COOPERATIVE INTERSECTION COLLISION AVOIDANCE SYSTEM – STOP SIGN ASSIST

TRAFFIC-BASED FOT

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FINAL REPORT

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395 John Ireland Blvd
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Prepared by
Ensar Becic
Michael Manser

HumanFIRST Program
Department of Mechanical Engineering
University of Minnesota

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EXECUTIVE SUMMARY

Although 60% of all intersection fatalities occur in an urban setting (FHWA, 2006), crashes that occur at rural intersections result in fatalities more frequently, most likely due to higher velocities of vehicles on rural highways. In the previous research efforts, the University of Minnesota developed an infrastructure-based Cooperative Intersection Collision Avoidance System - Stop Sign Assist (CICAS-SSA), designed to aid drivers in rejecting inappropriate gaps in traffic when crossing rural highway intersections. The current research effort summarized here is a traffic-based field operational test that examines the longer-term efficacy of the CICAS-SSA to reduce the frequency of collisions at rural stop controlled intersections. The study was conducted over a period of three years during which we recorded the frequency of crashes at the intersections at which the CICAS-SSA system was installed.

The long-term effectiveness of the CICAS-SSA in reducing the frequency of crashes was examined in a two-pronged approach. First, through the examination of crash data we compared the frequency of collisions both before and after the installation of the CICAS-SSA system at several test intersections. This allowed us to determine a baseline rate of the frequency of crashes at the test intersections prior to the installation of the CICAS-SSA systems and compare it to crash rate following the CICAS-SSA installation. This approach included comparing the test intersection crash frequency against control alternatives. Second, by performing a statistical modeling analysis, a crash prediction model was developed that assessed the extent to which the actual frequency of crashes at the tested intersections matched the predictive frequency. The results are interpreted in terms of the efficacy of the CICAS-SSA to reduce the frequency of collisions at rural intersections in Minnesota.
1. INTRODUCTION

This report presents the continuation and the final research study of the Cooperative Intersection Collision Avoidance System-Stop Sign Assist (CICAS-SSA) research project. The research effort described in this report summarizes the results of the Traffic-Based Field Operational Test (FOT) task and, more specifically, the degree to which the CICAS-SSA is associated with the frequency of crashes at rural intersections. As part of this report, the background and literature related to this work, importance of conducting longer-term field research, the research hypotheses, and description of the research design are presented. The final portion of the report presents the results and an interpretation of the findings.

2. BACKGROUND AND LITERATURE

The technological advancements that led to various improvements in automobile manufacturing also contributed to an increase in a variety of safety systems, both vehicle- and infrastructure-based. Vehicle-based systems such as collision avoidance systems (CAS) have received considerable attention from both the OEM manufacturers, as well as researchers in industry and academia. On the other hand, the research on infrastructure-based systems has not been as extensive. This is particularly the case for infrastructure-based systems that do not warn, but rather present driving-related information to drivers. The need for infrastructure-based systems has arisen for locations associated with high frequency of crashes, such as intersections.

Although 60% of all intersection fatalities occur in an urban setting (FHWA, 2006), crashes that occur at rural intersections result in fatalities more frequently (Knapp, Campbell & Kienert, 2005), most likely due to higher velocities of vehicles on rural highways. A failure to accurately estimate the gap between cross-traffic vehicles is one of the major factors contributing to crashes at these intersections (Laberge, Creaser, Rakauskas & Ward, 2006; Preston & Storm, 2003), where higher velocities of vehicles reduce driver’s ability to accurately estimate time-to-contact (Hancock & Manser, 1997; Kiefer, Flanagan & Jerome, 2006), thereby increasing the risk of crashes.

