Radar-Activated LED Stop Sign in a Rural Setting Pilot Project in Saskatchewan

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Paper prepared for presentation at the
Road Safety Policy Development – Past, Present Future Session
of the 2014 Conference of the
Transportation Association of Canada
Montreal, Quebec

Abstract

Human factors indicate that too little stimulation can lead to driver inattention, which is a contributor to crash frequency. Saskatchewan is characterised by long, straight, rural roads with low driver workload. It is likely that low driver workload may be a factor in preventable collisions at the junction of Provincial Highway 35 and Provincial Highway 16 (Yellowhead Highway), which has experienced multiple fatal and injury collisions.

The purpose of this paper is to discuss the implementation and current operation of the radar activated LED Stop signs at the junction of Provincial Highway 35 and Provincial Highway 16, which were installed by the Saskatchewan Ministry of Highways and Infrastructure (SMHI) in 2012 to mitigate a trend in right angle collisions. The existing traditional intersection improvements included illumination, Stop Ahead signs, dual oversize Stop signs equipped with red flashing beacons, and transverse pavement rumble strips.

Ten years of collision data indicated that the trend in right angle collisions was not affected by the existing improvements, which were implemented over several years. The sight lines to this intersection are unobstructed and the Stop signs with red flashing beacons are visible from vehicles approaching several hundred metres away. When the Stop signs with the continuously flashing beacons were replaced with the LED Stop signs, the beacons were reinstalled on the intersection light standards so collision trends could be monitored without changing more than one aspect of the intersection at a time. The radar-activated lights on the Stop sign operate differently than continuous beacons in that they are only activated when vehicles approach the intersection at a speed that suggests they will not be able to comfortably decelerate to stop safely. Comfortable deceleration distances were calculated with sign mounted radar aimed at the distance where drivers will have to “slam on brakes” in order to stop at the junction.

The pilot project duration is a minimum two years, after which SMHI hopes to determine whether the LED Stop signs should be considered as a safety improvement at other locations throughout the provincial network. The goals of the pilot project are to determine the reliability of the system components, how much maintenance it requires, the cost to maintain the system, and to determine the effects of the system on traffic.

1.0 INTRODUCTION

The Saskatchewan Ministry of Highways and Infrastructure (SMHI) operates 26,000 km of roadways throughout Saskatchewan, many of which are in rural settings with low to moderate traffic volumes. Every year, there are around 10,000 collisions on the provincial network, with an average cost to society of 440 million dollars [1].

Highways in Saskatchewan are characterised by long, relatively straight, rural roads with low driver workload. Human factors indicates that too little stimulation can lead to driver inattention, which is a contributor to crash frequency. This is reflected in Saskatchewan highway collision statistics as collision rates tend to increase as the highway functional hierarchy drops [2]. It is likely that low driver workload may be a factor in preventable collisions at the junction of Provincial Highway 35 and Provincial Highway 16 (Yellowhead Highway), which has been the location of multiple fatal and injury collisions. Because of the severe nature of the collisions occurring at this intersection, in recent years, the total collision cost is six times higher than the average annual collision cost for provincial highway junctions.

In December 2012, SMHI implemented radar activated light-emitting diode (LED) Stop signs on Highway 35 to mitigate the trend in right angle collisions at Highway 16. These signs are intended to provide warning only to drivers who approach the intersection at a speed that suggests they will not be able to comfortably decelerate to stop safely. The majority of drivers are attentive to the requirement to stop ahead and operate their vehicles accordingly. This is the first collision avoidance system trialed by SMHI.

The purpose of this paper is to discuss the implementation and current operation of the radar activated LED Stop signs at the junction of Provincial Highway 35 and Provincial Highway 16. The goal is that the results of the ongoing pilot project will indicate whether this system is appropriate as an additional tool for mitigating serious collisions at provincial highway junctions.

2.0 HIGHWAY 16 AND HIGHWAY 35 JUNCTION

2.1 Study Location

Highway 16 (Yellowhead Highway) is a major economic corridor spanning the province from Manitoba to Alberta and serves as a key link for regional traffic between the major centres of Winnipeg, Saskatoon and Edmonton. The junction of Highway 16 with Highway 35 is approximately 200 kilometres east of Saskatoon. At this location, both highways are two-lane, undivided with speed limits of 100 kilometres per hour (km/h). The average annual daily traffic (AADT) on Highway 16 at the junction averages 1955 vehicles per day (vpd) [3]. Just east of the junction is the Village of Elfros with a population of less than 100 (*2011 census*). Highway 35 is a low-volume rural highway that connects Highway 16 to Highways 5 and 15 to the north and south, respectively. It has a low functional classification on the provincial hierarchy and primarily serves to provide direct access to homesteads and farmland. The AADT on Highway 35 near its junction with Highway 16 averages 530 vpd to the north and 800 vpd to the south [4]. Highway 35 is two-way stop controlled at the junction and intersects at ninety degrees (Figure I).

