Traffic Sign Brightness, Performance Measures and Driver Safety: A Synopsis

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Abstract

Sign visibility is critical to traffic safety, operation, and efficiency. Recent studies have investigated requirements for sign brightness that allow for quick yet accurate information acquisition. Findings suggest that larger signs and increased brightness provide for faster information acquisition by the driver. Furthermore, sign improvement programs suggest that crash reductions are possible with systematic sign upgrades. Recently, the city of Albuquerque, New Mexico, has upgraded its traffic signs in multiple sections of the city. The city has been replacing all traffic signs district by district, which allowed researchers from the Texas Transportation Institute (TTI) to have control sites alongside treatment (sign upgrade) sites. The study reports on the crash frequencies not only before-and-after the treatment in districts that have undergone sign upgrades, but also with districts with no sign upgrades, serving as control sites. Findings indicate that, when viewed collectively as a systemic treatment, the upgraded signs may have contributed to reducing as many as 13 nighttime crashes across the entire collection of the treated segments.

Introduction

Public transportation agencies aim to improve their constituents' safety while maintaining a rapid and efficient transportation infrastructure. Traffic signs are an important element of this roadway infrastructure, aimed to provide valuable and timely information to drivers. Although ensuring that the traffic signs provide this valuable and timely information will not eliminate crashes, failing to provide the timely and accurate information to drivers will almost certainly lead to severe inefficiencies if not further crashes.

The timeliness and accuracy of traffic sign information acquisition has been investigated in a variety of studies over the last few decades. As a surrogate measure for timeliness and accuracy, many of these studies investigated "legibility distance" or "comprehension distance", the distance to the sign at which the driver is first able to read and understand the sign. It is often hypothesized that increasing the legibility distance will afford drivers with more time to comprehend the sign message and react to it when necessary. Therefore, it was important to find out the first point a sign would become legible. However, when identifying legibility thresholds, researchers often did not limit nor measure the time the subjects used to acquire the information from the signs, which would translate to eyes-off-the-road time during actual driving and as such, could have safety implications.

More recently, a study conducted at the University of Iowa [1] has investigated drivers' information acquisition times from traffic signs. While earlier driver eye fixation studies showed that drivers often fixate on signs for multiple seconds during sign reading, this study offered data that relates sign size and brightness to information acquisition time. The findings indicate that increasing sign size and/or brightness reduces information acquisition time. Researchers conclude that reducing information acquisition time from signs may help explain safety improvements as drivers can allocate more time and attention to their primary task of driving.

While the above-mentioned study offers fundamental scientific evidence, which suggests that larger and/or brighter signs should help mitigate crashes in the aggregate, quantifying the effect of brighter signs on crash reduction in the field poses some challenges. Crashes are relatively rare and occur for multiple reasons, and reaching a critical data mass with solid statistics investigating the effect of a single factor in isolation usually takes multiple years in a typical before-and-after study. And over the course of these years, quite often, multiple, uncontrollable changes such as seasonal variations, and changes in traffic patterns and volumes could occur, all of which can change crash rates and make it difficult to run a "controlled experiment" and attribute any variations in the crash rates to a single factor such as traffic sign upgrades. One approach to overcome these challenges is to "observe" the effect of the uncontrolled factors at a similar "control site" rather than trying to control them to minimize their effects. Later, the trends in the control site can be compared to those in the treatment site to determine the effect of the treatment.

A recent study conducted by TTI [2] had utilized this approach. They investigated the crash rates in the city of Albuquerque at segments of the city where all signs were upgraded with retroreflective sheeting that comply with ASTM D4956 Type XI, and other similar segments of the city were designated as "control segments". The results suggest that brighter signs indeed offer safety benefits.

Literature Review

The human factors literature provides a wealth of findings ranging from the fundamental psychophysical luminance (brightness) levels that the driver needs to be able to read a sign as a function of font, contrast and other factors, to field studies that investigated the gaze directions and durations of drivers while reading signs in real-world driving conditions.

Luminance Needs of Drivers from Signs at Nighttime

Studies on the luminance needs of drivers from traffic signage at nighttime can be categorized into two segments for the practitioner: (1) threshold (or minimum) levels, and (2) optimal levels.

The threshold levels refer to the luminance levels where the design driver (i.e. 85th percentile driver) could just start reading the sign message. Optimal levels refer to the luminance levels where sign reading is comfortable, and relatively effortless for the same design-driver.

