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The effects of intersection collision warning systems on gap selection and stopping characteristics

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The effects of intersection collision warning systems on gap selection and stopping characteristics

by

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ABSTRACT

Over 8,500 fatalities occurred in the United States at intersections, or were intersection-related representing almost one-quarter of fatalities. Given the small percentage of roadway that intersections represent, the design of intersections provides a distinct challenge concerning safety, especially when poor sight vision is present. There has been a correlation found between smaller gap acceptance and crashes at intersections. Warning systems have been found to be an effective way to stop vehicles at intersections and identify acceptable gaps.

The Minnesota Department of Transportation installed an intersection collision warning system at select two-way stop-controlled intersections throughout the state in spring of 2015. The following study looks at changes in driving behavior resulting from the installation of the ICWS at the installation sites and nearby intersections that display similar traits. The metrics studied include the rate at which vehicles stop at the intersection, the location of stopping, and the gap acceptance.

The findings support the claim that cameras are effective in stopping vehicles at the intersections of installation. The stopping rate study saw an increase of 4.88% to 5.26% at treatment locations. The findings of the stopping location and gap selection studies were generally inconclusive. No treatment site displayed a significant increase in gap rejection rate.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

According to the National Highway Traffic Safety Administration, over 8,500 fatalities occurred in the United States at intersections, or were intersection-related in 2013 (Fatality, 2015). During 2013, nearly one-quarter of fatalities occurred at intersections. Given the small percentage of roadway system that intersections represent, the design of intersections provides a distinct challenge concerning safety (Intersection, 2005). Crashes at intersections are more likely to be angle crashes which have a higher risk of serious or fatal injury. Poor sight conditions is a characteristic that can lead to further safety concerns. With insufficient sight conditions, the gap between vehicles that can be observed is decreased. There has been a correlation found between smaller gap acceptance and crashes at intersections (Tupper, 2011). The problem of poor sight conditions is amplified at intersections that exhibit high speeds due to vehicles moving through the small area of sight in less time.

In order to address these issues at high speeds, the Minnesota Department of Transportation has installed an intersection collision warning system (ICWS) in various locations throughout the state on rural highways where sight distance and/or crash history are a problem. All locations selected for the intersection collision warning system occur at a two-way stop control intersection. This system utilizes LED-based signs and non-intrusive sensors to alert minor roadway vehicles of approaching traffic. In addition, traffic on the major roadway is alerted if a vehicle may be entering the traveled way from the side road. The flashing warning signal is visible to drivers a large distance before the intersection.

In order to understand the effectiveness of the intersection collision warning system, video of the intersection was recorded and analyzed before and after the installation of the ICWS. In total, six intersections were recorded. Three of these sites, referred to as the treatment sites, are locations that ICWS signs were installed. The remaining three sites, referred to as control sites, are intersections with similar characteristics to the treatment sites, and located within one to five miles of the treatment site. Four cameras were utilized at each intersection to capture driver actions. Two cameras were placed along the major roadway 300-500 feet from the intersection in both directions. A video trailer with telescoping mast arms was used to provide an aerial view of the intersections. Two additional cameras were installed at driver level adjacent to the intersection. The view of these cameras was the side of the car at the stop sign with the goal of viewing the driver and their head movements.

Activity was recorded at each site for seven days consecutively. Several key parameters were extracted from the video data. The main parameters of interest included stopping characteristic on the minor road, conflicts, roadway conditions, accepted gap duration, and rejected gap duration.

1.2 RESEARCH OBJECTIVES

The objective of this research was to determine the safety benefits provided by installing an intersection collision warning system in Minnesota. This was accomplished by evaluating driving data before and after installation of the system. The following metrics were analyzed after data collection:

- Gap acceptance before and after installation of system
- Gap rejection before and after installation of system
- Percentage of vehicles that do not stop at intersection
- Percentage of vehicles that stop before or at stop bar

1.3 THESIS ORGANIZATION

This thesis is organized into five chapters. It starts with this chapter, which gives background into the problems associated with intersections; especially those with poor sight vision. This chapter then goes on to list the research goals. Chapter 2 contains information on previous research already completed on and relating to the topic. Chapter 3 provides information on the intersections used in the study as well as how the data were collected and reduced. This is followed by chapter 4, which discusses the methodology, analysis, and results of the study. Finally, chapter 5 discusses overall findings and conclusions.

CHAPTER 2: LITERATURE REVIEW

2.1 EXTERNAL COLLISION WARNING SYSTEMS

2.1.1 Early Implementation

The Federal Highway Administration has been at the forefront of many leading safety research projects. In the late 1990s, the FHWA conducted research on a first of its kind system that warns drivers of other vehicles near an intersection (Penney, 1999). The purpose of the Intersection Collision Warning System (ICWS) was to enhance driver awareness of the traffic situation at the intersection by providing timely and easily understood warnings of vehicles entering the intersection. A field study was conducted with three phases; before, acclimation, and after. Measures of effectiveness were recorded during the evaluation. These measures were as follows:

1. Sign response speed – The vehicle speed at intermediate loop detectors. The location of these loops allowed motorists to respond to the sign's message and understand their closeness to the intersection.
2. Intersection arrival speed – The vehicle speed at the intersection loop detectors. The loops were positioned within the intersection approaches and reflect intersection arrival speed.
3. First speed reduction – The difference in speed between points approximately 950 feet before the intersection and the intermediate loop detector mentioned in the first measure of effectiveness.
4. Second speed reduction – The difference in speed between the intermediate and intersection loop detectors.

5. Overall speed reduction - The difference in speed between the advance and intersection loop detectors.
6. Projected times to collision (PTC) – The theoretical elapsed times to which an approaching vehicle on the major roadway would collide with an intersection vehicle from the minor roadway. The values can also be considered as the amount of time existing for potentially colliding motorists to take an accident-avoidance action.

Results of the ICWS show that intersection approach speeds were lower following installation. Additionally, the vehicle group exhibiting the shortest 10^{th} percentile PTCs during the before condition averaged longer PTCs and lower intersection approach speeds during the after periods. This means that those at the greatest risk of collision showed slower speeds after the installation of the ICWS.

2.1.2 Implementation in Minnesota

The state of Minnesota has led in the implementation of intersection collision warning systems. With this comes a large amount of research on the effectiveness of the installed systems.

As part of the Minnesota Department of Transportation's Innovate Ideas Program, an Intersection Warning System (IWS) was developed in the 2000s decade. This project developed an active roadside warning system to detect mainline traffic and alert cross-street drivers (SRF, 2009). This project counters a high cost of full signalization by offering a low-cost system that utilizes vehicle detection, data processing, wireless communications, signing, and solar power systems. This research looked at data before and after implementation and focused on two measures of effectiveness (MOEs). The first MOE is the traffic conflict rate, which measures the rate of traffic conflicts at an intersection. Traffic conflicts are described as sudden braking, sudden acceleration, or swerving. The other MOE is the traffic conflict severity, which measures the "time to collision" as well as "risk of collision". In addition to the data evaluation, user perception of the system was also assessed.

Traffic conflict rate saw a considerable decrease from the before period to the after period. A conflict rate of 3.9 conflicts per 1,000 vehicles in before condition saw a decrease of 54 percent to 1.8 conflicts per 1,000 vehicles in the after condition (SRF, 2009). In regards to the other measure of effectiveness, the change in traffic conflict severity was negligible. In response to a survey regarding the newly implemented system, approximately half of responses indicated that the use of the flashing sign resulted in the driver paying more attention at the intersection. A large number of users understood the system, with only 10 percent needing further explanation of the meaning of the flashing sign. In general, the public had positive responses to the system.

A different study in the state of Minnesota looked into validating the use of a warning system. This study looks at the use of the Cooperative Intersection Collision Avoidance System-Stop Sign Assist (CICAS-SSA) sign. The sign is used in a two-way stop controlled intersection condition at a divided highway. The design of the sign consists of a divided highway image overlaid with yellow or red icons that represent approaching vehicles that are at a distance at which the driver on the minor road should proceed with caution or at a distance that is considered unsafe to enter the intersection

(Rakauskas et al., 2009). This validation field test involved 48 participants using a single unit vehicle as well as an additional 13 truck drivers using a large truck.

The use of the CICAS-SSA sign was associated with the rejection of shorter gaps in traffic (Rakauskas et. al, 2009). There was an increased 80th percentile rejected gap lengths when the sign was on compared to when the sign was off. There were no significant effects of the sign on accepted gap length, lead gap length, time-to-contact, or safety margin. This means that this study found the system to reduce the safety risk without changing how the driver moves through the intersection. Drivers found that the sign was usable and positive overall. Overall, two-thirds of drivers self-reported that they used the sign, however as age increased, the driver was less likely to use the CICAS-SSA sign.

2.1.2.1 Minnesota ALERT System

Of all intersection-related crashes in Minnesota from 2000 to 2010, 96 percent had critical reasons attributed to drivers (Choi, 2010). Among driver-attributed reasons for crashes was inadequate surveillance (44%) and false assumption of others' actions (8%). The results of these studies led to the AASHTO Strategic Highway Safety Plan's recommendation to "provide an automated real-time system to inform drivers of the suitability of available gaps for making turning and crossing maneuvers." (NHCRP, 2003). The Minnesota Department of Transportation has been involved in researching the use of real-time warning systems at intersections to replace static advance warning signs.

One potential countermeasure to intersection crashes is the use of an Advance Light-Emitting Diode Warning System (ALERT). Research of this project included the development, installation, and analysis of this system over two years. The initial intersection for system implementation exhibited poor sight conditions due to a vertical curve on the main road (Kwon et. al, 2010). Two static signs displaying the message “BLIND INTERSECTION AHEAD 35 MPH” were located 520 ft from the intersection in the original layout. The ALERT system consists of three blinker signs and four vehicle detectors. The main approach blinker sign displays the message “CROSS TRAFFIC WHEN FLASHING” for westbound traffic 525 ft east of the intersection. The blinker sign for the minor road approaches display the message “VEHICLE APPROACHING WHEN FLASHING”. These signs were installed across the intersection from approaching traffic. In addition to the signs, vehicle detectors were installed upstream of the intersection on the major road and on the minor road at the stop sign. All electrical power for this ALERT system is supplied by renewable solar energy. Communication between vehicle detectors and blinker signs are transmitted wirelessly. The system was shown to work effectively at reducing vehicle speeds. During conflict situations, vehicle speed decreased with an average decrease of 4.5 mph (Kwon et. al, 2010). The system was also successful in eliminating vehicles from rolling-through the stop sign during conflict situations, however, the number of roll-throughs during non-conflict situations increased. The ALERT system was successful but also had aspects that could be improved.

The main focus of the ALERT system was kept with a few changes to make phase 2 of the Advanced LED Warning System for Rural Intersections (ALERT-2). In order to mitigate the problem with vehicles rolling-through the stop sign when no conflict exists, a change was made in the sign system (Kwon et. al, 2014). ALERT-2 incorporated LED blinker STOP signs in place of typical stop signs on the minor approaches. This feature was activated when a vehicles passes the STOP AHEAD sign and turns off when the vehicles arrives at the stop sign. ALERT-2 still utilized renewable solar energy for all electrical power and wireless communication between vehicle detectors and blinker signs. The findings of ALERT-2 showed that the ALERT-2 system kept or improved all of the benefits of the ALERT-1 system (Kwon et. al, 2014). 92% of responses in the ALERT-2 mail-in survey were believed that the system improved the safety of the intersection. During phase 1 of ALERT, this number was 72% (Kwon et. al, 2010). Phase 2 of ALERT also utilized a vehicle activated blinker STOP sign. 98% of responses to the mail-in survey agreed that the vehicle activated blinker STOP sign obtained their attention (Kwon et. al, 2014). In addition to survey results, ALERT-2 studied the occurrence of roll-through vehicles at the intersection. Before installation, 28.15% of vehicles rolled-through the stop sign regardless of conflict. The roll-through percentage decreased to 17.38% after installation. Included in this number are a roll-through percentage of 16.22% in no-conflict cases and 1.16% in conflict cases. Phase 2 of ALERT was successful in increasing safety in the intersection and mitigating roll-through occurrences.

