Changes in Intersection Scanning Behavior Due to Intersection Collision Warning Systems

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Abstract

Around 16 percent of all fatalities in rural areas occur at intersections. Right angle crashes are the most common rural intersection crash type and are frequently a result of inadequate scanning, failure to yield, gap acceptance or sight distance issues. One promising solution to address rural intersection safety issues is intersection conflict warning systems (ICWS). Although the system has shown promise towards improving driver behavior and reducing crashes at rural intersections, the impact has not been well quantified. The Department of Transportation of the northern U.S. state of Minnesota (MnDOT) has invested significant resources into ICWS based on early indications of system effectiveness. As a result, they were interested in determining the effectiveness of the ICWS. Since the study took place in the short-term, a crash analysis was not possible. Instead, several surrogate safety measures were evaluated before and after installation of the ICWS. The systems are expected to improve driver behavior such as stopping leading to a reduction in crashes. However, some concerns have been raised that drivers may overly rely on the system to indicate the presence of on-coming cross traffic and may therefore be less likely to stop or appropriately scan when the ICWS is not active.

Left and right glance behavior were evaluated before and after installation of ICWS at 4 rural intersections in Minnesota. In all cases the average number of glances both left and right increased at 1-month after installation as compared to the before period. The average number of glances to the right increased by up to 0.7 and the average number of glances to the left increased by 0.9. Additionally, the number of glances to the left and right was higher during the 1-month after period when the system was activated compared to when the system was not activated.

Keywords: rural intersection, intersection collision warning, traffic safety, glance behavior

1. Introduction

1.1 Background

Around 16 percent of fatalities in rural areas occur at intersections (IIHS, 2019). Intersection characteristics correlated to rural intersection crashes include speed limit, number of approaches, and presence of horizontal curvature (Sun et al, 2021). Driver behavior is a major contributor to rural intersection crash risk with inappropriate gap selection being one of the main contributing causes. Inappropriate gap selection accounted for 56% of all right-angle crashes at rural Minnesota thru-stop intersections (Preston et al. 2004, Harder et al. 2003). 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 (Alexander et al. 2007). Drivers failing to stop on the minor approach have been found to account for 25% of right angle crashes (Harder et al. 2003). Retting et al. (2003) found that crashes where drivers failed to stop at stop signs were more likely to result in injuries than crashes where drivers stopped. Characteristics correlated to failure to yield right of way include age (McGwin and Brown 1999, Keay et al. 2009), speeding, vision obstruction, and inattention/distraction (Campbell et al. 2004).

Proper visual scanning at an intersection is also important given complicated geometric features and multi-directional traffic (Bao and Boyle, 2009). Kosaka et al. (2007) demonstrated that experienced drivers scanned twice more before crossing or turning at intersection than inexperienced drivers and concluded a crash was more likely to occur as a vehicle approaches faster and a driver looked right or left fewer times before entering an intersection. This is exacerbated at rural intersections by high approach speeds resulting in significant speed differences between on-coming traffic on the major approach and those making a maneuver from the minor stop-controlled approach. Savage et al (2021) noted head+eye scanning behavior was important in detecting hazards at intersections. When drivers failed to detect hazards in a simulator study, one of the primary reasons was eye scanning only without head movement.

One unique and promising solution to address rural intersection safety is use of intersection conflict warning systems (ICWS). ICWS are usually installed at the minor approach of rural intersections with two-way stop control. The system warns drivers at the minor approach when on-coming vehicles on the crossing road are present. In some cases, a warning sign may also be placed along the major approach to warn mainline drivers that a vehicle is approaching the minor street stop. Although no action is required of the major street driver, it does alert them in case a minor street vehicle does not stop or misjudges a gap.

