Safety Performance Assessment of Stop-Operated Intersection Equipped with Active Road Sign

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Abstract

Aware of the importance of traffic signs, alignments visibility and placement on road safety, deployment of Light-Emitting Diode (LED) signs (also known as Active Road Signs) has been increased especially at locations with known history of potential for high Collision occurrence. The effects of these types of signs are not yet fully understood. The expected benefits of the proposed active signage are enhancing traffic flow efficiency and improving safety of road users, especially under adverse weather conditions and hectic driving environments.

To quantify the effects of the proposed treatment, Cross-Section Observational studies in safety and driving behavior has been conducted for STOP sign on a selected test bed.

The main objective was to determine the impacts of deploying such treatments on roadway safety and traffic operation.

An unbiased comparison has been conducted under same condition with same sample series. The result of this study proves a statistically significant improvement in drivers' compliance to the required command addressed by the STOP sign. This compliance is either due to attracting driver attention and making drivers more alerted about the driving environment or improvement in perception and understanding the command.

Keywords:
STOP sign, Stop-controlled Intersection, Active Signage Systems; Cross-Section Safety Analysis; Light Emitting Diodes; Sign sheeting; Stopping; Traffic safety; Traffic Signs; Traffic Speed; Visibility;

Introduction

To date, the time interval requirements for the driver to detect, recognize, read, and respond on roadside posted signs have been determined (Schieber 1987). The difficulty of interpreting complex nighttime or under bad road weather conditions scenes has been also studied before with respect to conventional overhead guide signs (Freedman 1985). The difficulties to the path ahead which causing drivers distraction from understanding signs might be due to low-contrast, low-diffusion, ambiguity, or additional elements such as rain, fog, snow, storm, visual noise, clutter, information load, and complexity (ITE 2005).

Other driving behaviors to which the driver must attend and the amount of time these behaviors require have also been identified and there are guidelines for distance required, relative to speed.

The American Association of Highway and Transportation Officials (ASSHTO) provides tables for recommended sight distances and design speeds in order to meet safety requirements in approaches, intersections, curves and other network facilities. The tables are based on one second perception and 1.5 seconds reaction time(AASHTO 2004). There are recommendations based on grades, vehicle types and geometry of intersections and approaches. For instance, for intersections with STOP sign AASHTO provides detail analysis for sight distance requirement while considering the time gap needed for vehicles performing both crossing and turning maneuvers. Harwood and his associates recommend sight distance for a passenger car at a stopped controlled intersection to be based on a distance equal to 7.5 s of travel time at the design speed of the major road (Harwood et al. 2000).

AASHTO recommend Minimum Required Stopping Sight Distance (MRSSD) from the conflict line (for instance stop line at intersection) to be calculated as follow (AASHTO 2004).

Equation 1

$$MRSSD = V_s T_r + \frac{V_s^2}{2a \pm 2gG}$$

Vs is the velocity or 'set' speed for side or traffic controlled road (m/s), *Tr* the driver's perception–reaction time (s), default 2.5 s, *g* the gravitational constant (9.81m/s2), *a* is the deceleration rate (m/s2), default 3.4m/s2, and *G* the grade in decimal.

From these data the sight distances that the driver requires for using overhead guide signs can be predicted.

For Yield- and Stop-Controlled Intersections (SCI), signs should be visible from a sufficient distance to command drivers' attention and this needed to be safely before entering the intersection. This is the same requirements for all other regulatory or warning symbol signs such as chevrons on sharp curves or pedestrian crossing and school zones. Thus, the Available Sight Distance (ASD) for a sign should be greater than the minimum required stopping sight distance (Awadallah 2009).

In recent years, many studies investigated the proper ASD with respect to ambient light conditions and human factors such as drivers' eyesight. The maximum recognition distance and the distance at which the signs should be easily recognized are based on night time ambience, traffic sign background luminance, luminance contrast, complexity and size of symbol on sign, and geometry of the facility (Harwood et al. 2000) .

