Automated Mobile Highway Sign Retroreflectivity Measurement

Final Report for Highway-IDEA Project 75

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INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS
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EXECUTIVE SUMMARY

Highway signs, which are used to promote highway safety and efficiency, need to command attention and give adequate time for driver response (1). At nighttime, the visibility of the signs depends on the retroreflectivity of the sheeting material on the signs. The retroreflectivity is a measure of the amount of light emanating from vehicle headlamps that is reflected directly back, by the sign, to the driver of the vehicle (figure 1). The current practice for ensuring that the signs are performing at night as required consists of either visual inspection, measurement of retroreflectivity with a hand-held retroreflectometer, or systematic periodic replacement of signs regardless of whether they are deficient or not. None of these approaches are ideal. Visual inspection is too subjective, hand-held retroreflectometer measurements are tedious, time-consuming, and sometimes dangerous, and systematic replacement is not cost effective.

This report describes a prototype of a digital video image analysis system that measures the brightness of highway signs using nighttime video images taken by a camera mounted in a moving vehicle.

The concept is that by using an inexpensive video camera and laptop computer mounted in a vehicle (figure 2), a measurement of the brightness and visibility of the sign can be made. The system uses real time image analysis of night images of signs acquired on a mobile platform moving at highway speeds, illuminated by normal vehicle head lamps. Using video images at night results in measurements that are as closely as possible reflect what the human eye sees.

The innovation is in using state of the art video imaging hardware and designing real time image analyzing software to identify and measure the brightness of the sign in real time from live video images (as the vehicle travels along the roadway) or from recorded digital video images. The video hardware uses high speed IEEE 1394 (“firewire”, “i.LINK”) connectivity to bring digital images from the camera to the computer in real time. The purpose designed video software (figure 3) analyzes images by first identifying the sign, classifying the type of sign, measuring the brightness of the sign, and determining if it meets minimum standards. Each sign is measured multiple times as the vehicle moves down the highway. The maximum measurement is taken and recorded in a data file, along with the time and a thumbnail image of the sign. Future enhancements will add GPS coordinates or mileage reference to the data file.

FIGURE 1. Stop sign illuminated by headlights of a vehicle.

The goals of this project were to prove the concept and develop a prototype that could identify signs by color and measure the retroreflectivity at a given measured distance for signs that are relatively isolated. These goals were achieved with two modifications. Brightness is measured rather than retroreflectivity, and instead of measuring at a given distance, the signs are measured continuously, and the largest measurement is retained.
Results of this research have not only demonstrated that this is a viable way to evaluate the effectiveness of the signs at night, but research has also shown that the retroreflectivity of signs as measured by portable retroreflectometers is not well correlated with the visibility of the signs.
1. IDEA PRODUCT, CONCEPT, AND INNOVATION

1.1 BACKGROUND: THE PURPOSE OF HIGHWAY SIGNS
Highway signs serve the purpose of communicating to the motoring public the information they require for guidance and direction and to warn them about upcoming hazards. When properly informed the drivers can focus their attention on safely controlling their vehicle, and not on wondering where the next exit might be or whether they are on the correct road. When informed of upcoming hazards, drivers can reduce their speed and increase their awareness, and be confident to resume their normal speeds to keep traffic moving in the absence of hazards. In all, a well-informed driver will be more comfortable, less stressed, and less likely to make mistakes or poor judgments that could potentially cause vehicle crashes.

In the daytime signs are typically well illuminated by ambient light, and assuming correct placement, are generally easy to read. At nighttime the situation is quite different. The only source of light is likely to be emanating from the headlamps of the driven vehicle itself, and the only way that the sign can be seen from an appropriate distance is if the sign is retroreflective (Fig. 1). (Retroreflected light is light that is reflected back in the exact direction from whence it came.) Inadequate or deteriorated signs are difficult to read at night, especially for older drivers, and this is thought to contribute to crashes, injuries, and fatalities.

The current version of the Manual on Uniform Control Devices (MUTCD) (1) specifies that warning and guide signs must be made retroreflective, but does not yet specify minimum retroreflectivity standards. In response to a 1993 US congressional directive, Congress has mandated that the Federal Highway Administration (FHWA) must develop "a standard for a minimum level of retroreflectivity that must be maintained for..." the Federal Highway Administration is evaluating and helping develop instruments and tools to measure retroreflectivity and will in time be modifying the MUTCD to institute retroreflectivity standards for signs, much like as has been done for pavement stripes.