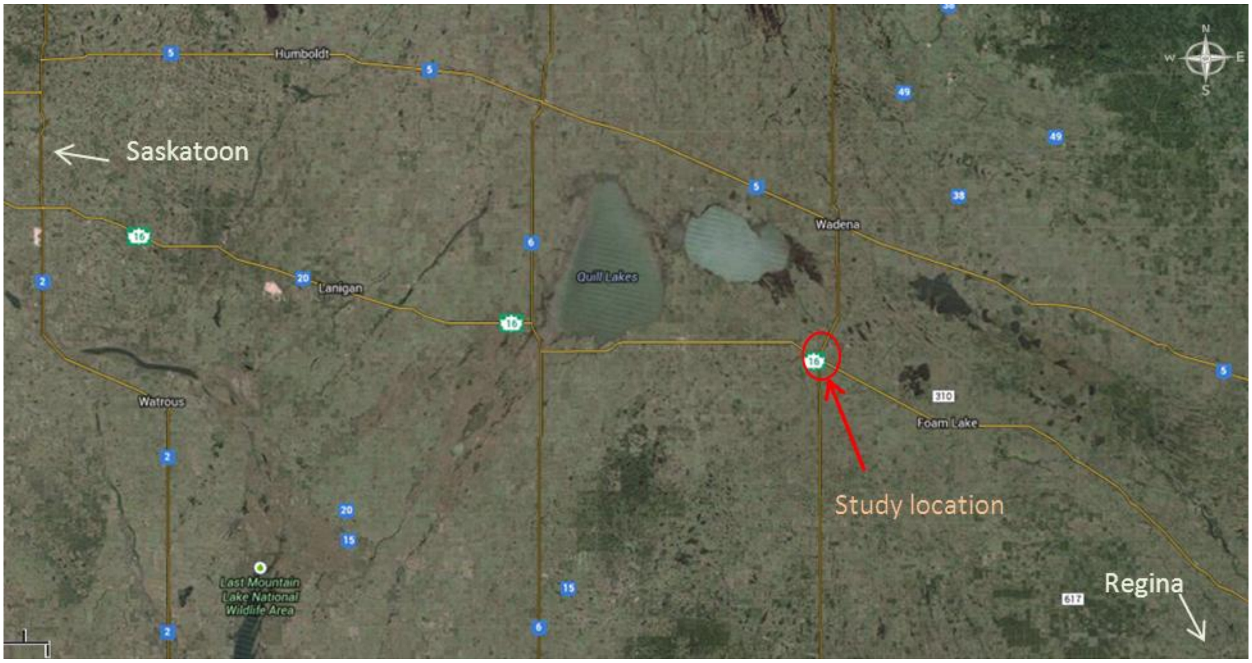

Figure I – Study Location: Junction of Hwy 16 and Hwy 35 [5]

Characteristic of roads in central Saskatchewan, Highway 35 has minimal horizontal or vertical curves. There is a gentle horizontal curve in Highway 35 approximately one kilometre north of the junction. There is low driver workload within the vicinity of the junction with Highway 16. Distances from the north and south junctions with Highways 5 and 15 are 24 kilometres and 50 kilometres. At both of these junctions, Highway 35 has the right-of-way, while the intersecting highways are stop controlled; however, the speed on Highway 35 is reduced to 40 km/h through Wadena and Bankend, which are 25 kilometres north and south of the Highway 16 junction, respectively. These are the closest points from the Highway 16 junction where drivers traveling along Highway 35 are required to make an operational change.

Highway 16 east of Saskatoon is also characterised by long stretches of straight, flat roadway. There are numerous horizontal curves as the east alignment is slightly south towards Winnipeg, however these curves have open radii and most do not require warning signs. The nearest major decision point for Highway 16 traffic is approximately 50 kilometres west where Highway 16 intersects Highway 6 at an offset, creating a T-intersection.

2.2 Collision History

While it is a low volume, rural junction with unobstructed sight lines and low driver work-load, the junction of Highway 35 with Highway 16 has been the location of severe collisions over time and the subject of increasing public concern.

Collision data was obtained from Saskatchewan Government Insurance's Traffic Accident Information System. Prior to 2012, when the radar activated flashing lights were installed, there were five right angle collisions in the ten year period between 2003 and 2012. Although the collision frequency does not deviate significantly from the provincial average, the severity and associated costs are significantly above average [5]. The collision comparison presented in

Table I includes only non-wildlife collisions within 0.15 kilometres of the intersection for all locations.