2.1.3 Implementation across the United States

Many states across the United States have implemented various infrastructure-based ITS intersections. One of these methods is warning the driver on a through approach of too high an intersection entry speed and directing the driver to slow down (Bryer, 2011). An evaluation of a system that provides speed feedback to all drivers was found to produce a 7 mph reduction of 85th percentile approach speeds. Through route activated warning systems have been implemented in Missouri, Minnesota, North Carolina, Pennsylvania, and Virginia, as well as others. Among these states, Missouri and North Carolina have more than ten through route activated warning systems. Simple before and after crash comparisons show a 51 percent reduction in overall crashes. This includes a reduction in severe crashes by 59 percent, a reduction in angle crashes by 58 percent, and a reduction in severe angle crashes by 77 percent.

A unique research project involving an intersection collision avoidance system didn't take place on a road at all, but instead a driving environment simulator. Participants in this study drove through a simulated intersection twelves times each day for five days (Manser, 2011). On days one and five, there were no intersection support systems used. On days two, three, and four, the Cooperative Intersection Collision Avoidance System – Stop Sign Assist (CICAS-SSA) signs were utilized. The study showed significant short-term behavioral adaptation effects. Drivers rejected more gaps closer to the warning threshold with more system exposure. Additionally, drivers had longer wait times upon first viewing the system but were significantly shorter by the third day.

2.2 GAP SELECTION

There are several factors affecting the drivers' gap acceptance behavior. Research studies have found that drivers are more likely to accept smaller gaps when moving straight than other turning movement (Alexander et al., 2006). Similarly, drivers accept a small gap when the approach speed of the mainstream vehicle is high (Yan et al., 2007). Drivers are also found to be aware of the mainstream vehicle in front of which the gap should be accepted. Studies have found that drivers accept larger gaps in front of trucks but accept small gaps in front of medium sized family cars (Alexander et al., 2002). Similarly, increase in the waiting time was also found to decrease the accepted gap size (Ashworth et al., 1977). However, the effect of day and night time was not found significant (Alexander et al., 2002).

The use of driving simulators is a valuable tool in measuring gap acceptance. In an Australian study of T-intersections, drivers accepted shorter gaps when turning across traffic compared to merging with traffic (Beanland et al., 2013). A different driving simulator study found that nearly 50% of the sample accepted gaps in the traffic stream of 7.5 seconds when turning left and only 10% of participants accepted a 6.5 second gap when proceeding straight or turning right (Overton, 2012). As this testing progressed, gaps accepted were found to decrease.

A binary logit model can be used to define the different factors affecting the drivers' left turn gap acceptance separately. A study found gap duration, total wait time, and median type as significant factors in the model (Devarasetty et al., 2012).

CHAPTER 3: SITE INFORMATION AND DATA COLLECTION

3.1 INTERSECTIONS

The Minnesota Department of Transportation has installed numerous intersection collision warning system devices throughout the state since 2014. All statewide locations share common characteristics but also have traits that can vary. All of the systems were installed at a two-way stop controlled intersection. Many of the sites have poor sight distance at the stop signs. This may be caused due to a horizontal or vertical curve in the roadway. There may also be trees are other obstacles obstructing the view. In most instances, the major roadway, or street that does not have a stop control, has a larger volume of travelers than the minor road, or street that does have a stop sign. These systems do not appear in heavy residential areas, however, there are systems near communities as well as rural areas. Speed limits on roadways where the ICWS were installed range from 30 to 60 miles per hour. Some locations with devices installed are two lane roads while other locations are four lanes. The majority of sites are undivided roadways, but there are also locations that are divided highways. The presence of turning lanes on the major and minor roadways varies from location to location as well. The next portion of this paper will take a closer look at the intersections that were observed for this research.

The research team was tasked with evaluating changes in driver behavior after installation of ICWS. There were concerns that drivers were less likely to stop when the ICWS indicated no on-coming traffic. There was also interest in understanding whether the ICWS change gap acceptance behavior. Additionally, there was concern that drivers may change their stopping or gap acceptance behavior at other intersections where no ICWS was present. The study selected two intersections where the ICWS was installed in 2014 along with an adjacent intersection with similar characteristics with no ICWS.

The selection process for research sites in this study was based largely on the availability of nearby intersections. The main criteria for intersection selection to be used as a treatment site was poor sight conditions. It is also important that the two-way stop controlled intersection be located on a rural highway. The ability to find an acceptable control site was found to be more difficult for this study. The goal was to find a control site that mimics the treatment site as closely as possible and shares drivers.

The first characteristic to consider in comparing the intersections is the number of lanes. This includes the presence of turn lanes and through lanes on major and minor roadways. This is important to consider because turn lanes on minor roadways can influence queuing and sight distance, while major roadway turn lanes will increase the travel distance for vehicles turning left and traveling through the intersection. Related to the number of lanes is the presence or absence of a median. Another intersection characteristic to compare is the skew between roadways. Similar skews are ideal in order to best replicate driver actions while approaching the intersection. The traffic volume is also considered in choosing the control site. The volumes may not be equal but it is important that they are comparable. The minor roadway traffic volume must be high enough to provide sufficient information. An annual average daily traffic volume of 1,000 is preferred but a volume of at least 750 vehicles is acceptable. Another intersection characteristic to consider is the speed limit of both approach legs. The minor and major roadway speed limits of the control intersection should mimic those of the treatment intersection. In regards to location, only intersections within six miles of treatment sites were considered for the control site, with preference given to intersections at least one mile from the treatment site.

For each treatment site, all intersection characteristics must be considered and weighed. Due to the large number of attributes that are considered in a small area, not every treatment location is going to have an exemplary control location to test. During this research project, video from three treatment locations and their corresponding control locations was available. While these control intersections mimicked the treatment intersections, one treatment site was at a divided 4 lane highway, which introduced complications in data collection. For this reason, this paper looks at four intersections, a set of treatment and control intersections in Isanti County and a set of treatment and control intersections in Chippewa County.

3.1.1 Isanti

One of the selected treatment intersections was Minnesota State Highway 47 (MN47) and County Road 8 (Co8). The site is located in Isanti County and is approximately 40 miles north of downtown Minneapolis. MN47 is the major roadway, while Co8 is the minor roadway and has a stop control. Both MN47 and Co8 are two lane undivided highways. The intersection approaches are roughly perpendicular. Both approaches of MN47 have a left and right turn lane in addition to the through lane. Co8 has two lanes on the west approach, one that acts as a right turn lane and one that is a dual through lane and left turn lane, while the east approach has one lane for all movements. The AADT for MN 47 is 7,400 vehicles. Although intersection volume is known, turning movements counts are unknown, but it is assumed most vehicles pass through the intersection. On Co8, the AADT is 2,300 vehicles, with an even number of vehicles turning left, right, and traveling through from the random sample of vehicles examined. This is a rural highway with a speed limit of 55 mph in all directions. Isanti county and the intersection location can be seen in figure 1.

The control site for MN47 & Co8 is located four miles north of the treatment site at the intersection of Minnesota State Highway 47 and County Road 5 (Co5). MN47 is

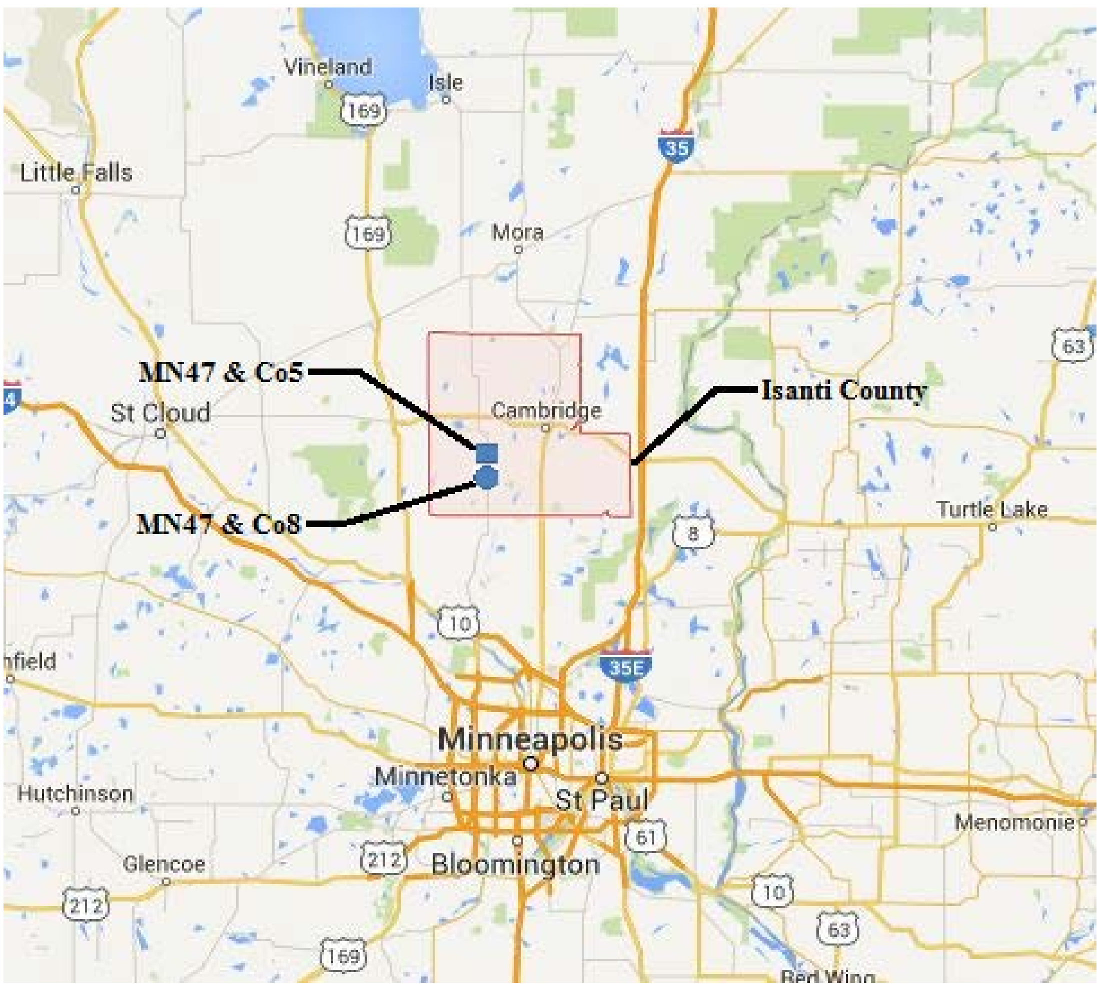

Figure 1: Isanti County intersections (Google Maps. Google, 2015.)

also the major roadway for this location while Co5 is the stop-controlled minor roadway. Similar to the treatment location, both roadways are two lane, undivided roads that intersect at a 90-degree angle. Also comparable to the treatment intersection, MN47 has turn lanes for right and left movements, in addition to a lane for through movements. Unlike the MN47 and Co8 intersection, the minor roadway of the control location, Co5, no turning lanes are present, with only one lane for all movements on both legs. This is understandable considering that Co5 has nearly half of the AADT as Co8, with approximately 1,350 vehicles per day. This portion of MN47 has considerably less vehicles than the treatment location, servicing 3,750 vehicles per day. This location is also a rural highway with speed limits of 55 miles per hour.