Other studies investigated both visibility (ability to see signs) and legibility (ability to read/interpret signs). Schnell et al. have deployed simulation to evaluate the required ASD in laboratory environment (Schnell et al. 2004). The ASD for a sign may be determined via field testing using drivers with minimum acceptable visual acuity. Awadallah et al. performed this test via a reflector-meter that measures sign retro-reflectivity. Jones and his affiliates proposed a technique to perform the test in a normal open road environment using digital cameras and stereoscopic image processing techniques (Jones et al. 2012) and finally Altamira suggest a tool to analyse availability of sight distance based on 3d visualization (Altamira et al. 2010).

Problem statement and objective

According to Highway Safety Information System 55% of total Collisions occur at nights. That accounts for a quarter of total driving. Among road network facilities, roadway intersections are known to be vulnerable with 45% of total Collisions (DOT 2014). At intersections with different control devices, STOP sign operated intersection are the most vulnerable facilities with highest Collision rate leading to fatal or serious injuries (Hauer & Persaud 1996). 21% of Collisions are known to be due to environment surrounding the driver to be the cause (DOT 2014) and "Inadequate and poorly maintained signs" often cited as a contributing factor. 7.9% of fatalities and 11.1% of total Collisions occurred at SCI. In Canada 2728 individuals have lost their lives at stop-controlled intersections between 1999 and 2011 (National Collision Database Online 2014).

On the other hand approximately 60% of CSI Collisions are due to violation of traffic signs. (Moon et.al 2008). There are two reasons known behind the violations:

1. Unintentional violation of the sign due to improper perception of the sign,
2. Deliberate violation, when travelers intentionally do not comply with the control device (sign) command.

The unintentional violation of the signs are due to poor visibility or illegibility of signs or alignments. The required condition addressed by Manual on Uniform Traffic Control Devices (MUTCD) for traffic signs to meet is to command drivers' attention. As mentioned earlier it's required for ASD to be greater than MRSSD to tackle this issue. There are some scenarios in which implementation of Active Road Signs will improve drivers guidance and hence safety. This compliance improvement is due to either attracting driver attention and making drivers more alerted about the enviornment with conflict point or improvement in perception and understanding the command.

In this study we attempted to identify if LED STOP sign among all active sign systems is more effective in commanding drivers' attention than common retro-reflective signs. The main objective was to determine the impacts of deploying such systems on roadway safety by monitoring the drivers' compliance to the command (Full or Rolling stop).

Illuminated Signs,

The Traffic Association of Canada (TAC) characterize Active (illuminated) Signs as a type of road sign which is not rely on vehicle headlights for illumination (TAC 2000) . These type of signs are being visible from a greater distance and can emit light so they can be seen from a greater distance, typically over 1 km.

The illuminated signs should be considered wherever reflectorized signs are not effective; for example, where background light sources or other uncontrollable distractions reduce visibility of signs, at decision points on high speed/high volume facilities or where vehicle headlights may not adequately illuminate the signs. Use of prismatic lens retro-reflective sheeting shall not be considered a substitute for sign illumination, especially in urban areas. Some studies investigated the effectiveness of these kind of materials and compared them under different road conditions. Gates and his team have evaluated eight applications of signs with enhanced conspicuity properties. The research team concluded that fluorescent and prismatic sign sheeting materials and Embedded Light Emitting Diodes (LED) in sign faces have many statistically significant beneficial results (Gates et al. 2004). In another atempt, increase in safety effectiveness of retro-reflectivite signs has been investigated on 339 locations in the state by Federal Highway Administration (Bhagwant et al. 2008). Empirical Bayes (EB) methods were incorporated in their before-after analysis and they have excluded signs with subsequent strategies such as a signal or a flashing beacon. The study was designed to detect a 10-percent reduction in all crashes with 90-percent confidence.

According to Gates and his team, a LEDs embedded in STOP sign will reduce %28.9 and %52.9 respectively in the number of vehicles not fully stopping and the number of vehicles moving through the intersection without slowing down (Blow-through). Gates’s study didn’t provide crash estimation or index of safety effectiveness of LED signs. Some other studies investigated similar LED STOP signs and achieve statistically significant decrease in vehicle approach speeds ranging from 3.05 to 5.5 Km/h with %7 percent decrease in average speed (Public & Messages 2013). Both studies showed the treatment have positively affected driver behavior and mainly during nighttime.

