University Transportation Research Center - Region 2

Final Report

High Visibility Reflective Sign Sheeting Evaluation

Performing Organization: Lighting Research Center, RPI

December 2014

Sponsor(s):
New York State Department of Transportation (NYSDOT)
University Transportation Research Center - Region 2

University Transportation Research Center - Region 2

The Region 2 University Transportation Research Center (UTRC) is one of ten original University Transportation Centers established in 1987 by the U.S. Congress. These Centers were established with the recognition that transportation plays a key role in the nation's economy and the quality of life of its citizens. University faculty members provide a critical link in resolving our national and regional transportation problems while training the professionals who address our transportation systems and their customers on a daily basis.

The UTRC was established in order to support research, education and the transfer of technology in the field of transportation. The theme of the Center is "Planning and Managing Regional Transportation Systems in a Changing World." Presently, under the direction of Dr. Camille Kamga, the UTRC represents USDOT Region II, including New York, New Jersey, Puerto Rico and the U.S. Virgin Islands. Functioning as a consortium of twelve major Universities throughout the region, UTRC is located at the CUNY Institute for Transportation Systems at The City College of New York, the lead institution of the consortium. The Center, through its consortium, an Agency-Industry Council and its Director and Staff, supports research, education, and technology transfer under its theme. UTRC's three main goals are:

Research

The research program objectives are (1) to develop a theme based transportation research program that is responsive to the needs of regional transportation organizations and stakeholders, and (2) to conduct that program in cooperation with the partners. The program includes both studies that are identified with research partners of projects targeted to the theme, and targeted, short-term projects. The program develops competitive proposals, which are evaluated to insure the mostresponsive UTRC team conducts the work. The research program is responsive to the UTRC theme: "Planning and Managing Regional Transportation Systems in a Changing World." The complex transportation system of transit and infrastructure, and the rapidly changing environment impacts the nation's largest city and metropolitan area. The New York/New Jersey Metropolitan has over 19 million people, 600,000 businesses and 9 million workers. The Region's intermodal and multimodal systems must serve all customers and stakeholders within the region and globally.Under the current grant, the new research projects and the ongoing research projects concentrate the program efforts on the categories of Transportation Systems Performance and Information Infrastructure to provide needed services to the New Jersey Department of Transportation, New York City Department of Transportation, New York Metropolitan Transportation Council , New York State Department of Transportation, and the New York State Energy and Research Development Authorityand others, all while enhancing the center's theme.

Education and Workforce Development

The modern professional must combine the technical skills of engineering and planning with knowledge of economics, environmental science, management, finance, and law as well as negotiation skills, psychology and sociology. And, she/he must be computer literate, wired to the web, and knowledgeable about advances in information technology. UTRC's education and training efforts provide a multidisciplinary program of course work and experiential learning to train students and provide advanced training or retraining of practitioners to plan and manage regional transportation systems. UTRC must meet the need to educate the undergraduate and graduate student with a foundation of transportation fundamentals that allows for solving complex problems in a world much more dynamic than even a decade ago. Simultaneously, the demand for continuing education is growing – either because of professional license requirements or because the workplace demands it – and provides the opportunity to combine State of Practice education with tailored ways of delivering content.

Technology Transfer

UTRC's Technology Transfer Program goes beyond what might be considered "traditional" technology transfer activities. Its main objectives are (1) to increase the awareness and level of information concerning transportation issues facing Region 2; (2) to improve the knowledge base and approach to problem solving of the region's transportation workforce, from those operating the systems to those at the most senior level of managing the system; and by doing so, to improve the overall professional capability of the transportation workforce; (3) to stimulate discussion and debate concerning the integration of new technologies into our culture, our work and our transportation systems; (4) to provide the more traditional but extremely important job of disseminating research and project reports, studies, analysis and use of tools to the education, research and practicing community both nationally and internationally; and (5) to provide unbiased information and testimony to decision-makers concerning regional transportation issues consistent with the UTRC theme.

UTRC-RF Project No: 55505-08-03

Project Date: December 2014

Project Title: High Visibility Reflective Sign Sheeting Evaluation

Project's Website:
http://www.utrc2.org/research/projects/high-visibility-reflective-sign-sheeting

Principal Investigator:

Mark S. Rea
Senior Research Officer
Lighting Research Center
Rensselaer Polytechnic Institute
Email: ream@rpi.edu

Co-PI:

Dr. John D. Bullough
Senior Research Scientist
Lighting Research Center
Rensselaer Polytechnic Institute
Email:bulloj@rpi.edu

Co-Authors:

- Nicholas P. Skinner
- Ute C. Besenecker

Lighting Research Center
Rensselaer Polytechnic Institute
Troy, NY

Performing Organizations: Lighting Research Center, Rensselaer Polytechnic Institute (RPI)

Sponsor(s):

New York State Department of Transportation (NYSDOT)

University Transportation Research Center - Region 2, A Regional University Transportation Center sponsored by the U.S. Department of Transportation's Research and Innovative Technology Administration

To request a hard copy of our final reports, please send us an email at utrc@utrc2.org

Mailing Address:

University Transportation Reserch Center
The City College of New York
Marshak Hall, Suite 910
160 Convent Avenue
New York, NY 10031
Tel: 212-650-8051
Fax: 212-650-8374
Web: www.utrc2.org

Board of Directors

The UTRC Board of Directors consists of one or two members from each Consortium school (each school receives two votes regardless of the number of representatives on the board). The Center Director is an ex-officio member of the Board and The Center management team serves as staff to the Board.

City University of New York
Dr. Hongmian Gong - Geography
Dr. Claire McKnight - Civil Engineering
Dr. Neville A. Parker - Civil Engineering

Clarkson University
Dr. Kerop D. Janoyan - Civil Engineering

Columbia University
Dr. Raimondo Betti - Civil Engineering
Dr. Elliott Sclar - Urban and Regional Planning

Cornell University
Dr. Huaizhu (Oliver) Gao - Civil Engineering
Dr. Mark A. Turnquist - Civil Engineering

Hofstra University
Dr. Dilruba Ozmen-Ertekin - Civil Engineering
Dr. Jean-Paul Rodrigue - Global Studies and Geography

New Jersey Institute of Technology
Dr. Priscilla P. Nelson - Geotechnical Engineering
Dr. Lazar Spasovic - Civil Engineering

New York University
Dr. Mitchell L. Moss - Urban Policy and Planning
Dr. Rae Zimmerman - Planning and Public Administration

Polytechnic Institute of NYU
Dr. John C. Falcocchio - Civil Engineering
Dr. Elena Prassas - Civil Engineering

Rensselaer Polytechnic Institute
Dr. José Holguín-Veras - Civil Engineering
Dr. William "Al" Wallace - Systems Engineering

Rochester Institute of Technology
Dr. James Winebrake

Rowan University
Dr. Yusuf Mehta - Civil Engineering
Dr. Beena Sukumaran - Civil Engineering

Rutgers University
Dr. Robert Noland - Planning and Public Policy
Dr. Kaan Ozbay - Civil Engineering

State University of New York
Michael M. Fancher - Nanoscience
Dr. Catherine T. Lawson - City & Regional Planning
Dr. Adel W. Sadek - Transportation Systems Engineering
Dr. Shmuel Yahalom - Economics

Stevens Institute of Technology
Dr. Sophia Hassiotis - Civil Engineering
Dr. Thomas H. Wakeman III - Civil Engineering

Syracuse University
Dr. Riyad S. Aboutaha - Civil Engineering
Dr. O. Sam Salem - Construction Engineering and Management

The College of New Jersey
Dr. Michael Shenoda - Civil Engineering

University of Puerto Rico - Mayagüez
Dr. Ismael Pagán-Trinidad - Civil Engineering
Dr. Didier M. Valdés-Díaz - Civil Engineering

UTRC Consortium Universities

The following universities/colleges are members of the UTRC consortium.

City University of New York (CUNY)
Clarkson University (Clarkson)
Columbia University (Columbia)
Cornell University (Cornell)
Hofstra University (Hofstra)
Manhattan College (MC)
New Jersey Institute of Technology (NJIT)
New York Institute of Technology (NYIT)
New York University (NYU)
Rensselaer Polytechnic Institute (RPI)
Rochester Institute of Technology (RIT)
Rowan University (Rowan)
Rutgers University (Rutgers)*
State University of New York (SUNY)
Stevens Institute of Technology (Stevens)
Syracuse University (SU)
The College of New Jersey (TCNJ)
University of Puerto Rico - Mayagüez (UPRM)

** Member under SAFETEA-LU*

UTRC Key Staff

Dr. Camille Kamga: *Director, Assistant Professor of Civil Engineering*

Dr. Robert E. Paaswell: *Director Emeritus of UTRC and Distin*guished Professor of Civil Engineering, The City College of New York

Herbert Levinson: *UTRC Icon Mentor, Transportation Consultant and Professor Emeritus of Transportation*

Dr. Ellen Thorson: *Senior Research Fellow, University Transportation Research Center*

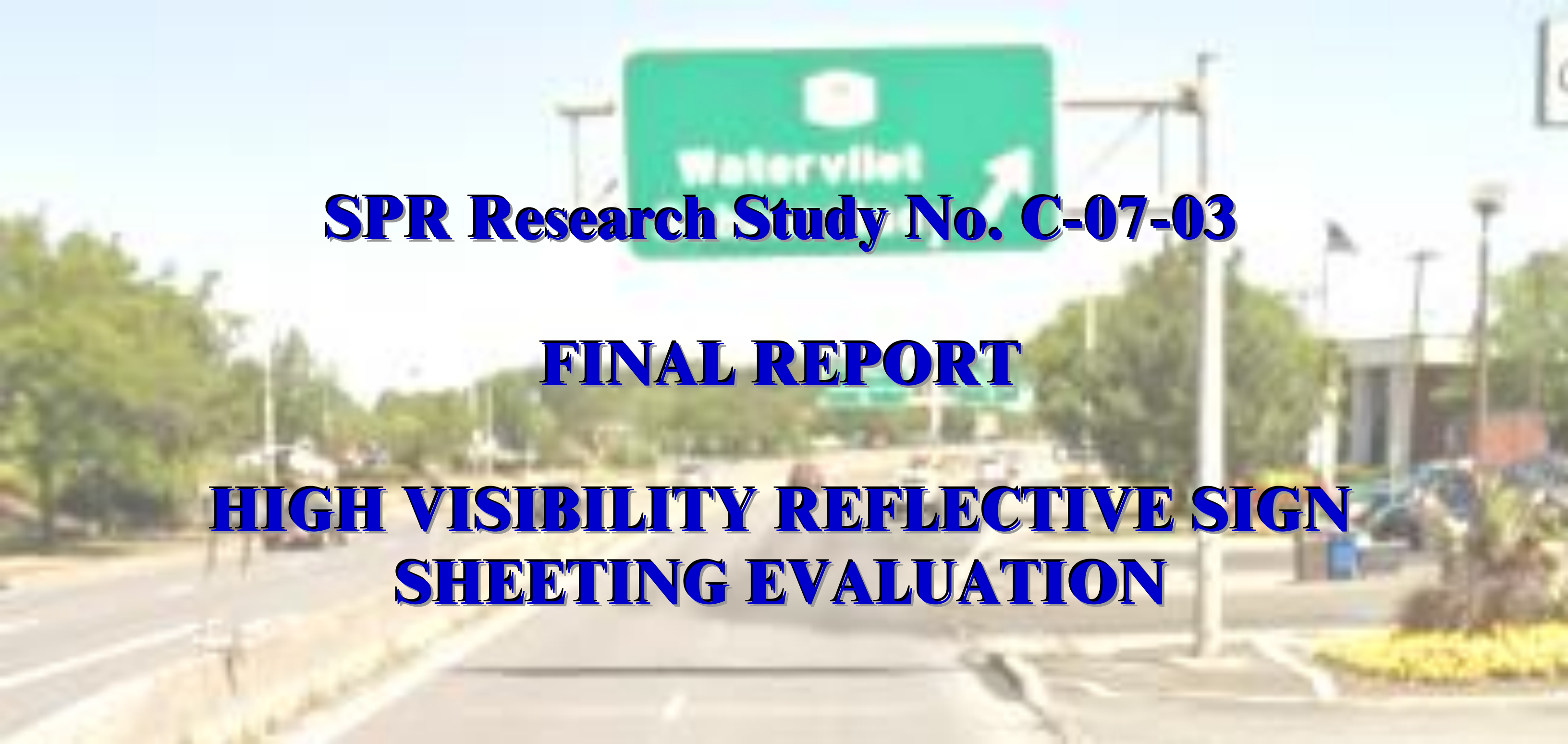
Penny Eickemeyer: *Associate Director for Research, UTRC*

Dr. Alison Conway: *Associate Director for Education*

Nadia Aslam: *Assistant Director for Technology Transfer*

Nathalie Martinez: *Research Associate/Budget Analyst*

Andriy Blagay: *Graphic Intern*



SPR Research Study No. C-07-03

FINAL REPORT

HIGH VISIBILITY REFLECTIVE SIGN SHEETING EVALUATION

Authors:

John D. Bullough
Nicholas P. Skinner
Ute C. Besenecker

Conducted for the

NEW YORK STATE DEPARTMENT OF TRANSPORTATION

By the

LIGHTING RESEARCH CENTER
RENSSELAER POLYTECHNIC INSTITUTE

Mark S. Rea, Principal Investigator
John D. Bullough, Co-Principal Investigator

21 Union Street, Troy, NY 12180

December 2014

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
C-07-03		

4. Title and Subtitle

HIGH VISIBILITY REFLECTIVE SIGN SHEETING EVALUATION

5. Report Date

December 2014

6. Performing Organization Code

7. Author(s)

John D. Bullough, Nicholas P. Skinner and Ute C. Besenecker

8. Performing Organization Report No.

9. Performing Organization Name and Address

Lighting Research Center
Rensselaer Polytechnic Institute
21 Union Street
Troy, NY 12180

10. Work Unit No.

11. Contract or Grant No.

55505-08-03

12. Sponsoring Agency Name and Address

NYS Department of Transportation
50 Wolf Road
Albany, NY 12232

UTRC/CCNY
160 Convent Avenue
MR, Suite 910, NY, NY 10031

13. Type of Report and Period Covered

Final Report (2010-2014)

14. Sponsoring Agency Code

15. Supplementary Notes

Patrick Galarza from the NYS Department of Transportation served as Project Manager. Project funded in part with funds from the Federal Highway Administration (FHWA).