Literature is relatively more resourceful on the threshold luminance levels and legibility distances for a design-driver (i.e. 85th percentile or median vision, depending on choice) and for a given sign. In the case of threshold legibility distance as the dependent variable, the distance from the sign where the driver was first able to read a sign successfully was recorded. The main independent variables in these studies were typically the luminance of sign legend (or copy) and sign background, font type and physical size, and driver age. Sign luminance may be directly controlled, or could be a function of multiple other variables such as sign location, vehicle headlights, and vehicle type. By studying the effect of these independent variables on the threshold legibility distance (the dependent variable), researchers aimed to maximize the threshold legibility distance, and thereby allow for more time and distance to read a sign at night.

Carlson and Hawkins [3] of TTI reported on the US Federal minimum retroreflectivity coefficients currently in effect in the US Manual on Uniform Traffic Control Devices (MUTCD) for in-service signs. These minimums had been established by identifying the minimum required luminance levels for different sign categories, often at the levels that would accommodate the 50th percentile of US drivers over the age of 55 years. Legibility distances are reported in "legibility index", which is the ratio of the legibility distance to the letter height of the sign legend. The required legibility distance has, in most cases, been benchmarked at a legibility index of 40 ft per inch of letter height. For instance, a sign with ten (10) inch letters will be legible at 400ft, a sign with sixteen (16) inch letters will be legible at 640ft. At the 40 ft/in legibility index requirement, their findings suggest a minimum required luminance for guide sign legends of 2.3 cd/m^2 and 3.2 cd/m^2 for the 50th percentile US drivers over the age of 55 years and 65 years, respectively. To accommodate a higher percentage of drivers, i.e. 98th percentile design drivers at the same 40 ft/in legibility index, the luminance levels will have to be increased significantly, to over 30 cd/m^2 for overhead signs and to 38 cd/m^2 for street name signs. The required luminance was assessed by gradually increasing headlight brightness (and thereby the sign brightness) while situated in a static vehicle. Information acquisition time was not limited or measured.

Sign Luminance Needs for Optimal Sign Legibility

Aktan and Schnell [4] compared the threshold levels to optimal sign luminance levels. They investigated sign background luminances ranging from 0.4 cd/m2 to 300 cd/m^2 for positive (legend brighter than background), and from 10 cd/m^2 to 1200 cd/m^2 for negative contrast signs (legend darker than background), and luminance contrasts ranging from 1 to 37. At a given luminance level, the 15th percentile (higher performing) driver could read the sign at approximately twice the distance the 85th percentile (lower performing) driver could. For highway series D letters at around 80 cd/m^2 of background luminance, the legibility indices for the 15th percentile, median, and the 85th percentile drivers were around, 60 ft/in, 45 ft/in, and 30 ft/in respectively. At a luminance of 1 cd/m^2, the respective indices were approximately 37 ft/in, 30ft/in, and 20 ft/in. The difference in the legibility indices from 1 cd/ m^2 to 80 cd/m^2 suggests nearly a 50% improvement in the threshold legibility distances. Researchers investigated luminances up to 1,200 cd/m^2. While they saw no negative impact, increasing the luminance from 100 cd/m^2 to 1,200 cd/m^2 provided only an additional 5% in the legibility index. The researchers also found that comfortable legibility occurred at nearly 75% of the threshold legibility distance. These researchers employed a similar method as in the TTI study [3], where subjects were given unlimited time to read the signs.

Schnell, Aktan, and Li [5] investigated sign luminance requirements for nighttime legibility of symbolic traffic signs. They studied the effect of internal sign contrast and background luminance on the threshold legibility distance (translated to visual angle). They reported on two major legibility patterns: First, that the effect of contrast on legibility is significant at low luminance levels, and second, that the legibility of investigated highway fonts was improved with increasing sign luminance. Like the previous studies, this study allowed for unlimited sign viewing time.

Sivak and Olson [6] reviewed earlier human factors studies to determine the optimal luminance requirement for traffic signs. They found 75 cd/m^2 to be the optimal sign sheeting luminance for white sign legend.

Aktan and Burns [7] investigated actual sign luminances of various traffic signs made of sign sheetings ranging from ASTM D4956 Type I up to ASTM D4956 Type XI, under low-beam headlight illumination in the field. The signs were mounted on right shoulder, left shoulder, and overhead positions. The test vehicle was an SUV, and they used a CCD photometer to measure the luminances in the scene as observed by the driver. The observed luminances were typically below 40 cd/m^2 for right shoulder mounted signs, and below 10 cd/m^2 for left shoulder mounted signs.