Table I - Collision Rate Comparison
Study Intersection vs. all Four-Leg Provincial Junctions

	Provincial Average [6]	Jct Hwy 16 & Hwy 35	Difference
Multi-car (2+) Collision Rate*	0.476	0.540	13.4%
Collision Rate incl. single vehicle collisions	0.865	0.540	-37.6%
Fatal & Injury Collision Rate	0.257	0.540	110.1%
Intersection Collision Cost	$114,214	$686,500	501.1%

*where Collision Rate = collisions per million entering vehicles

Over the past ten years, all the intersection collisions at the junction of Highway 16 and 35 have resulted in injuries, with fatalities in 2010 and 2011. Subsequently, SMHI experienced increased pressure from the public to investigate options to improve safety at this location.

While the low number of collisions makes it nearly impossible to discern trends, there was no indication that any of the collisions could be attributed to weather, lighting, or road surface conditions. The majority of collisions occurred in the summer, in the daylight, and on dry pavement. This information indicates that collisions are likely occurring due to driver error, either failure to stop at the Stop sign on Highway 35 or misjudging approaching vehicle speed or adequate gaps on Highway 16.

2.3 Existing Intersection Treatments

The existing Stop signs on Highway 35 at the junction are clearly visible for both north and south directions, with unrestricted sight lines to the intersection and along Highway 16.

An Institute of Transportation Engineers' (ITE) publication on Stop signs prescribes several treatments to consider at locations where there is a history of drivers failing to stop at existing Stop signs where adequate visibility is not an issue [7]:

- Stop Ahead signs;
- Oversized Stop and Stop Ahead;
- Double (left-side) Stop sign.
- Two transverse rumble strips in the approach lane in advance of the Stop Ahead and before the Stop sign;
- Two additional transverse rumble strips to supplement the first two locations;
- Intersection illumination;
- Flashing red beacon in conjunction with the Stop signs or an overhead intersection control beacon with flashing red for the minor street and flashing yellow for the major street; and
- Actuated flashers on the top of a Stop sign. A detector would be in the pavement in advance of Stop sign. As a vehicle approaches, a red flasher would appear. This solution would address the driver expectancy problem and give more attention to the Stop sign.

SMHI's standards include consideration of several different intersection treatments options. Over the course of several years, SMHI implemented several typical rural highway intersection improvements at the junction of Highway 16 and Highway 35 to address ongoing concern with right-angle collisions. These include:

- Stop Ahead signs;
- Oversized Stop signs;
- Double (left-side) oversized Stop signs;
- Four sets of transverse rumble strips;
- Intersection delineation lighting; and,
- Continuous flashing red beacons on top of all four Stop signs;

Despite these visual and audio tactile warning devices on both legs of Highway 35, severe right-angle collisions continued to occur at a rate no lower than in years prior to the installation of various treatments. The sight distance to this intersection is unobstructed and the Stop signs with red flashing beacons are visible from vehicles approaching several hundred metres away. In addition, the Stop Ahead and junction signing provides additional clues of the upcoming intersection and change in roadway environment. As discussed in the preceding section, it is difficult to estimate what measures may be effective prior to implementation due to the low frequency of collisions and subsequent lack of certainty on causation. SMHI reviewed further traditional safety treatments, including flashing amber lights, overhead red flashing lights, and overhead Stop signs.

SMHI receives numerous requests for infrastructure improvements, but with a finite amount of funding, must follow a consistent and defendable strategy for prioritizing and implementing improvements throughout the network. The decision to install specific collision counter-measures is typically based on a warrant "point-system" evaluation based on characteristics of the specific location, including traffic volume, collision data, sight distance, roadway geometrics, and operational considerations.

Flashing amber lights are a warning device used to encourage drivers to exercise caution. Flashing amber lights are usually only programmed for installation under SMHI's Safety Improvement Program where an average of three preventable collisions per year occurs over the most recent three year period. If there is other capital work programmed at or near an intersection, meeting the minimum threshold of collisions is not required for justifying installation; however, the following criteria must still be met:

- Intersection of a major arterial highway with a major arterial highway or an intersecting roadway with an AADT greater than 1500 vpd; and
- The speed limit on the through highway is greater than 80 km/hr.

Overhead red flashing lights can be used in conjunction with red flashing lights above Stop signs. SMHI considers them only in special circumstances where additional warning for motorists is required, based on the discretion of the engineer.