16. Abstract

Highway signs are a critical part of the roadway infrastructure, providing important information to drivers to assist in navigation, identify potentially hazardous roadway locations, and to remind drivers of safe operating practices. Ensuring that signs have sufficient visibility to the driving public is a key undertaking by transportation agencies such as NYSDOT. In order to assist NYSDOT in evaluating and comparing different materials for photometric and visual performance, the present project was conducted to select and validate a visibility model for use as a basis for performance specifications, to develop a practical methodology for conducting field measurements of sign performance along roadways, and to develop practical tools to assist highway engineers in making informed quantitative decisions about the levels of performance provided by different materials. In addition to describing the methods for an approach to visual performance based specifications, a spreadsheet tool for calculating sign luminance and visibility was also developed.

17. Key Words	18. Distribution Statement
Retroreflectivity; visual performance; sign visibility	No Restrictions

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	47	

Form DOT F 1700.7 (8-72)

DISCLAIMER

This report was funded in part through grant(s) from the Federal Highway Administration, United States Department of Transportation, under the State Planning and Research Program, Section 505 of Title 23, U.S. Code. The contents of this report do not necessarily reflect the official views or policy of the United States Department of Transportation, the Federal Highway Administration or the New York State Department of Transportation. This report does not constitute a standard, specification, regulation, product endorsement, or an endorsement of manufacturers.

ACKNOWLEDGMENTS

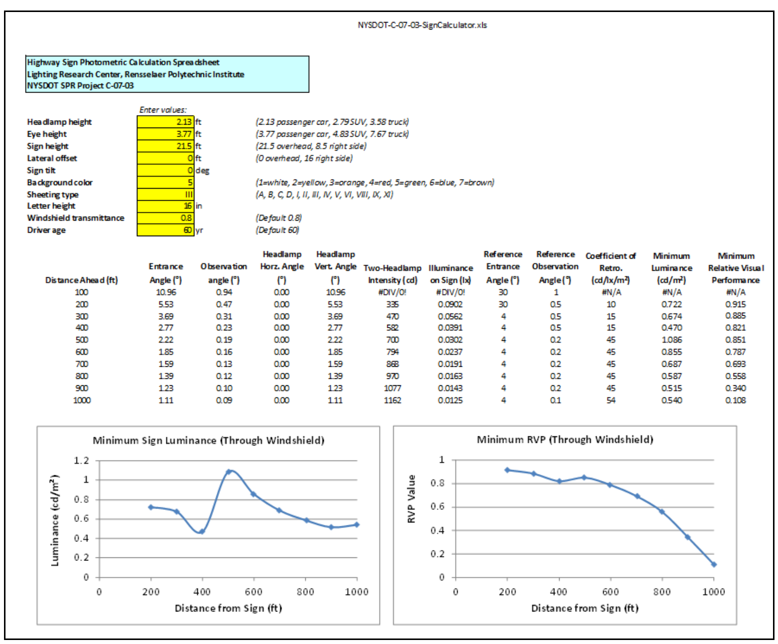
This study was funded by the New York State Department of Transportation (NYSDOT) and by the Federal Highway Administration (FHWA). The project was administered through the Region 2 University Transportation Research Center (UTRC) at the City University of New York under the direction of Dr. Camille Kamga of UTRC. Patrick Galarza from NYSDOT served as the NYSDOT Project Manager. Mark Rea was the Principal Investigator and John Bullough was the co-Principal Investigator. Helpful input and contributions to the project were provided by Barbara Abrahamer, Rajendra Amin, Moysey Eppel, Pratip Lahiri, Fred Lai, Kevin Ledlon, Carlos Quiles and Ramesh Ramanathan from NYSDOT Main Office and Region 11; and by Emmett McDevitt from FHWA.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Highway signs are a critical part of the roadway infrastructure, providing important information to drivers to assist in navigation, identify potentially hazardous roadway locations, and to remind drivers of safe operating practices.

Ensuring that signs have sufficient visibility to the driving public is a key undertaking by transportation agencies such as NYSDOT. In order to assist NYSDOT in evaluating and comparing different materials for photometric and visual performance, the present project was conducted to select and validate a visibility model for use as a basis for performance specifications, to develop a practical methodology for conducting field measurements of sign performance along roadways, and to develop practical tools to assist highway engineers in making informed quantitative decisions about the levels of performance provided by different materials.


NYSDOT-C-07-03-SignCalculator.xls

Highway Sign Photometric Calculation Spreadsheet
Lighting Research Center, Rensselaer Polytechnic Institute
NYSDOT SPR Project C-07-03

	Enter values:		
Headlamp height	2.13	ft	(2.13 passenger car, 2.79 SUV, 3.58 truck)
Eye height	3.77	ft	(3.77 passenger car, 4.83 SUV, 7.67 truck)
Sign height	21.5	ft	(21.5 overhead, 8.5 right side)
Lateral offset	0	ft	(0 overhead, 16 right side)
Sign tilt	0	deg	
Background color	5		(1=white, 2=yellow, 3=orange, 4=red, 5=green, 6=blue, 7=brown)
Sheeting type	III		(A, B, C, D, I, II, III, IV, V, VI, VIII, IX, XI)
Letter height	16	in	
Windshield transmittance	0.8		(Default 0.8)
Driver age	60	yr	(Default 60)

Distance Ahead (ft)	Entrance Angle (°)	Observation angle (°)	Headlamp Horz. Angle (°)	Headlamp Vert. Angle (°)	Two-Headlamp Intensity (cd)	Illuminance on Sign (lx)	Reference Entrance Angle (°)	Reference Observation Angle (°)	Coefficient of Retro. (cd/lx/m²)	Minimum Luminance (cd/m²)	Minimum Relative Visual Performance
100	10.96	0.94	0.00	10.96	#DIV/0!	#DIV/0!	30	1	#N/A	#N/A	#N/A
200	5.53	0.47	0.00	5.53	335	0.0902	30	0.5	10	0.722	0.915
300	3.69	0.31	0.00	3.69	470	0.0562	4	0.5	15	0.674	0.885
400	2.77	0.23	0.00	2.77	582	0.0391	4	0.5	15	0.470	0.821
500	2.22	0.19	0.00	2.22	700	0.0302	4	0.2	45	1.086	0.851
600	1.85	0.16	0.00	1.85	794	0.0237	4	0.2	45	0.855	0.787
700	1.59	0.13	0.00	1.59	868	0.0191	4	0.2	45	0.687	0.693
800	1.39	0.12	0.00	1.39	970	0.0163	4	0.2	45	0.587	0.558
900	1.23	0.10	0.00	1.23	1077	0.0143	4	0.2	45	0.515	0.340
1000	1.11	0.09	0.00	1.11	1162	0.0125	4	0.1	54	0.540	0.108

In addition to describing the methods for an approach to visual performance based specifications, a spreadsheet tool for calculating sign luminance and visibility was also developed.

1. INTRODUCTION

Highway signs are a critical part of the roadway infrastructure, providing important information to drivers to assist in navigation, identify potentially hazardous roadway locations, and to remind drivers of safe operating practices.

The Manual on Uniform Traffic Control Devices (MUTCD) requires that guide signs (the typical green signs along highways that contain destination and exit information) be either illuminated or retroreflective. In many locations in New York State, particularly in and around New York City (New York State Department of Transportation [NYSDOT] Region 11), overhead guide signs are often illuminated by NYSDOT with external lighting systems in order to ensure sufficient visibility, even though NYSDOT also uses retroreflective materials in all of its signs. External sign lighting systems entail high installation and operating costs, require difficult maintenance especially in urban locations with high traffic densities, and can contribute to light pollution. Using materials with sufficient retroreflectivity to ensure good visibility might obviate sign lighting in some situations. However, it is also desirable to prevent over-specifying the performance of sign materials.

The present report summarizes research activities undertaken to assist NYSDOT in evaluating sign materials based on their existing performance specifications, and to validate performance in the field in addition to predicting performance during the design stage.

2. VISUAL PERFORMANCE CRITERIA FOR HIGHWAY SIGNS

Specifications for the performance of retroreflective sign materials (e.g., those published by ASTM or AASHTO) are given in terms of photometric performance such as the luminance of the sign material for a given (cd/lx/m^2) illuminance under specific geometric conditions. In the laboratory and in the field (as described in the following chapter), photometric measurements of the luminance of a sign can be made. By themselves, these photometric quantities do not translate directly into meaningful measures of visibility.

The relative visual performance (RVP) model (Rea and Ouellette, 1991) is a calculation model (see Appendix) that predicts the speed and accuracy of visual processing for different combinations of several important visual parameters:

- Background luminance
- Luminance contrast between target and background
- Target size
- Observer age

The model was shown (Bullough, 2009) to be highly correlated with visual acquisition times for simulated overhead guide signs in a study conducted by Schnell et al. (2009). It was also found to be highly correlated with symbol orientation identification times in a separate laboratory study of highway sign visibility (Goodspeed and Rea, 1999).

The present chapter includes two components: the first describes a laboratory study to determine the feasibility of using the relative visual performance (RVP) model to assess sign legibility, and the other is a short review of published literature on factors related to the conspicuity of signs.

Laboratory Study

The luminance and contrast quantities in the RVP model (Rea and Ouellette, 1991) are based on achromatic visual responses and do not account for the color of the target nor its background. For example, if a sign were to have red letters on a green background, with both letters having the same luminance, the RVP model would predict the letters to be invisible since they produce zero luminance contrast. However, it would be possible to read such a sign because of the color contrast. Preliminary evidence (Eastman, 1968) suggests that the visibility of an object against its background is influenced by color contrast only when the luminance contrast is low, but in the study by Eastman (1968) only a subjective measure of visibility based on a rating scale was used. For this reason, and to assess the ability of the RVP model to provide meaningful information regarding the ability of a driver to quickly and accurately respond to colored information presented on a sign, a laboratory study of visual performance was conducted.

Experimental Stimuli

Various combinations of foreground and background colors were used to create images of Landolt rings, figures commonly used for assessing performance. Some examples of the images are shown below in Figure 1. All of the Landolt ring images were created using Adobe

Photoshop and were sized to 96 x 96 pixels. The colors used were chosen to approximate the appearance of colors used on road signs and are summarized in Table 1. There were a total of 224 combinations of background color, foreground color, and ring orientation (the gap in the ring could be located up, down, left or right) created.

Figure 1. Three examples of various colors and orientations of Landolt rings which subjects were presented for identification are shown above. The Landolt ring images were displayed to the subject one at a time.

Table 1. Luminances of the colors used to create the Landolt rings are shown with the high and low luminance levels as measured on the computer screen used.

	Chromaticity		Luminance (cd/m^2)		
	x	Y	High	Medium	Low
White	0.3182	0.3463	62.00	7.63	0.94
Black	0.2744	0.2975	1.21	0.15	0.02
Red	0.5722	0.3432	16.12	1.94	0.23
Blue	0.1590	0.1534	10.35	1.27	0.16
Green	0.2785	0.3985	10.36	1.47	0.21
Yellow	0.4185	0.4696	52.15	6.73	0.87
Orange	0.5461	0.3600	26.55	3.27	0.40
Brown	0.3415	0.2752	6.64	0.77	0.09

Three overall light levels were tested in the experiment by using a neutral filter placed over the screen of the computer used to generate and display the Landolt rings. The nominal transmittance of the filter was about 10% (and ranged from 12% to 14% for the specific colors used). An even lower set of luminances was produced by placing two sheets of the neutral filter in front of the screen. All of the luminances for each color at each light level range (high, medium and low, corresponding to zero, one and two filters, respectively) are listed in Table 1.

Experimental Procedure

A LabView (National Instruments) program was custom written to perform the testing. The main screen view of this program is shown in Figure 2. The program displayed the Landolt ring images one at a time based on a randomized order. The subject was instructed to indicate which direction the opening of the Landolt ring was oriented using the arrow keys on the keyboard as soon as possible after the image was displayed. The software then removed that image from the screen, and recorded the image information, indicated direction, and reaction time. The software then waited a randomly selected period of time of 2 to 5 seconds and displayed the next ring image. This process was continued until the subject viewed and had rated all 224 images. A progress indicator was included in the software so that the subjects could gauge their overall progress.