1.2 OBJECTIVES
The objective of this project is to demonstrate that the nighttime visibility of highway signs can be measured using imaging analyzing software, imaging equipment, and vehicle headlamps as an illumination source, and to build an inexpensive prototype of a mobile real time system that can accomplish this task, using off the shelf hardware. This approach is better than current technologies, which consist of hand-held measurement devices that are not capable of analyzing large numbers of signs, nor of measuring average values over physical extent of a sign. This approach will also have significant advantages over an FHWA mobile measurement device under development, which requires a laser range finder, a second operator, and electronic strobes, and results in significantly higher capital and maintenance costs.

1.3 PREVIOUS WORK
A literature review has revealed a small body of work with regard to sign recognition, standards, and testing. A significant number of papers deal with automated sign recognition (2-18) under daylight conditions. A significant number of papers deal with sign retroreflectivity standards, visual evaluations, and seeing distance (19-26). A single paper proposes a mobile system (27). A prototype of a mobile system is described on FHWA web sites (28-30). Previous work by this author in mobile measuring systems include laser-based pavement stripe retroreflectivity (31) and mobile imaging of highway features for inventorying (32).

1.4 MOBILE IMAGE BASED MEASURING SYSTEM
The sign measurement system described herein was designed as a low cost system to be mounted in any vehicle, using nighttime images of signs illuminated by vehicle headlamps, thus making measurements that as best as possible reflect what the human eye can see. The system uses inexpensive, state of the art, off the shelf hardware to acquire the images. Purpose designed software acquires, classifies, and analyzes the brightness of the images in real time, and reports results to a data file.

1.4.1 Hardware
The system makes use of a color digital video camera, a laptop computer, and a high speed IEEE 1394 ("firewire", "i.LINK") connectivity to bring digital images from the camera to the computer in real time.

The laptop computer is a Sony Vaio, chosen because it was the only laptop brand fully able to support firewire imaging.

A Sony DFW-V500 firewire camera is a YUV-422 camera that contains lookup tables (as do most cameras) to render colors the way they appear to the human eye. Being a fire wire camera, it can input directly into the laptop.
computer without the need for image capturing devices. The camera is a 1/3" color CCD camera using a 25 mm lens with a maximum aperture of F1.4.

Figure 1 shows the camera and laptop computer as it is installed and used in the vehicle. A makeshift mounting bracket with a ball head holds the camera in place at a fixed angle to the path of the vehicle.

1.4.2 Software Components

1.4.2.1 Overview

Software development was considered to be the most important development for this application. Microsoft Foundation Classes® (MFC) under 32 bit Microsoft Windows® Operating System (WIN32) were used. C++ was used as the development language and DirectShow® and COM® (Component Object Model) as the core API’s. Image-processing algorithms were developed in-house, and integrated under Microsoft Visual C++® environment.

1.4.2.2 Direct Show

Microsoft DirectShow is architecture for streaming media on the Microsoft Windows platform. DirectShow is the successor to Microsoft Video for Windows and Microsoft ActiveMovie, and it improves on these older technologies in significant ways. It is based on Microsoft’s Component Object Model (COM) architecture and is part of DirectX®.

DirectShow is an application programming interface (API) for client-side video and image processing. It offers three core features and all of them are used in this application:

1. Video capture,
2. Video playback,

1.4.2.3 Video Capture

Video capture is the process of acquiring a digital video image. With the capture graph and capture filter supplied by DirectShow, and Microsoft Windows Driver Model® (WDM), Microsoft provides a powerful software environment for developers to build portable image applications almost independent of internal/external devices, so we can preview live video, capture live video as AVI (Audio Video Interleave) file, save the buffer of the live video as a BMP file, using captured data to do real time analysis, etc.

With WDM drivers, the camera manufacturer is responsible for providing the interface to the camera. All the relevant camera settings including brightness, contrast, hue, saturation, sharpness, gamma, white balance, and backlight compensation (which is actually shutter speed) can be set, and most importantly, any automatic settings can be disabled (Figure 4). This is critical to producing reproducible measurements, and eliminates the need for continual calibration.

![FIGURE 4. Setting parameters using the video capture filter.](image-url)
1.4.2.4 Image Analysis

In order to measure the signs, the individual signs must be isolated, classified, and measured, and the data must be stored in a meaningful way.