Studies have indicated that ICWS can result in lower intersection approach speeds, reduced conflicts, improved compliance with traffic control, and improved gap selection (Golembiewski and Chandler 2011; Weidemann et al. 2011; Rakauskal et al. 2009; Ismail et al. 2014). Weidemann et al. (2011) evaluated an intersection in Minnesota instrumented with an ICWS and found a 4.5 percent decrease in speed after installation of the system. Another study evaluated speed changes at a single intersection where an ICWS had been installed (Hallmark et al. 2018). The researchers collected speed before and then at 4 months after installation. Average speeds decreased by around 1.4 mph at the intersection proper and by around 0.5 mph at the point where drivers first observed the sign. Rakauskas et al. (2009) evaluated another ICWS in Minnesota and found an increase in 80th percentile gap size for vehicles making a through movement when the system was activated. Tian et al (2021) evaluated the impact of of ICWS using a driving simulator and found the system improved driver gap acceptance.

Several simple before and after crash analyses were conducted by various researchers and reductions in total crashes up to 46% and severe crashes up to 72% were reported (Missouri DOT, 2011; North Carolina, 2011). Other studies have suggested that when the ICWS is not activated, drivers may be less likely to stop (Tian et al, 2021) and in some cases minor crash increases have occurred (Weidemann et al. 2011). For instance, Weidemann et al. 2011 reported an increase of 13% to 24%.

A study by Simpson and Troy 2013 conducted a crash analysis of ICWS in North Carolina. They evaluated 74 intersections with ICWS throughout the state, altough not all intersection configurations were consistent. Additionally, installation occurred at different times and as a result, the before and after period differed. The average before period was 5 years and at a minimum of one year of after data were available for each intersection. They also selected control intersections which had similar geometric characteristics. An analysis was conducted using empirical Bayes to develop crash modification factors (CMFs) based on different configurations and geometry. In general, a CMF for total crashes of 0.75 was reported.

Kwon and Ismail 2014 conducted an evaluation of an early version of the ICWS which is currently used in Minnesota. That system was set up to detect vehicles at both the minor and major approach and LED blinker warning signs are activated showing, "Vehicle Approaching When Flashing". They compared the number of roll-through stops before and after installation and found a decrease from 28% to 14%. The researchers also compared roll-through stops at the time the system was activated compared to not activated system and found only 1% of vehicles engaged in a roll-through while the system was active. Speeds were also compared, and they found that the average speed during peak period decreased from 52.0 to 50.8 mph.

Himes et al. 2016 evaluated ICWS in Minnesota, Missouri, and North Carolina using an empirical Bayes before–after analysis. Crash modification factors were developed for total crashes for two-lane roads intersecting with a two-lane side road (CMF = (0.73) and for four-lane roads intersecting at two-lane minor road (CMF = 0.83).

1.2 Scope and Objective

Although intersection conflict warning systems have shown promise in improving driver behavior and reducing crashes at rural intersections, the impact has not been well quantified. The Minnesota* Department of Transportation (MnDOT) invested significant resources into ICWS based on early indications of system effectiveness. As a result, they were interested in determining the effectiveness of the systems. The study collected data before and immediately after (1-month) installation of the ICWS. Since the study took place in the short-term, a crash analysis was not possible. As a result, surrogate safety measures, such as stopping behavior, stopping position, and intersection glance behavior were evaluated before and after installation of ICWS. This paper focuses on changes in intersection glance behavior. Visual scanning has been used as a surrogate measure for safety in several other studies (Angell et al. 2015; Bowers et al. 2019). Other metrics are reported elsewhere (Hallmark et al. 2017; Thapa et al. 2018).

**Minnesota is a state in the midwestern portion of the United States.*

2. Methodology

2.1 Site Selection

A list of all known sites where ICWS was planned for installation coincident with this project was provided by MnDOT. Test sites were considered for ease of data collection. This included checking that trees/shrubs, steep ditches, or other object along the roadway would not restrict use of video recording lines of sight. Treatment sites were also examined for atypical characteristics rail lines or significant vertical or horizontal curve along one approach near the intersection, sight distance issues, etc. Resources were available to collect data at five sites and those selected are noted in Table 1. All were rural intersections with paved major and minor approaches. The intersections are hereafter referred to by the county in which they were located (i.e. McLeod).