The consecutive fatal collisions in 2010 and 2011 reinforced that this intersection may need non-traditional treatments to influence driver behaviour. The advanced warning signs, intersection illumination, continuous flashers on the dual oversized Stop signs and rumble strips were not eliminating deadly multi-car collisions. Nevertheless, the majority of drivers operate their vehicles in a safe manner and do not need additional warning at the intersection. Adding additional counter-measures such as increasing the size of the Stop Ahead signs or adding overhead Stop signs and flashing red lights could have been considered; however, SMHI officials began to discuss counter-measures that could target aggressive or inattentive motorists with a higher likelihood of running the Stop signs.

3.0 COLLISION AVOIDANCE SYSTEM

In order to enhance conspicuity of the approaching intersection and the Stop signs, the use of LED lights around the perimeter of the Stop signs was considered. Intelligent traffic systems that would only target drivers that had a higher likelihood of not stopping at the Stop signs was discussed. As a starting point, it was assumed that approach speed would likely be the easiest parameter to measure and indicate the possibility that a vehicle may not have adequate distance to stop in advance of the junction. Therefore, the use of a radar actuated signs was investigated.

3.1 Literature Review

3.1.1 LED Traffic Signs

The Transportation Association of Canada's (TAC) Manual of Uniform Traffic Control Devices for Canada (MUTCDC) permits adding LED units on the sign border of Stop signs, Yield signs, or Traffic Control Paddles when increased conspicuity of the signs is required. LED-embedded Stop signs may be used at locations with a high frequency of collisions resulting from a failure to recognise the traffic control. This is defined as at least two reportable crashes per year over a three year period, or three or more over a five year period. The manual also states that LED-embedded traffic signs shall not be used on approaches equipped with a flashing beacon [9].

At the time when SMHI were exploring the use of LED Stop signs, the MUTCDC was undergoing updates and did not yet address these types of signs. Section 2A.07 of the Federal Highway Administration's (FHWA) MUTCD prescribes the American standards for placing LED lights on the borders of various signs, including Stop signs. These specifications were in place prior to TAC finalizing the MUTCDC updates, and the signs installed by SMHI were FHWA approved. The flash rate and requirement for synchronised signs are some of the similarities between the standards.

Detection of an object is more likely if the object is dynamic, (i.e. moving or flashing) than static [10] and as SMHI was looking for an attention grabbing warning device, SMHI officials only considered flashing LED over continuous perimeter lights.

SMHI had not previously used embedded LEDs within standard signs, and their use is not common in the province. To SMHI's knowledge, LED perimeter lighting on pedestrian crosswalk signs and Stop signs have only been used in low speed urban environments. Therefore, the effectiveness in a higher speed rural environment within the province was uncertain.

A study on safety effects of embedded LEDs in Stop signs, conducted in 2004 by the Texas Transportation Institute, found a 28.9 percent reduction in the number of vehicles not fully stopping and 52.9 percent reduction in the number of vehicles moving through the intersection without significantly slowing [11]. A similar study conducted by the Virginia Transportation Research Council in 2007 found a statistically significant decrease in vehicle approach speeds and concluded that LED Stop signs positively affected driver behavior [12].

3.1.2 Radar Activated Road Signs

Radar has been used for many years in road signs to measure vehicle speed and provide feedback to motorists. Its use is widespread and effective in urban and rural environments and applications. Most traffic engineering applications of radar is for measuring approaching speeds and providing information to motorists, or providing enforcement of the regulatory speed limit.

The benefit to having a radar activated warning system is to implement a system that will only target the vehicles that are at a higher risk of not stopping in advance of the intersection based on approach speed and distance to the intersection.

As there are several radar devices on the market with many different applications and limitations, SMHI relied on the advice of local traffic device and sign suppliers to assist them in determining the most economical radar device that would accommodate their intended use with the LED Stop sign.

3.1.3 Radar Actuated LED Stop Signs

Radar actuated LED Stop signs have been trialled in Virginia successfully using a speed detection system to identify vehicles approaching a Stop sign at too-high of an approach speed at a given point on the roadway. Drivers exceeding a specified speed either activate a flashing beacon on an advance Stop Ahead warning sign or cue lights on the perimeter of a Stop sign to begin flashing. The findings of this trial is that the system "is beneficial to consider on high-speed stop approaches where the intersection cannot be readily seen and where other traditional countermeasures such as advanced Stop Ahead warning signs, doubling up on Stop signs, and transverse rumble strips have not reduced running Stop sign violations. While the technology is ready, it is believed that there are few stop-controlled intersections where frequent Stop sign running events and crashes due to the driver's failure to observe the traffic control device are experienced and where enhanced passive systems have not addressed this problem already" [13].