Sign Isolation

Each image, while in the frame buffer, is checked for the substantial presence of a sign. The method used is a region growing algorithm, based on the vector angle color similarity measure and the use of the principal component of the covariance matrix as the "characteristic" color of the region, with the goal of a region-based segmentation which is perceptually-based.

Sign Classification

From the Manual on Uniform Traffic Control Devices (MUTCD) (33), there are in total 7 kinds of signs by colors: blue, brown, green, orange, red, yellow, and white, so the target sign is identified in terms of colors. These were used both for the classification and measurement.

These colors divide into three groups:

1. The "dull" (nominally black, nominally zero retroreflectivity) color is where each of the Red, Green, and Blue (R, G, B) buffer values are all less than 50 (on a scale of 255). These values are considered so low that they cannot be effectively measured.

2. The "bright" color consists of white, yellow, or orange, which are the highly retroreflective colors. These are defined by R, G, and B values all greater than 50.

3. The "specific" color consists of red, green, blue, or brown which are the lower retroreflectivity colors. These are defined by all any combination of R, G, B values where at least one is above 50 and another below 50.

The actual classification of the sign is determined by the intensity of the red, green, and blue (R,G,B) values, and the ratios of these values, in the following algorithm:

If the total percentage of the specific color is < 10% of the sign area:

If the bright color's R = G = B and the specific color's R = G = B, then it is white sign;
Else if the bright color's R = G >> B (R/B>3), it is a yellow sign;
Else it is orange sign;
Else
  If the specific color's R >> (B & G) and R>75, it is red sign,
  Else if the specific color's B >> (R & G) and B>75, it is blue sign,
  Else if the specific color's G >> (R & B) and G>75, it is green sign,
  Else it is brown sign.

Sign Intensity Measurement

The intensity or brightness is simply the measure of the value of one or more of the R,G,B buffers:

<table>
<thead>
<tr>
<th>Color</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>Average of R, G, B buffers</td>
</tr>
<tr>
<td>Yellow</td>
<td>Average of R, G buffers</td>
</tr>
<tr>
<td>Orange</td>
<td>Average of R, G buffers</td>
</tr>
<tr>
<td>Red</td>
<td>R buffer</td>
</tr>
<tr>
<td>Green</td>
<td>G buffer</td>
</tr>
<tr>
<td>Blue</td>
<td>B buffer</td>
</tr>
<tr>
<td>Brown</td>
<td>Average of the R, G, B buffer</td>
</tr>
</tbody>
</table>

Data Storage

In order to store the results of the analysis, including real time video analysis, analysis of stored AVI files, stored bitmaps files results, or individual still frames extracted from AVI files, the identical file structure is used to create a data storage subsystem. The analyzed data can be saved as plain text (*.txt) file which can be used for database analysis, but the data
can also be saved in hypertext markup language (*.html) file which can be used in a web browser. The target signs, which are saved as small JPEG files, are displayed in the html files as embedded images (Appendix 5).

1.4.3 User Interface

1.4.3.1 Overview

In this application, there are three analysis modes, allowing analysis from live streaming video, recorded video (AVI files) and static images (BMP files), and a fourth mode to display the analyzed results.

![Live capture interface](image)

**FIGURE 5.** Live capture interface.

1.4.3.2 Live streaming video

Figure 5 shows the analysis interface for live streaming video, as well as the capture interface:

1. The video window shows a “live” image, if the Preview box is checked.
2. The capture directory can be set for storing AVI or BMP files. AVI capture is initiated by the Start Capture button, while BMP files are snapped by the Snap Still button. File names are incremented at each capture event if the Increment box is checked.
3. If the Analyze box is checked, the live video images are analyzed. Each time a sign is detected, results are displayed on the screen, including: sign type, sign size (in pixels), bright color (number of pixels, bright color percentage, average R, G, B values, and bright color value), specific color (number of pixels, specific color percentage, average R, G, B values, specific color value), sequence detection result (detected sign number), and a thumbnail image of the current (or previously) detected sign is displayed.
4. If Print All Data To File is checked, analyzed results are output to a text file on disk, and thumbnail images are stored on disk.
1.4.3.3 Pre-recorded AVI video

Figure 3 shows the analysis interface for AVI files. It is similar to the live streaming video, with the following differences:

1. The AVI file can be played and controlled. Using 3 buttons (Play, Pause and Stop), or the slider bar the AVI file can be played and positioned. The current frame number is displayed with the total number of frames in the sequence.
2. Save Buffer results in the current image being saved as a BMP disk file.
3. Print All Data To File results in each analysis (each detected frame, which would typically include multiple views of the same sign) being written to disk. Otherwise only the highest measured value of an individual sign is recorded.