The current report examines the longer-term efficacy of an infrastructure-based information system to reduce the frequency of collisions at rural intersections. Furthermore, the report focuses on stop-controlled intersections, separated by a median, in which traffic from a minor road crosses the multi-lane highway (see Figure 1).
Early research examining the causes of crashes at rural stop-controlled intersections revealed that in most crashes the drivers failed to stop at the median and crossed the intersection in a single-stage maneuver (Preston, Storm, Donath & Shankwitz, 2004). In a single-stage maneuver, drivers cross the intersection in a single crossing, without making a stop in the median (see Figure 1). Given that the median in such intersections is typically controlled by a yield sign, a one-stop maneuver can be considered a driving strategy. It should be noted that not all medians at divided rural stop controlled intersections are controlled by a yield sign; some intersections have a stop sign at the median requiring drivers to make a complete stop before crossing the second set of lanes. In the current report, however, we examine the intersections where median is controlled by a yield sign.

One solution for ameliorating the frequency of crashes at rural stop controlled intersections would include a technological approach. One such approach was based on a Cooperative Intersection Collision Avoidance System-Stop Sign Assist (CICAS-SSA) proposed by Preston et al. (2004) and was created with a goal of helping drivers identify and reject small gaps when crossing rural intersections, specifically when crossing a divided rural highway from a stop sign.
controlled county road. The University of Minnesota developed an interface for the CICAS-SSA (see Figure 2) which was designed in such manner that a driver viewing the CICAS-SSA sign for the first time would be able to comprehend and use the information presented on the sign easily (Creaser, Manser & Rakauskas, 2008). An existing road sign (i.e., divided highway) served as a basic platform on which the interface for the CICAS-SSA was designed (Laberge et al., 2006). The primary goal of this system is to aid drivers in rejecting small gaps at rural stop controlled intersections.

![Figure 2.](image)

**Figure 2.** Figure 2a depicts a common sign for a divided highway, located on a minor road. Figure 2b depicts the CICAS-SSA sign.

In the initial stages of the CICAS-SSA project, numerous interfaces were identified and tested and the sign that resulted in the greatest comprehension and usability (Creaser et al., 2008) was forwarded for further testing. Following the identification of the optimal interface, on-road and driving simulation studies were conducted to determine the extent to which the interface of the CICAS-SSA was effective in improving drivers’ rural intersection crossing performance (i.e., rejecting small gaps) (Rakauskas, Creaser, Manser, Graving & Donath, 2009). The simulator study was conducted at in the HumanFIRST driving environment simulator at University of Minnesota and the on-road study took place at the intersection of Trunk Highway (TH) 52 and County State Aid Highway (CSAH) 9 near Cannon Falls, Minnesota. The primary goal of these studies was to evaluate the efficacy of CICAS-SSA interface in aiding drivers in rejecting inappropriate crossing gaps under realistic, but safe conditions (i.e., exact replica of the intersection in the simulator), followed by the same examination in a real-world setting.

The effectiveness of the CICAS-SSA was assessed through a trial-based approach in which the participants drove across the intersection (both simulated and real-world studies) with and without the aid of the CICAS-SSA. The intersection crossing performance (e.g., gaps rejected) when the CICAS-SSA was present (i.e., treatment condition) was compared to crossings in which the sign was not activated (i.e., control condition). While the results did not show a significant benefit of the CICAS-SSA the results also did not reveal any adverse consequences as the results of the presence of the sign.
The CICAS-SSA sign was then moved from the roadside, the location for which it was originally designed, to inside a vehicle. In the initial effort to transition this system from an infrastructure to an in-vehicle-based system, several interfaces were examined to determine the optimal design to implement inside a vehicle via a driving environment simulation study (Becic, Manser, Creaser & Donath, 2012a). The interface that performed best resembled the roadside interface of the CICAS-SSA. The results of the driving environment simulator study showed that drivers presented with an in-vehicle CICAS-SSA were less likely to accept a small gap and were more likely to make a complete stop before entering the intersection. These beneficial effects were found when visibility was limited (i.e., fog was present) but no effect was found under clear visibility conditions when drivers relied on their own perceptual faculties to cross the simulated intersections. Also examined was the impact of an in-vehicle CICAS-SSA under distracting conditions (Becic, Manser, Drucker & Donath, 2013) as well as across different age groups (Becic, Manser, Creaser & Donath, 2012b). As the final step in the in-vehicle stage of the CICAS-SSA project the efficacy of the optimal design of the in-vehicle CICAS-SSA was examined across younger and older drivers in a field study (Becic et al., 2012b). Overall, the results of these studies showed positive effects of the use of the in-vehicle CICAS-SAS under limited visibility conditions, but also that distracting conditions did not pose any negative impact on the use of the system.