SMHI did not consider radar actuated flashing LED lights on the Stop Ahead signs as the Stop Ahead signs are placed back far enough for all road users to safely stop, and would result in another system that had higher potential for additional warning to the majority of drivers versus drivers that are inattentive to a degree that prevent the current measures from being effective. The observation from the Virginia study that additional countermeasures will likely have little effect on the majority of attentive drivers confirmed that a system employed by SMHI at the junction of Highway 16 and 35 should target only inattentive or aggressive drivers as best possible. The study also gave SMHI a positive indication that such a system could be applied successfully in Saskatchewan.

3.2 System Design

3.2.1 Stopping Sight Distance - Theory

For a successful collision avoidance system, the warning must be actuated in time for a driver to have sufficient distance to perceive the device or situation, react, and brake in advance of the junction.

Stopping distance is the distance required for a vehicle to come to a complete stop, and is a function of the vehicle speed, the driver's detection, recognition, decision, and response time (collectively referred to as perception-reaction time), and the deceleration rate.

$$Stopping\ Sight\ Distance = Perception\ Reaction\ Distance + Braking\ Distance$$

$$SSD = vt + \frac{v^2}{2g(\eta_b \mu \pm WG)} = vt + \frac{v^2}{2a \pm 2gG}$$

Where:

SSD = stopping sight distance (m)
v = approaching vehicle speed (m/s)
t = driver perception reaction time (s)
g = gravitational acceleration (9.81 m/s^2)
η_b= braking efficiency
μ = coefficient of roadway adhesion
W = vehicle weight (N)
a = deceleration rate (m/s^2)
G = roadway grade (m/m)

Pavement friction (f) is considered to be the most sensitive parameter in calculating stopping sight distance [14]. TAC's Table 1.2.5.2 provides values for f corresponding to various design and operating speeds. These are considered conservative as they are based on tests conducted several decades ago with worn tires on wet pavement.

$$SSD = vt + \frac{v^2}{2g(f \pm 2G)}$$

Another method for calculating braking distance is to assume a deceleration rate, based on typical rates derived from theory and field tests. The ITE Traffic Control Devices Handbook suggests 3.05 m/s^2 as an appropriate comfortable deceleration rate for passenger vehicles based on driver and occupant comfort. American Association of State Highway and Transportation Officials (AASHTO) and Human Factor design values generally indicate comfortable deceleration rates of around 3.40 m/s^2.

Design perception reaction times (PRT) generally range from 1.0 to 2.5 seconds (s). The lower range of PRT is utilised in instances where the driver is expecting a situation such as in traffic signal timing applications [15]. TAC suggests 2.5 s being representative of the 90th percentile of drivers and situations. The ITE Handbook also recommends applying a PRT of 2.5 s for computing stopping sight distances for most traffic control-related braking responses. However, more complex driving situations may call for increased PRT. TAC recommends 3.0 s to 4.5 s to reflect reactions of inattentive drivers to "complex or inconspicuous stimuli" [16].

3.2.2 Stopping Sight Distance – Recent Test Findings

While the standard PRT and deceleration rates noted above were used by SMHI as a starting point for determining the parameters for the radar activated LED Stop sign implementation on Highway 35, further literature review indicated opportunity to fine tune the system to target the motorists with a higher probability of violating the Stop sign. The system will work most effectively if the warning is deployed with enough time / distance for a distracted driver to react and stop the vehicle, but not designed too conservatively to be activated with ample time and acting as a false alarm. False alarms may result in ineffectiveness of the system over time.

Design standards for infrastructure geometry and features such as sign placement, conspicuity, etc., are based on the majority of drivers or some reasonable percentile of the population. Alternatively, crash avoidance systems should be designed to capture uncommon driver decisions (a minority of drivers) such as those that may result in violation of a traffic control device.

Based on recent field tests conducted by the Virginia Tech Transportation Institute (VTTI) for various studies, using a higher deceleration rate than the typical high range for "comfortable" design and a lower PRT may be appropriate for the LED Stop sign in SMHI's application as a crash avoidance tool.

Field tests to model realistic driver PRT and deceleration rates for designing yellow clearance intervals at signalized intersections, observed a range of 2.31 m/s^2 to 7.31 m/s^2 for initial traveling speeds of 72 km/hr to 88.5 km/hr. The mean and median for the faster initial speeds tests were 3.91 m/s^2 and 3.82 m/s^2, with a standard deviation of 0.74 m/s^2 [17]. Even more interesting to SMHI was a 2004 experiment to determine deceleration rates of approaching vehicles not representative of the typical driver, but reflective for situations more likely to result in violation of both signalized and stop-controlled intersections. This particular research involved activating LED Stop signs similar to the system SMHI was looking to employ. The field tests indicate that 4.22 m/s^2 is the deceleration rate the average distracted driver is willing to assume in order to avoid running the intersection after an LED Stop sign warning light system is deployed [18].