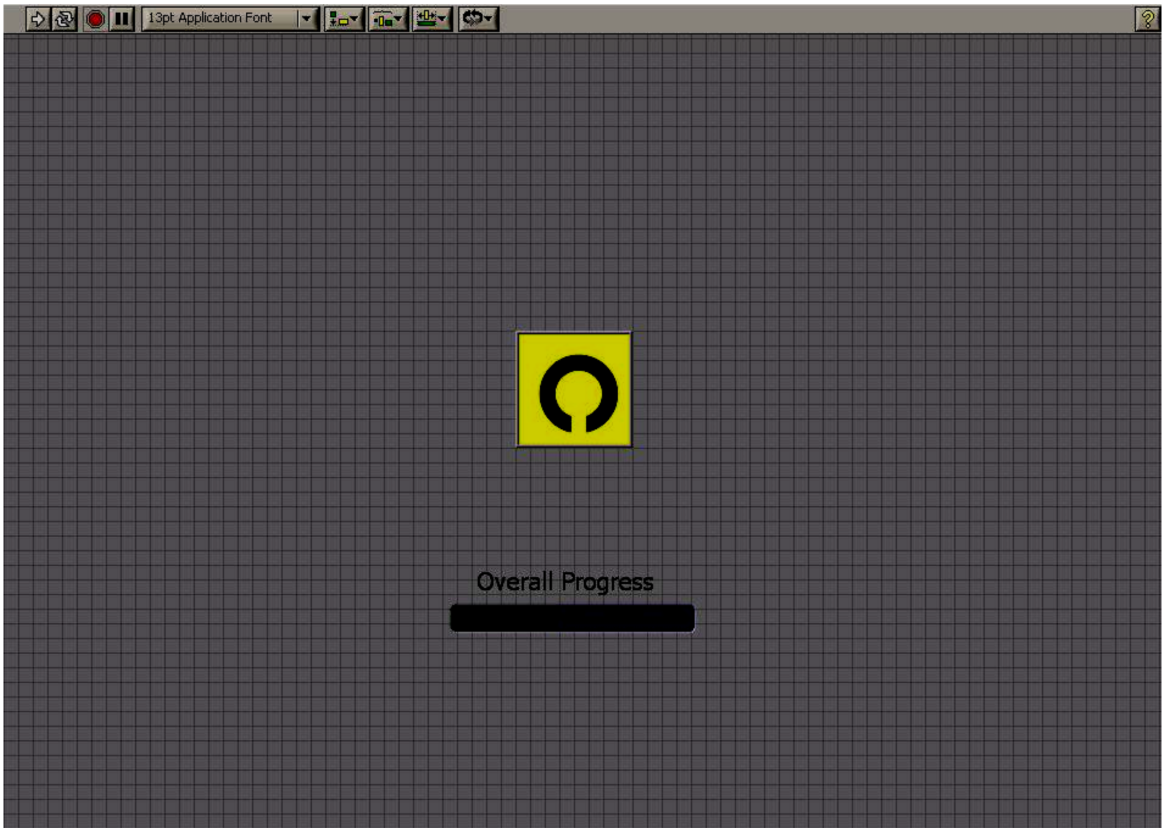


Figure 2. Subjects' view of the custom LabView program with a Landolt ring image shown.

For the high luminance range (no filters), 12 subjects (aged 21 to 53 years, mean 31 years, s.d. 9 years) participated. For the medium luminance range (one filter), six subjects (aged 22 to 53 years, mean 32 years, s.d. 12 years) participated, and for the low luminance range (two filters), six subjects (aged 23 to 53 years, mean 35 years, s.d. 10 years) participated. A total of 5,376 experimental trials (24 subject sessions x 56 color combinations x 4 orientations) were performed in the experiment.

Results

For each of the three luminance ranges, there were statistically significant ($p<0.05$), negative correlations between the calculated RVP values and the median response times measured for each color combination. Table 2 summarizes the calculated correlation coefficients for each set of data and for the set consisting of all three luminance ranges.

Table 2. Calculated correlation coefficients (r) between calculated RVP values and measured median response times.

Luminance Range	Correlation Coefficient (r)	Statistical Significance
High	-0.26	$p<0.05$
Medium	-0.33	$p<0.01$
Low	-0.30	$p<0.05$
Combined Data	-0.36	$p<0.01$

For most of the conditions at all light levels, the luminance contrast between the background and the Landolt rings was high, so that most of the calculated RVP values were greater than 0.8, close to or on the plateau of visual performance above which increased luminance or contrast is not likely to improve visual performance (Rea, 1989). A smaller subset of the data consisted of conditions where either the luminance contrast or the background luminance was very low, and where the calculated RVP values were all less than 0.5.

As described by Eastman (1968), when luminance contrast is high, color contrast is relatively unimportant to visual performance, but when luminance contrast is low, the color contrast would be expected to play a larger role in the overall speed and accuracy of performance. To test this hypothesis, the color contrast values of each color pair were calculated, based on the vector distance between the chromaticity coordinates in Table 1, and this color contrast value was used as another independent term in the regression analysis.

For the total combined set of data and for the subset consisting of low RVP values, including the color contrast term into the regression model improved the goodness of fit as characterized by the correlation coefficient (r) between the predicted and modeled values. Each time, larger color contrasts were associated with shorter response times. The color contrast term had a larger impact for the low RVP conditions (increasing the absolute value of the correlation coefficient), when luminance contrast was more likely to be low, as summarized in Table 3.

Table 3. Correlation coefficients (r) associated with regression models taking into account achromatic visual performance only (RVP) or RVP and color contrast between the Landolt rings and their backgrounds.

Data Set	Correlation Coefficient (r): RVP only	Correlation Coefficient (r): RVP and Color Contrast
All data	-0.360	-0.363
Low RVP data	-0.606	-0.668

Discussion

The experimental data and comparison with the RVP model and color contrasts indicate that consideration of color contrast as well as achromatic luminance and luminance contrast results in improved predictions of sign legibility, as measured by the speed of identifying the orientation of differently colored Landolt rings, for a wide range of luminances spanning those experienced in the field. Especially when RVP is low, due largely to low luminance contrast, such as brown letters on blue backgrounds, or red letters on green backgrounds, color contrast can overcome the low luminance contrast to result in relatively short response times. This is suggested by the improvement in the regression model correlation coefficient, from -0.606 to -0.668.

However, it should be recalled that it would be very unlikely for a transportation agency to select color combinations resulting in very low luminance contrast such as brown/blue or red/green. Most sign color combinations experienced in the field result in very high luminance contrast (Bullough et al., 2010), similar to most of the combinations used in the present experiment. In this situation, including a color contrast term into the regression model had only a negligible improvement in the regression model correlation coefficient, from -0.360 to -0.363. This suggests that for most practical conditions, the calculated RVP quantity alone is a practical and statistically reliable ($p<0.05$) measure of sign visibility. Furthermore, if and when it might misestimate visual performance because of color contrast, it will result in an underestimate (actual visibility would be somewhat higher than predicted by RVP), which means it is a conservative measure of sign visibility.

Annotated Bibliography on Sign Conspicuity

The project team reviewed literature on sign conspicuity in order to identify factors related to increasing the noticeability of signs along the highway, such as in urban locations, and field measurement of sign luminances. Following each literature citation, key points related to the conspicuity of highway signs are summarized.

Akagi Y, Seo T, Motoda Y. 1996. Influence of visual environments on visibility of traffic signs. Transportation Research Record (1553): 53-58.

- Subjects were asked to drive through locations varying in visual complexity and report information about highway signs
- The distance when they first glanced at a sign was defined as the detection distance
- Especially for older drivers (> 30 years), detection distances were negatively correlated with the visual noise ratio (defined as the area subtended by extraneous objects in the field of view divided by the area of the field of view)

Burns DM, Donahue TJ. 2001. Brightness and color of fluorescent yellow and fluorescent yellow green retroreflective signs: Comparison of laboratory and field measurements. *Transportation Research Record* (1754): 48-56.

- Laboratory measurements and field measurements of sign luminances under corresponding conditions were somewhat correlated but there was a substantial amount of scatter between corresponding measurements

Fontaine MD, Carlson PJ, Hawkins HG. 2000. *Evaluation of Traffic Control Devices for Rural High-Speed Maintenance Work Zones: Second Year Activities and Final Recommendations*, 1879-2. College Station, TX: Texas Transportation Institute.

- The use of fluorescent orange signs in work zones was liked by work crews

Gates TJ, Carlson PJ, Hawkins HG. 2004. Field evaluations of warning and regulatory signs with enhanced conspicuity properties. *Transportation Research Record* (1862): 64-76.

- Fluorescent red stop signs resulted in greater numbers of drivers stopping on roadways

Gutierrez JA, Ortiz de Lejarazu, Real JA, Mansilla A, Vizmanos J. 2012. Dynamic measurement of traffic sign luminance as perceived by a driver. *Lighting Research and Technology* 44(3): 350-363.

- Dynamic measurement of roadway sign luminances using a camera system are limited in the range they are able to measure accurately
- The presence of extraneous light sources in the field of view results in measured values that are higher than they should be because of scatter and blooming

Hummer JE, Scheffler CR. 1999. Driver performance comparison of fluorescent orange to standard orange work zone traffic signs. *Transportation Research Record* (1657): 55-62.

- A real-world field evaluation of fluorescent orange work zone signs revealed an association between the fluorescent color and slightly fewer traffic conflicts
- Fewer vehicles were in the closed lane approaching the work zone with fluorescent signs
- Mean driving speeds increased but variance in speeds decreased with fluorescent signs

Neale VL, Barker JA, Dingus TA, Brich SC. 1999. Evaluation of unassigned sign colors for incident management trailblazing. *Transportation Research Record* (1692): 17-23.

- Exploring different color combinations of signage for work zones and detours, the authors concluded that yellow letters on purple or black letters on light blue resulted in the fewest late-braking maneuvers when many tight curves were present
- Black letters on light blue resulted in the fewest turn errors of all color combinations, and were preferred by older drivers; younger drivers preferred yellow letters on purple

Olson PL. 1988. *Minimum Requirements for Adequate Nighttime Conspicuity of Highway Signs*, UMTRI-88-8. Ann Arbor, MI: University of Michigan.

- When subjects were expecting to see a sign their detection distances were approximately twice of those when they were not expecting to see a sign

Schieber F, Goodspeed CH. 1997. Nighttime conspicuity of highway signs as a function of sign brightness, background complexity and age of observer. *Proceedings of the Human Factors and Ergonomics Society*, pp. 1362-1366.

- Simulated sign luminances of 5 cd/m² or 50 cd/m² were presented in scenes of varying visual complexity
- Higher sign luminances resulted in shorter detection times (1.3 s vs. 1.6 s for a tenfold difference in luminance for complex backgrounds and no difference for simple backgrounds) and more accurate color identification only for the most visually complex backgrounds

Schnell T, Bentley K, Hayes E, Rick M. 2001. Legibility distances of fluorescent traffic signs and their normal color counterparts. *Transportation Research Record* (1754): 31-41.

- Daytime legibility distances of signs using fluorescent colored materials were slightly longer in clear weather than those of signs using conventional colors

Scialfa CT, Ho G, Caird JK, Graw T. 1999. Traffic sign conspicuity: The effects of clutter, luminance and age. *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting*, pp. 108-112.

- Visual search times by younger and older subjects was longer for cluttered scenes relative to uncluttered scenes, and longer for older subjects
- Search times were not affected by luminance of the signs

Simon L, Tarel J-P, Bremond R. 2007. A new paradigm for the computation of conspicuity of traffic signs in road images. *Proceedings of the International Conference of the 26th Session of the Commission Internationale de l'Eclairage*, pp. D4-38—D4-41.

- Gaze times to signs in the field of view are inversely proportional to their conspicuity

Takemoto A, Hirasawa M, Asano M. 2008. Improving the nighttime visibility of signs and workers in road work zones in Japan. *Transportation Research Board Annual Meeting*, Washington, DC.

- Signs with short and simple text were judged as easier to understand than ones with text and pictograms

Zwahlen HT, Schnell T. 1997. Visual detection and recognition of fluorescent color targets versus nonfluorescent color targets as a function of peripheral viewing angle and target size. *Transportation Research Record* (1605): 28-40.

- Fluorescent-colored targets and in particular, fluorescent yellow-green targets, were detected with greater probability than other colors

Summary

In general, the research studies cited above support the notion that sign luminances that support legibility (being able to read the sign) will also support conspicuity of the signs, even in quite complex environments. Schieber and Goodspeed (1997) reported that a tenfold increase in sign luminance provided a modest (0.3 s) improvement in sign detection only when the background of the sign was very complex. When the background was lower in complexity, sign luminance played little role. This finding was reinforced by Scialfa et al. (1999) who found no influence of sign luminance on conspicuity regardless of background complexity. A model of sign conspicuity developed by Forbes (1972) found that for urban conditions, even a sign with the same background as that of typical urban conditions resulted in a detection distance of 1000 m or longer.

3. MEASUREMENT EQUIPMENT AND PROCEDURES

The present chapter summarizes work undertaken in the present project to develop a simple measurement procedure and to evaluate photometric measurement systems for sign measurements. The measurement procedure developed was used to compare the performance of different measurement instrumentation systems.

Measurement Procedure

In a location near the Lighting Research Center laboratory, a simple measurement geometry was set up (Figure 3). A sign panel was set up 32 ft ahead of the measurement location where the measurement instrument (either a camera as shown in Figure 3 or a luminance meter as described below) was positioned. Source 1 in Figure 3 was a PAR30 halogen spot lamp with a 9 degree beam, using 45 W and dimmed to 50% power using an autotransformer. Source 2 was a PAR38 halogen spot lamp with a 10 degree beam, using 100 W. During most typical measurements, Source 2 would not be present, but it was used primarily to assess the role of scattered light on measurement accuracy.

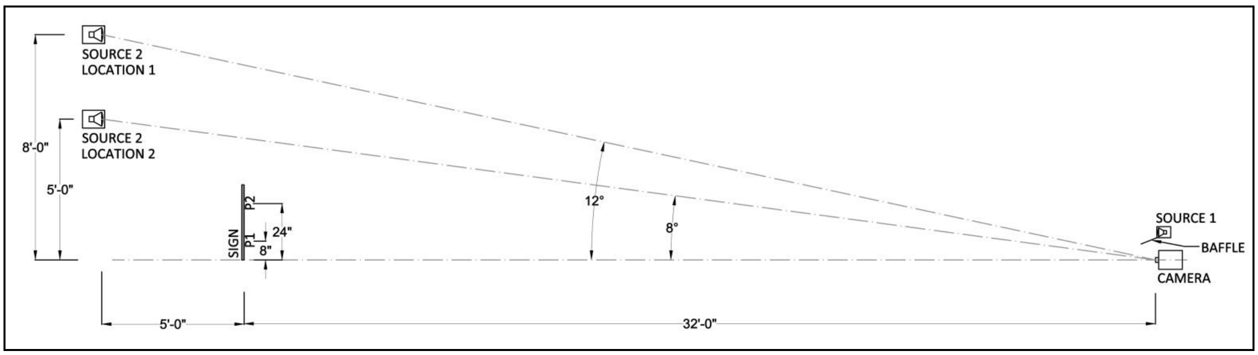


Figure 3. Measurement setup.