![Pre-recorded AVI video interface](image)

FIGURE 6. Bitmap image interface

1.4.3.4 Static BMP images

Figure 6 shows the analysis interface for BMP images.

1. The Analyzed Results are the same as in the other interfaces. Print to File allows saving of analysis results.
2. Analyze Options allows Manual and Automatic isolation of the sign. Automatic sign detection prints a green dashed box around the sign. Alternatively the user can use the mouse to draw a rectangle to manually isolate the sign.
3. Image properties are displayed on the screen, such as File Name and Image Size. When the cursor is passed over the image, the Current Position and Current Color values are displayed.
1.4.4 Capabilities and Limitations
This methodology is capable of measuring the brightness of highway traffic signs using the vehicle's own headlamps, and a vision system that most closely represent what the human eye can see, including receiving poor measurement results from signs with good retroreflective materials but situated where the geometry is poor, as for examples on inside horizontal curves. The measurement is done in real time at highway speeds, and produces a record that includes a small thumbnail image of the sign as well as the measurement data, and could easily be tied to GPS position information.

Limitation of the method includes the necessity of making measurements at nighttime, and the fact that measurements are more efficient using high-beam illumination, which is more disruptive to traffic. A current limitation, which could be overcome with further development, is the necessity for having relatively isolated signs with limited extraneous noise in the image. Further research will be needed to measure in noisy highway scenes, including tracking multiple signs in the same sequence of images, identifying and rejecting light sources that are not signs, and separating signs that are touching or partially overlapped.

1.4.5 Potential Impact
The potential impact of this technology is great. It will provide the tool to effectively measure the retroreflectivity of signs at a lower cost, thus allowing better-informed management decisions on which signs need replacing. This will result in safer highways, and more contented and less stressed drivers.

Given that manual hand-held measuring devices by their very nature are limited in the number of signs they can measure in a given time, and the labor (and cost) intensive nature of the process, this new measurement tool will allow more signs to be measured at a lower unit cost, as well as multiple measurements being made on each sign, to increase the statistical reliability of the measurement.

The ease and simplicity of this new analysis will result in:
1. More reliable test results.
2. More testing, resulting in better and more statistically valid characterization.
3. Faster measurements, allowing a greater proportion of the sign inventory to be checked in a given cycle.
4. Lower unit costs per measurement sample, resulting in less of a burden on operators.

2. INVESTIGATION AND PLANS FOR IMPLEMENTATION

2.1 OVERVIEW
The investigation consisted of two phases, static testing of signs to determine the relationship between the measured brightness of the signs with retroreflectivity and dynamic testing to evaluate the feasibility of measuring on the road.

2.2 STATIC STUDIES

2.2.1 Signs
The signs used for this investigation were provided by the Missouri DOT (32 different signs in all). These were:

1. Yellow (curve), 4 signs,
2. White (speed), 6 signs,
3. Red (stop), 4 signs,
4. Yield (red and white), 4 signs,
5. Blue (service), 3 signs,
6. Brown (public use), 4 signs,
7. Green (toward), 4 signs,
8. Orange (construction) 3 signs.

Each sign nominally had 4 replicates, in each of the following categories.

1. New sign with high grade sheeting,
2. New sign with engineer grade sheeting,
3. Sign taken out of service for the purpose of this project, intermediately worn.
4. Sign taken from the scrap pile, completely worn.
The signs were measured for retroreflectivity, using a Delta RetroSign Type 4500 Retroreflectometer provided by the Missouri DOT (Appendix 1). In each case the category 3 and 4 signs were hand picked to provide a complete range of retroreflectivities.

For the blue and orange signs, only three were used, as it was difficult to find specific values for the signs. For the white signs, two additional signs were added, to cover the range of low retroreflectivity.

2.2.2 Vehicle Modifications

The vehicle halogen headlamps were replaced with brighter Xenon lamps. A camera mount was fabricated on the front dash of the vehicle (Figure 2), with the camera location slightly to the left and down from the point of observation of the driver, to preserve as best as possible the observation angle of the driver while avoiding interfering with the drivers vision.