It is reasonable to assume that an inattentive driver will not initiate braking at the same point as an attentive driver. Doerzaph's research specific to PRT for distracted drivers approaching a flashing LED Stop sign indicates a 0.15 s increase from the baseline 1.0 s PRT for a non-distracted driver [19].

Although 1.15 s is lower than the TAC and ITE recommended 2.5 s, it follows reason that a Stop sign is a very standard sign that would be instantly recognized with sudden reaction likely, even with an initially inattentive driver. The detection time is negligible as the detection is considered to be at the onset of the flashing lights for a target motorist, as the majority of motorists may take more time to detect the traffic control devices, but would have adequate time to react and decelerate without the need for the crash avoidance warning system. The flashing lights and impending intersection would likely shock the individual into a quick reaction of brake application.

Different stopping sight distances based on adjustments to PRT, deceleration rates, and roadway friction coefficients are compiled in Table II, presented on page 15 of this paper. The research supports a higher deceleration rate than the typical high range for "comfortable" design and a PRT lower than 2.5 s to be appropriate in SMHI's application of the LED Stop sign as a crash avoidance tool.

3.2.3 System Selection and Integration

SMHI was unable to find off-the-shelf radar actuated LED Stop signs; radar and LED Stop signs were only available as separate systems. SMHI looked at the feasibility of combining the systems to develop the integrated system that would meet their needs.

SMHI found two options available for blinking embedded LED Stop signs from local suppliers. The options were either eight red LEDs around the perimeter or forty red LEDs around the perimeter. The eight LED sign offered Smart Activation options, which can allow for 24/7 continuous blinking, timer activation, wireless control activation, and vehicle detection activation, while the forty light sign can only blink continuously.

SMHI found the limitation with radar to be the distance at which the radar optimally measures vehicle speeds. While the radar systems can be set to different activation speeds, the general limitation was the fixed distance at which the radar devices can detect and accurately measure a speed. Radar devices were available for a few different distances, from 90 metres (m), 305 m and greater. The optimal range for radar detection and sign activation is dependent on the stopping distance required by an approaching vehicle. As discussed in Section 3.2.1, there are a few influential factors, including driver PRT and behaviour, road surface conditions, vehicle weight, speed, and braking mechanisms. It would be possible to install multiple radar guns to measure different distances from the intersection and set to different cut-off speeds. This type of system would turn on if it detected that vehicles were not decelerating as they approach the intersection. However, this alternative was not considered economically feasible at this time.

The radar component (vehicle detector and transmitter) is approximately 46 percent of the system cost for the supply, and customising the LED system with several radars would likely be a significant additional cost. SMHI decided that the cost of such a custom system was too great for the pilot project as the aim was to be low cost in order to be a suitable crash avoidance measure for application in rural lower volume roadways at provincial junctions.

The angle and height of the radar gun must be precise to get an exact range. Depending on the mounting apparatus, it is unlikely that the radar gun could be angled with enough precision to measure speeds at a distance different from its design range. SMHI opted for a device that measured a range of 90 m for regular vehicles (137 m for trucks and large vehicles), and set the minimum cut-off speed to 65 km/h (i.e. vehicle traveling 65 km/h or faster at 90 m from the Stop sign distance will activate the blinking LED lights). The lights remain flashing for ten seconds. Based on a 1.15 s PRT and 65 km/hr, to stop in advance of the intersection from 90m would require a deceleration rate of 2.35 m/s^2. For vehicles traveling at 100 km/hr this would require 6.65 m/s^2 deceleration for passenger vehicles and 3.67 m/s^2 for larger vehicles. While the deceleration rate of 6.65 m/s^2 would not be “comfortable,” it is less than the highest measured deceleration rates achieved in the field tests described in Section 3.2.2.

The system SMHI ultimately chose consisted of:

- Oversized LED Stop signs with eight LED lights embedded around the perimeter on both sides of the road;
- SS300 K-Band Doppler speed sensor/sign control system mounted on the sign post of the sign facing approaching traffic;
- A radio communication device (transmits the “on” signal from the radar system to the sign on the left side of the road); and
- Solar panels mounted above each sign.

The advantages of this radar was the small size of the device for easy mounting and installation, the low power usage compared with alternatives, low speed cut-off, clock/ calendar function, and electronic components designed and tested to -40°C.

The system was supplied and installed for $11,002 per approach, which included one radar, two blinker beam wireless radios, and two oversized solar LED Stop signs. Therefore, the total intersection treatment was $22,004. The system had a parts and labour warranty for one year after installation.