Source 1 in Figure 3 represented the light source that would be used by the retroreflective material to reflect back toward the measurement location. This measurement procedure would allow systematic adjustments of the geometry between the measurement instrument and the source of retroreflected light, as well as the sign panel and extraneous stray light sources that would be used, if any.

Comparison of Measurement Instrumentation

In order to assess different measurement systems, the project team conducted a series of measurements using two types of instruments: a digital camera based system for measurement of luminance (Radiant Imaging CCD Camera), and a hand-held luminance meter (Minolta, LS-100).

An objective for this experiment was to test and evaluate if the camera system could be used to reliably measure the luminance of roadway signs including conditions in the presence of extraneous light sources such as streetlights or vehicle headlights. A concern with using a camera to measure luminance on outdoor signage is that stray light can distort the measurements (Rea and Jeffrey, 1990). The camera was calibrated according to manufacturer specifications before the experiment and all measurements were compared to those of a Minolta luminance meter.

The camera was installed in line with a 29 x 24 inch white diffuse sign showing Landolt rings. Source 1 was located right next to the camera to illuminate the sign to a constant level of 12 lx. Source 2 was placed behind the sign as indicated at 8 degrees and 12 degrees off-axis to create two different stray light testing conditions. All equipment (camera, light sources, sign) was installed in line with each other at a height of 57 inches (center to ground).

Table 4. Luminance Measurements of Sign Panel Under Different Stray Light Conditions

	Imaging Camera (cd/m^2)	Luminance Meter (cd/m^2)
Condition 1: No backlight	3.1	3.2
Condition 2: With backlight (12^o off axis)	3.5	3.3
Condition 3: With backlight (8^o off axis)	15.5	7.5

Results

Table 4 shows the luminance data as measured using the camera based system and the luminance meter. With no extraneous light present, the values were very consistent with each other (within about 3%). When the extraneous light source was located 12 degrees off-axis, the difference increased to about 6%. The luminance value for the camera increased by 13%, while that of the luminance meter increased only by 3%. When the extraneous light source was 8 degrees off-axis, the luminance value for the camera was more than twice (107% higher) than that for the luminance meter, having increased by a factor of five (400% higher) from the case with no extraneous light present. Even the luminance meter exhibited a substantial increase in luminance for this condition, being 134% higher in luminance than the no-extraneous-light condition.

Figures 4, 5 and 6 show luminance maps from the camera system and corresponding digital images. The effects of stray light within the camera are noticeable in Figure 5 and especially so in Figure 6, where optical artifacts are vividly present.

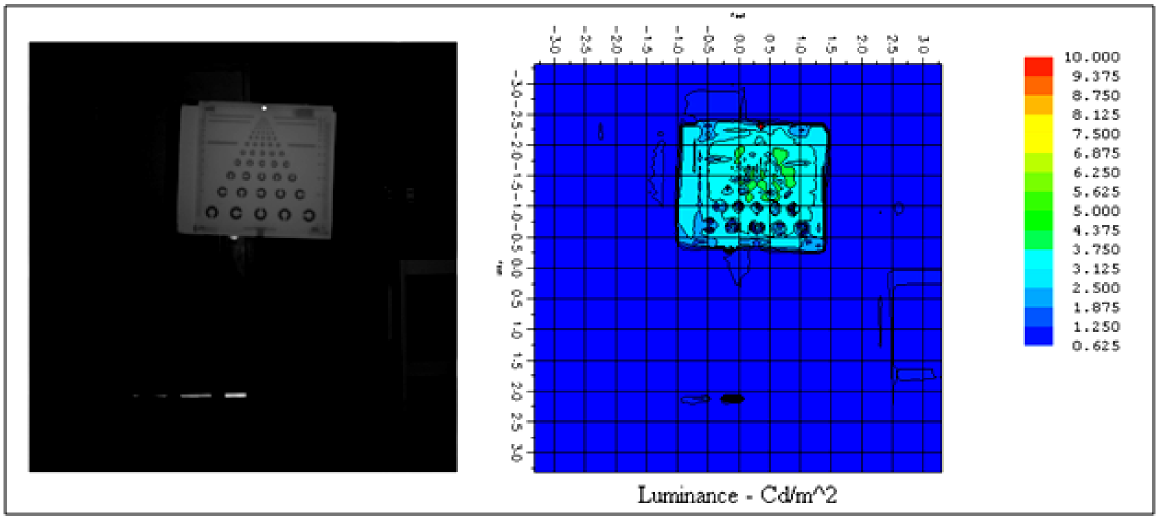


Figure 4. Sign panel luminance with no extraneous light source present. Also shown is the output from the calibrated camera luminance measurement system.

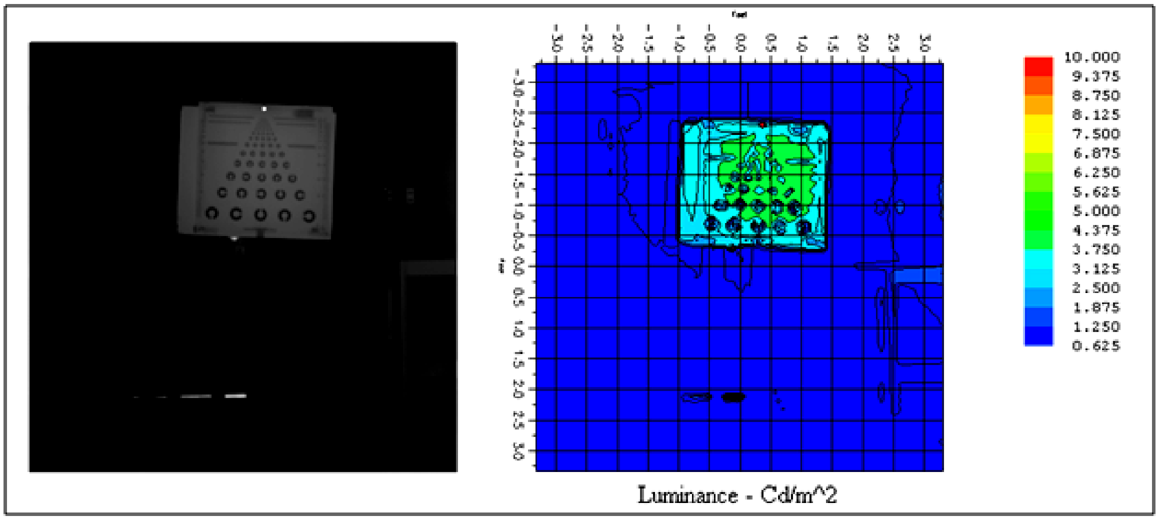


Figure 5. Sign panel luminance with an extraneous light source located 12 degrees off-axis, outside the field of view of the camera.

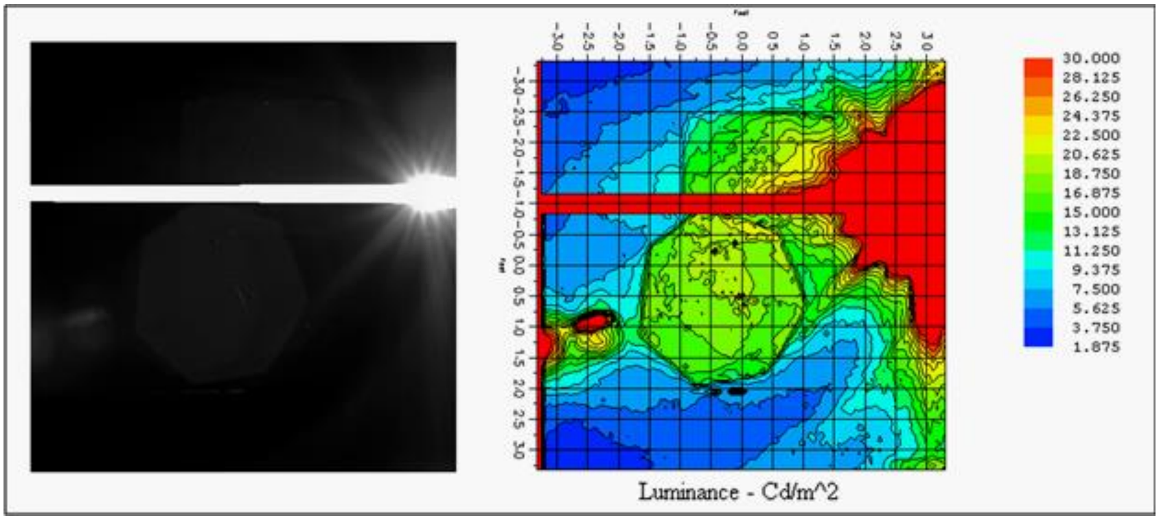


Figure 6. Sign panel luminance with an extraneous light source located 8 degrees off-axis, within the field of view of the camera.

Importantly, the presence of the extraneous light source 8 degrees off-axis required the digital camera system to utilize a different calibration file from the one used to record data for the previous two conditions. However, the present results suggest that while any measurement instrument will suffer from a degree of inaccuracies when stray light is present, a digital camera system is especially prone to inaccuracy, which was also observed by Rea and Jeffrey (1990) and identified more recently by Gutierrez et al. (2012) in their evaluation of digital camera sign measurement methods.

For this reason, a luminance meter was used to conduct photometric field measurements of signs as described in a subsequent chapter of this report.

Assessment of Minimum Retroreflectivity Compliance Kit

The project team also procured a Minimum Retroreflectivity Compliance Kit (manufacturer, Avery Dennison) to evaluate its utility for gauging the performance of retroreflective signs in the field. The kit has two components:

- A set of “standard” 2-ft by 2-ft signs in common color combinations (white on green, black on white, black on yellow, black on orange, white on red)
- Small 6-inch square material samples of individual colors

The first set of items (denoted the “standard” signs) are meant to be installed outdoors at the facility from which sign inspections will be performed, and viewed by an inspector from distances of 100 ft and 600 ft in order to provide a sense of what brightness signs meeting minimum retroreflectivity levels produce. Then, recalling those brightness levels, the inspector can rate existing signs along roadways of each type as “good,” “marginal” or “replace” based on whether the signs exceed the brightness of the test signs, appear similar in brightness, or are less bright.

The second set of items (6-inch samples) are meant to be used for signs judged “marginal” to provide side-by-side comparisons of the brightness of the sign with that of the test panels. The samples can be clipped to the sign face and a flashlight that comes with the kit would be used to illuminate the sign and test sample.

What is less clear from the documentation of the kit is the impact of geometry on the resulting luminance (and therefore, the brightness appearance) of the samples. They are each labeled with a single retroreflectivity value, but many retroreflective materials have different coefficients of retroreflection for different orientations. The method described by the kit using the hand held light source and visually judging the materials results in the source and eyes being relatively close to each other in terms of the angle from the material.

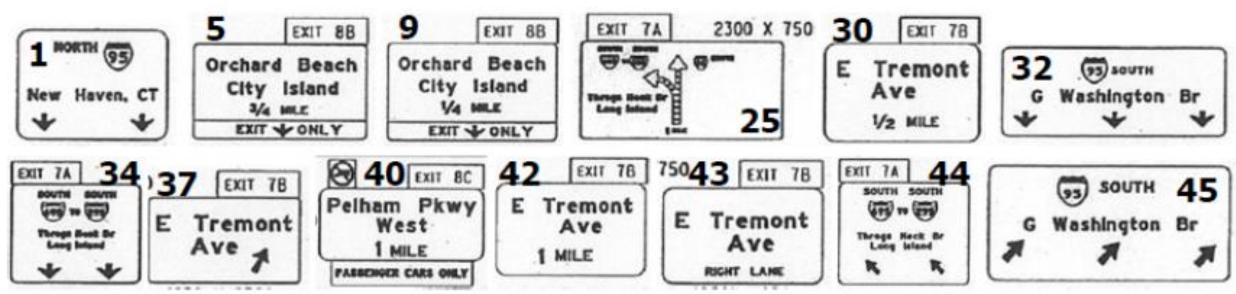
To test whether the specific orientation or measurement location of the observer influences the resulting retroreflection coefficient, measurements were made of a white sample panel in the Levin Photometry Laboratory at the Lighting Research Center, while it was illuminated by the hand-held light source aligned with the input optics of a luminance meter. Measurements were made at a constant distance and the observation angle ranged from 0 degrees (directly in front of the sample) to 30 degrees to the right and left along a semi-circle, so that the measurement distance (and the illuminance at the sample location) remained constant. In all cases the measured luminance, which was 140 cd/m^2 at 0 degrees, was within +/- 5% (133 to 147 cd/m^2) of the 0 degree value. This suggests that the materials will not be overly sensitive to the precise measurement location, and that the specific mounting locations of the “standard” signs do not have to correspond precisely to the locations they would have on a real roadway. (This concern arose because a photograph in the promotional literature for the kit shows all eight “standard” signs mounted on posts with heights no more than about 8 ft and some heights about 5 ft above the ground.)

Before using the “standard” signs to judge retroreflectivity, since they rely on the inspector’s ability to remember the brightness of several different signs before traveling to the sign locations that will be inspected, personnel may wish to use the direct comparison method to assess inspectors’ abilities to make these judgments. The side-by-side method using the test samples is much more precise but also more time-consuming because it requires samples to be mounted into each sign and then removed, one at a time.

4. REGION 11 FIELD MEASUREMENT RESULTS

Identification of Signs for Field Measurement

Region 11 of NYSDOT installed a number of signs along the Bruckner and Cross-Bronx Expressways in New York City using two different high visibility reflective sign sheeting materials. Specifically, Type IX and Type XI sheeting meeting the specifications of the American Society for Testing and Materials (ASTM) specifications for retroreflective sign sheeting materials were installed. In general these specifications require increasingly higher levels of retroreflectivity (in cd/m^2/lux) than sheeting materials meeting Type III designations. Which sign panels used which materials were unknown to the project team at the time measurements were made.