Table 1: Location of Evlauation Sites

County	Intersection	Roadway
McLeod	MN7 and County Rd 1	2-lane/2-lane
Pipestone	MN 23 and County Rd 16	2-lane/2-lane
Cottonwood	MN 60 and County Hwy 1	4-lane divided/2-lane
Isanti	MN 47 and County Rd 8	2-lane/2-lane
Chippewa	MN 7 and MN 15	2-lane/2-lane

The ICWS in Minnesota were installed and monitored by a contractor. The team worked with the contractor and coordinated data collection before and 1-month after installation. The ICWS configuration for the minor stop controlled approaches is shown in Figure 1. The system has a set detection zone and monitors traffic on the major approach. When vehicles are present within the detection zone on the major street, the system activates and displays the message "TRAFFIC APPROACHING" to the minor stop controlled approach. Additionally, two lights on the top of the sign flash in an alternative pattern.

2.2 Data Collection

Data were collected using trailers with a telescoping mast and array of cameras. The trailers were placed to record an aerial view of vehicles approaching the intersection. A post mounted camera was also placed on a Telspar pole and mounted across from the stop sign on the minor approach. It recorded video at approximately face level for approaching vehicles and was used to record driver behavior as they approached the intersection.

Data were collected for a week before and at 1-month after installation of each ICWS. Once the equipment was placed in the field, data were collected continuously. The equipment was placed and cameras adjusted to the appropriate intersection area during data collection setup. Project members had remote control over the camera pan-tilt-zoom features so cameras could be re-positioned from the office as needed to ensure the appropriate locations were collected and to trouble shoot when necessary. For instance, the camera position occasionally moved due to strong winds and required adjustment.

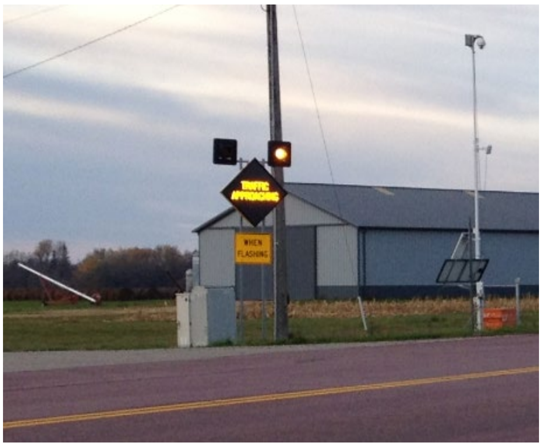

Figure 1: Intersection Collision Warning System

2.3 Data Reduction

Data were manually reduced from the video by data reductionists. Data were reduced only for the minor stream vehicles. Information were coded only for weekdays from 6 am in the morning to 8 pm in the evening. Nighttime video was too grainy to be consistently utilized. Due to the large amount of video data that resulted and resources to reduce data, only a sample of vehicles were reduced. A random time generator was developed in an Excel sheet and vehicles in freeflow were randomly selected and coded.

Driver characteristics were coded using the minor camera located at the minor approach. Driver information such number of glances to the right, number of glances to the left, and presence of distraction (if obvious) were coded for each randomly selected vehicles. Number of glances were coded by establishing two predefined points for each intersection and then measuring the number of glances to each direction that occurred during this interval. As a result, glances associated with a head movement were recorded. Eye movements to check for on-coming traffic could not be identifeid if they were not associated with an obvious head movement.

Start and end points were fixed such that drivers' glances were recorded as soon as vehicles approach the stop bar until it departed to the major stream. Several studies have indicated the majority of intersection scanning occurs within 100 feet of the intersection (Jackson, 2017; Savage et al, 2021).