3.1.2 Chippewa

The second treatment site which was evaluated is the intersection of Minnesota State Highway 7 (MN7) and County Road 15 (Co15). The site is located in Chippewa County near the city of Montevideo and is approximately 120 miles west of downtown Minneapolis and 35 miles east of the South Dakota border. MN7 acts as the major roadway, while Co15 is the minor roadway and has a stop control. Both MN7 and Co15 are two lane undivided roadways. There is a significant skew between the two roadways, which can be seen in Figure 2. There is also a vertical curve on the north leg of MN7 that may cause site distance issues. There are no turning lanes at any of the four approaches of the intersection. However, many cars were observed using the shoulder of the Co15 east leg as a right turning lane. The traffic patterns are based on the city of Montevideo, with many of the cars coming from the town, or going towards the town.

Figure 2: Chippewa County treatment site (Bing Maps. Bing, 2015.)

The AADT for MN7 is 1,800 vehicles, with the majority of this traffic turning left from the north leg to the east leg. On Co15, the AADT is 2,950 vehicles, with most of the vehicles turning right from the east leg onto the north leg of MN7. This intersection is on the outer portions of Montevideo, with lower speeds than the Isanti County sites. The speed limit on Co15 is 30 miles per hour on the east leg in the direction of Montevideo and turns to 50 miles per hour on the west leg. MN47 has a speed limit of 50 miles per hour in both directions. Chippewa county and the intersection location can be seen in Figure 3.

Figure 3: Chippewa County intersections (Google Maps. Google, 2015.)

The control intersection for MN7 & Co15 was selected to have similar characteristics as the treatment intersection and is located approximately seven miles east of the treatment site at the intersection of Minnesota State Highway 7 and County Road 6 (Co6). MN7 is again the major roadway for this location while Co6 is the stop-controlled minor roadway. Similar to the treatment location, both roadways are two lane, undivided roads. Unlike the treatment location, this these roadways meet at a 90-degree angle. This location is also comparable to the treatment intersection in that no legs of the intersection utilize turning lanes. While still near Montevideo, the control site is located in a rural setting with speed limits of 55 miles per hour in all directions. MN7 has approximately 3,200 vehicles per day in this location while Co6 has fewer than 1,000 vehicles daily.

3.2 DATA

3.2.1 Data Collection

This project involves the use of the ALERT-2 system described in section 2.1.2.1 of this paper. There are many pieces of technology permanently installed near each treatment location. Two blinker stop signs were utilized, one on each minor approach leg. These signs contain red LEDs around the perimeter of the sign. Accompanying the blinker stop signs on the minor roadway are radars to detect vehicles approaching the intersection. When a vehicle is detected approaching the stop sign, the LEDs blink to give extra warning of the stop sign. When the vehicle arrives at the stop sign, the blinker sign turns off. In addition to the blinker stop signs, the treatment site also contains four blinker warning signs. Two warning signs display "APPROACHING TRAFFIC" with LEDs facing stopped vehicles on opposite sides of the intersection. In addition, two warning signs display "ENTERING TRAFFIC" upstream of the intersection in both directions. In conjunction with these signs is the use of radar to detect vehicles near the intersection. Each approach leg utilizes the radar for initiating a warning sign. The radar upstream of the intersection on the major roadway triggers the "APPROACHING TRAFFIC" warning sign. The radar on the minor roadway approach leg activates the blinker stop sign as well as the "ENTERING TRAFFIC" warning sign. All warning signs and radar units are powered through the use of solar panels and battery cabinets.

Figure 4 describes the use of equipment at each intersection. Radar is used to detect vehicles approaching on all legs of the intersection. In the case of figure 4, when radar detects a vehicle on the north leg or the south leg, LED signs 1 and 3 flash to warn traffic on the minor roadway of approaching traffic on the major roadway. The length of the flashing LED sign is determined by the speed of the vehicle and the distance to the intersection to supply the warning until the vehicle passes through the crossing. When a vehicle is stopped at the east or west leg of figure 4, LED signs 2 and 4 flash to warn traffic on the major roadway that a vehicle may be entering the traffic.

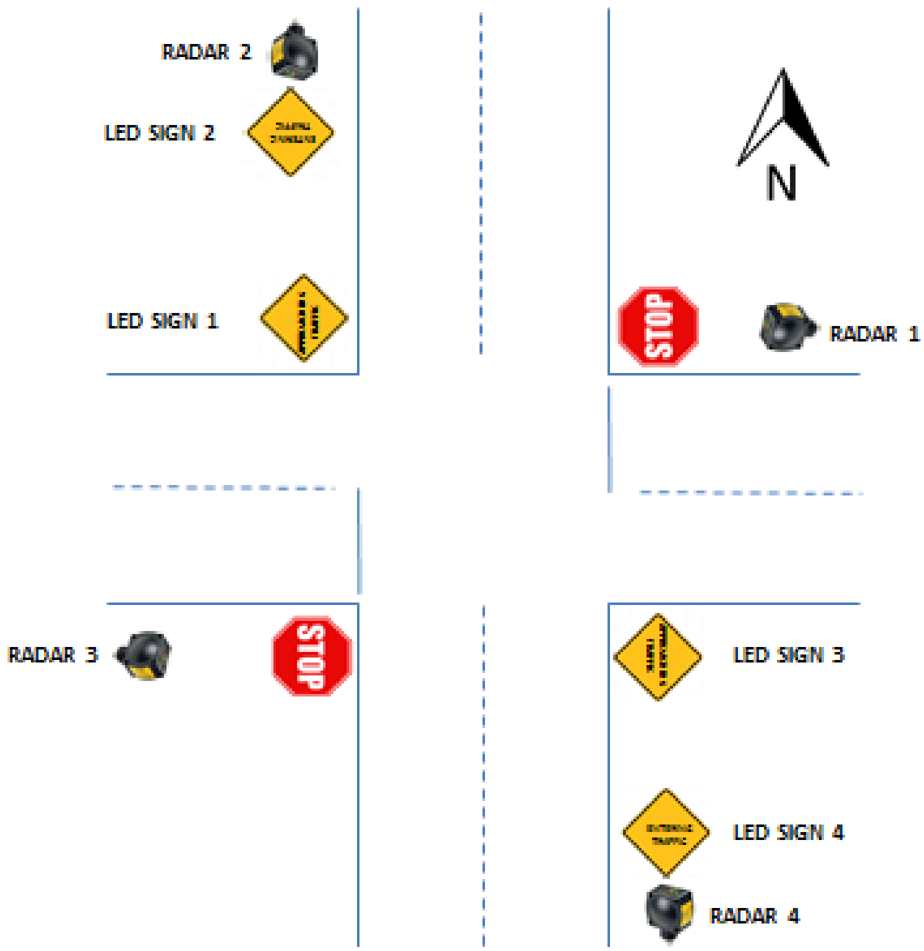

Figure 4: ICWS intersection

Video data were collected at each location before and after installation of the ICWS. An array of video trailers/cameras were used and video collected at each intersection for one week during the before period and one week during the after period. The cameras were recording the intersection continuously for the week period, which required an effective answer to video storage. With the video recording process lasting a week at a time, and multiple sites throughout the state of Minnesota, a decision was made to find a camera to be moved between locations. The solution to these problems came through Live View Technologies in supplying mobile cameras on trailers. Figure 5 displays the trailer with the camera set up and Figure 6 displays the trailer ready to be moved.

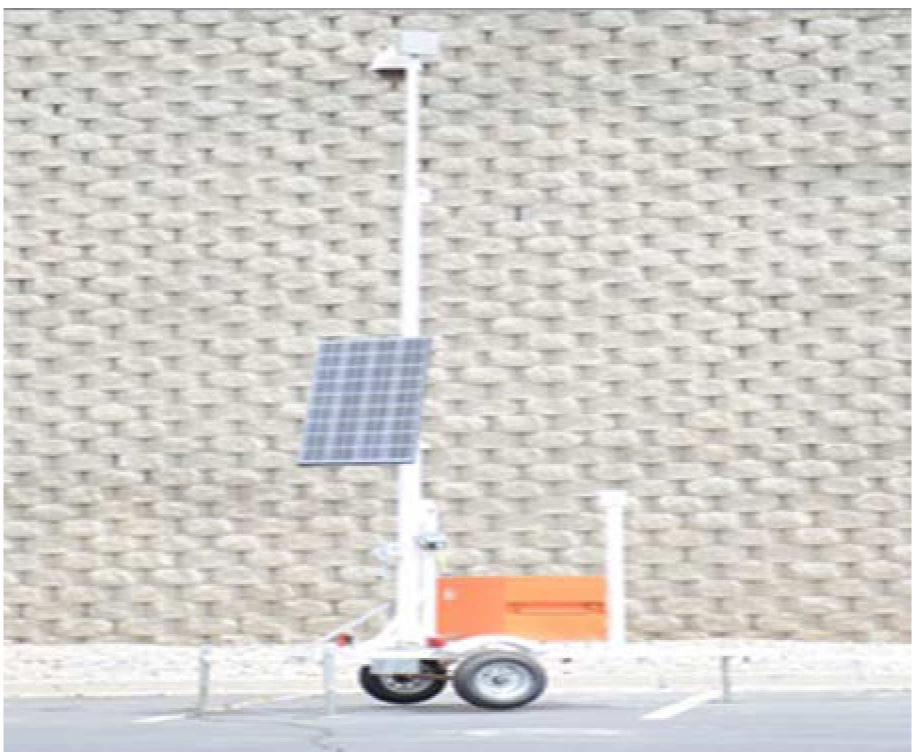

Figure 5: Mobile camera trailer set up (Live View Technologies, 2014.)

Figure 6: Mobile camera trailer (Live View Technologies, 2014.)

Live View Technologies mobile can be utilized in many situations. The wheels made the cameras portable and easily moved with a pickup and driven to their final location for viewing in most cases. Adjustable base legs allowed the trailer to be leveled on uneven ground, which was in a ditch most times for this project. Another useful feature is the ability to raise the camera up to 25 feet to gain better sight of an intersection. The trailer camera has pan, tilt, and zoom capabilities, which allow any area of the intersection to be seen. Most importantly, solar power can be captured and used to operate the camera and wireless internet connection. The camera mast also provides an ideal location to attach the solar panel. Immediately after a camera is turned on, a user can see and alter the camera view online in real time. With the use of removable memory, video was saved and downloaded after the week of data collection is finished.

Each intersection utilizes four cameras to make all approaches available for viewing. The camera setup at the intersection of MN47 and County Road 8 in Isanti County is displayed in Figure 7. The camera layout of the other 3 intersections are found in Appendix A. Cameras T63 and T64 are mobile trailer cameras in the ditch of MN47. These cameras are used to view all aspects of the intersection. The vehicles approaching the stop signs are visible and the videos from these cameras are used to determine the stopping motions of the vehicles and the gaps between cars on MN47. In addition to the two mobile trailer cameras, each intersection utilizes two post-mounted cameras. These cameras are identical to the ones used on the trailer but are attached to a post in the ground at approximately the same height as vehicle windows. The cameras are facing the vehicles stopped at the stop sign in an attempt to see what the drivers are looking at while they are stopped.