Location number	Sign number(s)	Direction	Mounting	Distance	Viewing Station	Comments
8	9	NB	Arm	150	8+840	
4	40, 5	NB	OH Structure	150	8+140	
1	1, 1	NB	OH Structure	200	7+695	
24	25, 42	SB	Bridge	130	9+280	
30	34, 32, 30	SB	OH Structure	200	8+490	Best view from LEFT Lane
33	34, 32, 43	SB	OH Structure	200	8+095	
36	34, 32, 37	SB	OH Structure	200*	7+850	* View at 150 m also, 7+800
38A	44, 45	SB	OH Structure	135	7+650	

distances in meters

Table 5. Guide signs and locations selected for the initial field measurement sample. Also shown are the viewing distance(s) and mounting types for each sign. Multiple sign numbers appear at different locations when duplicate sign panels appeared before a highway exit.

Using construction drawings for the sign installation provided by NYSDOT and a review of the photolog data for these highways in order to determine lines of sight, the project team identified a number of signs that were practical for field measurements (Table 5). Sign numbers and viewing station locations correspond to those locations identified on the construction drawings.
Most of the viewing distances for the selected signs were between 130 and 200 m from the signs. One of the criteria for the selection of signs was that they needed to have sufficient “white space” (which actually was green) so that the measurement spot of a narrow-angle luminance meter could be fixated on the sign surface. Since previous measurements (Bullough et al., 2010) showed that the relative luminance ratio between the green sign background and the white

characters on the sign was constant regardless of the material type, only the green backgrounds were measured. This permitted measurements to be made without complex optical accessories in place, which could increase the scatter within photometric instrumentation and reduce measurement precision.

Measurement Procedure

Photometric measurements were made using a narrow-angle luminance meter (Minolta, LS-110) with a 0.33^{o} aperture. This aperture, in contrast to a luminance meter with a larger (1^{o}) aperture, permitted measurements to be made from a larger distance than would have otherwise been possible.

Coordinating with engineering staff from NYSDOT Region 11 and with NYSDOT's traffic control contractor, the procedure developed in conjunction with NYSDOT was to measure the signs along the northbound direction of the segment of the Bruckner/Cross-Bronx Expressway containing the signs to be measured, and then to turn around and measure the signs in sequence along the southbound direction. For the initial set of measurements conducted in October 2013, the measurements started after 10 p.m. For the second set of measurements conducted in September 2014, the measurements started after midnight. The measurements occurred during clear weather and while the outdoor temperature was in the upper $50s^{o}$ to lower $60s^{o}$ F on both nights. The dew point during all of the measurements was below 50^{o} F so that signs were never impacted by moisture condensation during the measurement sessions.

During both sessions, researchers rode in a passenger vehicle (2012 Lexus RX 350, a crossover sport-utility vehicle [SUV]) operated by a NYSDOT engineer. One researcher used a lidar range finder (Bushnell) to measure the distance to the signs from the front passenger side seat, and another sat in the seat behind the driver and measured luminances over the shoulder of the driver to simulate the driver's line of sight. All measurements were made through the front windshield, which was clean and free of scratches or other damage. At the designated measurement distance, a luminance measurement was made for each sign panel at a particular location while the passenger vehicle's low beam headlamps were switched on (trucks for traffic control turned their headlights off during measurements but kept their flashing beacons and other flashing lights on). Then, a luminance measurement was made for each sign panel with the low-beam headlamps of the passenger vehicle switched off. The measurements at each location typically took between 1 and 2 minutes. Following the last measurement at each location, the headlamps of the passenger vehicle were switched back on, and a NYSDOT engineer contacted the traffic control trucks, which turned their headlamps on. The passenger vehicle and traffic control trucks then drove to the next measurement location. All measurements were made from the rightmost traffic lane, adjacent to (but not in) the emergency lane.

Signs at eight locations were measured (5 in the southbound direction, and 3 in the northbound direction). Between 1 and 3 sign panels were measured at each location. Each entire measurement session took under two hours to complete.

Measurement Results: Session 1

Figures 7 through 15 show the sign panels that were measured along with the luminances of the sign panels with and without the passenger vehicle's headlamps switched on. Also listed in the captions are the precise measurement distances for each set of signs.

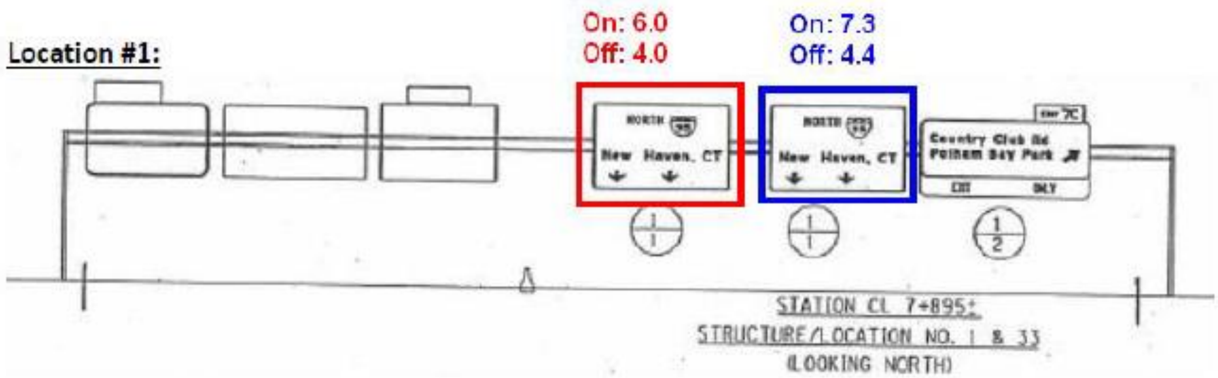


Figure 7. Luminances (in cd/m^2) of the green backgrounds of the signs for the first northbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 198 m.

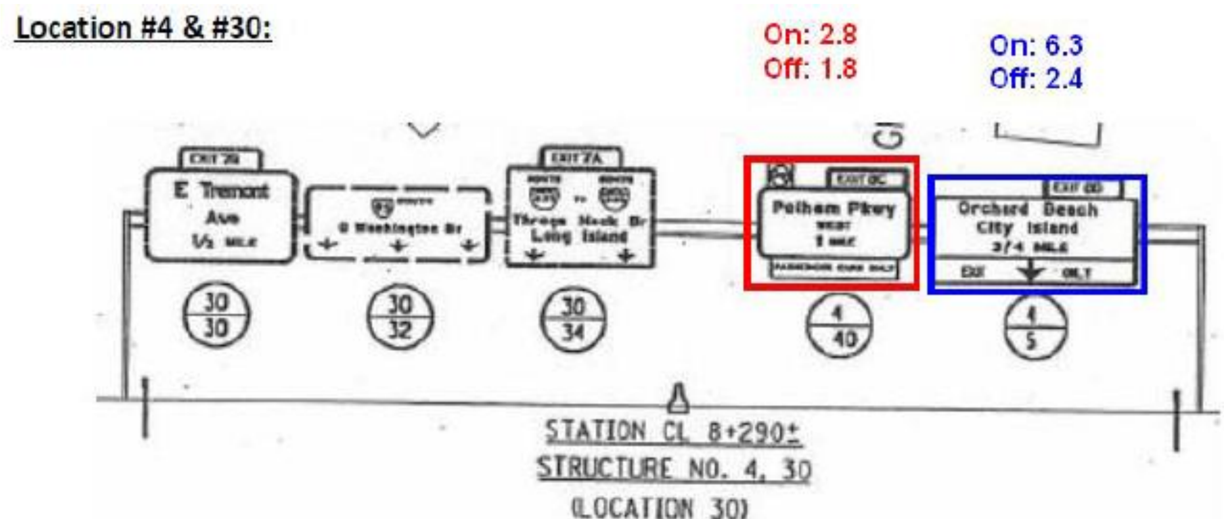


Figure 8. Luminances (in cd/m^2) of the green backgrounds of the signs for the second northbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 153 m.

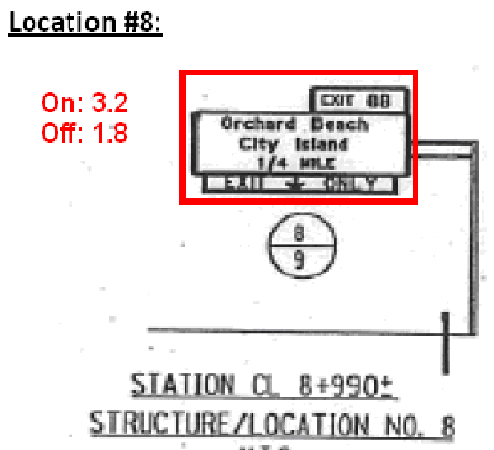


Figure 9. Luminances (in cd/m^2) of the green background of the sign for the third northbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 144 m.

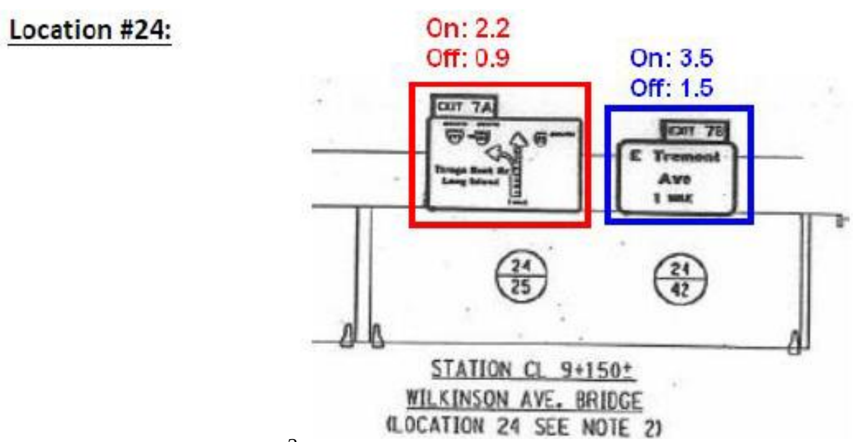


Figure 10. Luminances (in cd/m^2) of the green backgrounds of the signs for the first southbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 142 m.

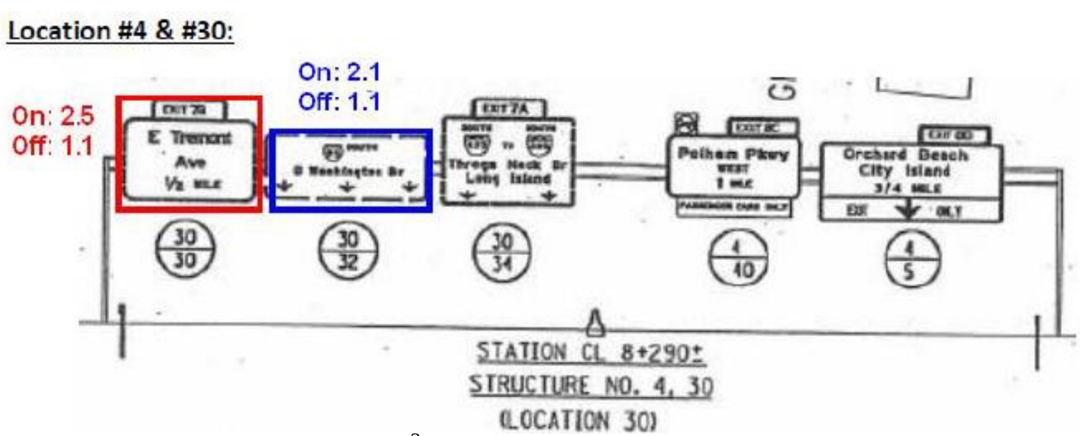


Figure 11. Luminances (in cd/m^2) of the green backgrounds of the signs for the second southbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 188 m.

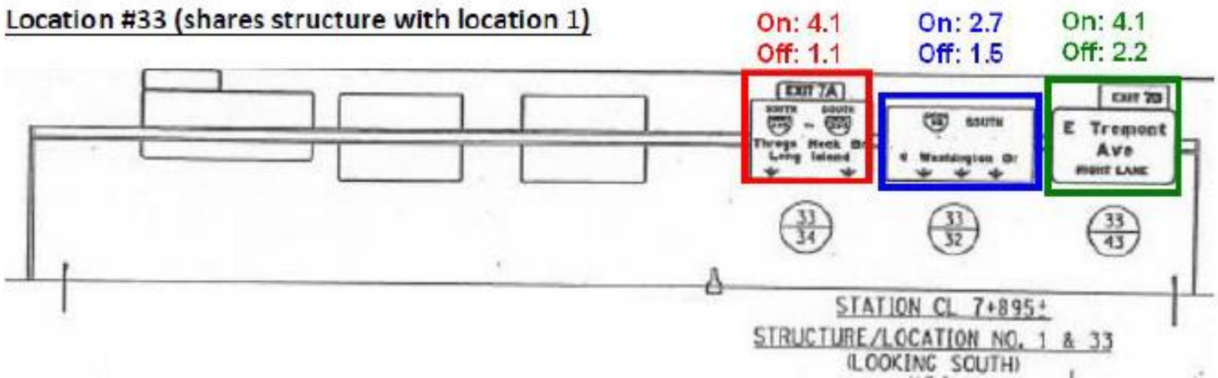


Figure 12. Luminances (in cd/m^2) of the green backgrounds of the signs for the third southbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 200 m.

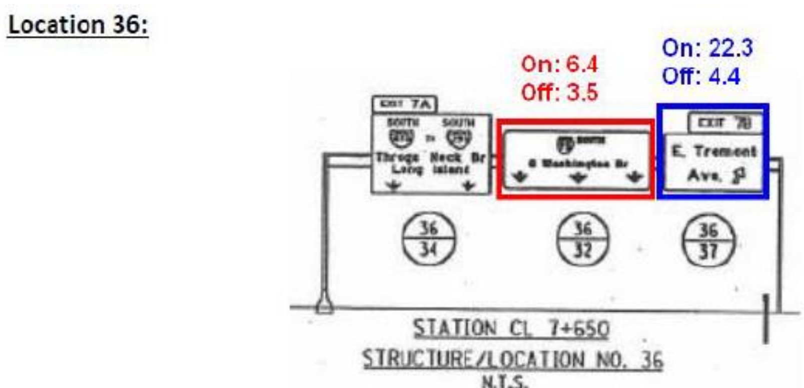


Figure 13. Luminances (in cd/m^2) of the green backgrounds of the signs for the fourth southbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 199 m. Note: The same signs were measured from a different distance as shown in Figure 14.