If vehicles stopped before the stop bar or start point, number of glances were not coded for that specific vehicle since the side of the vehicle could not be viewed. In some scenarios it was difficult to see individual drivers such as during rain, reflection of sunlight, and tinted glass on the vehicle. As a result, driver information could not be collected for all vehicles selected for sampling. For each driver coded, the level of confidence in being able to view the driver in the video was also coded since the view of the driver was not always clear. Additionally it was reasonably difficult to determine distraction and as a result it was not further evaluated as a metric of interest.

3. Analysis and Results

The number of glances were evaluated to determine whether drivers improved intersection scanning. Intersection scanning is the process of looking left and right to determine presence and location of on-coming vehicles. There was no defined example of what good scanning behavior entails. A study by Savage et al (2021) indicated drivers who failed to detect hazards were less likely to engage in head+eye scans. Kosaka et al. (2007) found experienced drivers scanned intersections twice as much as inexperienced drivers and concluded that a crash was more likely to occur as a vehicle approaches faster and a driver looked right or left fewer times before entering an intersection. As a result, it was assumed that an increase in glances to the left or right indicate better scanning behavior. There was a concern that drivers may scan less if they overly rely on the system. On the other hand, drivers may pay more attention if the warning system is active.

The number of times a driver glanced left or right at the intersection was coded as described in Section 2.3. Due to intersection geometry, the side facing cameras at Chippewa could not be oriented properly to collect data. As a result, driver data was not available for this intersection and only 4 intersections are included in the analysis. Glances were reduced for all turning movements. However, it was felt that right turning vehicles would scan differently than left turning or through vehicles. As a result, left and through vehicles were combined.

Figure 2 shows average number of right glances and confidence interval for each site. As noted in the data reduction section, data were only reduced for daytime dry weather conditions. As shown, the average number of right glances increased at all four intersections at 1-month after installation of the ICWS. All of the differences were statistically significant indicated by non-overlapping confidence intervals. The greatest increase was at the Pipestone location where the average number of glances to right increased from 0.6 to 1.9 (196% increase). As noted, McLeod experienced an increase from 1.7 to 2.4 (39% increase), Cottonwood 0.8 to 1.2 (49%), and Isanti 1.5 to 1.8 (23% increase).