Figure 7: Isanti treatment intersection camera layout

3.2.2 Data Reduction

The number of vehicles traveling through each intersection daily was several thousand. All data reduction was completed manually for this research. Consequently it was not feasible to reduce information for every vehicle on the stop controlled approaches. A method for randomly selecting a subset of vehicles was developed. A random fifteen-minute segment was selected from each daytime hour (the options for the 8 o'clock hour were 8:00-8:15, 8:15-8:30, 8:30-8:45, and 8:45-9:00). Data were not reduced during the nighttime since the intersections were not illuminated and it was difficult to view vehicles. Once a 15-minute segment was selected, data were reduced for the first five eligible vehicles. A vehicle was considered eligible if it was a vehicle in "normal flow" to the stop sign. This study was most interested in vehicles approaching the intersection without vehicles stopped ahead of them, so vehicles queued were not recorded. Each hour had five vehicles reduced, unless there were less than five eligible vehicles, in which case the number of vehicles eligible was the number of vehicles reduced.

Several pieces of data were reduced for each vehicle, some of which were not necessary for this research but were collected for other research. Each vehicle was assigned a unique ID. The location of the vehicle within the video datasets was recorded so the vehicle could be easily found later if needed. The file name consists of 20 numbers and a letter in "########_############_X" format. The first eight numbers are unique to the video while the last twelve digits describe the time at the start of video in YY/MM/DD HH:MM:SS format. The date and time at video beginning are also input into the data.

The time the vehicle arrived and departed the stop sign were recorded. The arrival time is defined as when the vehicle comes to a complete stop. If the vehicle never completely stops, the arrival time is considered when the nose of the vehicle crosses the stop bar. Departure time was defined as the time when the nose of the vehicle first crosses the outside painted lane line, and into the traveled way. An example of this can be seen in Figure 9, at the intersection of MN7 & Co6 in Chippewa County. With the arrival and departure time entered, the duration between times was calculated.

	File Name	mm/dd/yyyy	Universal Time	Video Time	Video Time	Video Time
			(hh:mm:ss)	(hh:mm:ss)	(hh:mm:ss)	(mm:ss)
	Time					
ID	File Name	Date	Time of day at video beginning	Arrival Time (Video)	Departure Time	Duration

Figure 8: Vehicle time characteristics

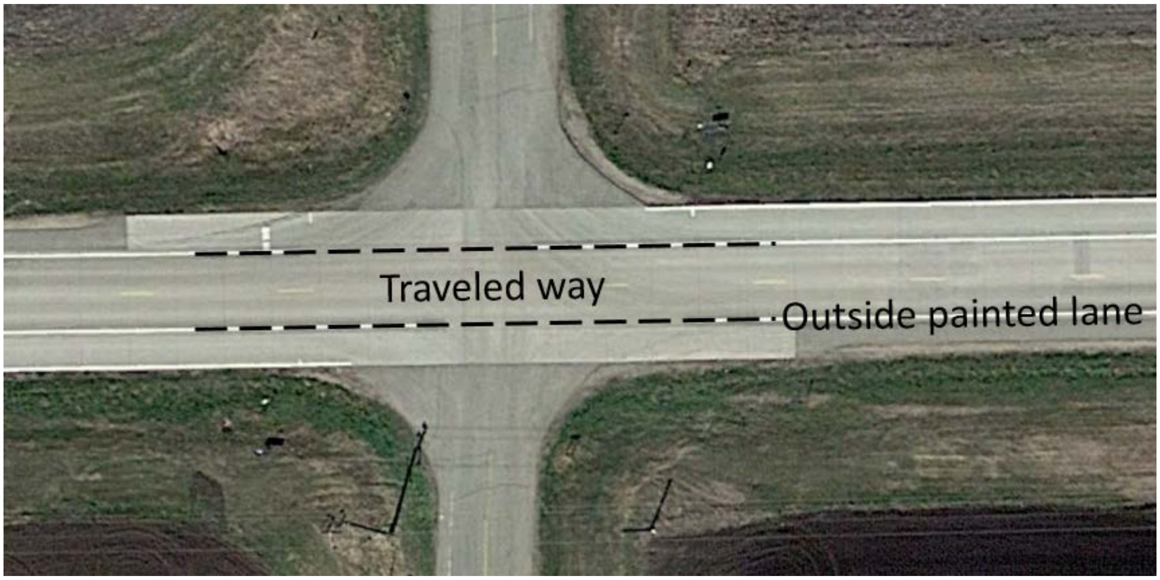

Figure 9: Departure time location (Google Maps. Google, 2015)

The next group of data reduced relates to vehicle identification and stopping movement. The vehicle type was recorded with the following options:

- motorcycle
- passenger car

- minivan or sports utility vehicle
- pickup
- bus
- heavy trucks
- farm vehicles
- other

A note was taken if a vehicle was pulling a trailer as well. The color of the vehicle was the next information recorded (to assist in identifying the vehicle later if needed). The next piece of information logged was the turning movement and type of stop of the vehicle. Four classifications were used for type of stop. A complete stop consists of a vehicle making a clear and defined stop. The next few terms have a small amount of ambiguity. Slow rolling is considered when a vehicle has clear braking at the stop sign but never comes to a complete stop. This is roughly equivalent to slowing to five miles per hour or less without stopping. The next level of stopping is defined as fast rolling. This involves clear braking but never completely stopping and going through the stop sign faster than a slow roll. Fast rolling approximately equates to driving between five and fifteen miles per hour at the stop sign. The final term for type of stop is no slow. This involves the lack of clear braking at the stop sign and driving through the stop sign at more than 15 to 20 miles per hour. In addition to type of stop, the location of stopping was recorded. If the vehicle made a complete stop, where that vehicle stopped in relation to the stop bar was recorded.

Vehicle Type	Color	Turning Movement	Type of Stop	Stop Location
Vehicle				
1:Motorcycle	i.e.red	1:Left	1:Complete Stop	1:Before stop bar
2:Passenger Car	black	2:Through	2:Slow Rolling (Clear Braking)	2:At stop bar
3:Minivan/SUV		3:Right	3:Fast Rolling (Cruise Pass)	3:After stop bar
4:Pickup			4:No Slow	4: Non-stop
5: Buses				
6: Trucks				
7: Farm vehicle/others				
(Add letter "T" as trailor)				

Figure 10: Vehicle and stopping classification

Next, the intersection collision warning system status and conflicts were recorded. The approach leg of the vehicle was recorded. The next piece of data reduced is the status of the warning system. The status of the blinking LED lights is recorded, whether they are blinking or not at arrival to the stop sign as well as departure into the intersection. This was only reduced when the ICWS was present. This indicates whether a vehicle was approaching on the major roadway. These columns of data only apply to the treatment sites after installation. The following two columns describe if there is a conflict at the intersection. If there is a near collision, vehicle acting strangely, or a pedestrian at the intersection, the situation is described.

Intersection Leg	ICWA Status at Arrival	ICWA Status at Departure	Conflicts	Conflict Comments
Conflict Type				
1:North Leg	1:Activated	1:Activated	1:No	Description of conflicts
2:East Leg	2:Unactivated	2:Unactivated	2:Yes	(indicate if there are pedestrians or bicyclists)
3:South Leg	3:Unknown	3:Unknown		
4:West Leg				

Figure 11: Warning system status and conflicts

Ambient conditions were also recorded. This starts with the weather during the video. Nearly all video occurred during sunny or cloudy conditions, but some periods had rain or fog. Due to the time of the video recording, no snow conditions were experienced.

Time of day was also recorded. Daytime is considered to be from sunrise to sunset. For the sake of this research, dawn is the period between the start of civil twilight and sunset, as determined by www.timeanddate.com. Similarly, dusk is the time from sunset to the end of civil twilight. The period from dusk until dawn is considered nighttime. The differentiation between an intersection with and without artificial light is also included. Generally, the quality of video during nighttime hours was of very poor quality and no information was able to be collected. Finally, the pavement surface is described. The roadway is considered wet if there is water draining. In most other cases, the roadway is measured as dry, since there were not any snow conditions.

1:Sunny	1:Daytime	1:Dry
2:Cloudy	2:Dawn/dusk	2:Wet
3:Rain	3:Nighttime-lighitng	3:Snow
4:Snow	4:Nighttime-no lighting	
5:Fog		
Roadway Enironment		
Weather	**Lighting Condition**	**Pavement Surface**

Figure 12: Environmental conditions

The final group of data reduced is related to gaps between vehicles on the major roadway. The first piece of information recorded is the accepted gap. If there are no rejected gaps, this is the period from the arrival time to the time when a vehicle on the major roadway crosses the intersection. If a gap is accepted between two vehicles, the accepted gap is considered to be the time from the first vehicle crossing the intersection to the next vehicle crossing the intersection. Once a gap reached twenty-one seconds, the gap was considered 20+ seconds to prevent determining very large gaps that do not effect a drivers' decision to enter the intersection. It was considered important to note if two vehicles were stopped at the intersection side by side. Most of these situations were eliminated with the determination of “eligible” vehicles. Another special situation tracked is when there was a platoon of vehicles approaching on the major roadway. A platoon is considered to be three or more vehicles with a three second or less gap between each vehicle. The rejected gap duration is found similar to accepted gap expect that the identified vehicle at the stop sign does not enter the intersection. In addition to the gap duration, the direction of the vehicle is also recorded. In Figure 14, the east and west legs were stop-controlled. In the event of an intersection with stop signs on the north and south approaches, the left and right turn options will be attached to the eastbound and westbound options.

Second	A Neighboring Vehicle Exists	Number of Vehicle in Plooton
20+	0: No	>=3
	1: Yes	
Gap		
Accepted Gap	**Neighboring Vehicle**	**Vehicle Plooton**

Figure 13: Accepted gap and intersection conditions

count	Second	1:Northbound
		2:Northbound-left
		3:Northbound-right
		4:Southbound
		5:Southbound-left
		6:Southbound-right
		7:Eastbound
		8:Westbound
Gap		
Number of Rejected Gap	**Rejected Gap1**	**Rejection Direction 1**

Figure 14: Reject gap conditions

3.2.3 Isanti Data

The before video was captured from September 5, 2014 through September 11, 2014 in Isanti County. A summary of all dates of video capture can be found in Appendix

B. During the recording of video, a malfunction caused nearly two days of video to be lost at the treatment site, the intersection of MN47 & Co8. In total, 270 vehicles were viewed and reduced at the Isanti treatment intersection. Passenger cars account for the highest percent of vehicle classification with 38.5% (104 of 270). Minivans/SUVs and pickups make up most of the rest of the vehicles with 28.5% and 24.4%, respectively. This location does not see a large amount of heavy traffic, with only 5.9% of traffic classified as heavy trucks. Of the measured vehicles, approaching the stop sign, 67.8% encountered an initial gap of twenty seconds or less. This is an interesting number to look at because it describes the percentage of vehicles that must make a decision based on oncoming traffic. Half of all vehicles (135 of 270) accepted a gap that was twenty seconds or less.

Four hundred thirteen vehicles were reduced from the control location, the intersection of MN47 & Co5, during the before period. Passenger cars accounted for 44.3% of measured vehicles (183 of 413) at the control intersection during the before period. 111 of the 413 vehicles (26.9%) were in the minivan and SUV category. Pickup trucks account for the third highest portion of vehicles with 18.4%. This site has a smaller heavy truck usage on its minor roadway, with 12 of the 413 vehicles classified as a heavy vehicle (2.9%). The remaining 7.5% of vehicles consists of motorcycles, bus, and trailer-carrying vehicles. Of the measured vehicles, approaching the stop sign, 56.4% encountered an initial gap of twenty seconds or less and 35.8% of all vehicles (85 of 413) accepted a gap that was twenty seconds or less.

The recording of the after video in Isanti County took place from May 6, 2015 to May 13, 2015. In total, 508 vehicles were viewed and reduced at the Isanti treatment site, MN47 & Co8. Passenger cars account for the highest percent of vehicle classification with 33.5% (170 of 508). Minivans/SUVs and pickups make up most of the rest of the vehicles with 28.1% and 23.8%, respectively. There was a slight increase in the number of heavy vehicles at this site compared to the before data. The amount of heavy trucks increased from 5.9% to 8.1%. This is a decent rise but does not raise any concerns. Of the measured vehicles, approaching the stop sign, 71.0% encountered an initial gap of twenty seconds or less and slightly more than half of all vehicles (262 of 504) accepted a gap that was twenty seconds or less.