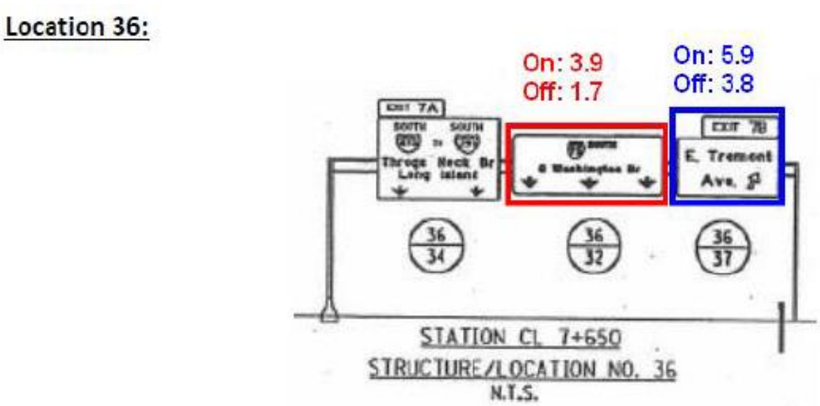


Figure 14. Luminances (in cd/m^2) of the green backgrounds of the signs for the fourth southbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 160 m. Note: The same signs were measured from a different distance as shown in Figure 13.

Location 38A:

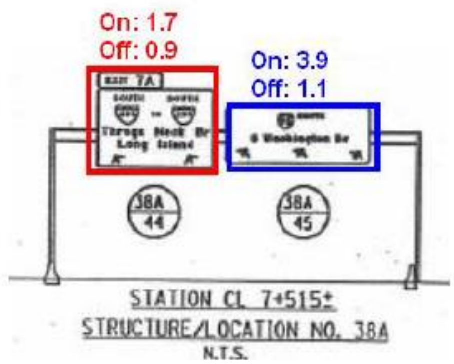


Figure 15. Luminances (in cd/m^2) of the green backgrounds of the signs for the fifth southbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 133 m.

Table 6 lists the ASTM types and measured luminance values, as well as the differences between each pair of values with headlamps switched on and off. This difference provides as estimate of the retroreflective luminance of the signs while disregarding luminance from ambient light along the highway from other sources of light. The maximum retroreflective luminance was 17.9 cd/m^2 and the lowest retroreflective luminance was 0.8 cd/m^2.

Northbound				
Location	ASTM Type	Luminance (headlights on, cd/m^2)	Luminance (headlamps off, cd/m^2)	Difference (cd/m^2)
1	XI	6.0	4.0	2.0
1	XI	7.3	4.4	2.9
4 & 30	IX	2.8	1.8	1.0
4 & 30	XI	6.3	2.4	3.9
8	IX	3.2	1.8	1.4
Southbound				
Location	ASTM Type	Luminance (headlights on, cd/m^2)	Luminance (headlamps off, cd/m^2)	Difference (cd/m^2)
24	IX	2.2	0.9	1.3
24	XI	3.5	1.5	2.0
4 & 30	IX	2.5	1.1	1.4
4 & 30	XI	2.1	1.1	1.0
33	IX	4.1	1.1	3.0
33	XI	2.7	1.5	1.2
33	XI	4.1	2.2	1.9
36 (199 m)	XI	6.4	3.5	2.9
36 (199 m)	XI	22.3	4.4	17.9
36 (160 m)	XI	3.9	1.7	2.2
36 (160 m)	XI	5.9	3.8	2.1
38A	IX	1.7	0.9	0.8
38A	XI	3.9	1.1	2.8

Table 6. Summary of photometric measurements and retroreflective luminances for each of the measured signs in each traveling direction.

Measurement Results: Session 2

Figures 16 through 24 show the sign panels that were measured along with the luminances of the sign panels with and without the passenger vehicle's headlamps switched on. Also listed in the captions are the precise measurement distances for each set of signs.

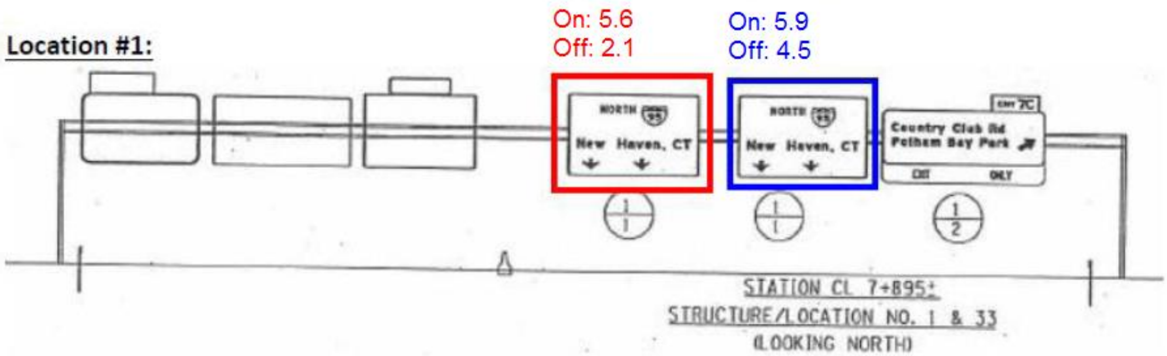


Figure 16. Luminances (in cd/m²) of the green backgrounds of the signs for the first northbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 195 m.

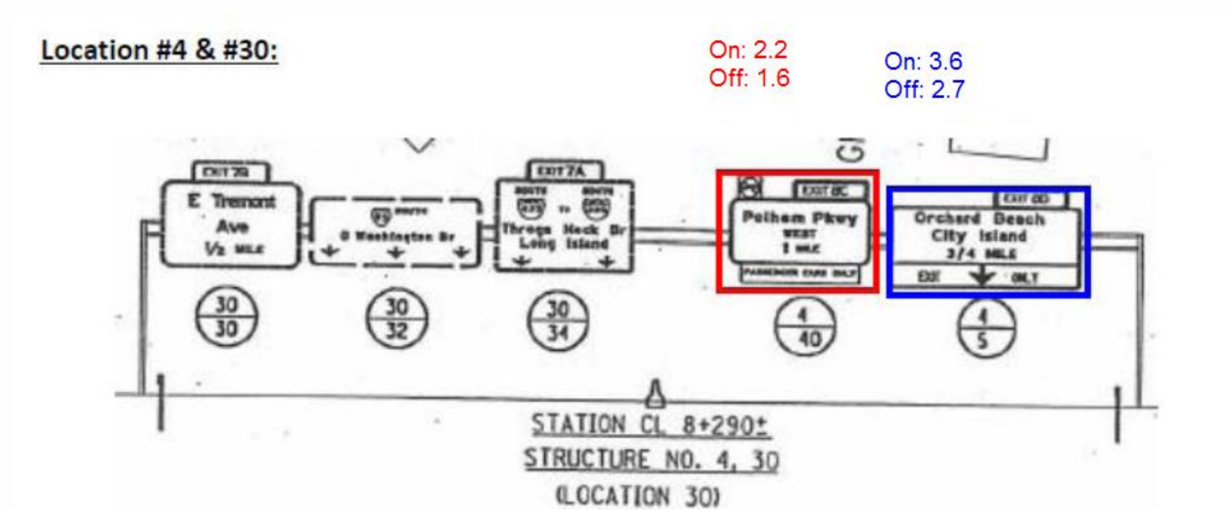


Figure 17. Luminances (in cd/m²) of the green backgrounds of the signs for the second northbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 148 m.

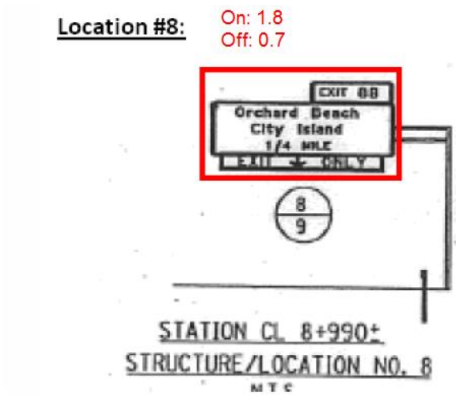


Figure 18. Luminance (in cd/m²) of the green background of the sign for the third northbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 111 m.

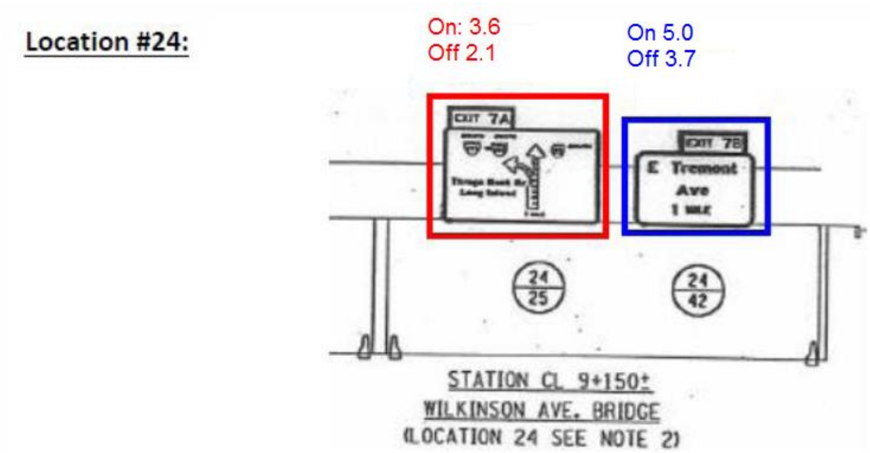


Figure 19. Luminances (in cd/m²) of the green backgrounds of the signs for the first southbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 122 m.

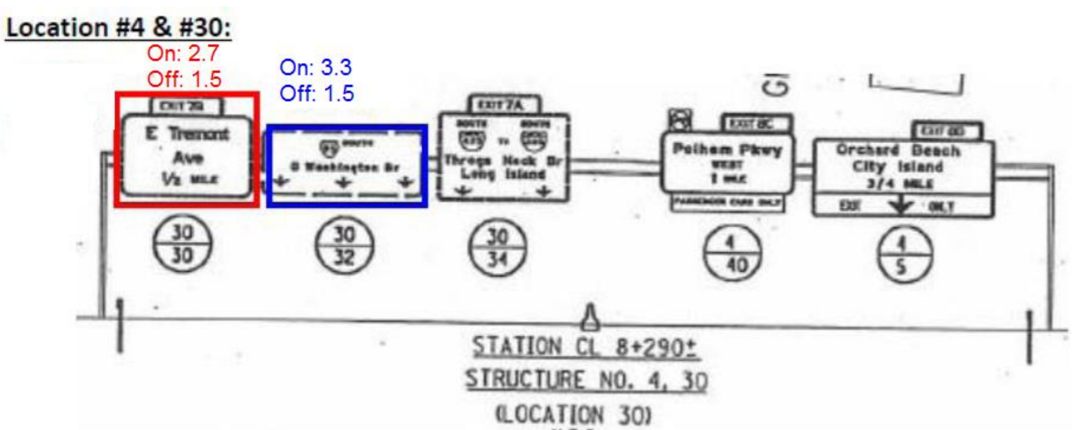


Figure 20. Luminances (in cd/m²) of the green backgrounds of the signs for the second southbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 107 m.

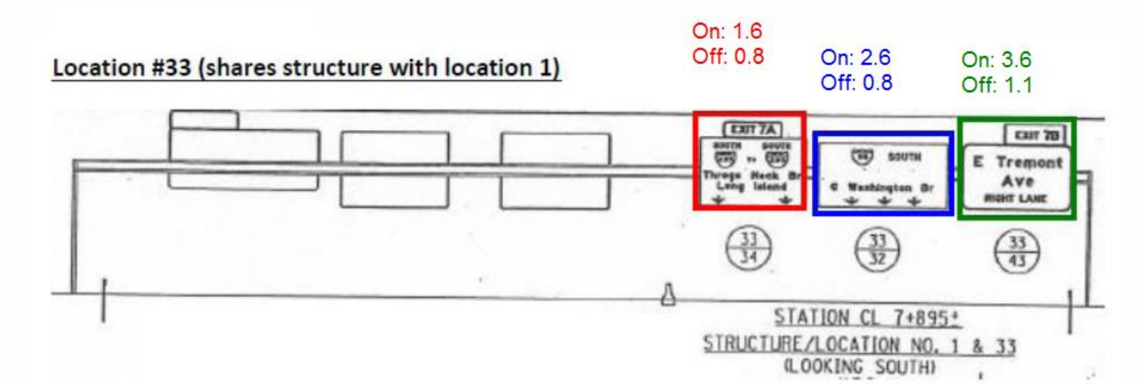


Figure 21. Luminances (in cd/m²) of the green backgrounds of the signs for the third southbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 189 m.