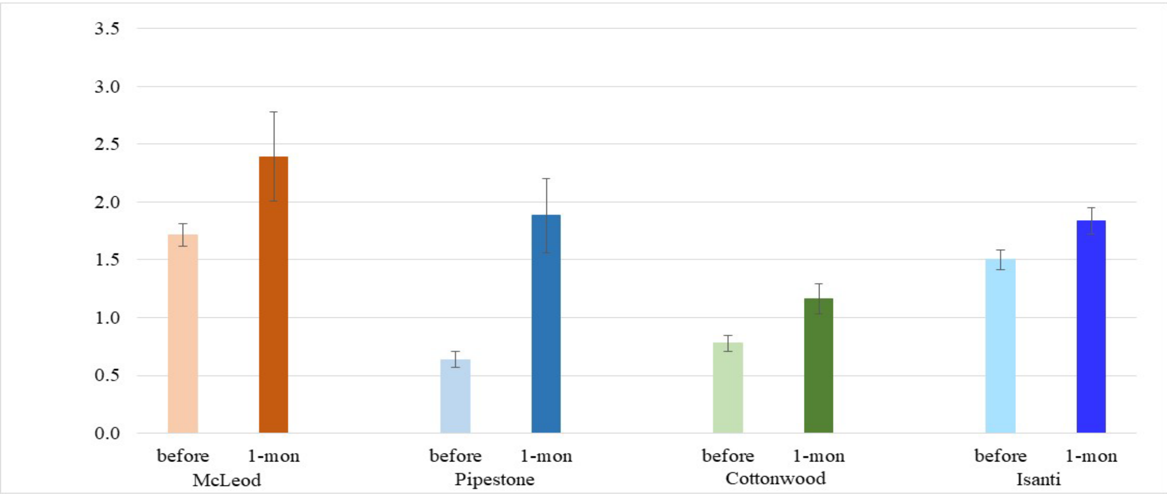

Figure 2: Changes in glances to the right

The change in average number of left glances is shown in Figure 3. The average number of left glances increased at the McLeod site from 1.6 before installation of the ICWS to 2.5 after, an increase of 56%. At the Pipestone site, the average number of left glances increased from 1.4 to 2.1 (50% increase). At Cottonwood they increased from 1.1 to 1.5 and at Isanti they increased from 1.3 to 1.8 (37% and 43% increase respectively). As noted, none of the confidence intervals overlapped.

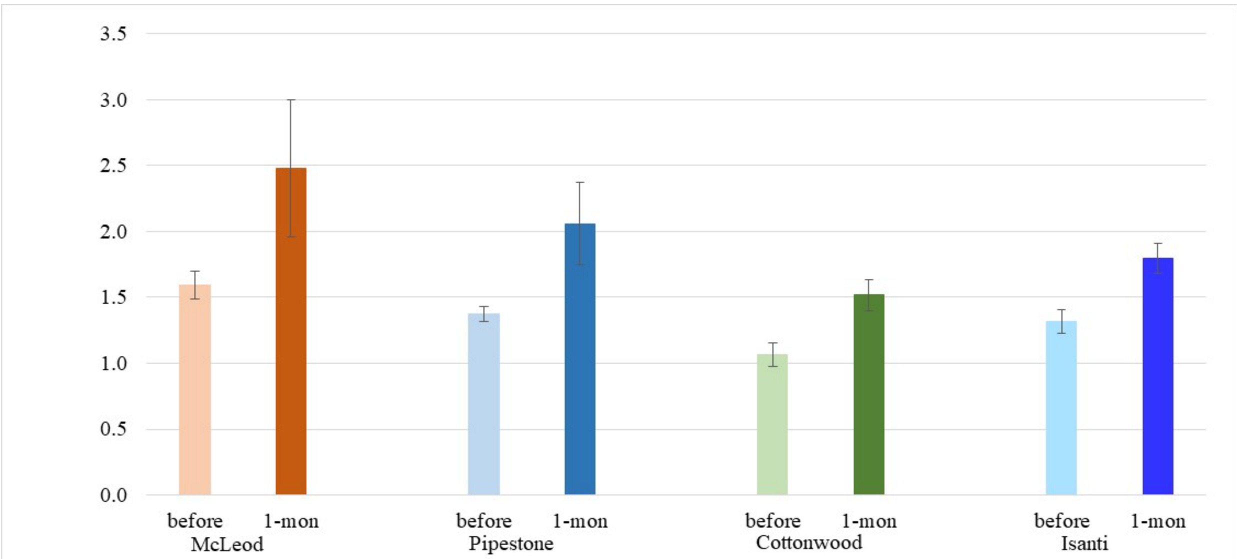

Figure 3: Changes in glances to the left

Glances were also compared for when the ICWS system was activated versus not activated for the 1-month after period. The ICWS was activated when the system detected an on-coming vehicle along the major street within the detection zone. The minor stream driver would see the message displayed in Figure 1 (activated). When a vehicle was detected along the minor street, but no accompanying driver was detected along the major stream within the detection interval, the sign would present a blank face to the minor street driver (not-activated).

Due to small sample sizes data were combined for the 4 intersections. As shown in Figure 4, drivers glanced more frequently to the left when the system was activated than not activated at the 1-month after period. On average drivers glanced left 2.1 times when activated compared to 1.5 times when the system was not activated ($p = 0.001$). This represents a 38% increase in the number of times a driver looked left. When the sign was not activated, the number of glances left was similar to the period before installation of the sign (1.4 versus 1.5 glances with differences not being statistically significant). The average number of glances to the right was an average of 1.5 times when the system was not activated compared to 1.9 times when the system was activated ($p = 0.017$). This indicates drivers glance to the right 27% more when the sign is activated. The average number of glances to the right when the sign was not activated was similar to the period before installation of the sign (1.4 versus 1.5 with the difference not statistically significant).