A study conducted by Bullough et al [8] reported the actual luminance levels from LED billboard signs. They found that the luminances measured between 150 cd/m^2 – 277 cd/m^2, with an average of 210 cd/m^2. These luminances far exceed the typical retroreflective traffic sign luminances as observed by drivers under low-beam headlamp illumination at night as reported in [7].

Sign Information Acquisition Time

Loftus and Ruthruff [9] investigated the effect of luminance and exposure time on information acquisition performance using a number-reading task. Their findings suggest that higher luminance yields faster information acquisition. They found that higher duration of exposure and/or luminance of text provided a higher rate of correct recall. Subjects acquired information faster at higher luminance levels than at lower luminance levels.

Schnell et al [1] investigated the information acquisition time from traffic signs as a function of accuracy level (chance of correct information recall), sign size, and sign legend luminance. This study provides valuable data on the exposure time requirements for the drivers to successfully read the message on a typical guide sign.

They hypothesized that brighter signs can communicate with drivers much more effectively, in that, increasing luminance beyond the above established legibility threshold of 3.2 cd/m^2 would yield faster information acquisition. Furthermore, they hypothesized that brighter signs would provide more accurate information transfer when exposure time is limited.

They had subjects ranging from 55 years to 82 years of age, all with valid Iowa driver's licenses. Their dependent measure was the information acquisition time, while they varied the following independent variables: sign legend luminance (5 levels: 3.2 cd/m^2, 10 cd/m^2, 20 cd/m^2, 40 cd/m^2, and 80 cd/m^2), text size (or legibility index at two levels: 33 ft/in, and 40 ft/in), and percentile accuracy of the responses (two levels: 50th and 84th percentile accuracy).

They used white-on-green guide signs as stimuli at varying luminance levels presented on a photometrically-calibrated LCD monitor. The stimuli featured three lines of street names, all composed of six-letter street names from the US, each with a corresponding, randomly generated exit number. The subject was given a street name first, and was asked to determine the exit number associated with that street name in the subsequent sign stimulus. The street name signs were similar to the sign shown in Figure 1. The exposure time was limited to five (5) seconds. If the subject was unable to respond after five seconds, the response time was recorded as five seconds, with a corresponding "failure".

Figure 1. The cue street name, and the subsequent sample sign stimulus used in [1]

The researchers found that luminance, legibility index, and the percentile accuracy all were statistically significant factors affecting the information acquisition time. They noted that some participants had difficulty in reading the information, especially at lower luminance levels of 3.2 cd/m^2 and 10 cd/m^2 at the 40 ft/in legibility index. Almost half the participants (9 out of 19) were unable to read the sign at 3.2 cd/m^2 luminance level. Five of the subjects could not read the sign at 10 cd/m^2 luminance level.

Pairwise comparisons of the five luminance levels show that each luminance level was statistically significantly different (at α=0.05) from one another in terms of information acquisition time. For instance, increasing the luminance from 40 cd/m^2 to 80 cd/m^2 reduced the information acquisition time, especially for the higher accuracy level (higher rate of sign comprehension). Shows the box plots for information acquisition time for 84% accuracy level.

Researchers concluded that:

- Highest tested luminance, 80 cd/m^2, provided fastest information acquisition thereby shorter time is required to reach a certain reading accuracy.
- If the viewing time is limited, higher sign luminance and/or larger letter sizes provide more accurate sign reading
- Larger sign size has a very similar positive effect in legibility performance. Larger signs improve information transfer performance.
- Information acquisition times are less affected by distance (or letter size) if the sign luminance is maintained at a high level
- Information transfer accuracy improves with increasing exposure time.
- Lowering information acquisition times from signs may leave more time for attending the primary driving task, which is a key factor in safety.