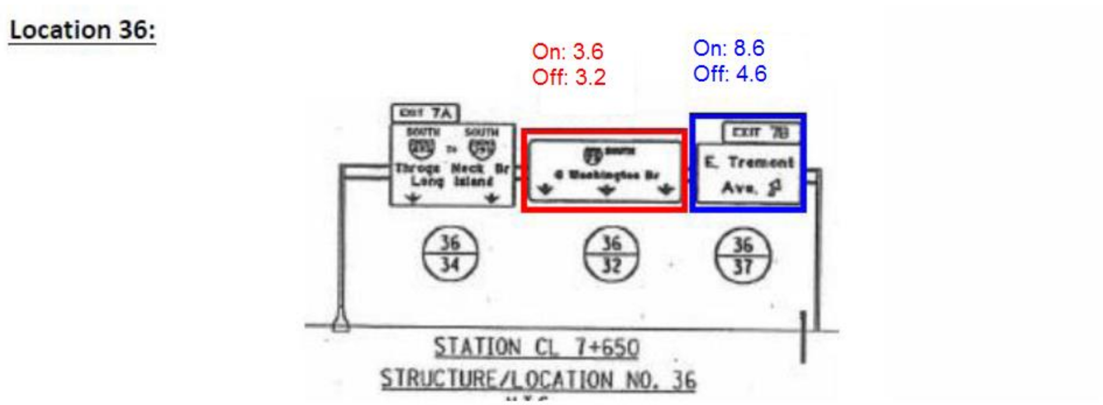


Figure 22. Luminances (in cd/m²) of the green backgrounds of the signs for the fourth southbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 210 m. Note: The same signs were measured from a difference distance as shown in Figure 23.

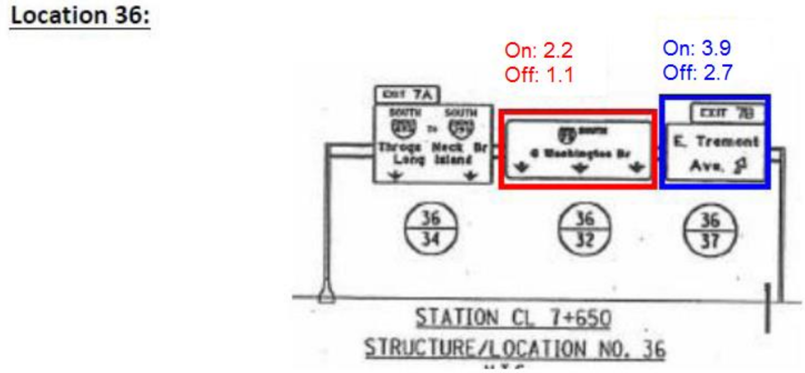


Figure 23. Luminances (in cd/m²) of the green backgrounds of the signs for the fourth southbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 150 m. Note: The same signs were measured from a difference distance as shown in Figure 22.

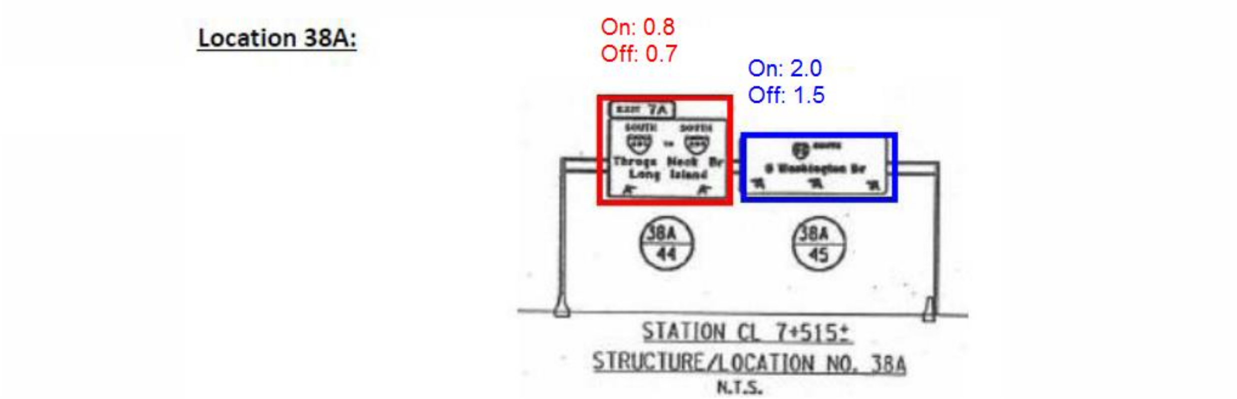


Figure 24. Luminances (in cd/m²) of the green backgrounds of the signs for the fifth southbound sign measurement location with measurement vehicle headlamps switched on and off. Measurement distance: 136 m.

Northbound				
Location	ASTM Type	Luminance (headlights on, cd/m²)	Luminance (headlights off, cd/m²)	Difference (cd/m²)
1	XI	5.6	2.1	3.5
1	XI	5.9	4.5	1.4
4 & 30	IX	2.2	1.6	0.6
4 & 30	XI	3.6	2.7	0.9
8	IX	1.8	0.7	1.1
Southbound				
Location	ASTM Type	Luminance (headlights on, cd/m²)	Luminance (headlights off, cd/m²)	Difference (cd/m²)
24	IX	3.6	2.1	1.5
24	XI	5.0	3.7	1.3
4 & 30	IX	2.7	1.5	1.2
4 & 30	XI	3.3	1.5	1.8
33	IX	1.6	0.8	0.8
33	XI	2.6	0.8	1.8
33	XI	3.6	1.1	2.5
36 (210 m)	XI	3.6	3.2	0.4
36 (210 m)	XI	8.6	4.6	4.0
36 (150 m)	XI	2.2	1.1	1.1
36 (150 m)	XI	3.9	2.7	1.2
38A	IX	0.8	0.7	0.1
38A	XI	2.0	1.5	0.5

Table 7. Summary of photometric measurements and retroreflective luminances for each of the measured signs in each traveling direction.

Table 7 lists the ASTM types and measured luminance values, as well as the differences between each pair of values with headlamps switched on and off. This difference provides as estimate of the retroreflective luminance of the signs while disregarding luminance from ambient light along the highway from other sources of light. The maximum retroreflective luminance was 4 cd/m^2 and the lowest retroreflective luminance was 0.1 cd/m^2. Although the measured values were generally lower than they were for the first set of measurements (about 40%-50% lower, on average), a paired, two-tailed Student's t-test revealed that the difference between the sets of measurements was not statistically significant ($p > 0.05$). There was, however, a modest but statistically significant positive correlation between the corresponding sets of measurement values ($r = +0.59$, $p < 0.01$). This finding should be tempered by the fact that the brightest sign in each measurement set (the rightmost sign at location 36, the fourth southbound location, when measured from about 200 m away) was the same, and was an outlier in both sets of data. The presence of this outlier means the distributions of the luminance values in each set were likely not normal and that the statistical significance of the correlation coefficient r should be interpreted cautiously. However, the fact that the same sign in the same location was the outlier in both sets does suggest a consistency between the measurements. The sign panel with the lowest luminance was also consistent between sessions.

The reduction in luminance for the second set relative to the first is probably not related to any meaningful degradation in the retroreflective performance of the sign materials themselves, for two reasons. First, sign retroreflectivity degradation studies have typically found annual retroreflectivity degradation rates of about 2% per year (summarized by Ré et al., 2011), not 40%-50% as suggested by the present luminance measurements. Second, experimenters observed that the vertical aim of the headlamps used in the measurement vehicle was substantially lower during the second set of measurements than it was during the initial set. Vertical downward aim of automotive headlights is not uncommon on vehicles in the U.S. (Skinner et al., 2010). It is most likely given this observation that the difference in measured luminances is largely caused by the difference in headlamp aim. Bullough et al. (2010) similarly found systematic differences in sign luminance were caused by differences in headlamp conditions between measurement sessions.

There was also a statistically significant difference (Mann-Whitney test, $p<0.05$) between the luminances of the Type IX (session 1: 1.6 cd/m^2, session 2: 0.9 cd/m^2) and Type XI (session 1: 3.1 cd/m^2, session 2: 1.7 cd/m^2) materials. On average, the luminances of the Type IX materials were 54% of the luminances of the Type XI materials. Interestingly, this corresponds well with the specified minimum differences between these two ASTM types for the geometric conditions associated with the measurements, where the specified minimum retroreflectivity for Type IX materials is 57% of the specified minimum for Type XI materials.

5. VISUAL PERFORMANCE ANALYSES

The current chapter describes the project team's approach to quantifying visibility of highway signs using the relative visual performance model, including the development of a spreadsheet tool for calculating minimum sign luminance and visual performance values.

Characterizing the Retroreflectivity of Different Material Types

Presently there are two classification systems used to describe the retroreflective properties of materials used for highway signage, one published by the American Society for Testing and Materials (ASTM, 2013) and one published by the American Association of State Highway and Transportation Officials (AASHTO, 2010). Both specifications are similar in that they describe the coefficient of retroreflection (in $cd/lx/m^2$) for a limited set of lighting and observation geometries.

The luminance of a retroreflective material depends not only upon the amount of light falling on it, as it does for matte, diffuse materials, but also upon the angle between the beam of light reaching the material surface and the normal or perpendicular angle from the surface itself. This angle is known as the entrance angle (Figure 25). The luminance also depends upon the relationship among the reflective material, the light source and the observer. The angle between an observer's line of sight toward the material and the line between the light source and material, known as the observation angle (Figure 25) also influences the luminance in the direction of the observer.

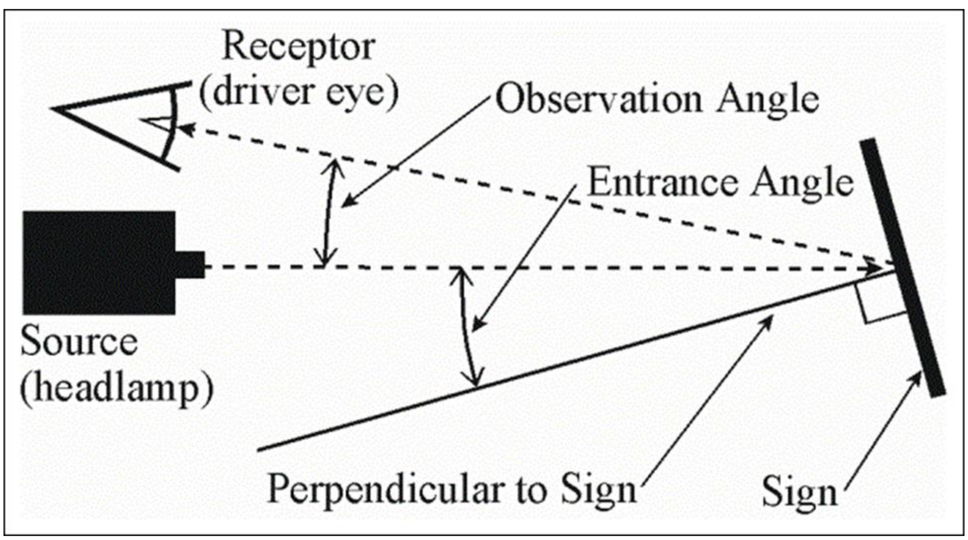


Figure 25. Simplified diagram of the entrance and observation angles describing retroreflectivity performance (from http://safety.fhwa.dot.gov).

The ASTM (2013) and AASHTO (2010) specifications describe performance for two entrance angles (typically 4^o and 30^o from the normal to the material surface) and for several observation angles usually with values between 0.1^o and 1^o (inclusive). The ASTM standard has several classifications designated by Roman numerals (I through XI, with several withdrawn categories) and the AASHTO specification designates categories by letter A through D. Table 8 shows, for one material type in the AASHTO specification, the minimum coefficients of retroreflectivity required for materials varying in color, for several entrance and observation angles. It can be seen in Table 8 that values for different colors differ, because the dyes used to create each color absorb differing amounts of light. As a consequence, white materials have the highest coefficient values while darker colors like blue and brown have much lower values.

Observation Angle (deg.)	Entrance Angle (deg.)	White	Yellow	Orange	Red	Green	Blue	Brown
0.2	-4	240	180	90	35	25	12	7.5
0.2	+30	120	90	45	20	12	6.0	3.5
0.5	-4	95	70	35	15	9.5	4.5	3.0
0.5	+30	50	35	20	7.0	4.5	2.5	1.5
1.0	-4	4.5	3.5	1.8	0.7	0.5	0.3	0.2
1.0	+30	2.5	2.0	1.0	0.5	0.3	0.2	0.1

Table 8. Minimum required coefficients of retroreflection for materials classified as AASHTO Type A, for different colors, and different entrance and observation angles.

Analysis Scenarios

Since the signs measured in Region 11 were all overhead guide signs using green background and with white letters, the analysis of retroreflective luminances was also based on overhead sign geometry using green as the color of the background sign sheeting. A sign height of 21.5 ft was assumed as well as a headlamp height of 2.79 ft and a driver eye height of 4.83 ft, based on normative data published by Carlson et al. (2010). A forward tilt of 3^o was also assumed. For the headlamps, data representing a 2004 U.S.-market-weighted low beam pattern (Schoettle et al., 2004) were used to estimate the luminous intensity from the headlamps in the direction of the signs. Both headlamps were assumed to be directly in the center of the vehicle behind the sign. Every 100 ft between 200 and 1000 ft from the sign, the entrance and observation angles were calculated for the light source/driver/sign geometry, and the luminous intensity from two headlamps in the direction of the sign was calculated. Using the inverse-square law, it was possible to estimate the illuminance on the sign according to the relationship:

$$E = I/d^2$$

Where E is the illuminance on the sign (in lux), I is the luminous intensity from the pair of headlamps (in cd) and d is the distance to the sign (in m, converted from ft to ensure proper units of illuminance).

Table 9 shows, for each of the distances from the sign between 200 and 1000 ft, the resulting entrance and observation angles and the illumination on the sign. The columns in Table 9 corresponding to the entrance and observation angles are color-coded based on the typical angles included in the published AASHTO (2010) and ASTM (2013) specifications. For example, if the observation angle is equal to or less than 0.5^o but greater than 0.2^o, the reference observation angle used to estimate the sign luminance is 0.5^o. It is assumed that the actual coefficient of retroreflection at angles less than a particular angle will be at least the same value as at the next largest reference angle. Similarly, entrance angles in Table 9 are color coded based on the next largest reference entrance angle (either 4° or 30°).

