LED lights draws the attention of the driver away from other critical features, such as driveways located prior to the cross street (Fitzpatrick, Chrysler et al. 2011). A laboratory study of different flashing beacon placements showed that participants exhibited a slightly longer response time to the signs with flashing beacons than those without beacons; however, this may have been caused by lighting conditions in the lab, with sudden bright lights causing a startle reaction (Fitzpatrick, Chrysler et al. 2011). Thus, the response does not necessarily apply to real-life applications of flashing beacons or flashing LED stop signs.

Studies have compared the effectiveness of multiple devices to enhance stop-controlled intersection safety. In addition to testing flashing LED stop signs, Gates, Carlson and Hawkins (2004) considered orange overhead flags as a low-cost method of increasing warning sign conspicuity, although these were only effective during daylight hours and tended to fade quickly. They also found that flashing beacons worked well in both day and night operations but were more costly to install and maintain than LED-flashing stop signs; the beacons also do not improve the legibility or conspicuity of the sign face/shape itself. Fitzpatrick, Chrysler et al. (2011) agreed with this fact, pointing out that the LED signs "have a distinct advantage over static signs (even those embellished with a flashing beacon) when the LEDs highlight the shape of the sign". However, the authors also showed that detection distance was similar with both signs with beacons and those with flashing LED signs.



Van Houten, Retting 2001

A 2001 study used a novel approach to LEDs at stop signs in an effort to get drivers to come to a complete stop at the intersection before pulling out into the lane of traffic. Animated eyes consisting of blue LEDs scanned right and left at a rate of 1 cycle per second. The LED eyes were activated by a microwave sensor that detected approaching vehicles. The authors reported a significant increase in the percentage of vehicles coming to a full stop before entering the intersections at the test sites (Van Houten, Retting 2001). While apparently showing a degree of success, this idea did not seem to catch on with the transportation community.

While the MUTCD gives specifications for the use of LED lights with various warning signs, studies have found that, while the flashing lights improve the detection distance, legibility distance suffers because of glare (Fitzpatrick, Chrysler et al. 2011). This is particularly true at nighttime, when words are detected earlier on signs without lights than those with flashing lights (Fitzpatrick, Chrysler et al. 2011). The unique shape and color of the octagonal stop signs make recognition easy for drivers to detect, even without being able to read the words. Engineers have shown support for this type of device because the visual enhancements are made directly to the face of the sign (Gates, Carlson & Hawkins 2004)).

Early studies expressed some concerns about power for the LED applications, but solar panels have been shown to be effective for supplying the small amount of power needed to enable the flashing lights. This makes flashing LED stop sign installations flexible enough for nearly any location (Winn, Rice 2009).
The LEDs, when flashing, provide a pixelated or bitmap image of the sign outline. This can be achieved either with a series of individual LEDs or several clusters of closely spaced LEDs that appear to the observer to be a single point of light. Each point of light is referred to as a pixel, and the spacing between pixels (center-to-center) is called the pitch. Pixels should have a maximum spacing of 8% of the sign size to create a reasonable outline of the sign to the viewer (Forbes, 2011).

It has been noted that the observer will turn away from the source of discomfort felt if the luminous intensity is too great, and the data shows that observers were 13 times more likely to identify the flashing lights to be "unbearably bright" under nighttime conditions in the laboratory than during daytime conditions. Studies indicate that it may be advantageous to use a higher intensity during the day, and a lower one at night (Fitzpatrick, Chrysler et al. 2011, Foomani, Alecsandru, & Awasthi 2015). Forbes (2011) recommended that the ratio of minimum to maximum luminance intensities should be a maximum of 5 to 1. The Institute of Traffic

Engineers (ITE) maintains maximum intensity at three times the minimum intensity for their LED signal head purchasing specifications (Robertson, Fitzpatrick 2014).

The Society of Automotive Engineers (SAE) sets minimum standards for luminous quality, and Robertson and Fitzpatrick (2014) indicated that agencies should focus more on that than on finding signs offering the highest luminous intensity. Using a single setting, Gates, Carlson & Hawkins (2004) set the luminous intensity at 600 candelas, stating that this was highly visible both during the day and at night. Although the MUTCD allows for both red and white LEDs on stop signs, the general consensus was that red should be used to match the color of the signs (Forbes, 2011).