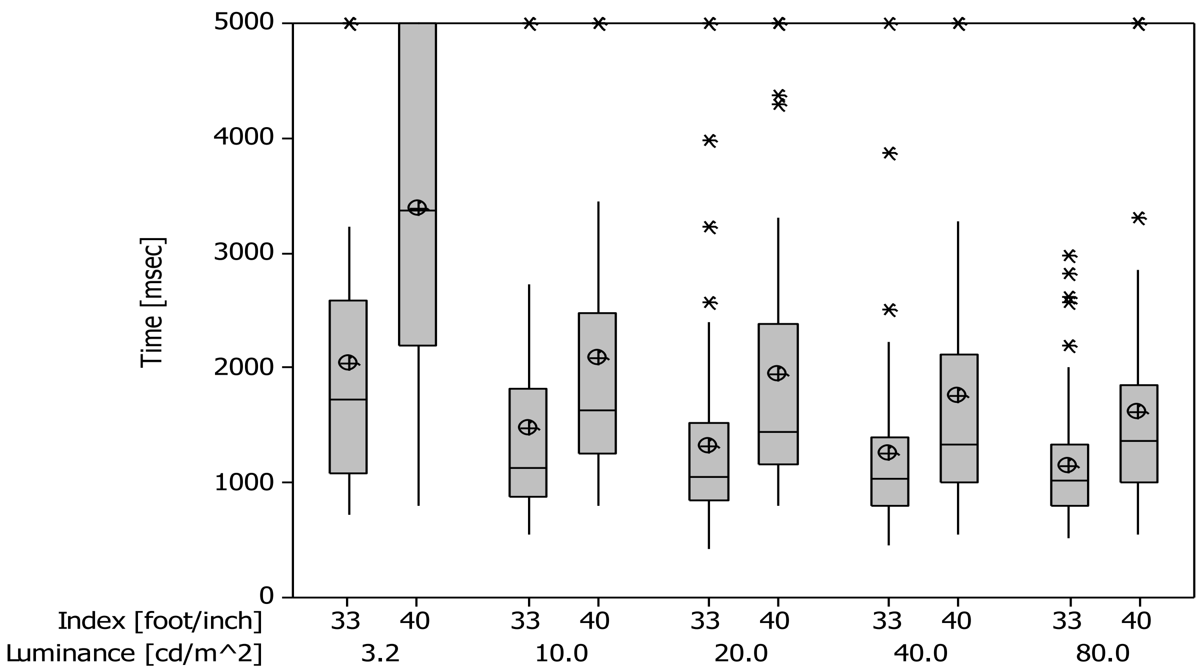

Figure 2. Information acquisition times as a function of luminance and legibility index to provide 84% correct answers (adopted from [1]).

Sign Luminance and Safety

Technical literature features numerous before-and-after (comparative) type studies that investigate crash rates before and after a treatment such as traffic sign upgrades. While multiple studies show an overall reduction in crashes after systematic sign upgrades, most of these studies do not account for uncontrolled factors, such as seasonal variations or traffic volume changes over the years. Accounting for these external, uncontrolled, and potentially significant factors require the use of a control site.

A recent study conducted by Brimley et al [2] of TTI studied the crash rates in the city of Albuquerque in New Mexico, U.S. In this study, researchers were able to identify separate treatment and control sites, similar in most aspects except that all the traffic signs at the treatment sites were upgraded to new signs with ASTM D4956 Type XI sheeting as a part of a city sign upgrade plan.

The crash rates in the treatment and control sites in the city of Albuquerque over a four-year period is given in Table 1.

Table 1. Crash rates in the control and treatment sites in Albuquerque, NM (Table adopted from [2])

	2011	2012	2013*	2014
City of Albuquerque				
Total Crashes	16,546	16,070	16,292	17,728
Fatal and Injury Crashes	4,798	4,190	4,614	4,959
Nighttime Crashes	2,529	2,462	2,612	2,943
Nighttime Fatal and Injury Crashes	678	581	685	732
Treatment Segments				
Total Crashes	293	256	242	304
Fatal and Injury Crashes	88	67	87	78
Nighttime Crashes	33	33	23	24
Nighttime Fatal and Injury Crashes	8	8	11	7
Control Segments				
Total Crashes	193	209	191	233
Fatal and Injury Crashes	59	51	52	66
Nighttime Crashes	22	20	17	23
Nighttime Fatal and Injury Crashes	3	8	10	10
			***Treatment occurred in 2013**	

The control segment crash trends provide a baseline expectation for the treatment site, in that, if the treatment has no impact, one would expect a similar trend in both the treatment and control sites. When the total crashes in the treatment and control segments are compared, the trends are similar. However, nighttime crashes do not seem to move in tandem between the control and treatment segments. The researchers note that, in contrast to the notable increase in nighttime crashes in Albuquerque and in the control segments, nighttime crashes in the treatment segments were somewhat flat. The researchers also noted a decrease in the nighttime fatal and injury crashes in the treatment segments. No such decrease was observed in Albuquerque or in the control segments.