Four hundred ninety vehicles were reduced from the control location, MN47 & Co5, during the after period. Passenger cars account for 36.9% of measured vehicles (181 of 490) at the control intersection during the before period. 139 of the 490 vehicles (28.4%) were in the minivan and SUV category. Pickup trucks account for the third highest portion of vehicles with 23.9%. Heavy vehicles make up 4.1% of measured vehicles on the minor roadway at this site. Of the measured vehicles, approaching the stop sign, 52.9% encountered an initial gap of twenty seconds or less and 36.3% of all vehicles (178 of 490) accepted a gap that was twenty seconds or less. A summary of vehicle data in Isanti County can be seen in Table 1.

Table 1: Isanti County Vehicle Summary

Isanti County	Treatment, Before	Control, Before	Treatment, After	Control, After
Vehicles	270	413	508	490
Car %	38.5	44.3	33.5	36.9
Minivan/SUV %	28.5	26.9	28.1	28.4
Pickup %	24.4	18.4	23.8	23.9
Heavy Truck %	5.6	2.9	8.1	4.1
Initial gap ≤ 20 s	67.8	56.4	71.0	52.9
Accepted gap ≤ 20 s %	50.0	35.8	52.0	36.3

3.2.4 Chippewa Data

The data gathered in Chippewa County contains a control location on a rural highway outside of Montevideo, Minnesota, to the east. The treatment site is located at the intersection of MN7 & Co15 on the west side of Montevideo, in an area with more businesses and residential houses. The before data collection period occurred from August 19, 2014 through August 25, 2014. A summary of all dates of video capture can be found in Appendix B. During this period, 424 vehicles were reduced from the treatment location. The Chippewa locations experienced a near even split between passenger cars, minivans and SUVs, and pickup trucks. The vehicle group with the highest percentage is minivans and SUVs with nearly one-third of the vehicles (140 of

424). Passenger car is the next highest vehicle group with 29.7% and pickup trucks account for 26.4% of vehicles recorded. A low number of heavy trucks make up the minor traffic, with 5.2% of vehicles at the treatment location. Of the measured vehicles, approaching the stop sign, 28.8% encountered an initial gap of twenty seconds or less and only 17.2% accepted a gap that was twenty seconds or less. This varies greatly from the Isanti sites.

Two hundred fifty-six vehicles were reduced from the intersection of MN7 & Co6, the control location, during the before period. During a period of time, the view of a camera was changed, losing video of the intersection for a large period of time. Passenger cars account for 29.7% of measured vehicles (76 of 256) at the control intersection during the before period. 70 of the 256 vehicles (27.3%) were in the minivan and SUV category. Pickup trucks account for the third highest portion of vehicles with 25.0%. This site has a larger heavy truck usage on its minor roadway, with 26 of the 256 vehicles classified as a heavy vehicle (10.2%). Of the measured vehicles, approaching the stop sign, 56.3% encountered an initial gap of twenty seconds or less and 31.3% of all vehicles (80 of 256) accepted a gap that was twenty seconds or less.

The recording of the after video in Chippewa County took place from April 28, 2015 to May 5, 2015. In total, 495 vehicles were viewed and reduced at the Chippewa treatment intersection, MN 7 & Co15. Minivans and SUVs account for the highest percent of vehicle classification with 30.7% (152 of 495). Pickup trucks and passenger cars make up most of the rest of the vehicles with 30.5% and 25.1%, respectively. There was a small increase in the number of heavy vehicles at this site compared to the before data. The amount of heavy trucks increased from 5.2% to 5.7%. Of the measured vehicles, approaching the stop sign, 33.5% encountered an initial gap of twenty seconds or less and 21.4% of vehicles (106 of 495) accepted a gap that was twenty seconds or less.

Four hundred fifty-four vehicles were reduced from the intersection of MN7 & Co6, the control location, during the after period. Minivans and SUVs account for 28.4% of measured vehicles at the control intersection during the after period. 127 of the 454 vehicles (28.0%) were in the passenger car category. Pickup trucks account for the third highest portion of vehicles with 24.9%. With 9.5% of vehicles recorded and reduced being heavy trucks, there is little difference compared to the before period at the control site. Of the measured vehicles, approaching the stop sign, 58.8% encountered an initial gap of twenty seconds or less and 39.2% of all vehicles (178 of 454) accepted a gap that was twenty seconds or less. A summary of vehicle data in Chippewa County can be seen in Table 2.

Table 2: Chippewa County Vehicle Summary

Chippewa County	Treatment, Before	Control, Before	Treatment, After	Control, After
Vehicles	424	256	495	454
Car %	29.7	29.7	25.1	28.0
Minivan/SUV %	33.0	27.3	30.7	28.4
Pickup %	26.4	25.0	30.5	24.9
Heavy Truck %	5.2	10.2	5.7	9.5
Initial gap ≤ 20 s %	28.8	56.3	33.5	58.8
Accepted gap ≤ 20 s %	17.2	31.3	21.4	39.2

CHAPTER 4: A STUDY OF INTERSECTION COLLISION WARNING SYSTEM EFFECTIVENESS IN MINNESOTA

4.1 INTRODUCTION

The following sections summarize several different analyses which were conducted to evaluate the intersection collision warning system utilized by the Minnesota Department of Transportation at select two-way stop-controlled intersections. The first analysis looked at the vehicles approaching the stop sign on the minor roadway approaches. Stopping behavior was modeled from two perspectives: type of stop and location of stop. These analyses were used to determine if the system changed the drivers stopping characteristics at the stop sign.

The second analysis evaluated driver gap acceptance before and after installation of an ICWS. A treatment location and control site were examined for each location in order to compare results. The results are observed as a percentage of gap acceptances for different gap duration groups.

4.2 STOPPING STUDY

The following section evaluated the effectiveness of the intersection collision warning system in stopping vehicles. Past warning systems experienced an increase in vehicles rolling through the stop sign during non-conflicts after installation of the warning system (Kwon et. al, 2010). To look at this problem, the percentage of vehicles rolling through the stop sign was analyzed across four locations. In addition, for vehicles that came to a complete stop, the location of stopping was examined to look for changes.

4.2.1 Type of Stop Study

4.2.1.1 Introduction

This analysis evaluated changes in stopping characteristics before and after system installation. The study looks at four intersections, two of which are sites that installed a warning system, and two sites that are located near the installation sites. The before video was recorded approximately 8 months prior to the after video.

4.2.1.2 Methodology

A before and after analysis was conducted to measure the change in complete stop and rolling stop rates. This was done across the before period to the after period for two treatment sites and two control sites. The data were first reduced as described in chapter 3. After the data were reduced, the complete stop rate and rolling stop rate for each period was calculated. The complete stop rate was completed using Equation 4-1. The rolling stop rate was completed using Equation 4-2.

$$complete\ stop\ rate = \frac{total\ number\ of\ vehicles\ performing\ complete\ stop}{total\ number\ of\ vehicles\ approaching\ stop\ sign} \times 100$$ **Equation 4-1**

$$rolling\ stop\ rate = \frac{total\ number\ of\ complete\ stop + total\ number\ slow\ rolling}{total\ number\ of\ vehicles\ appraching\ stop\ sign} \times 100$$

Equation 4-2

Complete stop rate and rolling stop rate were calculated for each intersection and stage. The changes in rate between each after period and the before period were then found.

4.2.1.3 Analysis

A test of proportions was used to determine if the changes in complete stop rate and rolling stop rate were statistically significant. This test was performed using Equation 4-3 in order to calculate a Z test statistic. The $\hat{\pi}_1$ term in this equation represents the stopping rate in the before period. Furthermore, n_1 represents the total number of vehicles approaching the stop sign during the before period. In this equation, $\hat{\pi}_2$ represents the stopping rate in the after period and n_2 represents the total number of vehicles approaching the stop sign during the after period.

$$Z = \frac{(\hat{\pi}_1 - \hat{\pi}_2)}{\sqrt{\frac{\hat{\pi}_1(100 - \hat{\pi}_1)}{n_1} + \frac{\hat{\pi}_2(100 - \hat{\pi}_2)}{n_2}}} \quad \textbf{Equation 4-3}$$

This Z test statistic was then compared to a Z table using α = 0.10 in order to determine significance at 90% confidence. Therefore, if Z was greater than 1.28 the resulting decrease in stopping rate was statistically significant and if Z was less than -1.28 then the increase in stopping rate was statistically significant.

4.2.1.4 Results

Overall, the warning system appeared to increase the stopping rate at the intersections of installation. However, the control sites appeared to see a decrease in the stopping rate.

Results for stopping rates can be seen in Table 2 and Table 3 with statistically significant changes in bold. Increases are numbers in blue and decreases are listed in red.

This scheme of bold to illustrate statistical significance is used throughout this chapter and the use of color is continued for the stopping study results.

The treatment sites experienced a significant increase in stopping rate after the installation of the ICWS. In Chippewa, the stopping rate sees an increase by 5.26% after installation with similar sample sizes. The Isanti location had a similar change in stopping rate, with an increase by 4.88%. In the case of Isanti, however, a malfunction caused video to be lost, and the before sample size is almost half of the after sample size.

Table 3: Treatment Stopping Rate Changes

	Chippewa Before	Chippewa After	Isanti Before	Isanti After
Stopping Rate (per 100 vehicles)	28.07	33.33	46.30	51.18
Sample Size	424	495	270	508
Change in Stopping Rate		**5.26**		**4.88**

The control sites in Chippewa and Isanti Counties experienced a decrease in stopping rate after installation of the warning system at a nearby intersection. The decrease in Chippewa County was statistically significant while the decrease in Isanti County was not statistically significant. The before data in Chippewa County had slightly more than half the sample size as the after data. The sample sizes in Isanti County were similar but the difference in stopping rate was less than 2%.

Table 4: Control Stopping Rate Changes

	Chippewa Before	Chippewa After	Isanti Before	Isanti After
Stopping Rate (per 100 vehicles)	48.05	44.27	44.55	42.86
Sample Size	256	454	413	490
Change in Stopping Rate		**-3.78**		-1.69

In addition to the stopping rate, the "slowing rate" was analyzed for the same data. The slowing rate was determined by adding the stopping rate and the percentage of vehicles that slowly roll through the stop sign. While stopping is certainly the ideal for all vehicles, limiting the number of vehicles that do not stop or slow down at the intersection is also a goal.

The two treatment sites both experienced statistically significant changes in slow rate. Chippewa County saw a significant increase in slow rate while Isanti County had a significant decrease in slow rate. Each intersection experienced a change in slow rate by approximately 3%. While the sample sizes of the Chippewa intersections were similar, the Isanti before period had near half the samples as the after period.

Table 5: Treatment Slowing Rate Changes

	Chippewa Before	Chippewa After	Isanti Before	Isanti After
Slowing Rate (per 100 vehicles)	93.16	96.16	92.59	89.57
Sample Size	424	495	270	508
Change in Slowing Rate		**3.00**		**-3.02**

Both control intersections saw a decrease in slowing rate after installation of an ICWS at a nearby intersection. While the Chippewa control site had an insignificant decrease in slowing rate, the control site in Isanti County experienced a significant decrease of nearly 4%. Again, the Chippewa before data had nearly half the sample size compared to the Chippewa after data.