2.2.3 Static Testing Range

A measuring range was set up to facilitate the static measurements. This was an outdoor range with interchangeable signs mounted on a sign post (Figure 1). The top of the sign was set to 8' high. The signs were mounted one at a time in order to preserve the entrance angle. The distance from the headlamps to the sign was set to 120' and the distance from the sign to the camera to 125'. The entrance angle was kept constant for a set of measurements, but no effort was made to keep the same entrance angle for a repeat set of measurements, as that can be expected to vary widely under normal driver conditions. This range can of course only be used at night, and this is considered to be the most realistic approach.

In repeat testing the vehicles were positioned at the same point, but no effort was made to retain exactly the same alignment. Systematic differences do occur as a result of small changes in vehicle alignment.

2.2.4 Results of Static Testing

2.2.4.1 Relationship Between Measured Brightness and Retroreflectivity

The relationship between the measured brightness of the signs and the retroreflectivity was determined by tests on the static range. Appendix 2 shows the results of the series of measurements. Appendix 3 shows the signs and the relationship between retroreflectivity and measured brightness. Appendix 4 shows the relationship for all the measurements.

As shown in Appendix 3 and 4, retroreflectivity and brightness can be correlated, but only within the same color. The "bright colors" orange, yellow and white show high retroreflectivity, and large variability in retroreflectivity but small changes in brightness, i.e. visibility is not very sensitive to retroreflectivity. The "dull colors", red, green, blue, and brown show a low retroreflectivity, with low variability in retroreflectivity, but large changes in brightness, i.e. visibility is very sensitive to retroreflectivity.

Yellow

Yellow colors are in general very bright, and visibility not highly correlated with retroreflectivity. From our analysis, anything with a retroreflectivity of more than 25 cd/m.m.lux will appear fairly bright.

White

White colors are in general very bright, and visibility not highly correlated with retroreflectivity. From our analysis, anything with a retroreflectivity of more than 50 cd/m.m.lux will appear fairly bright.

Orange

Orange colors are similar to yellow, in general fairly bright, and visibility is weakly correlated with retroreflectivity. From our analysis, anything with a retroreflectivity of more than 50 cd/m.m.lux will appear fairly bright.

Red

Red colors are generally fairly bright, and visibility is strongly correlated with retroreflectivity. From our analysis, anything with a retroreflectivity of 0 appears dim, and up to 50 cd/m.m.lux will appear fairly bright.

Blue

Blue colors are generally fairly bright, and weakly correlated with retroreflectivity. All three of our signs had high visibility but low (<25 cd/m.m.lux) retroreflectivity.
Brown
Brown colors are not bright and have low visibility, as well as low retroreflectivity.

Green
Green colors are moderately bright, and visibility is weakly correlated with retroreflectivity. From our analysis, anything with a retroreflectivity of > 25 cd/m.m.lux appears moderately bright, and no retroreflectivities greater than 25 cd/m.m.lux were found.

2.2.4.2 Reproducibility
Appendix 4 shows the results of imaging the same series of signs on six different occasions. Reproducibility is fairly good, and the differences are in general systematic, as a result of setting up with a slightly different geometry for each measurement. Each series of tests were conducted with slightly different vehicle positions, resulting in different angles of illumination of the signs. Using differing vehicle positions is considered appropriate, because this will be the case when a vehicle is running down the road.

All but one of the series of measurements were done using the vehicle high-beams.

2.2.4.3 High Beam Analysis vs. Low Beam Analysis
To make measurements using low beams requires modifications to the camera setup. To accommodate this, the lens aperture was opened from f4 to f2, and changes were also made to the internal camera setting to increase amplification. The results of using the low beam are a significantly higher signal to noise ratio, and also a less even illumination of the sign (Figure 7). This is even more critical in a noisy background, where the sign is not even recognizable under low beam conditions (Figure 8).

FIGURE 7. Left: High beam image. Right: Low beam image. Note increase of background noise.

FIGURE 8. Left: High beam image. Right: Low beam image. Note that the green sign in the left image almost completely disappears in the cluttered background of “lit” signs
Visibility Standards
It is not the purpose of this investigation to set visibility standards, however it would not be difficult to select a threshold intensity value from the results of Appendix 4. These standards may have to be different for each color, and will require careful calibration of the system to maintain consistency.

2.3 DYNAMIC STUDIES

2.3.1 Overview
Dynamic studies were done to demonstrate the measurement in real time and from moving AVI files, and also to reconcile the issue of seeing and measuring the same sign multiple times while moving along the highway.