In another recent study, (Davis & Investigator 2014) had a more comprehensive study over flashing STOP sign safety measures. According to the result from their study the estimated reduction of about 41.5% in right-angle crashes could be expected. With 95% confident this safety effectiveness is estimated to be between 0% and 70.8%.

On the other hand the visual discomfort from simulated traffic signals under nighttime viewing conditions has been assessed before and solutions such as dimming signals using light-emitting diodes has been proposed (Bullough et al. 2001)(ITE 2005). However the literatures reviewed over the results of previous conducted research and studies have shown the significant impacts on proper installation of illuminated traffic signs on drivers' understanding and hence safety performance. The *Institute of Transportation Engineers* (ITE) has provided the minimum performance requirements for 200 mm and 300 mm LED traffic signal modules including photometric requirements meanwhile application of LED in traffic signs was not been yet addressed (ITE 2005) (ITE 1998) The flashing frequency recommended by FHWA is that all LED units shall flash simultaneously at a rate of more than 50 and less than 60 times per minute (Federal Highway Administrator 2012).
In another attempts the luminous Intensity of flashing beacons signs (i.e. pedestrian crossing and school crossing) and the discomfort glare has been studied (Srinivasan et al. 2008) (Robertson et al. 2014).

Safety Analysis Method,
The overall objective in traffic safety analysis is to reduce crashes and crash severities. This make crash frequency or crash severities, or both, fundamental basis of safety analysis. According to Highway safety Manual (HSM) a "crash" is defined as a set of events that results in injury or property damage sue to at least one motorized vehicle with other motorized, un-motorized or object. Collision type, geometry, driver compliance to traffic operation, weather and visibility conditions are some indicators required for crash analysis. The number of crashes per year is called crash frequency and can be calculated as follow:
Equation 2

$$Cras\quad Frequency = \frac{Number\ of\ Cras\quad es}{Period\ in\ Years}$$

There are several types of safety analysis that transportation engineers undertake for safety studies. Transportation Research Board (TRB) in the National Cooperative Highway Research Program NCHRP (GRIFFITH et al. 2001) includes "Before and After" evaluation as one of the common methods for safety analysis. This method conducted to assess the safety effectiveness of a given type of improvement specially after introducing a new engineering treatment to an existing condition and monitor related countermeasures before and after treatment installation. The HSM (AASHTO 2010) purpose observational and experimental before and after and cross-sectional studies to be used for safety effectiveness evaluations.

The difference observed from before and after analysis will affect the safety performance function (SPFs) of a “base” statistical model which are widely used to estimate the average crash frequency of a facility type. This deference can be presented as Crash Modification Factor (CMF) which is the ratio of expected frequency with and without the intervention (Equation 3). The standard error related to CMF is also required to determine confidence intervals of the estimated changes. The number of crash $N_{Predicated}$ for a site type x can be predicted with Equation 4 (AASHTO 2010).

Equation 3

$$CMF = \frac{E\ N_{with}}{E\ N_{without}}$$

Equation 4

$$N_{Predicted} = N_{SPF\,x} \times \; CMF_{1x} \times CMF_{2x} \times \ldots CMF_{yx} \; \times C_x$$

C_x is required to calibration factor for time period and jurisdiction difference between model development and application.

One of the issues in before and after analysis is that the change is not just due to treatment and it’s recommended to consider all factors that might impact safety along with the safety impacts of the treatment. These factors can be classified in two major groups of recognized and certain (e.g. traffic flow) and unrecognized and uncertain factors (Hauer & Persaud 1996). In this study the two site section are relatively same in term of geometry and therefore the unrecognized factors are minimized.

Compliance to the STOP sign at SCI can improve the safety of the facility up to 60%. This improvement will be mainly in favor of pedestrians and non-motorized travelers.