Table 6: Control Slowing Rate Changes

	Chippewa Before	Chippewa After	Isanti Before	Isanti After
Slowing Rate (per 100 vehicles)	96.09	95.37	96.85	92.86
Sample Size	256	454	413	490
Change in Slowing Rate		-0.72		**-3.99**

The results of the stopping rate study at the treatment locations are encouraging but as expected. This confirms past studies that the system will increase the number of vehicles that stop at intersection with ICWS installation. The results at the control locations are somewhat alarming, with both sites seeing a decrease in stopping rate. In the case of MN7 & Co6, the Chippewa control site, the significant decrease in stopping rate may be attributed towards the large difference in sample size between the before and after data. This location also has an unobscured sight view from all angles of the intersection, which could play a role in vehicles not slowing down while approaching the stop sign.

The results of the slowing rate study are surprising in that Chippewa County's treatment site, MN7 & Co15, had a significant increase while Isanti County's treatment site, MN47 & Co8, had a significant decrease. This suggests that a larger percentage of vehicles "fast roll" or don't slow at the stop sign after the collision warning system is installed. The slowing rate at control sites seem to act similarly to the stopping rates at control sites after installation. Chippewa County did not exhibit a significant change in slowing rate but Isanti County displayed a similar change in slowing rate as stopping rate. It appears that surrounding factors of the intersections in Chippewa County lead more vehicles to respond to the system by slowing down while the intersections in Isanti County lead vehicles to go through the stop sign.

4.2.2 Location of Stop Analysis

4.2.2.1 Introduction

In addition to the rate at which the vehicles stop and slow at the stop sign, a study of the location at which vehicles stopped was also performed. This was done in order to determine if the system provided greater warning to drivers to allow them to stop before entering the traveled way. In the before videos, it was observed that many vehicles approached the stop sign and were required to rapidly brake if a vehicle was approaching on the major roadway. The goal of this study is to determine if the advanced warning of approaching traffic helps to limit the number of vehicles that stop near the traveled way. Since there were three characteristics in reducing where vehicles stopped, the vehicles stopping behind the stop bar and the vehicles stopping at the stop bar were combined. Also, since this study only looked at vehicles that came to a complete stop, the sample sizes were smaller than the stopping rate study.

4.2.2.2 Methodology

Similar to the stopping study, a before and after study was conducted to measure the change in location of stopping. This was done across the before period to the after period for two treatment sites and two control sites. The data were first reduced as described in chapter 3. After the data were reduced, the rate at which the vehicle stopped at or before the stop bar (stop at bar rate) for each period was calculated. To be considered as stopping before the stop bar, the vehicle was required to stop within one car length (about 20 feet) of the stop bar. The stop at bar rate was completed using Equation 4-4.

$$stop\ at\ bar\ rate = \frac{total\ number\ of\ stop\ at\ bar + total\ number\ of\ stop\ before\ bar}{total\ number\ of\ complete\ stop} \times 100$$

Equation 4-4

Stop at bar rate was calculated for each intersection and stage. The changes in rate between each after period and the before period were then found.

4.2.2.3 Analysis

A test of proportions was used to determine if the changes in stopping location were statistically significant. This test was performed using Equation 4-3 from earlier in Chapter 4 in order to calculate a Z test statistic. The $\hat{\pi}_1$ term in this equation represents the stop at bar rate in the before period. Furthermore, n_1 represents the total number of complete stops during the before period. In this study, $\hat{\pi}_2$ represents the stop at bar rate in the after period and n_2 represents the total number of complete stops during the after period.

This Z test statistic was then compared to a Z table using α = 0.10 in order to determine significance at 90% confidence. Therefore, if Z was greater than 1.28 the resulting decrease in stop at bar rate was statistically significant and if Z was less than -1.28 then the increase in stop at bar rate was statistically significant.

4.2.2.4 Results

Generally, the rate at which drivers stopped at or before the stop bar increased from the before period to the after period. Results from the study at all intersections can be seen in Tables 7 and 8. The same color scheme and bolding significant statistics is continued from earlier.

The treatment site in Chippewa County experienced a significant decrease in stop bar rate. The sample size of the before data in Chippewa was significantly smaller than the after data, with approximately 38% the number of vehicles sampled. Isanti County experienced a significant increase in stop at bar rate, with a 9.27% increase. The sample size of before data was approximately half of the after sample size.

Table 7: Treatment Stop at Bar Rate Changes

	Chippewa Before	Chippewa After	Isanti Before	Isanti After
Stop At Bar Rate (per 100 vehicles)	48.39	33.94	11.72	20.99
Sample Size	62	165	128	262
Change in Stop at Bar Rate		**-14.45**		**9.27**

Both control intersections experienced a significant increase in stop at bar rate after installation of the warning system. Chippewa County saw an increase of 12.21% in rate of stopping at or before the stop bar. Isanti also had a significant increase in stop at bar rate with near equal sample sizes.

Table 8: Control Stop at Bar Rate Changes

	Chippewa Before	Chippewa After	Isanti Before	Isanti After
Stop At Bar Rate (per 100 vehicles)	33.06	45.27	11.60	19.52
Sample Size	124	201	181	210
Change in Stop at Bar Rate		**12.21**		**7.92**

The dramatic difference in results between treatment intersections is quite surprising. The results from MN47 & Co8, the Isanti County treatment site, are what is expected from system installation. This result means that a greater percentage of vehicles that stop do so at or before the stop bar. The results for MN7 & Co15, Chippewa County treatment site, completely oppose these results. In this instance of MN7 & Co15, a larger number of vehicles that stop do so after the stop bar. These vehicles are stopping closer to the major road traveled way and are at a higher risk for crashes. One item of notice is that the overall number of vehicles that are coming to a complete stop increases significantly for both treatment locations. While the increases aren't as dramatic, the control locations also see a rise in the total number of stops.

4.3 GAP ACCEPTANCE Analysis

4.3.1 Introduction

This analysis evaluated changes in gap size selection between before and after system installation. The study looks at four intersections, two of which are sites that installed a warning system, and two sites that are located near the installation sites. This study was performed to determine if the warning system reduces the number of small gaps accepted.

4.3.2 Methodology

A before and after study was conducted to measure the change in gap rejection rates. The data were first reduced as described in chapter 3. After the data were reduced, the gaps were grouped into different time sets. Then the gap rejection rate for each period was calculated. The gap rejection rate was completed using Equation 4-5.

$$gap\ rejection\ rate = \frac{total\ number\ of\ gaps\ rejected\ in\ time\ set}{total\ number\ or\ gaps\ rejected + total\ number\ of\ gaps\ accepted} \times 100$$

Equation 4-5

The gap rejection rate was calculated for each intersection and stage. The changes in rate between each after period and the before period were then found.

4.3.3 Analysis

A test of proportions was used to determine if the changes in stopping location were statistically significant. This test was performed using Equation 4-3 from earlier in Chapter 4 in order to calculate a Z test statistic. The $\hat{\pi}_1$ term in this equation represents the gap rejection rate in the before period. The total number of gaps during the before period is represented by n_1 . In this study, $\hat{\pi}_2$ represents the gap rejection rate in the after period and n_2 represents the total number of gaps during the after period.

This Z test statistic was then compared to a Z table using $\alpha = 0.10$ in order to determine significance at 90% confidence. Therefore, if Z was greater than 1.28 the resulting decrease in rejection rate was statistically significant and if Z was less than -1.28 then the increase in gap rejection rate was statistically significant.

4.3.4 Results

In general, there is little correlation between the changes in rejection rate across the different study sites. Results for gap rejection rates can be seen in Tables 9 to 12 with statistically significant changes in bold. The grouping of gaps was determined by 4-second increments. In addition to those time groups, 2-second increments were also included during periods where gap selection is critical.

The results of the gap rejection analysis in Chippewa County at the treatment location are in Table 8. The only 4-second interval that had a significant change in rejection rate was a gap of 13-16 seconds. This interval had a 7.4% reduction in rejection rate. For the 2-second intervals, a gap of 5-6 seconds had a significant 31.2% reduction in rejection rate. The before data for this site had a small sample size for shorter 4-second intervals and all 2-second intervals.

Table 9: Chippewa Treatment Gap Rejection Rate Changes

Gap rejection rate (per 100 vehicles)	Chippewa Before	Chippewa After	Change in Reject Rate
1-4 seconds	100	100	0
5-8 seconds	62.5	51.3	-11.2
9-12 seconds	7.1	7.7	0.6
13-16 seconds	7.4	0	**-7.4**
17-20 seconds	0	3.7	3.7
5-6 seconds	100	68.8	**-31.2**
7-8 seconds	40.0	39.1	-0.9
9-10 seconds	16.7	10.0	-6.7
11-12 seconds	0	5.3	5.3

The Isanti treatment location displayed a clear pattern in the reject rate changes. During the early four-second intervals (1-4 seconds and 5-8 seconds), the change in rejection rate significantly decreases. Additionally, the later four-second intervals (13-16 seconds and 17-20 seconds), had a significant increase in rejection rate. This pattern also applied to the early and late two-second intervals, however, these changes in rejection rates were not significant.

Table 10: Isanti Treatment Gap Rejection Rate Changes

Gap rejection rate (per 100 vehicles)	Isanti Before	Isanti After	Change in Reject Rate
1-4 seconds	100	96.2	**-3.8**
5-8 seconds	68.2	58.8	**-9.4**
9-12 seconds	17.5	23.4	5.9
13-16 seconds	0	9.1	**9.1**
17-20 seconds	0	7.1	**7.1**
5-6 seconds	81.8	71.4	-10.4
7-8 seconds	54.5	45.1	-9.4
9-10 seconds	17.9	25.0	7.1
11-12 seconds	17.2	20.9	3.7

The change in rejection rate at the Chippewa County control site was not significant for any time interval. There was a 10.9% decrease in rejection rate during the 1-4 seconds interval in Chippewa County. Every other time increment experienced an increase in rejected rate after installation, although no changes were significant.

Table 11: Chippewa Control Gap Rejection Rate Changes

Gap rejection rate (per 100 vehicles)	Chippewa Before control	Chippewa After	Change in Reject Rate
1-4 seconds	100	89.1	-10.9
5-8 seconds	56.0	66.2	10.2
9-12 seconds	22.2	23.0	0.8
13-16 seconds	4.2	7.1	2.9
17-20 seconds	5.3	7.1	1.8
5-6 seconds	64.3	75.0	10.7
7-8 seconds	45.5	57.9	12.4
9-10 seconds	26.3	27.0	0.7
11-12 seconds	17.6	18.9	1.3

The changes in rejection rate at the control site in Isanti County are significant for most gap intervals. All vehicles reject gaps up to 4 seconds for before and after installation. Other than that interval, all other time groups experience a decrease in rejection rate, and most of the changes are significant.

Table 12: Isanti Control Gap Rejection Rate Changes

Gap rejection rate (per 100 vehicles)	Isanti Before	Isanti After	Change in Reject Rate
1-4 seconds	100	100	0
5-8 seconds	84.0	38.4	**-45.6**
9-12 seconds	37.7	14.3	**-23.4**
13-16 seconds	18.6	0	**-18.6**
17-20 seconds	2.1	0	-2.1
5-6 seconds	92.7	52.5	**-40.2**
7-8 seconds	71.8	26.1	**-45.7**
9-10 seconds	45.2	12.1	**-33.1**
11-12 seconds	30.3	16.7	-13.6

The overall results of the gap rejection study was more or less inconclusive. It appears that the results of these studies is dependent on the individual intersection characteristics. Many of the time intervals yielded inconclusive results. With a larger number of vehicles examined there may be an opportunity to collect more definitive results. The biggest concern comes from both sites in Isanti County. At MN47 & Co8, the treatment site, a higher percentage of drivers accept the smaller, more dangerous, gaps after the system is installed. In addition, a smaller percentage of drivers accept the larger, less dangerous, gaps after the installation of the ICWS. At MN47 & Co5, the control site, a higher percentage of drivers accept gaps, throughout all gap lengths. While it is concerning that the installation of the collision warning system leads to the lower gap rejection, the insignificant results at both Chippewa sites show that the results aren't universal.