2.3.2 Real Time Measurements
The real time measurement capability has been described in section 1.4.3, and analysis results are shown in Appendix 5.

2.3.3 Multiple Measurements of the Same Signs
Because the same sign will appear in multiple frames as the vehicle moves toward and then past the sign, some mechanism is required to select one of the measurements. Empirical evidence shows that the sign's brightness is fairly constant from the time the sign is large enough to read, until it starts fading as the vehicle gets close and the entrance angle gets too large. Thus it was determined to record only the highest measured result. Figure 9 shows an example of this relationship, filmed at a rate of 10 frames per second.

![Figure 9](image_url)

**FIGURE 9.** Top: Video sequence of a single yellow sign imaged along a highway (about every 8th frame is analyzed). Bottom: Brightness measurement of the yellow sign as a function of analyzed frame number (each frame showing a successively closer image of the sign).
2.4 Plans For implementation
The results of this investigation are published here and will be as well at the next Transportation Research Board Annual Meeting. Potential investors would be sought for the purpose of moving from a prototype to developing and marketing a final product. In the interim improvements will be made to measure in noisy highway scenes, including tracking multiple signs in the same sequence of images, identifying and rejecting light sources that are not signs, and separating signs that are touching or partially overlapped.

3. CONCLUSIONS

Based on the results of this study the following conclusions can be made.

1. The concept of using a mobile vision based system to classify and to measure the visibility of roads signs is found to have merit, and promises to be a useful tool to ensure the safety of the motoring public at night.
2. This method will be the closest possible analog to what eyes see when looking at signs, incorporating the normal illumination provided by the headlights, and subject to the same geometric disadvantages with signs that are disadvantageously placed.
3. The measurement method is mobile, fast, and safe, and it is uses state of the art inexpensive technology.
4. The method must be used at night, and may possibly be limited to use with high beams, and is for the moment limited to signs that are relatively isolated, not overlapping or situated in a noisy background.

Further discoveries that have been made relate to the retroreflectivity of signs. The retroreflectivity and visibility of signs are often poorly correlated. In this study:

1. Retroreflectivity was found to be a poor predictor of the visibility of white, yellow and to a lesser extent orange signs. These signs tend to be fairly uniformly visible down to very low values of retroreflectivity.
2. Retroreflectivity is a relatively good predictor of the visibility of red, and to a lesser extent of green and blue signs. These signs tend to be of low retroreflectivity but high visibility.
3. Brown signs are of low retroreflectivity and low visibility.

4. REFERENCES


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APPENDIX 1: RETROREFLECTIVITY* MEASUREMENTS

<table>
<thead>
<tr>
<th>SIGN**</th>
<th>Bright Color***</th>
<th>Specific Color****</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow (curve)</td>
<td>238 86 16 5</td>
<td>-</td>
</tr>
<tr>
<td>White (speed limit)</td>
<td>299 104 77 53 24 3</td>
<td>-</td>
</tr>
<tr>
<td>Red (stop)</td>
<td>295 77 261 38</td>
<td>31 23 48 10</td>
</tr>
<tr>
<td>Yield</td>
<td>286 71 43 37</td>
<td>33 20 9 4</td>
</tr>
<tr>
<td>Blue (service)</td>
<td>305 64 102</td>
<td>21 8 4</td>
</tr>
<tr>
<td>Brown (public use)</td>
<td>293 90 62 55</td>
<td>17 6 4 3</td>
</tr>
<tr>
<td>Green (town)</td>
<td>300 84 52 75</td>
<td>51 12 3 11</td>
</tr>
<tr>
<td>Orange (construction)</td>
<td>104 35 32</td>
<td>-</td>
</tr>
</tbody>
</table>

*Coefficient of reflected luminance (R' in cd/m².lux)

**4 versions for each sign: 1) New high grade sheeting; 2) New Engineer grade sheeting; 3) Used, taken out of service for this project; 4) Used, had previously been taken out of service because of loss of performance. For blues and orange it was not possible to get all versions. For white two extra poor quality signs were added to get a complete range of retroreflectivities. For orange, only three signs were made available.

***Bright color is white background on speed sign, yellow on curve sign, orange on construction sign, or white lettering on other signs.