Many studies including this study is using drivers' compliance to the sign as the performance measure of the treatment at SCI.
To observe this compliance, vehicles have been videotaped as they were approach the STOP signs. Processing video data allows to determined vehicle maneuver, deceleration and more over the occurrence of vehicles not-fully stopping (blow-through and roll-through). For statistical procedure all testing was performed at a confidence level of 95 percent and different attempts was made to perform the experiments so that biasing factors would be minimized.
Every attempt was made to collect data during the same times of day in a course of one week in November 2014. The noble approach in this study was to reduce the potential extraneous changes within the given site, including changes in the driving population, density, weather condition and other changes as the same sample units where used for each intersection with and without treatment and each attempt. An observers was instructed to score a vehicle as coming to a complete stop if prior entering the intersection. Recordings were scored in a random order. The primary observer never became aware of the purpose of the experiment. Two other observers aware about the purpose of study redid the task. Inter-observer agreement on the occurrence was calculated by dividing the percentage of times three observers agreed on the occurrence of behavior by the number of times they agreed on the occurrence of the behavior plus the number of times they disagreed.

Case Study

Two T-intersection has been identified in borough of Lachine in city of Montreal with mixed motorized and non-motorized traffic composition which elevate conflict risk especially between turning vehicles and pedestrians.
The major road is a two way, two lane link in parallel to highway 20 which is under rush hour traffic pressure (Figure 1).
The two, two-way, one lane minor collectors are perpendicular to the major link with almost identical properties in term of traffic volume, alignments and geometry.
All approaches are equipped with STOP signs. The two STOP signs on eastbound and westbound approaches on Rue Victoria intersection and 28th Ave are equipped with flashing LEDs embedded at each corner of

the sign-face had consistent flashing rate of 60 times per minute. The remaining four are standard retro-reflective sheeting STOP signs (Figure 2). All approaches has been included in the study.
For videotaping the selected camera was four GoPro Hero 3 video cameras, set to record 720p video at 30 frames per seconds. The camera is capable of recording up to 10 hours of video with backup battery pack. The GoPro camera is highly portable, allowing for extremely versatile installations, which was useful for this study. Four cameras covering all movements at intersections (Figure 3) has been installed over portable telescopic mast. Existing roadside infrastructure was used to facilitate the mounting of the camera system.

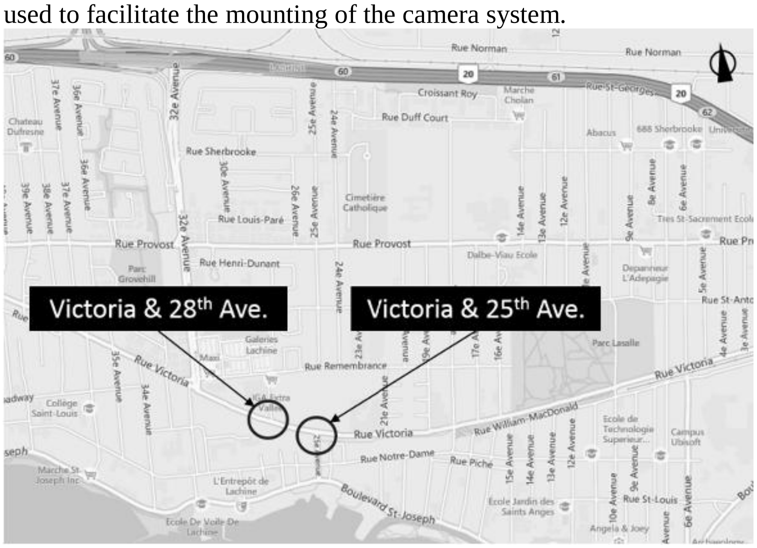

Figure 1 Test bed location

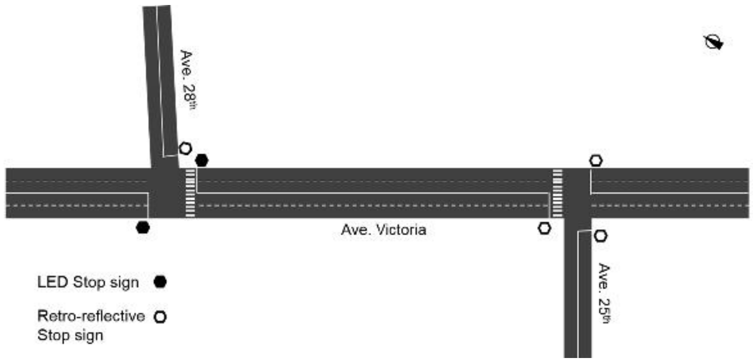

Figure 2 Site plan

The LED STOP signs are standard shape solar powered and was in place for more than 3 years. Hence the suggested warm up period required for before-and-after analysis was not necessary as the travelers has been already adapted to the sign (Figure 4).