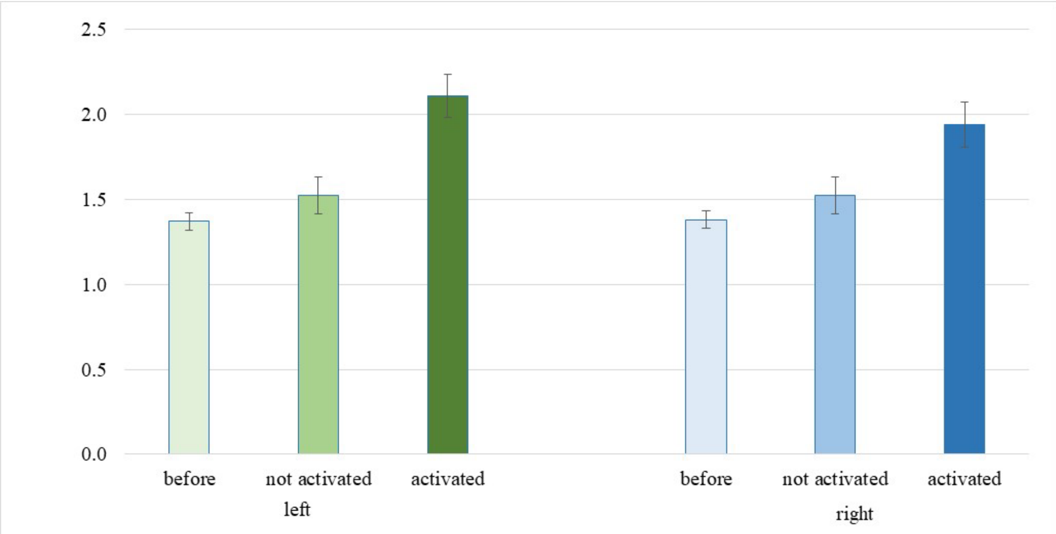

Figure 4: Changes in glances when system is activated/not activated

4. Discussion and Conclusions

Although intersection conflict warning systems have shown promise in improving driver behavior and reducing crashes at rural intersections, the impact has not been well quantified. The Minnesota DOT invested significant resources into ICWS based on early indications of system effectiveness. As a result, they were interested in determining the effectiveness of the systems. The study collected data before and immediately after installation of the ICWS. Several driver behavior metrics, such as stopping behavior, stopping position, and intersection glance behavior were evaluated before and after installation of ICWS. This paper focuses on changes in intersection glance behavior.

The study evaluated changes in left and right glance behavior before and after installation of intersection conflict warning systems at 4 rural intersections in Minnesota. Data were reduced only during the day light conditions. The average number of glances were summarized by different categories. In all cases the average number of glances both left and right increased at 1-month after installation of the ICWS as compared to the before period. Additionally, the number of glances to the left and right was higher during the 1-month after period when the system was activated compared to when the system was not activated.

Proper visual scanning at stop controlled intersections is important to ensure drivers have identified potential hazards (i.e. on-coming traffic, presence of pedestrians/bicylists). Studies have show that experienced drivers are more likely to scan intersections more and crashes are more likely when a driver looks left or right fewer times. As a result, improved scanning behavior is considered to have a positive impact on safety. As indicated, prsence of an ICWS lead to increased glances both to the left and right.

Several limitations were present. Data were collected at 5 intersections, but the driver face video could only be reduced for 4 intersections. As a result, only a limited number of intersections were represented. Additionally, other driver characteristics such as age could not be included due to difficulties in estimating age and sample size. The study only included glances that included a head movement. Eye scans without head movement also aid in intersection scanning but could not be reduced.

5. Acknowledgment

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