The CICAS-SSA project then examined the longer-term effectiveness of the roadside-based system and drivers’ behavioral adaptation, both studies conducted in on-road studies. As part of this evaluation in which data was collected over 11 months an “A-B-Ap” design was utilized that consisted of alternating presentations of the CICAS-SSA system (Off and On) to 30 drivers. This design allowed us to examine the efficacy of the system by assessing drivers’ baseline intersection crossing performance (‘A’ segment) and comparing it to their performance in the treatment condition (‘B’ segment). Furthermore, we collected drivers’ intersection crossing performance in the retention condition (‘Ap’ segment) during which the CICAS-SSA was deactivated to assess the degree to which the drivers’ learned behavior reverted to initial (i.e., baseline) level. Results of this study indicated that the presence of the CICAS-SSA resulted in an increased likelihood of drivers accepting critical gaps compared to their baseline driving behavior. The results also unveiled a degree of retention of that learned behavior (i.e., drivers’ likelihood of accepting critical gaps in the ‘Ap’ segment was greater compared to the baseline i.e., ‘A’ segment).

The naturalistic study examining the efficacy of the CICAS-SSA offered a unique opportunity to examine changes in drivers’ behavior as the result of exposure to this system. The transition of research from driving environment simulation to a real-world environment can be viewed as the final stage of a research process that examines the efficacy of driver support systems. Transitioning to this stage of testing has occurred infrequently for in-vehicle intersection assistive systems compared to other devices (see Fukushima, 2011). Specifically, few intersection assist evaluation studies have transitioned successfully from a pilot or test track controlled situations to a FOT. Even less frequent is the long-term naturalistic examination of such assistive systems. The driver-based examination of the CICAS-SSA effectiveness, as
assessed in the last research effort offered a longer-term observation of driver behavior when crossing rural intersections; however, it did not provide answers for the primary goal of the CICAS-SSA; the CICAS-SSA capacity to reduce the frequency of collisions when crossing rural intersections. The primary goal of the current research effort was to examine the extent to which the CICAS-SSA can reduce the occurrence of collisions in rural intersections under naturalistic driving conditions.

3. TRAFFIC-BASED FOT

Earlier research efforts showing positive usability ratings (Creaser et al., 2008), as well as the effectiveness of the CICAS-SSA under limited visibility conditions (albeit it for an in-vehicle system) (Becic, Manser, Creaser & Donath, 2012a) suggested a degree of utility of the CICAS-SSA that was the basis of continued evaluations of the system’s effectiveness. While the studies conducted in the later stages of the CICAS-SSA project did not reveal significant beneficial effects of the system, and some indicated a potential to increase in the rate of acceptance of smaller gaps (i.e., driver-based project) (Becic, Manser, Creaser & Donath, 2012a), those studies were not designed to directly answer the primary question which also represented their greatest limitation: Can the use of the CICAS-SSA reduce the frequency of collisions at rural intersections?

The results of the driver-based CICAS-SSA effort (Becic, Manser, Creaser & Donath, 2012a) revealed that drivers increased the frequency of accepting critical gaps (i.e., gaps smaller than 7.5 seconds) when the system was active compared to their baseline rate (i.e., inactive CICAS-SSA). Furthermore, drivers retained a level of this behavior after the CICAS-SSA was turned off. The data suggest that the presence of the CICAS-SSA did not impact performance in the expected direction rather than being less likely to accept a small gap drivers accepted small gaps with greater frequency when crossing the tested intersection. The results from the driver-based CICAS-SSA may simply suggest that drivers have shifted their criterion for selecting a crossing gap (i.e., lowering the criterion – accepting smaller gap) but it does not imply increased frequency of collisions. To determine if acceptance of smaller gaps would result in an increase in collisions in naturalistic driving conditions the research team conducted a Traffic-Based FOT over a three-year period during which we recorded the frequency of collisions at the intersections at which the CICAS-SSA was installed. Moreover, by using crash data from MnDOT, we looked at the frequency of collisions at those same intersections before the installation of the CICAS-SSA systems. This allowed us to determine a baseline rate, frequency of collisions at the tested intersections prior to the installation of the CICAS-SSA systems, and compared it to crash rate following the installation.