4.0 PERFORMANCE MONITORING

4.1 Monitoring

4.1.1 Project Goals

The goals are to determine if the system works continuously, how much maintenance it requires, the cost to maintain the system, and to determine the effects that the system has on the reduction of injury and fatal collisions. The first phase of the pilot project duration will be two years after the date of installation. After this time, SMHI will determine if the system should be considered at other locations as a crash avoidance system for intersections that experience a high rate of collisions or high severity / high cost collisions. Any new installations would also be monitored in tandem with the Highway 16 and 35 junction for a larger sample size to monitor trends that may be a result of the new systems.

The system must work continuously in order to be effective. If it requires constant repairs and is often shut down, there will be no reliability to any of the anticipated benefits to the system. In this situation, the Ministry may have to wait until a better off-the-shelf system is available, or procure intelligent technical systems design resources to develop a more fit for purpose system.

4.1.2 Inspections

The pilot project is regularly inspected to determine if the system is working properly. During the two winters it has been operating, the system has been inspected monthly to check if frigid temperatures hindered performance of any of the components. During these inspections, several things are checked:

- Whether the lights turn on;
- The speed at which the lights are activated;
- Evaluating if the lights are bright and visible;
- Evaluating if the lights are too bright and cause distractions;
- The distance at which the lights are activated;
- The length of time that the lights blink once activated;

Outside of winter months, SMHI maintenance and sign crews routinely check to make sure the flashing lights seem to be in working order and report on any repairs required.

The system was under warranty for a one year period from installation on December 6, 2012. During that time, there were no major operational or maintenance issues reported. The only maintenance has been minor, and has involved an embedded LED that has become detached from the sign. In the fifteen months of operation, the upkeep cost has been minimal.

4.1.3 Collision Avoidance Assessment

It should be noted that when the Stop signs with the continuously flashing beacons were replaced with the LED Stop signs, the beacons were reinstalled on the intersection light standards so collision trends could be monitored without changing more than one aspect of the intersection at a time.

Collision data will be reviewed for any indication of potential effects the system has on traffic. Two years is not a sufficient amount of time to statistically determine if the system is helping reduce the number of collisions; however, as time progresses, the collision data may indicate a positive trend. The project should be re-evaluated in five and ten years to determine if there is a change in the collision trend. SMHI is aware that the low frequency of the collisions pre-installation makes an analysis of the effects statistically weak.

Due to the low incidence of collisions on Saskatchewan's low-volume highways, measurable collision trends are difficult to determine, and therefore the effect of the new LED signs will likely need to be limited to anecdotal evidence for some time. Input from local SMHI maintenance and sign crews is of utmost importance and SMHI is also looking into alternatives for collecting information, as described in the following section. Aside from collision records and traffic volumes, pre-installation information was not collected, so any changes to driver behaviour can only be compared from memory or from observation and analysis at similar intersections without the system. It is understood that this is highly subjective.

4.2 Preliminary Performance Observations and Findings

4.2.1 Feedback

SMHI engineers asked local sign and maintenance crews for their comments on the system. The individuals solicited for comments were not necessarily familiar with the theory behind the system, and therefore were deemed to be an adequate representation of public perception. The general comments were that the radar should be sighted at a further distance, allowing more time to stop, and/or that the Stop Ahead signs should be retrofitted with embedded LEDs as well. Crews that are involved in inspections stated that they did not feel that the system was triggered at safe speeds, although they were able to come to a stop in advance of the junction.

The feedback indicates that although there may be confusion surrounding the fact that the lights are not intended to act as an additional warning systems for the majority of vehicles, the distance and speeds at which the system is activated may be appropriate to act as intended.

It should be noted that in the simulations, traffic on Highway 16 was monitored to ensure that the junction would be clear in the event that the inspection vehicle might not be able to stop in advance of the intersection. For this reason, inspections have not been conducted in conditions with low visibility.

4.2.2 Crash Avoidance

As noted, anecdotal evidence will likely be more indicative of effectiveness of the crash avoidance warning system than crash reduction; however, it is still worth noting that there have been no reported collisions at the intersection since inception of the crash avoidance system.

SMHI is currently exploring alternatives for anecdotally determining effectiveness. This may include motion sensored video cameras. However, there would need to be more discussion on how to interpret the videos in terms of determining appropriate sample data to analyse and useful parameters to review. For example, if video footage showed the system being activated (i.e. LED's flashing on the Stop sign) prior to brake lights being applied, this could be an indication that the system was effective. However, the monitoring system may not be able to identify what counter-measure was truly effective (i.e. response to the audio tactile markings). It may also be capturing a set of threshold braking if the video recording system does not capture the entire intersection, and without corresponding speed and deceleration information, it may be impossible to discern whether braking was being applied after engine-assisted deceleration from farther back, which would imply a driver that was likely aware of the intersection and Stop control.