The rate of flashing should be 50 to 60 times per minute, but can be increased to 120 times per minute (MUTCD 2009, Foomani, Alecsandru, & Awasthi 2015). Rates between 5 and 30 flashes per minutes should be avoided, as these could trigger epileptic seizures (Forbes 2011). The LED lights can flash 24 hours a day, be time-controlled or traffic activated (Forbes 2011, Winn, Rice 2009) and can even be a steady light (Li, Medina & Gibbons 2020). It is important that all LEDs in an intersection system operate simultaneously (Fitzpatrick, Chrysler et al. 2011, MUTCD 2009).

The obvious advantage to limiting the flashing LEDs to specific times is the fact that it saves power. Typically, these applications will flash continuously during times of darkness, and are triggered either by photo-sensor or a pre-programmed time of day. Traffic-actuated systems also save power, and flash only when required. This can also limit light intrusion on nearby properties.

Brockman, Graham et al. (2014) reported on a pilot project involving a traffic-activated flashing LED stop sign on a rural highway in Saskatchewan. This province is characterized by long, straight stretches of rural roads that can lead to driver inattention and increase the risk of crashes (Brockman, Graham et al. 2014). A stop-controlled intersection between Highway 16 and Highway 35 had a collision cost six times the average collision cost for provincial highway intersections. Existing safety interventions introduced over the prior decade, including illumination, “Stop Ahead” signs, stop signs with red flashing beacons, and transverse rumble strips, were unsuccessful at controlling right-angle crashes at that location – in fact, collision rates remained relatively constant despite these devices. The decision was made to replace the stop sign with a flashing beacon with a radar-activated flashing LED stop sign. It was designed to target only those vehicles at risk of not stopping before the intersection based on speed and distance to the intersection. The system would not be triggered by alert drivers decelerating at a safe speed as they approached the sign.

Oversized LED stop signs were installed, with SS300 D-Band Doppler speed sensor mounted on the signpost facing approaching traffic. A radio communication device transmitted the “on” signal, and solar panels supplied the power. The system was supplied and installed for $11,002 per approach, including one radar, two blinker beam wireless radios and two oversized solar LED stop signs. No results/feedback on this pilot project was found.

Most traffic-actuated systems utilize a detector upstream of the stop sign to identify approaching vehicles. Speed-detection technology was deployed at several stop-controlled intersections in North Carolina and Missouri; the systems identified vehicles approaching an intersection at too-high of an approach speed. Drivers exceeding a specified speed would trigger either a flashing beacon on a “Stop Ahead” warning sign, or the LED flashing lights on the stop sign itself (Bryer, 2011).

A detector can also be used without a speed sensor to cue the LED lights on the stop sign to begin flashing as an approaching vehicle is identified. Forbes (2011) developed an equation for a detector placement and flash time:

$$D = \frac{V^2}{2a}$$

Where: D = Distance from stopline to the detector (metres)
V = Posted speed limit of the approach (km/h)
a = Comfortable deceleration rate (12.3 km/h/s)

$$t = \frac{V}{a}$$

Where: t = Duration of flashing operation (seconds)

V = Posted speed limit of the approach (km/h)
a = Comfortable deceleration rate (12.3 km/h/s)

The author suggested that If detectors with speed-sensing capabilities are used, the detector placement should remain the same, but it might be advantageous to use a different flash rate based on the approaching speed. A faster flash rate could alert the driver to the need to decelerate quickly.

Forbes' suggestion for determining flash speed:

Measured Speed Minus Posted Speed in km/hr (m/hr)	Flash Rate (flashes per sec)
< 20 (12.4)	60
21 (13) < V < 35 (21.7)	90
V > 36	120

In a different LED traffic-actuated application, an integrated laser-triggered detection system was installed to cue an LED-enhanced "DO NOT STOP ON TRACKS" sign for vehicles approaching the zonal area of a rail grade crossing (Hellman 2020). This can represent a particular danger in areas where traffic backing up from an upstream traffic signal can result in vehicles queuing over a grade crossing, or within a danger zone of the crossing. The study showed a 26.6% decrease in vehicles stopped in the zonal area of the grade crossing following the LED-enhanced warning.