3.1. RESEARCH GOALS

The goal of the current research effort was to examine the long-term effectiveness of the CICAS-SSA in reducing the frequency of collisions. By employing different analyses methods, we examined the extent to which the presence of the CICAS-SSA reduced the frequency of crashes at three intersections in Minnesota. This was achieved by comparing the number of collisions of
different severities during the time at which the CICAS-SSA was present to the time prior to the installation of the system.

3.2. METHODS

3.2.1. Materials and Apparatus

3.2.1.1. Test Intersection Locations

TH 23 and CSAH 7. The CICAS-SSA system was activated at the intersection of TH 23 and CSAH 7, by Marshall, Minnesota on June 14, 2011. The major highway (TH 23) was a four-lane divided rural highway while the minor road (CSAH 7) was a two-lane road. When travelling on the minor road, the entrance to the intersection was regulated by a stop sign while the median was regulated by a yield sign (see Figure 3). The median was long enough to hold one vehicle in each direction.

![Figure 3. The first site of the CICAS-SSA, the intersection of TH 23 and CSAH 7, by Marshall, MN. Image retrieved from Google Maps.](image-url)
US 52 and CSAH 9. The CICAS-SSA system was activated at the intersection of US 52 and CSAH 9, by Cannon Falls, Minnesota on January 20, 2010. The major highway (US 52) was a four-lane divided rural highway while the minor road (CSAH 9) was a two-lane road. When travelling on the minor road, the entrance to the intersection was regulated by a stop sign while the median was regulated by a yield sign (see Figure 4). The median was large enough to hold two passenger-size vehicles in each direction.

![Figure 4. The second site of the CICAS-SSA, the intersection of TH 52 and CSAH 9, by Cannon Falls, MN. Image retrieved from Google Maps.](image)

US 169 and CSAH 11. The third location at which the CICAS-SSA system was activated was at the intersection of US 169 and CSAH 11, by Milaca, Minnesota on April 3, 2011. The major highway (US 169) was a four-lane divided rural highway while the minor road (CSAH 11) was a two-lane road. When travelling on the minor road, the entrance to the intersection was regulated by a stop sign while the median was regulated by a yield sign (see Figure 5). The median was large enough to hold one vehicle in each direction.
3.2.1.2. Infrastructure Data Collection System

The infrastructure data collection system consisted of three components: sensing, computation, and an infrastructure-based driver interface (i.e., roadside displays). Radar sensors were placed along the major road and were used to determine the position, speed, and lane of travel of vehicles approaching each test intersection. The radar sensors were used because of their high accuracy and durability. Data collected from these sensors was then computed to calculate trajectories and velocities of the vehicles on the major road that determined the TTC of those vehicles to the center point of the intersection. Based on these computations, the appropriate state of the CICAS-SSA was then displayed. The location of the CICAS-SSA at an example intersection is depicted in Figure 6.
Figure 6. Diagram of a stop-controlled intersection with relative location of CICAS-SSA signs. Lightly drawn signs represent the positions of the signs as seen by a vehicle approaching for the other side. Viewing locations while entering the highway from the minor road are indicated by a vehicle labeled ‘n’ (from stop sign, “near”) and ‘f’ (from median, “far”).

3.2.1.3. CICAS-SSA

The CICAS–SSA employed icons of different colors to illustrate the presence of a vehicle on the major road. The yellow icon indicated that a cross-traffic vehicle was approaching the intersection (i.e., gap between 7.5 and 11 s) and the driver should exercise caution when crossing. As the cross-traffic continued to get closer, the yellow icon was replaced by a red icon (i.e., gap less than 7.5 s) thus indicating to the driver that they should not proceed because a cross-traffic vehicle was close to the intersection. The lack of an icon indicated that the system did not detect a cross-traffic vehicle within its sensor range (i.e., gap greater than 11 s, depending on the velocity of the cross-traffic vehicle). Tables 2 and 3 show different states of the CICAS-SSA as presented on the near and far displays (see Figure 6 for their location at an intersection).
Table 1. Display states of the CICAS-SSA as presented on the near display.