CHAPTER 5: SUMMARY AND CONCLUSIONS

5.1 GENERAL CONCLUSIONS

This thesis evaluated the intersection collision warning system installed at select two-way stop-controlled intersections in Minnesota. Initial video was recorded during fall of 2014 and after video was recorded in spring of 2015 shortly after installation of the system. In addition to sites where a system is installed, a similar intersection near installation was also studied in order to observe how the new system effects driving patterns. This study looks at the effectiveness of the ICWS at stopping and slowing down drivers at the stop-controlled approach. The study also analyzes changes in gap selection of drivers after system installation.

The type of stop study found a significant increase in complete stop rate at both treatment intersections. This is an ideal result for these sites, and supports the results from the ALERT-2 research conducted by the Minnesota DOT (Kwon et. al, 2014). One cause for concern is the finding that both control sites experienced a decrease in complete stop rate, with one location having a significant decrease. While the complete stop rate had conclusive results, the outcome of the slowing rate study were inconclusive. The treatment sites had conflicting results, with one location seeing a significant increase in slowing rate and the other location having a significant decrease in slowing rate. Both control sites had a decrease in slowing rate, with one decrease of significance. These control results support the cause for concern brought up during the complete stop analysis.

The findings of the location of stop study were also inconclusive. The Chippewa treatment location had a significant decrease in stop at bar rate, while the Isanti treatment location had a significant increase in stop at bar rate. Both control sites also experienced a significant increase in the stop at bar rate. It is noteworthy that the Chippewa treatment site may be an outlier due to the significant skew it exhibits, while the three other intersections meet at right angles.

The gap acceptance study saw varying results based on the intersection. The Chippewa treatment site, an intersection with a large skew, saw little significant changes and no pattern in change of rejection rate for time intervals. The Isanti treatment site showed a strong pattern in rejection rate changes with significance, however, the changes are contrary to the intended results. The treatment site saw the number of people accepting small gaps increase while the number of people accepting large gaps decreased. The control sites had contrasting results with each other, despite having strong correlation within the site. The Chippewa County control site had an increase in rejection rate regardless of gap, while the Isanti County intersection had a significant decrease in rejection rate for most gap intervals.

Overall, the main finding of the research conducted as a part of this thesis support the idea that the intersection collision warning system increases safety due to increasing the stopping rate. However, other safety aspects such as stopping location and gap selection cannot conclusively be supported.

5.2 FUTURE RESEARCH

The studies in this thesis were performed before the completion of the intersection collision warning system project. For this reason, all data to be collected and reduced was not available to use. In the future, data will be available of the actions completed by more drivers. These actions can be analyzed to give a better idea of the driver changes resulting from the system installation. The camera used for recording video did not allow for a clear view of the intersection during night hours. The differences between daytime and nighttime hours is another future inclusion.

5.2.1 Stopping Study

The study in this thesis occurred before installation and within one month of installation. Future video recording at these intersections is planned which will allow for long term observation of behaviors. The inclusion of other treatment and control sites will also make trends more visible and conclusive.

5.2.2 Gap Acceptance Study

Long term results will be important in the study of gap acceptance. The inclusion of a larger sample size for each gap will also make the results less susceptible to outliers.

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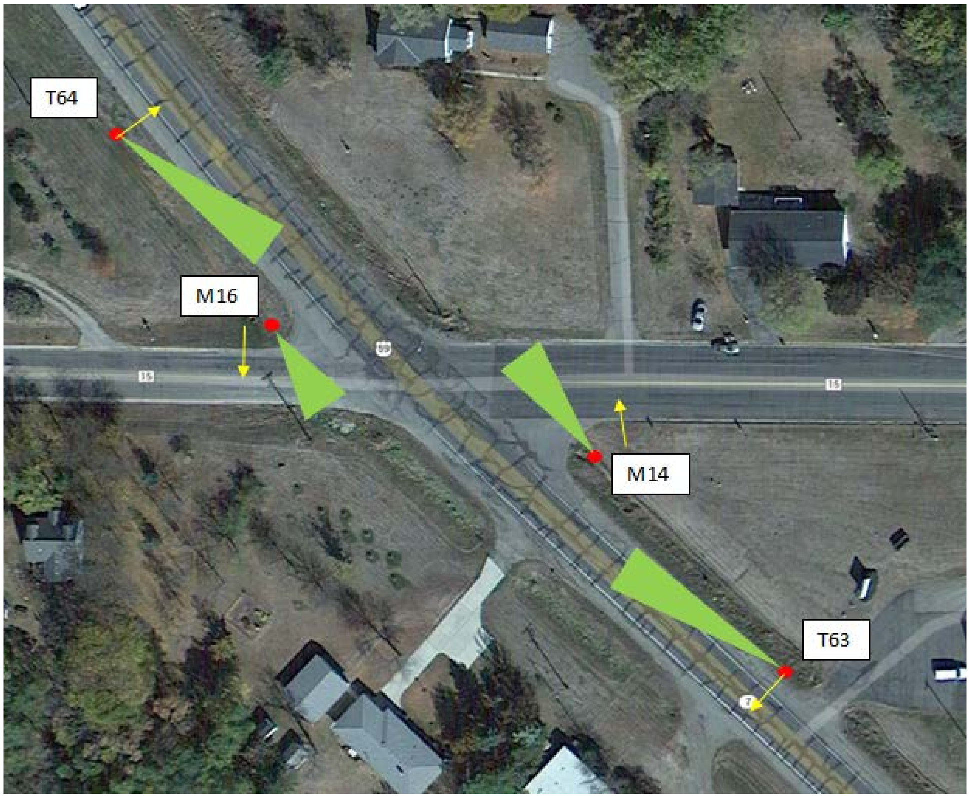
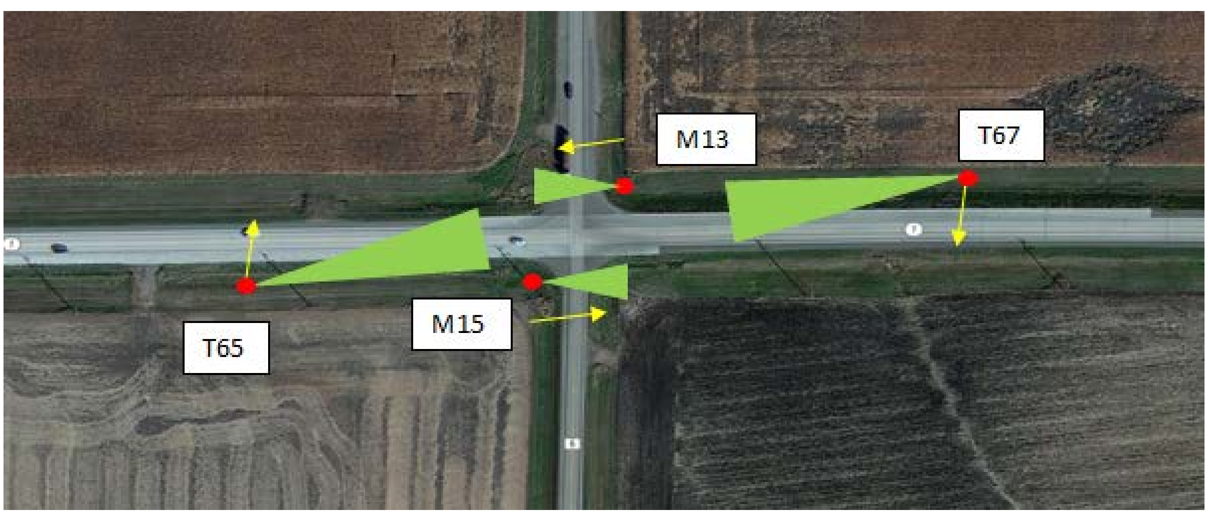
APPENDIX A: INTERSECTION CAMERA LAYOUT



Chippewa Treatment Camera Layout



Chippewa Control Camera Layout

Isanti Control Camera Layout

APPENDIX B: SUMMARY OF VIDEO RECORDING EVENTS

County	Phase	Intersection	Recording Start Date	Recording End Date
Isanti	Before	MN47 & Co8 (treatment)	September 5, 2014	September 11, 2014
Isanti	Before	MN47 & Co5 (control)	September 5, 2014	September 11, 2014
Isanti	After	MN47 & Co8 (treatment)	May 6, 2015	May 13, 2015
Isanti	After	MN47 & Co5 (control)	May 6, 2015	May 13, 2015
Chippewa	Before	MN7 & Co 15 (treatment)	August 14, 2014	August 25, 2014
Chippewa	Before	MN7 & Co6 (control)	August 14, 2014	August 25, 2014
Chippewa	After	MN7 & Co 15 (treatment)	April 28, 2015	May 5, 2015
Chippewa	After	MN7 & Co6 (control)	April 28, 2015	May 5, 2015