****Dull color is the background on the other signs (red, green, blue, brown). Black is not considered as it has 0 retroreflectivity.
## APPENDIX 2: STATIC BRIGHTNESS* MEASUREMENTS

<table>
<thead>
<tr>
<th>SIGN**</th>
<th>Bright Color***</th>
<th>Specific Color****</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow (curve)</td>
<td>204</td>
<td>198</td>
</tr>
<tr>
<td></td>
<td>172</td>
<td>163</td>
</tr>
<tr>
<td></td>
<td>136</td>
<td>124</td>
</tr>
<tr>
<td></td>
<td>94</td>
<td>68</td>
</tr>
<tr>
<td>White (speed limit)</td>
<td>204</td>
<td>197</td>
</tr>
<tr>
<td></td>
<td>187</td>
<td>199</td>
</tr>
<tr>
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<td>191</td>
</tr>
<tr>
<td></td>
<td>173</td>
<td>165</td>
</tr>
<tr>
<td>Red (stop)</td>
<td>188</td>
<td>177</td>
</tr>
<tr>
<td></td>
<td>162</td>
<td>146</td>
</tr>
<tr>
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<td>181</td>
<td>167</td>
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<td></td>
<td>148</td>
<td>127</td>
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<tr>
<td>Yield</td>
<td>213</td>
<td>203</td>
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<td>170</td>
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<tr>
<td></td>
<td>151</td>
<td>132</td>
</tr>
<tr>
<td>Blue (service)</td>
<td>195</td>
<td>183</td>
</tr>
<tr>
<td></td>
<td>201</td>
<td>185</td>
</tr>
<tr>
<td></td>
<td>194</td>
<td>184</td>
</tr>
<tr>
<td>Brown (public use)</td>
<td>165</td>
<td>149</td>
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<tr>
<td></td>
<td>137</td>
<td>115</td>
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<tr>
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<td>121</td>
</tr>
<tr>
<td></td>
<td>114</td>
<td>92</td>
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<tr>
<td>Green (town)</td>
<td>199</td>
<td>188</td>
</tr>
<tr>
<td></td>
<td>169</td>
<td>156</td>
</tr>
<tr>
<td></td>
<td>156</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>140</td>
</tr>
<tr>
<td>Orange (construc-tion)</td>
<td>179</td>
<td>205</td>
</tr>
<tr>
<td></td>
<td>153</td>
<td>185</td>
</tr>
<tr>
<td></td>
<td>152</td>
<td>185</td>
</tr>
</tbody>
</table>

*in greyscale units, 0-255, red buffer-red sign, green buffer-green sign, blue buffer-blue sign, average of red, green, blue buffer, white sign and brown sign, average of red and green buffer, yellow sign and orange sign.

**4 versions for each sign: 1) New high grade sheeting; 2) New Engineer grade sheeting; 3) Used, taken out of service for this project; 4) Used, had previously been taken out of service because of loss of performance.

***Bright color is white background on speed sign, yellow on curve sign, orange on construction sign, or white lettering on other signs.

****Specific color is the background on the other signs, red, green, blue, brown. Black is not considered as it has 0 retroreflectivity.

* denotes analysis done with low beam lights, with larger camera aperture and amplifier settings.
APPENDIX 3: TEST SIGN IMAGES AND CORRELATION BETWEEN RETROREFLECTIVITY AND BRIGHTNESS

YELLOW (YIELD) SIGNS
White (speed limit sign)

ORANGE (CONSTRUCTION SIGNS)
RED (STOP) SIGNS

White (stop sign)

Gray scale intensity vs. retroreflectivity (cd/lm²/m²).

Red (stop sign)

Gray scale intensity vs. retroreflectivity (cd/lm²/m²).
YIELD SIGNS

White (yield sign)

Red (yield sign)
BLUE (SERVICE) SIGNS

White (service sign)

Blue (service sign)
BROWN (PUBLIC USE) SIGNS

White (public use sign)

Brown (public use sign)
GREEN (CITY) SIGNS

White (town sign)

Green (town sign)
APPENDIX 4: REPRODUCIBILITY STUDIES

BRIGHT COLORS

Yellow (Yield Sign)

White (Speed Limit Sign)

White (Speed Limit Sign)
SPECIFIC COLORS

Red (Stop Sign)

Red (Yield Sign)

Blue (Service Sign)
APPENDIX 5: TYPICAL HTML DATA OUTPUT FILE

Typical data in html output format, displayed in Internet Explorer®, showing a thumbnail image, time of measurement, sign type, sign measurement of both the "bright" and "specific" colors.