<table>
<thead>
<tr>
<th>CICAS-SSA States Near Display</th>
<th>Message Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><strong>DIVIDED HIGHWAY</strong></td>
</tr>
<tr>
<td><img src="image2.png" alt="Image" /></td>
<td>Do not enter the intersection; a vehicle is detected too close to the intersection travelling to the right (time-to-contact is less than 7.5 seconds).</td>
</tr>
<tr>
<td><img src="image3.png" alt="Image" /></td>
<td><strong>DIVIDED HIGHWAY</strong></td>
</tr>
<tr>
<td><img src="image4.png" alt="Image" /></td>
<td>A vehicle is detected approaching the intersection, travelling to the right (time-to-contact is greater than 7.5 seconds). Drivers may be able to cross, but should proceed with caution.</td>
</tr>
<tr>
<td><img src="image5.png" alt="Image" /></td>
<td><strong>DIVIDED HIGHWAY</strong></td>
</tr>
<tr>
<td><img src="image6.png" alt="Image" /></td>
<td>No vehicles are detected approaching the intersection travelling to the right that are within the sensor range. Drivers may be able to cross, but should proceed with caution.</td>
</tr>
</tbody>
</table>
3.3. EXPERIMENTAL DESIGN

The long-term effectiveness of the CICAS-SSA in reducing the frequency of crashes was examined in a two-pronged approach. First, a safety analysis based on the collected crash data that the University of Minnesota research team received from MnDOT was completed. Second, an advanced analysis of the impact of the CICAS-SSA was completed by using a crash prediction model that was developed as part of the Intersection Decision Support (IDS) effort to predict crash frequency for dangerous rural intersections in Minnesota (Davis, Tilahun & Mesa, 2006).

3.3.1. Safety Analysis

Crash data obtained from MnDOT for the three test intersections, as well as other relevant rural intersections at Minnesota was used to carry out this analysis. It is important to note a limitation with the crash data employed in the current work. The crash data database was a rich source of information in that it contained several pieces of information associated with each crash (e.g., diagram of a crash indicating the type of crash, number of vehicles involved, etc). An initial

Table 2. Display states of the CICAS-SSA as presented on the far display. The lanes of traffic that a driver already crossed were grayed out.

<table>
<thead>
<tr>
<th>CICAS-SSA States Far Display</th>
<th>Message Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Diagram" /></td>
<td>Do not enter the intersection; a vehicle is detected too close to the intersection travelling to the left (time-to-contact is less than 7.5 seconds).</td>
</tr>
<tr>
<td><img src="image" alt="Diagram" /></td>
<td>A vehicle is detected approaching the intersection, travelling to the left (time-to-contact is greater than 7.5 seconds). Drivers may be able to cross, but should proceed with caution.</td>
</tr>
<tr>
<td><img src="image" alt="Diagram" /></td>
<td>No vehicles are detected approaching the intersection travelling to the left that are within the sensor range. Drivers may be able to cross, but should proceed with caution.</td>
</tr>
</tbody>
</table>
attempt was made to remove all crashes involving a single vehicle; however, if this filtering was applied there would be no certainty that a the crash vehicle was not on a minor road and that major road traffic played no role (e.g., perhaps a minor road vehicle accelerated quickly to cross the first set of lanes because of a major road vehicle and then hit a sign) in a crash. In addition, the crash diagram associated with each crash column that should indicate the type of crash was often marked as “unknown” which limited the ability to accurately determine crash type. An attempt was made to examine only crashes associated with the CICAS-SSA (e.g., minor and major road vehicle right angle crashes), however, the remaining crash count was insufficient to support a statistically rigorous investigation. As a result, crashes that were included in the analysis included different types of collisions including CICAS-SSA related collisions and others that the CICAS-SSA was not designed to prevent. The inclusion of crashes unrelated to the CICAS-SSA was equally represented in the crash data both before and after CICAS-SSA installation, thus, the potential impact of including all the crash data may be limited.