APPENDIX C: SAMPLE REDUCED DATA

ID	File Name	Date	Time of day at video beginning	Arrival Time (Video)	Departure Time	Duration	Vehicle Type	Color	Turning Movement	Type of Stop
Data Dictionary	File Name	mm/dd/yyyy	Universal Time (hh:mm:ss)	Video Time (hh:mm:ss)	Video Time (hh:mm:ss)	Video Time (mm:ss)	1:Motorcycle	i.e.red	1:Left	1:Complete Stop
							2:Passenger Car	black	2:Through	2:Slow Rolling (Clear Braking)
							3:Minivan/SUV		3:Right	3:Fast Rolling (Cruise Pass)
							4:Pickup			4:No Slow
							5: Buses			
							6: Trucks			
							7: Farm vehicle/others			
	T63						(Add letter "T" as trailor)			
	Time						Vehicle			
1	10000009_140819171444_L	8/19/2014	17:14:44	0:00:03	0:00:06	0:00:03	6	white	2	1
2	10000102_140819181443_L	8/19/2014	18:14:43	0:30:22	0:30:25	0:00:03	6	silver	2	1
3		8/19/2014	18:14:43	0:30:19	0:30:23	0:00:04	3	white	3	2
4		8/19/2014	18:14:43	0:32:00	0:32:03	0:00:03	6	black	3	2
5		8/19/2014	18:14:43	0:32:44	0:32:52	0:00:08	3	black	1	2
6		8/19/2014	18:14:43	0:32:42	0:32:47	0:00:05	6	silver	3	2
7	10000195_140819191444_L	8/19/2014	19:14:44	0:00:47	0:00:50	0:00:03	3	black	3	2
8		8/19/2014	19:14:44	0:01:05	0:01:10	0:00:05	3	black	3	2
9		8/19/2014	19:14:44	0:01:46	0:01:50	0:00:04	4	white	3	2
10		8/19/2014	19:14:44	0:03:41	0:03:50	0:00:09	4	white	2	1
11		8/19/2014	19:14:44	0:03:40	0:03:43	0:00:03	3	gray	3	2
12	10000289_140819201444_L	8/19/2014	20:14:44	0:30:18	0:30:21	0:00:03	2	black	3	2
13		8/19/2014	20:14:44	0:30:39	0:30:44	0:00:05	3	white	2	1
14		8/19/2014	20:14:44	0:30:56	0:30:59	0:00:03	3	white	3	2
15		8/19/2014	20:14:44	0:31:00	0:31:03	0:00:03	4	red	3	2
16		8/19/2014	20:14:44	0:32:14	0:32:19	0:00:05	2	black	2	2
17	10001145_140820051444_L	8/20/2014	5:14:44	0:40:38	0:40:40	0:00:02	4	red	2	3
18		8/20/2014	5:14:44	0:41:52	0:41:58	0:00:06	3	gray	2	2
19		8/20/2014	5:14:44	0:42:21	0:42:24	0:00:03	4	white	2	2
20	10001240_140820061445_L	8/20/2014	6:14:45	0:15:25	0:15:29	0:00:04	4T	red	2	1
21		8/20/2014	6:14:45	0:16:14	0:16:18	0:00:04	6	orange	3	2
22		8/20/2014	6:14:45	0:17:40	0:17:42	0:00:02	4	white	1	2
23		8/20/2014	6:14:45	0:18:20	0:18:24	0:00:04	3	black	2	2
24		8/20/2014	6:14:45	0:18:45	0:18:48	0:00:03	3	black	3	2
25	10001334_140820071447_L	8/20/2014	7:14:47	0:00:28	0:00:31	0:00:03	4	black	2	2
26		8/20/2014	7:14:47	0:00:58	0:01:00	0:00:02	2	gray	2	3
27		8/20/2014	7:14:47	0:02:14	0:02:16	0:00:02	6	white	2	2
28		8/20/2014	7:14:47	0:02:46	0:02:51	0:00:05	4	black	3	2
29		8/20/2014	7:14:47	0:03:18	0:03:21	0:00:03	4	black	2	2
30		8/20/2014	7:14:47	0:46:17	0:46:26	0:00:09	4	red	3	1
31		8/20/2014	7:14:47	0:46:28	0:46:41	0:00:13	3T	gray	3	1
32		8/20/2014	7:14:47	0:46:45	0:46:49	0:00:04	3	black	3	2
33		8/20/2014	7:14:47	0:46:55	0:46:59	0:00:04	3	white	3	2
34		8/20/2014	7:14:47	0:47:00	0:47:03	0:00:03	6	white	2	2
35	10001428_140820081446_L	8/20/2014	8:14:46	0:46:45	0:46:48	0:00:03	3	gray	3	2
36		8/20/2014	8:14:46	0:47:50	0:47:53	0:00:03	2	silver	3	2
37		8/20/2014	8:14:46	0:48:13	0:48:16	0:00:03	4	black	3	2
38		8/20/2014	8:14:46	0:48:45	0:48:49	0:00:04	2	gray	3	2
39		8/20/2014	8:14:46	0:49:44	0:49:49	0:00:05	2	silver	2	1
40	10001617_140820101446_L	8/20/2014	10:14:46	0:32:00	0:32:02	0:00:02	3	black	3	3
41		8/20/2014	10:14:46	0:33:05	0:33:07	0:00:02	2	white	2	2
42		8/20/2014	10:14:46	0:33:10	0:33:14	0:00:04	2	red	3	2
43		8/20/2014	10:14:46	0:34:47	0:34:52	0:00:05	6	white	3	2
44		8/20/2014	10:14:46	0:34:57	0:35:00	0:00:03	4	red	3	2
45	10001806_140820121446_L	8/20/2014	12:14:46	0:15:45	0:15:57	0:00:12	4	red	1	1
46		8/20/2014	12:14:46	0:15:59	0:16:03	0:00:04	4	black	3	2
47		8/20/2014	12:14:46	0:16:04	0:16:08	0:00:04	3	silver	3	2
48		8/20/2014	12:14:46	0:16:13	0:16:18	0:00:05	3	silver	2	2
49		8/20/2014	12:14:46	0:17:08	0:17:10	0:00:02	6	gray	3	3
50		8/20/2014	12:14:46	0:45:30	0:45:33	0:00:03	3	black	3	2

Data Dictionary	1:Before stop bar	1:North Leg	1:Activated	1:Activated	1:No	Description of conflicts	1:Sunny	1:Daytime	1:Dry	Second
	2:At stop bar	2:East Leg	2:Unactivated	2:Unactivated	2:Yes	(indicate if there are pedestrians or bicyclists)	2:Cloudy	2:Dawn/dusk	2:Wet	20+
	3:After stop bar	3:South Leg	3:Unknown	3:Unknown			3:Rain	3:Nighttime-lighitng	3:Snow	
	4: Non-stop	4:West Leg					4:Snow	4:Nighttime-no lighting		
							5:Fog			
		Conflict Type					Roadway Enironment			
ID	Stop Location	Intersection Leg	ICWA Status at Arrival	ICWA Status at Departure	Conflicts	Conflict Comments	Weather	Lighting Condition	Pavement Surface	Accepted Gap
1	2	2			1		1	1	1	17
2	3	4			1		1	1	1	19
3	4	2			1		1	1	1	20+
4	4	2			1		1	1	1	20+
5	4	4			1		1	1	1	20+
6	4	2			1		1	1	1	20+
7	4	2			1		1	1	1	20+
8	4	4			1		1	1	1	20+
9	4	2			1		1	1	1	20+
10	2	4			1		1	1	1	20+
11	4	2			1		1	1	1	20+
12	4	2			1		1	2	1	20+
13	3	4			1		1	2	1	20+
14	4	2			1		1	2	1	20+
15	4	2			1		1	2	1	20+
16	4	4			1		1	2	1	20+
17	4	2			1		1	2	1	16
18	4	4			1		1	2	1	16
19	4	4			1		1	2	1	20+
20	3	4			1		1	1	1	19
21	4	2			1		1	1	1	20+
22	4	2			1		1	1	1	20+
23	4	4			1		1	1	1	20
24	4	2			1		1	1	1	20+
25	4	4			1		1	1	1	20+
26	4	2			1		1	1	1	20+
27	4	2			1		1	1	1	14
28	4	2			1		1	1	1	20+
29	4	2			1		1	1	1	20+
30	2	2			1		1	1	1	17
31	3	2			1		1	1	1	20+
32	4	2			1		1	1	1	20+
33	4	2			1		1	1	1	20+
34	4	2			1		1	1	1	20+
35	4	2			1		1	1	1	20+
36	4	4			1		1	1	1	15
37	4	2			1		1	1	1	20+
38	4	2			1		1	1	1	20+
39	3	4			1		1	1	1	20+
40	4	2			1		1	1	1	20+
41	4	2			1		1	1	1	20+
42	4	2			1		1	1	1	20+
43	4	2			1		1	1	1	20+
44	4	2			1		1	1	1	19
45	3	4			1		1	1	1	20+
46	4	4			1		1	1	1	20+
47	4	4			1		1	1	1	20+
48	4	2			1		1	1	1	20+
49	4	2			1		1	1	1	20+
50	4	2			1		1	1	1	20+

Data Dictionary	A Neighboring Vehicle Exists	Number of Vehicle in Plooton	count	Second	1:Northbound	Second	1:Northbound	Second	1:Northbound
	0: No	>=3			2:Northbound-left		2:Northbound-left		2:Northbound-left
	1: Yes				3:Northbound-right		3:Northbound-right		3:Northbound-right
					4:Southbound		4:Southbound		4:Southbound
					5:Southbound-left		5:Southbound-left		5:Southbound-left
					6:Southbound-right		6:Southbound-right		6:Southbound-right
					7:Eastbound		7:Eastbound		7:Eastbound
					8:Westbound		8:Westbound		8:Westbound
	Gap								
ID	Neighboring Vehicle	Vehicle Plooton	Number of Rejected Gap	Rejected Gap1	Rejection Direction 1	Rejected Gap 2	Rejection Direction 2	Rejected Gap 3	Rejection Direction 3
1	0		0						
2	0		0						
3	0		0						
4	0		0						
5	0		0						
6	0		0						
7	0		0						
8	0		0						
9	0		0						
10	0		2	1	4	7	5		
11	0		0						
12	0		0						
13	0		1	4	4				
14	0		0						
15	0		0						
16	0		0						
17	0		0						
18	0		0						
19	0		0						
20	0		0						
21	0		0						
22	0		0						
23	0		0						
24	0		0						
25	0		0						
26	0		0						
27	0		0						
28	0		0						
29	0		0						
30	0		0						
31	0		1	6	1				
32	0		1	11	1				
33	0		0						
34	0		0						
35	0		0						
36	0		0						
37	0		0						
38	0		0						
39	0		0						
40	0		0						
41	0		0						
42	0		0						
43	0		0						
44	0		0						
45	0		0						
46	0		2	6	5	2	5		
47	0		0						
48	0		0						
49	0		0						
50	0		0						
	0		0						

APPENDIX D: DATA DICTIONARY

Category	Variable Name	Data Description	Units	Example Value
Time	File Name	The name of the video file	-	-
	Date	The date of the video was recorded	mm/dd/yyyy	12/31/2014
	Time of day at video begaining	The UTC time at the beganing of the video	hh:mm:ss	14:02:36
	First Appearance Time	The first time the vehicle appeared in the video frame		
	Arrival Time	The vehicle arrival time is determined at when the vehicles' front bumper just passes the stop bar. If a vehicle has a complete stop before the stop bar (did not pass the stop bar), the arrival time is recorded at the moment of their complete stop.	hh:mm:ss	0:00:11
	Departure Time	When the vehicle is completely merged into the main road (vehicle traveling direction is aligned with the roadway direction).	hh:mm:ss	0:00:36
Roadway Environment	Duration	The total duration of the subject vehicle waited on the minor road. (duration=departure time - arrival time).	hh:mm:ss	0:00:25
	Weather	Weather condition at the intersection	-	Sunny/Cloudy/Rain/Snow
	Lighting Condition	Light condition at the intersection	-	Daytime/Dawn & Dusk/Nightime - lighitng/ nighttime-no lighting
Drivers	Pavement Surface	Pavement surface condition on the main road	-	Dry/Wet/Snow
	Driver Age	Drivers Age	-	Young/Adult/Old/unknown
	Driver Gender	Driver Gender	-	Male/Female/Unknown
	Distractions	The types of distraction for the driver of the subject vehicle	-	Cellphone/smowking/eating&drinking/talkingtopassenger/others
Vehicle	Video Confidence Level	The level of confidence to see the driver in the subject vehicle	-	High/Medium/Low/Unobservable
	Vehicle Type	The vehicle classification is based in FHWA's guideline (shown on the right).	-	Motorcycle/PassengerCar&Minivan/Pickup/Buses/Truck and Others
	Color	The color of the subject vehicle	-	Red/Black/White
	Turning Movement	The turining direction of the subject vehicle	-	Left/Through/Right
	Type of Stop	Indicate if the subject vehicle makes a complete stop or rolling stop	-	Complete Stop/Rolling Slow/Rolling Fast/No Stop
	Stop Location	the stopped location of the subject vehicle	-	Before stop bar/at stop bar/after stop bar/non-stop
Conflict Type	Intersection Leg	The intersection leg indicates where that the subject vehicle comes from	-	North leng/East leg/South leg/West leg
	ICWA Status at arrival	The operation status of the ICWA status at the vehice's arrival	-	Activated/Unactivated/Unknown
	ICWA Status at departure	The operation status of the ICWA status at the vehicle's departure	-	Activated/Unactivated/Unknown
	Conflicts	Indicate if the subject vehicle has conflicts with the vehicles on the main road	-	Yes/No
	Comments	Descrption of the conflict	-	-
Gap	Accepted Gap	The accepted gap of the subject vehicle	Second	1- 10 seconds or 10+
	Neighboring Vehicle	Indicate if a nerboring vehicle exists	-	1/0
	Vehicle Plooton	The number of vehicles in the vehicle plooton on the main road	-	0-99
	Number of Rejected Gap	The total number of rejected gap before the subject vehicle accepted the gap	-	0-99
	Rejected Gap N	The duration of the rejected gap N	Second	0-99
	Rejected Direction N	The travelling direction of the rejected vehicle	-	Northbound/Eastbound/Southbound/Westbound