Other methods could include human observations with speed guns and range finders to document the number of potential violations (based on stopping sight distance theory) where the system was not deployed and/or the number of false alarms. Collecting a useful amount of data would require numerous lengthy observations of a variety of conditions for a proper survey of all conditions over a sufficient amount of time. This information could be useful in the future as a baseline to compare with adjustments in terms of distance of radar detection or changes to the speed thresholds. However, the number of man hours required would likely be prohibitive.

SMHI will continue to look for ways to improve radar timing and operation, as well as monitoring strategies. This includes exploring alternate parameters the system could track. Preliminary suggestions include having an intelligent system that could account for the variations that affect the braking distance. This could include adjustments for changes in braking time based on seasonal or weather fluctuations. If remote changes to the radar settings were possible, SMHI could adjust the radar to activate the lights at closer braking distances for dry pavement conditions, and greater distances for wet pavement or snow / icy conditions. Another parameter could include adjustments for design vehicles. If vehicle classification was available on the radar or in advance of the intersection with intelligent data transfer to the radar system, braking times could be adjusted based on the design vehicle approaching.

5.0 CONCLUSIONS

Based on the lack of measureable effectiveness of existing intersection treatments and ongoing public concern due to recent fatalities in 2010 and 2011, SMHI engineers began to look to more innovative approaches that could increase motorist attention in advance of the Stop condition on Highway 35.

SMHI determined that their preferred approach of mitigating future angle collisions at the junction was to install a warning system that targeted only drivers traveling at excessive speeds in advance of the Stop signs as an indication of the driver's failure to recognise the stop condition ahead. In general, design parameters are based on the majority of the driving population, while crash avoidance systems should be designed for the non-common driver that is inattentive or overly aggressive.

Unfortunately, SMHI found that limitations in radar technology meant installing a cost effective system to activate at a theoretically ideal stopping sight distance was not possible for a range of approach speeds. In addition, effectiveness of the system will be difficult to prove. Due to the low volumes on Saskatchewan highways, measurable collision trends are difficult to determine and therefore the effect of the new LED signs will likely need to be limited to anecdotal evidence for some time.

Despite the limitations, SMHI is trialling radar actuated LED Stop signs at the junction of Highway 35 and Highway 16. The system is being monitored for reliability and suitability as a crash avoidance system. Inspections are conducted regularly to determine issues with operations and maintenance of the system. SMHI will continue to look for opportunities to improve the system operation and functionality as well as the collection and analysis of information relevant to its effectiveness.

Should the trial be deemed effective, the next steps in the project will be to establish criteria for further implementation as another tool for improving intersection safety on provincial roadways in Saskatchewan.

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Table II – Stopping Sight Distances

OPERATING SPEED (km/h)	DISTANCE TO PERCEIVE AND REACT (m)				BRAKING DISTANCE (m)				STOPPING SIGHT DISTANCE (m)		
	1.15s PRT	1.5s PRT	2.5s PRT	TAC - Table 1.2.5.3[1]	Comfortable Deceleration[2] $a = 3.05\ m/s^2$	$a = 3.50\ m/s^2$	Doerzaph's Deceleration $a = 4.22\ m/s^2$	TAC - Table 1.2.5.3[2]	low end	high end	TAC - Table 1.2.5.3
	PRT = perception reaction time										
50	16.0	20.9	34.8	32.7-34.7	31.6	27.6	22.9	24.8-28.1	39	66	60-65
60	19.2	25.0	41.7	36.1-42.9	45.5	39.7	32.9	36.1-42.9	52	87	75-85
70	22.4	29.2	48.7	50.4-62.2	62.0	54.0	44.8	50.4-62.2	67	111	95-110
80	25.6	33.4	55.6	64.2-83.9	81.0	70.5	58.5	64.2-83.9	84	137	115-140
90	28.8	37.5	62.6	77.7-106.2	102.5	89.3	74.1	77.7-106.2	103	165	130-170
100	32.0	41.7	69.5	98.0-135.6	126.5	110.2	91.4	98.0-135.6	123	196	160-210
110	35.2	45.9	76.5	116.3-170.0	153.1	133.4	110.6	116.3-170.0	146	230	180-250

[1] Range is due to assumed operating speeds

[2] Standard Comfortable Decelertion Rates 3.05 m^2/s - 3.50 m/s^2 based on industry design guidelines

BRAKING DISTANCE

$$d = \frac{v^2}{254(f \pm G)} \quad = \frac{v^2}{2a}$$