The frequency of the collisions at the tested intersections was compared to the crash frequency at control intersections, those rural intersections in Minnesota that met the requirements for the control test intersections. The control intersections were included in the analyses to address a potential environmental confound. It is possible that any changes in the crash frequency at the tested intersections could be due to general reduction in crashes across the state or significant change in ADT, rather than the impact of the CICAS-SSA. The examinations of the crash frequency for the control intersections thus allowed us to account for this potential confound. The control intersections were selected on the bases of similar ADT for the major and minor roads, as well as similar crash frequency and crash type as the tested intersections.

### 3.3.2. Crash Prediction Analysis

The long-term effectiveness of the CICAS-SSA was also examined using the crash prediction model that was developed for two-way, stop-controlled, median-separated rural intersections (Davis et al., 2006). Davis and colleagues created a model that predicts crash frequency and has been used in the early stages of the IDS project. This model consists of two components: Easily observed features of an intersection and unique/hidden features of an intersection. Easily observed features include:

- ADT for the major leg
- ADT for the minor leg
- Number of major leg approach access points within 250 feet of the intersection
- Measure of the intersection’s skew

Each of these four features was then assigned a specific coefficient (weight) before being entered into the model. These coefficients were based on the variance that each of these features has on crash frequency.
3.4. RESULTS

3.4.1. Safety Analysis

As part of this analysis, for each of the tested intersections three alternative intersections were selected to act as controls. Each of the control intersections was matched to the test intersections as closely as possible. In particular, the following intersection features were the same between the tested intersection and each of its alternatives:

- Speed limit on the major leg
- Angle of the crossing (e.g., right angle, skewed)
- Stop sign controlled intersection (i.e., stop sign on the minor road; yield at the median)
- Median separated rural intersection
- The presence of turn lanes

In addition, the following are intersection features and selection conditions for which we also attempted to select the best alternative intersection:

- ADT on the major leg for an alternative intersection was within 50% of ADT on the major leg of the CICAS-SSA intersection
- The number of fatal and major injury crashes at alternative intersections was as close as possible to the number of similar crashes at the test intersection. Due to high crash and fatality rate at the intersection of TH 52 & CSAH 9, it was not possible to find alternative intersections with such high rate of crashes.

Table 3 represents the number of collisions for each of the tested intersections and their alternates, across collision type (e.g., fatal, “B” crash). It was observed that the number of fatalities and injuries remained the same at TH 52 & CSAH 9, while it was reduced at the TH 169 and CSAH 11. The number of crashes resulting in minor injuries and property damage was reduced in both of these intersections following the installation of the CICAS-SSA. The data at the alternative intersections for TH 52 & CSAH 9 showed that the number of crashes remained the same following the introduction of the system. The data also showed a reduction for the alternative intersections for TH 169 & CSAH 11. Data for TH 23 & CSAH 7, and its alternative intersections was difficult to interpret due to the very low number of crashes at those locations.

The research team also conducted a Crash Prediction analysis because of the limitations associated with interpreting descriptive data. Specifically, descriptive data is not intended to indicate a possible effect of a system, a possible trend in the data, or an indication of a reduction/decrease of the crashes following the installation of the CICSA-SSA.
Table 3. The crash rate for three test intersections and their alternatives, for the period of time during the activation of the CICAS-SSA and the same period prior to the activation.