The cost of the 2014 pilot in Saskatchewan was $11,002 per approach, including a radar-based detection unit (Brockman, Graham et al. 2014). A more current (2020) study put the cost of a solar-powered LED stop sign at less than $10,000 including installation (not including a vehicle-detection system) (Li, Medina & Gibbons 2020). Gates, Carlson & Hawkins (2004) gave a comparison between standard stop sign sheeting and completed LED stop signs, and the total installed cost of both in 2004 dollars:

Sign	Application	Sign Cost[a]	Total Installed Cost[b]
 48-in. Stop	Standard Red ASTM Type III	$19.20	$350
	Flashing LED Stop Sign	$895.00 (for completed sign)	$1226
	Change	4661%↑	350%↑

[a] Based on unit prices of $1.20 per ft² for standard color ASTM Type III sheeting, $4.00 per ft² for fluorescent color microprismatic sheeting, and $3.46 per ft² for standard color microprismatic sheeting. Cost information obtained from Texas DOT Traffic Operations Division on August 6, 2003.
[b] Includes an estimated fixed rate of $331 for labor and sign support hardware.
[c] Standard red microprismatic Stop signs were not evaluated in the research performed here. Standard red microprismatic Stop signs are recommended due to the unavailability of fluorescent red microprismatic sheeting.

The ultimate goal of flashing LED stop signs is to reduce the number of crashes and injuries at stop-controlled intersections. Arnold & Lantz (2007) showed that the benefits in terms of reduced crashes exceeded the costs of the installed measures if only one crash was prevented. This was noted in a comparison of the cost of the pilot project with the cost of a crash, assuming that a benefit/cost ratio greater than 1 indicated that the benefits of the countermeasure exceeded the cost of implementation:

Flashing LED Stop Sign			
Cost of Pilot (2006 Dollars)	Crash Type	Cost per Injury (2006 Dollars)	Benefit/Cost Ratio (C/A)
$2210	Fatality	$3,341,620	1512.05
$2210	Incapacitating Injury	$231,343	104.68
$2210	Evident Injury	$46,269	20.94
$2210	Possible Injury	$24,420	11.05
$2210	Property Damage Only	$2,570	1.16

Most research on the effectiveness of flashing LED stop signs has been done in the past 10-15 years, and several of the studies have involved a very small number of intersections – in some cases, only one test site. While more research is warranted, existing studies have shown that the LED-enhanced signs are able to capture the attention of approaching drivers and reduce the percentage of crashes at stop-controlled intersections. However, to maintain the desired effect of these applications, they should be used sparingly, and only under specific conditions, or when previous safety measures have not been successful in reducing the crash rates.

From Li, Medina & Gibbons' (2020) toolbox of safety countermeasures at unsignalized intersections:

Source: Tapco[6]

Name	LED-Enhanced Stop Sign
Category	Engineering Countermeasures
Subcategory	Signs, Enhanced Signs
Source	MUTCD (Section 2A.07; Sign R1-1), MDOT[1], VTRC[2], TTI[3]
Safety Benefits	CMF: 0.59[1,4] (CMFs for replacing standard Stop sign with LED Stop sign)
Usage Type	Spot treatment, Visibility treatment
Target Problem	Low Stop sign compliance, Low visibility
Cost	Low ($$)
Keywords	Stop Control, Light-Emitting Diode, LED, Visibility, Unsignalized, Low Cost

Usage

- Used at stop-controlled intersection approaches to enhance conspicuity of traditional Stop signs. The LED-enhanced Stop sign may result in a higher Stop sign compliance rate, particularly during lower-visibility conditions such as at night and in fog.
- Studies suggest that the use of LED-enhanced Stop signs could result in a significantly higher compliance rate and lower speeds, particularly during low-visibility conditions such as nighttime.[2,3]
- Targeted users of this device are motor vehicles and bicycles. Pedestrians and other users will benefit as well due to an improved Stop sign compliance rate.

Pros and Cons

- High visibility, relatively low cost, higher compliance rate.
- Associated with higher cost compared to traditional Stop signs; requires a power source.

Installation and Configuration

Follow installation guidelines for standard Stop signs (MUTCD 2B.05: Stop Sign [R1-1]). In addition:[5]

- Size of sign can be 30 x 30, 36 x 36, or 48 x 48 in.
- LEDs can be set to flash or steady mode.
- LEDs have low power requirements and are typically powered by stand-alone solar panel units.
- Can be activated by vehicles or on continuously throughout the day.
- Need to make sure not to overuse LEDs in signs, as drivers may become accustomed to their presence and fail to respond as desired.
- Can be applied in conjunction with other treatments to increase sign conspicuity.
- LEDs must be red or white if used with Stop (R1-1) or Yield (R1-2) signs, white if used with other regulatory signs, and white or yellow if used with warning or school signs.

Example Applications

Many states have used LED-enhanced Stop signs.