Figure 3 camera snapshot EB Victoria Ave. and 28th Ave.

Figure 4 Solar panel powered LED STOP sign with

Results

Statistically significant reductions of 27.8% in the occurrence of vehicles not-fully standstill (blow-through and roll- through) were observed during evaluation periods. On average 75.6% of motorists came to a complete stop at sites with LED stop sign.

Figure 5 and 6 are showing the compliance to STOP sign ratio for each approach at each intersection and each recording session (Total 14 sessions). The maximum traffic flow recorded was less than 800 veh/h/ln on the major approach.

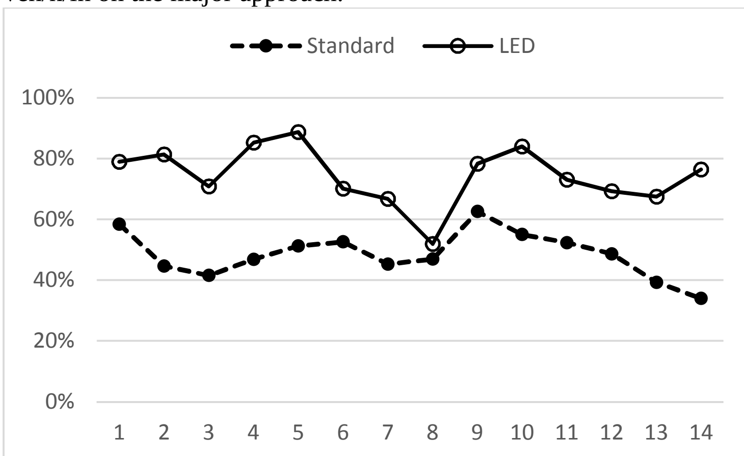

Figure 5 – Victoria Ave. West-bond approach STOP sign compliance ratio

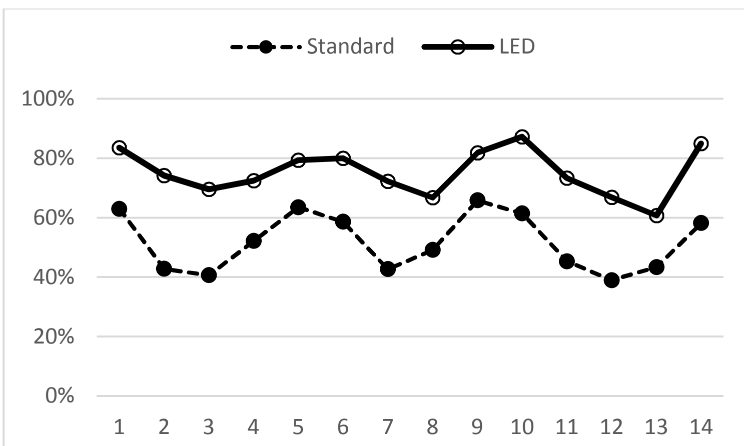

Figure 6 - Victoria Ave. East-bond approach STOP sign compliance ratio

While considering all other criteria between the two sites were equal, the compliance improvemnet from the experimient was significiane. Considering the crash analysis conducted before proofed the impact of the CMF with the treatment %37.7 to %59.2 improvement with %65-%70 confidence in right-angle crashes and %9.6 to %76.4 with higher confidence (95%).

To check on the Bayesian computations, the procedure described in Appendix 9A of Highway Safety Manual (AASHTO 2010) has been deployed.

It's necessary to mention that the spontaneous regression to the mean effects on Collision rates has been considered the same for both sites.

Conclusion

The use of Stop signs with flashing LEDs embedded at corners of the sign-face had statistically significant beneficial effects on stopping compliance even in daytime when compared to standard Stop signs.

Results of this study showed that this treatment increases the percentage of motorists coming to full stop and hence decreased the number of right angle conflicts which is common at SCI.

In implementation of such treatments it's important to consider possible threads such as vandalism due to their novelty, potential driver distraction and losing the attraction.

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All errors and the views expressed in this research are, however, solely ours.

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