<table>
<thead>
<tr>
<th>Intersection</th>
<th>Condition</th>
<th>Begin Date</th>
<th>End Date</th>
<th>“Fatal -A” Crashes</th>
<th>“B” Crashes</th>
<th>“C” Crashes</th>
<th>“PDO” Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S. 52&amp; CSAH 9</td>
<td>Before</td>
<td>Jun 2006</td>
<td>Jan 2010</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>Jan 2010</td>
<td>Jun 2013</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>MN 65 &amp; MSAS 103</td>
<td>Before</td>
<td>Jun 2006</td>
<td>Jan 2010</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>Jan 2010</td>
<td>Jun 2013</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>US 169 &amp; CSAH 19</td>
<td>Before</td>
<td>Jun 2006</td>
<td>Jan 2010</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>Jan 2010</td>
<td>Jun 2013</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MN 60 &amp; CR 112</td>
<td>Before</td>
<td>Jun 2006</td>
<td>Jan 2010</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>Jan 2010</td>
<td>Jun 2013</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>U.S. 169 &amp; CSAH 11</td>
<td>Before</td>
<td>Feb 2009</td>
<td>Apr 2011</td>
<td>2</td>
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<tr>
<td>US 169 &amp; CSAH 1</td>
<td>Before</td>
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<td>Apr 2011</td>
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<td></td>
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<td>Jun 2013</td>
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<tr>
<td>US 169 &amp; CR 108</td>
<td>Before</td>
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<td>Apr 2011</td>
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<td>0</td>
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<tr>
<td></td>
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<td>Jun 2013</td>
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<tr>
<td>MN TH 23 &amp; CSAH 7</td>
<td>Before</td>
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<td>Jun 2011</td>
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<td>1</td>
<td>4</td>
<td>2</td>
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<tr>
<td></td>
<td>After</td>
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<td>Jun 2013</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
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<tr>
<td>US 2 &amp; CSAH 17</td>
<td>Before</td>
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<td>0</td>
<td>0</td>
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<td>Jun 2013</td>
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<td>0</td>
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<tr>
<td>US 2 &amp; CSAH 18</td>
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<td></td>
<td>After</td>
<td>Jun 2011</td>
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<td>0</td>
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<td>US 60 &amp; CSAH 1</td>
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<td>Jun 2011</td>
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<td>0</td>
<td>3</td>
<td>0</td>
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<tr>
<td></td>
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<td>Jun 2011</td>
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<td>0</td>
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3.4.2. Crash Prediction Analysis

Unlike the Safety Analysis, the Crash Prediction analysis used the crash data of all relevant rural intersections in Minnesota, regardless of their ADT or frequency of collisions to determine the effectiveness of the CICAS-SSA. While the Safety Analysis compared the tested intersections to similar control intersections, the Crash Prediction analysis used a much greater number of intersections in the analysis while accounting for different values of factors such as ADT. The goal of this analysis was to compare the frequency of two-vehicle rural intersection crashes following the CICAS-SSA installation at three different locations to what would have been expected had the intervention not been installed. This was accomplished by predicting the crash frequency for the years 2010-2013 using the statistical model described in the initial IDS analysis (Davis et al., 2006) and then computing the crash modification factor. The following measures were obtained:

- $\Theta$ (theta) = observed / predicted
- Standard deviation
- Confidence interval (e.g., 95%)

As the initial step, crash data from the relevant 4-lane rural intersections were used to construct a statistical model relating expected crash frequency to ADT. ADT estimates were there entered into the model to predict what the crash frequency would have been had the CICAS-SSA interventions not taken place. The crash prediction model provided the predicted number of crashes during the time period when the system was activated which was then compared to the observed number of crashes:

$\Theta$ (theta) = observed / predicted

A value of 1 would indicate no impact of the CICAS-SSA, a value > 1 would indicate a change in the number of crashes that is greater than predicted while a value < 1 would indicate a decrease in crash frequency compared to the predicted crash rate.

Crash records for the period of time during which the CICAS-SSA was present at the three intersections (see Table 3) were extracted for the overall crash count. Crash data since 2002 was used to calculate the predicted crash count at each of the test intersections. The computation of the Predicted Crash count is presented in Table 4.
Table 4. Predicted crash rate for the three CICAS-SSA intersections with crate rate during the activation of the system and the same time period prior to the activation.