Figure 3 illustrates the comparison of treatment and control segment in terms of the total and nighttime crashes.

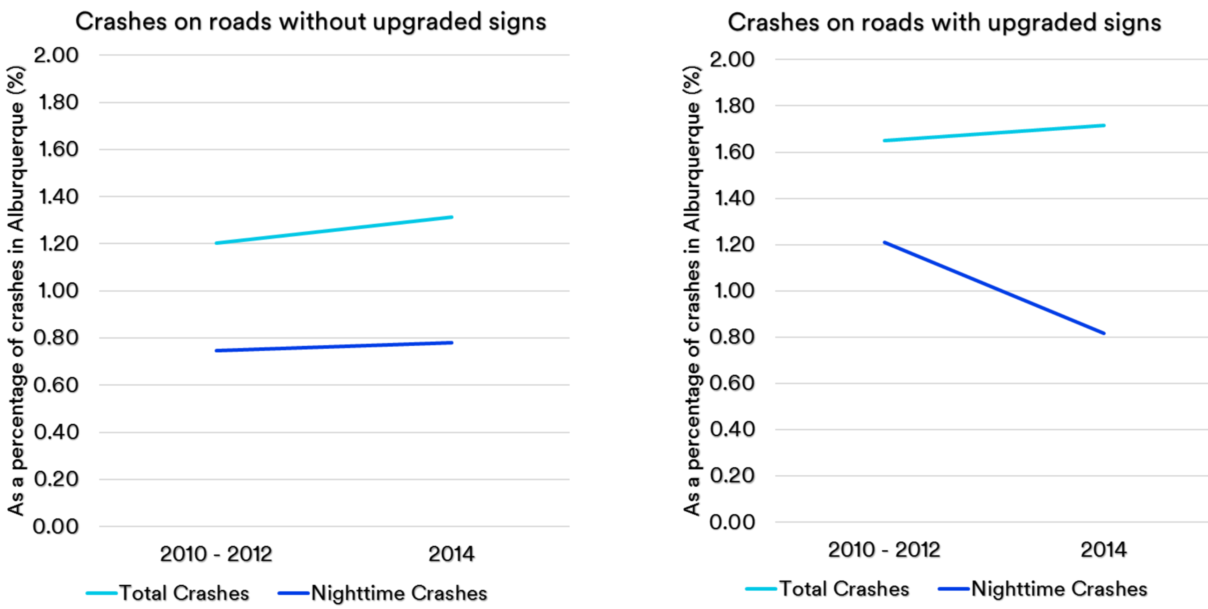

Figure 3. Comparison of treatment and control segment in terms of the total and nighttime crashes in [2].

Conclusions

Recent studies suggest that systematic sign upgrades with better, brighter sheeting may provide notable safety benefits for the driving public at night. One such recently published study investigated the crash rates for segments of the city of Albuquerque, in New Mexico, U.S. As these studies usually span over multiple years, conditions at the test sites may change that would have an impact on safety regardless of the treatment. In this study, researchers identified control sites to account for the baseline trends, which allowed for a comparison to isolate the effect of sign upgrades, where all traffic signs in the treatment segments were replaced with signs made of ASTM D4956 Type XI-compliant retroreflective sheeting. The results show a positive safety improvement as a result of these sign upgrades.

More fundamental human factors studies suggest that the improvement in the information transfer speed of brighter signs might help explain this safety improvement. Researchers argue that brighter signs, well above the threshold legibility levels, allow drivers to obtain information much quicker and/or more accurately. As these brighter signs perform their primary duty of information transfer much more rapidly, they provide drivers with more time to attend to their primary driving task, and thereby improve safety.

Many earlier human factors studies that investigate threshold legibility levels for sign reading are also very valuable in terms of determining the threshold points. However, these threshold levels reflect minimum baseline and are below the levels that yield quick and confident information acquisition. They have been utilized to determine minimum levels for sign replacement rather than guaranteeing optimal sign performance. Research suggests that traffic signs that provide luminances closer to the optimal levels offer immediate safety benefits for agencies and motorists as a simple and actionable safety improvement. **See the difference between High Intensity Prismatic and Diamond Grade™ reflective sheeting.**

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