Li, Medina & Gibbons 2020

References:

Arnold, E. D., Lantz, K. E. (2007). *Evaluation of Best Practices in Traffic Operations and Safety: Phase I: Flashing LED Stop Sign and Optical Speed Bars*. Retrieved from http://www.virginiadot.org/vtrc/main/online_reports/pdf/07-r34.pdf

Arnold, G., & Overton, A. (2007). Flashing LED Stop Signs. *IMSA Journal, 45*(1), pp 42-43.

Brockman, C., Graham, J., Fertuck, J. R., Churko, A. J. (2014). *Radar-Activated LED Stop Sign in a Rural Setting - Pilot Project in Saskatchewan*. http://conf.tac-atc.ca/english/annualconference/tac2014/s-24/brockman.pdf

Bryer, T. (2011). *Stop-Controlled Intersection Safety: Through Route Activated Warning Systems*. Retrieved from http://safety.fhwa.dot.gov/intersection/resources/fhwasa11015/traws.pdf

Crowson, G., Jackels, J., Athey Creek, C. (2011). *Design and Evaluation Guidance for Intersection Conflict Warning Systems (ICWS)*. Retrieved from http://enterprise.prog.org/Projects/2010_Present/developingconsistencyIWS/Design_and_Eval_Guidance/Guidance%20for%20ICWS%20Version%201-122011.pdf

Davis, G. A., Hourdos, J., Xiong, H. (2014). *Estimating the Crash Reduction and Vehicle Dynamics Effects of Flashing LED Stop Signs*. Retrieved from http://www.dot.state.mn.us/research/TS/2014/201402.pdf

Fitzpatrick, K., Chrysler, S., Sunkari, S., Cooper, J., Park, B.-J., Higgins, L., . . . Federal Highway, A. (2011). *Modern Traffic Control Devices to Improve Safety at Rural Intersections*. Retrieved from http://tti.tamu.edu/documents/0-6462-1.pdf

Foomani, M., Alecsandru, C., Awasthi, A., & Canadian Transportation Research, F. (2015). *Safety Performance Assessment of Stop-Operated Intersection Equipped with Active Road Sign*. Web retrieved from https://ctrf.ca/wp-content/uploads/2015/05/CTRF2015FoomaniAlecsandruAwasthiTransportationSafetySecurity.pdf

Forbes, G. (2011). *Recommended Practices for LED-Embedded Traffic Signs (LETS)*. Retrieved from https://www.tac-atc.ca/sites/default/files/site/doc/Bookstore/ptm-ledsgn-e.pdf

Gates, T. J., Carlson, P. J., Hawkins, H. G., & Transportation Research, B. (2004). FIELD EVALUATIONS OF WARNING AND REGULATORY SIGNS WITH ENHANCED CONSPICUITY PROPERTIES. *Transportation Research Record*(1862), p. 64-76. doi:https://doi.org/10.3141/1862-08

Harder, K. A., Bloomfield, J., Chihak, B. J. (2003). *REDUCING CRASHES AT CONTROLLED RURAL INTERSECTIONS*. Retrieved from http://www.lrrb.org/PDF/200315.pdf

Hellman, A. (2020). *LED-Enhanced Sign Research to Reduce Vehicle Queuing at Highway-Rail Grade Crossings*. Retrieved from https://railroads.dot.gov/elibrary/led-enhanced-sign-research-reduce-vehicle-queuing-highway-rail-grade-crossings

Li, E., Medina, A., & Gibbons, R. B. (2020). Safety Countermeasures at Unsignalized Intersections–A Toolbox Approach.

National Joint Committee on Uniform Traffic Control Devices (U.S.). (2009). *Manual on uniform traffic control devices for streets and highways.* Washington, D.C. Retrieved from https://mutcd.fhwa.dot.gov/pdfs/2009r1r2/mutcd2009r1r2edition.pdf.

Van Houten, R., Retting, R. A. (2001). INCREASING MOTORIST COMPLIANCE AND CAUTION AT STOP SIGNS. *Journal of Applied Behavior Analysis, 34*(2), p. 185-193.

Winn, M., & Rice, E. (2009). *Embedded LEDs in Signs [summary]*. Retrieved from https://rosap.ntl.bts.gov/view/dot/49231

Xiong, H., Davis, G. (2012). *Crash Reduction Effects of Flashing LED Stop Signs*. Digital/other retrieved from https://trid.trb.org/view/1130489