<table>
<thead>
<tr>
<th>Site</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crash Count</td>
<td>Major ADT</td>
</tr>
<tr>
<td>TH 52 &amp; CSAH 9</td>
<td>15 (3 years)</td>
<td>17500</td>
</tr>
<tr>
<td>TH 169 &amp; CSAH 7</td>
<td>13 (3 years)</td>
<td>9600</td>
</tr>
<tr>
<td>TH 23 &amp; CSAH 11</td>
<td>5 (3 years)</td>
<td>6000</td>
</tr>
</tbody>
</table>

Once the Predicted Crash was computed, we calculated the Estimated Crash Modification Factor (θ) using WinBUGS 1.4.3 (http://www.mrc-bsu.cam.ac.uk/bugs/winbugs/contents.shtml). The WinBUGS software implements a method for computing posterior distributions called Markov Chain Monte Carlo (MCMC) (Lunn et al., 2000). The summary of those computations is included in Table 5.

Table 5. Calculation of crash modification factor (θ) and confidence interval.

<table>
<thead>
<tr>
<th>Theta (θ)</th>
<th>Mean</th>
<th>St. Deviation</th>
<th>2.5 %ile</th>
<th>97.5 %ile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.16</td>
<td>.34</td>
<td>.66</td>
<td>1.98</td>
</tr>
</tbody>
</table>

The results showed a crash modification factor greater than 1, meaning that the actual number of crashes at the CICAS-SSA treated intersections was greater than the predicted crash count; however, after extracting the standard deviation from the data to improve the validity of the result, we were able to calculate a confidence interval, showing that there was 95% confidence that the CICAS-SSA intervention resulted in anywhere from 34% decrease to 98% increase in crash frequency. This represents a large range that includes both the decrease and the increase in crash frequency indicating that the magnitude of any change associated with the presence of the CICAS-SSA is too small to detect with the existing sample size.

3.5. DISCUSSION

The primary goal of the current study was to examine the long-term efficacy of the CICAS-SSA and its capacity to reduce crashes at rural intersections. This was accomplished through a three-year study during which data was collected on crash frequency on the test intersections as well as other relevant 4-lane rural intersections in Minnesota.
A field operational test can be viewed as the optimal method of evaluation of any driver safety system. The principal goal of this stage of research was to examine the extent to which the findings from other modes of research (e.g., simulator, limited on-road) transfer to the real world conditions. Crash frequency is the most relevant measure when evaluating the efficacy of any system designed to reduce fatality rate; however, this measure has a downside – crashes occur infrequently, thus limiting their statistical usefulness, especially when conducting a research over a short period of time (2-3 years). In addition to selecting the most optimal research method, the focus of investigation can also alter the extent to which the findings represent the real state of the world.

The results of the current study are in line with the findings from the previous CICAS-SSA research efforts. Most of the previous CICAS-SSA examinations reported either a lack of an impact of the system (drivers’ acceptance of critical gaps did not differ between treatment and control conditions) or a beneficial impact in very specific conditions (e.g., limited visibility). The results from the driver-based CICAS-SSA study (Becic, Manser, Creaser & Donath, 2012b) showed evidence that the presence of the CICAS-SSA can result in an increased likelihood of drivers accepting critical gaps compared to their baseline driving behavior (prior to the activation of the CICAS-SSA).

The findings of the previous studies in the CICAS-SSA project do have a common thread; the impact of the CICAS-SSA is limited. That is also the finding of the current study. It is likely that the period of intervention time (up to three years) was not sufficient to establish a strong effect, but it is also possible that the impact of the CICAS-SSA in reducing the frequency of crashes is rather limited.

The primary limitation of this research effort can be attributed to insufficient data regarding CICAS-SSA related crashes, a limitation that cannot be addressed at the current time. Conducting another set of analyses in several years could provide sufficient data from which to obtain significant findings and narrow the confidence interval. In addition, other factors influencing the efficacy of the CICAS-SSA cannot be discounted. For example, while the CICAS-SSA is designed to support drivers understanding of gaps between approaching vehicles, the test intersections may have presented challenges to drivers in other ways such as limited sight distance, different roadway configuration, and the location of intersection relative to populated areas to name a few. These potential experimental confounds at the test intersection may have supported the lack of significant differences in the present work.
4. REFERENCES