Distance (ft)	Average Observation Angle (deg)	Average Entrance Angle (deg)	Intensity Toward Sign (cd)	Illum. on Sign (lx)
200	1.00	2.40	275	0.0740
300	0.65	0.70	446	0.0533
400	0.47	0.40	552	0.0371
500	0.37	0.90	670	0.0288
600	0.31	1.20	763	0.0228
700	0.26	1.45	877	0.0193
800	0.23	1.70	1008	0.0170
900	0.20	1.83	1167	0.0155
1000	0.18	1.95	1288	0.0139

≤ 0.2 degrees	≤ 4 degrees
0.2 < x ≤ 0.5 degrees	4 < x ≤ 30 degrees
0.5 < x ≤ 1 degrees	

Table 9. Geometric and illumination conditions from low-beam headlamp illumination, for overhead guide signs viewed from difference distances.

Finally, in order to estimate the luminance as observed by a driver, a windshield transmittance of 80% is assumed in the present analyses, which is a typical value based on several field measurements.

Minimum Sign Luminances

Figure 26 shows, for the four AASHTO (2010) sign material types, the minimum luminances that can be expected in conjunction with low beam headlamps for the geometric conditions listed in Table 9, plotted as a function of the distance from the sign. Figure 27 shows the corresponding information for each of the ASTM (2013) material types.

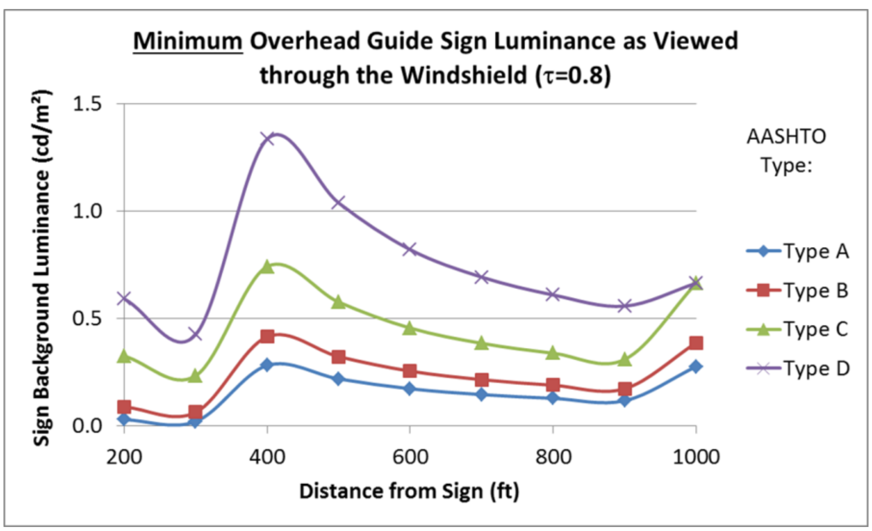


Figure 26. Minimum overhead sign luminance, as a function of distance from the sign, for each of the AASHTO (2010) sheeting types.

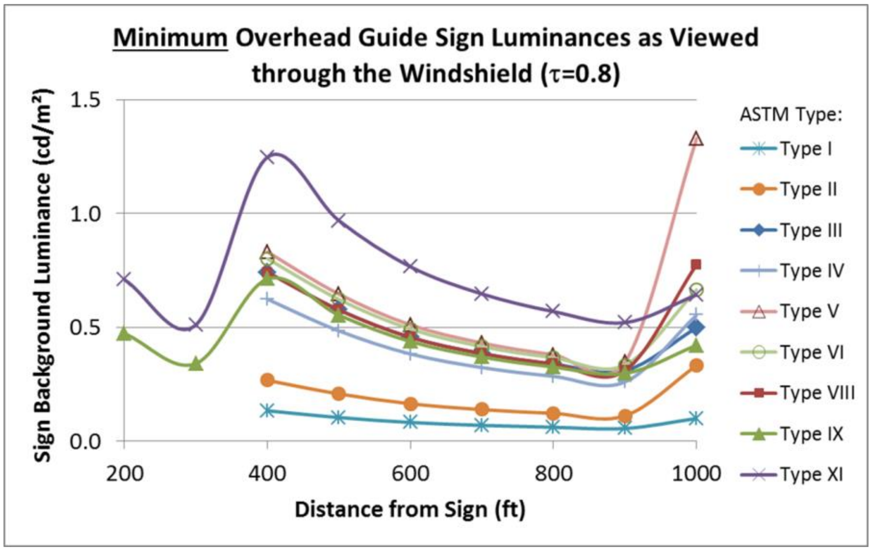


Figure 27. Minimum overhead sign luminance, as a function of distance from the sign, for each of the ASTM (2013) sheeting types.

It can be seen that each of the curves in Figures 26 and 27 are composed of different segments; each segment corresponds to a particular range of observation angles (i.e., less than 1^o but greater than 0.5^o, less than 0.5^o but greater than 0.2^o, and less than 0.2^o). All of the entrance angles are less than 4^o. Some curves (i.e., for ASTM types I and II) do not have values corresponding to distances less than 400 ft; this is because the specified definitions of these types do not include observation angles greater than 0.5^o, and there is therefore no definition of minimum performance.

Of interest, it can be seen from Figure 27 that at the greatest distance investigated (1000 ft), the ASTM type V material has the highest luminance, even though its luminance at shorter distances is not among the highest of the materials. This material is commonly used for delineator applications, where its high luminance at long distances would be beneficial.

It should also be recalled and emphasized that the luminance values in Figures 26 and 27 are *minimum* values based on the limited angles included in the material type specifications. For a particular sheeting material meeting any of these types one would expect the actual luminance for any particular geometry could be substantially higher than shown in these figures. With a full set of measurement data corresponding to angles at much smaller intervals than the tabulated retroreflectivity data published by AASHTO (2010) and ASTM (2013) it would be possible to provide more accurate estimates of the sign luminances for a given geometry. However, the data in these figures represent a floor below which the luminances would not be expected to fall, for each material type.

Minimum Visual Performance

By themselves, the data in Figures 26 and 27 do not indicate whether the information on a sign with those luminances is legible or not. Using the relative visual performance (RVP) model (Rea and Ouellette, 1991), such analyses can be made. It is assumed, based on measurement data from Bullough et al. (2010) for overhead guide signs, that the luminance contrast between the green background and the white letters on the signs is 0.8, and that the letter size of interest is a 16-in. letter height. A driver age of 60 yr is assumed, this being at the upper limit of the RVP model, beyond which systematic changes in the visual system begin to break down and results in substantial variation among individuals.

For sign symbols corresponding to these assumptions, and using the sign luminance values in Figures 26 and 27, Figure 28 shows the resulting RVP values for each of the four AASHTO (2010) sign material types as a function of viewing distance, and Figure 29 shows the same for the ASTM (2013) types.

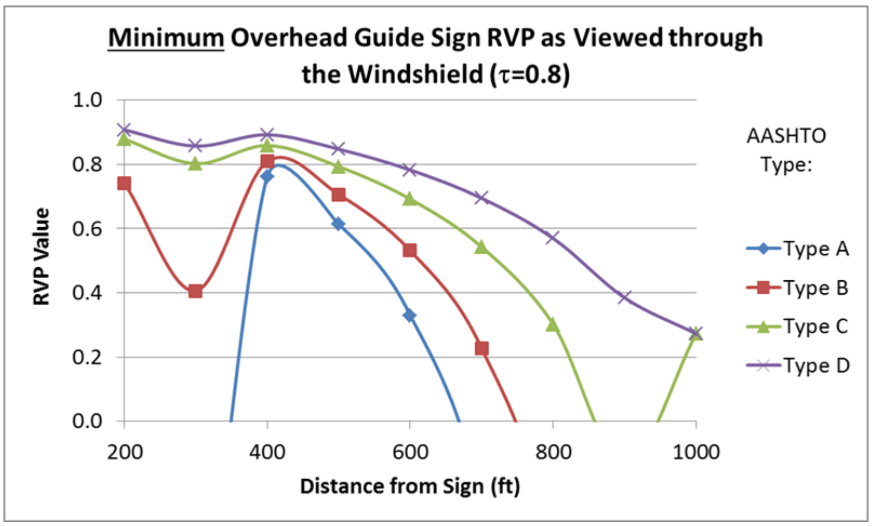


Figure 28. Minimum RVP values corresponding to each AASHTO (2010) sign material type, as a function of viewing distance, for a 60-year-old driver.

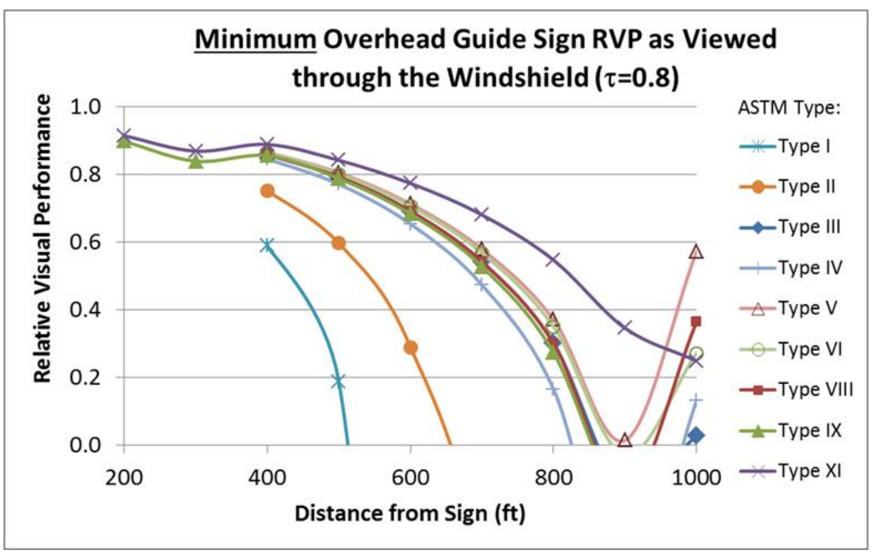


Figure 29. Minimum RVP values corresponding to each ASTM (2013) sign material type, as a function of viewing distance, for a 60-year-old driver.

These curves provide the user with quantitative comparison of the minimum RVP that each material type provides under a particular geometric condition. A subsequent chapter of this report describes a calculation tool for performing similar calculations for different material types, colors, and geometric sign positions including sign tilt, and including different vehicle/driver characteristics (e.g., large trucks, windshield transmittance, and driver age). The usefulness of these curves can be illustrated by comparing the luminance and RVP curves in Figures 26 through 29 with the measured data from the Region 11 field measurements. Figure 30 shows the measured luminances for each measurement session plotted as a function of the distance at which they were measured, alongside the luminance curves for the AASHTO (2010) types, and Figure 31 shows the same alongside the curves for the ASTM (2013) types.

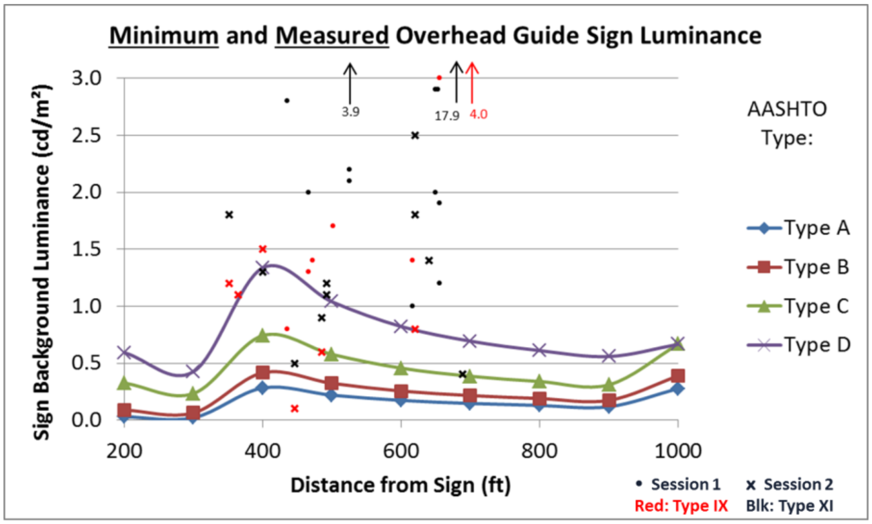


Figure 30. Measured sign luminances for both measurement sessions, plotted as a function of the measurement distance. Also shown are the minimum luminances expected for each AASHTO (2010) sign material type. Different symbol shapes/colors represent different sessions and sheeting materials.

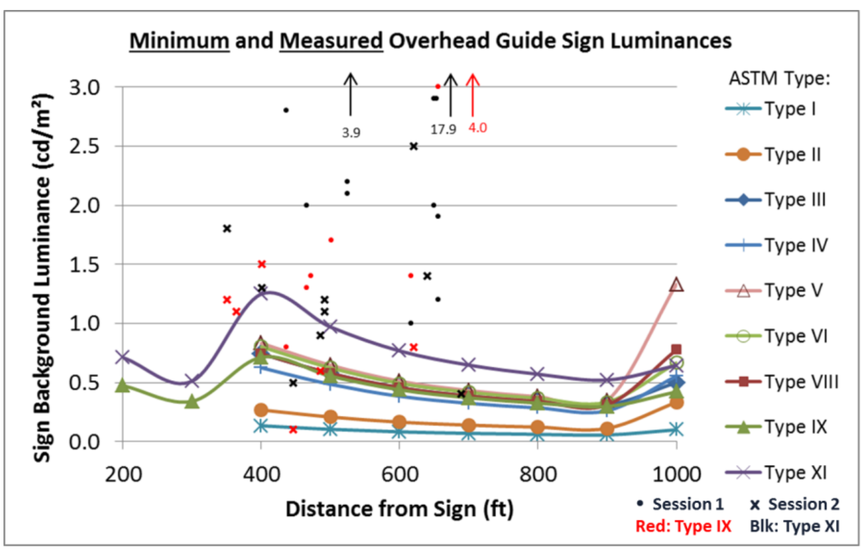


Figure 31. Measured sign luminances for both measurement sessions, plotted as a function of the measurement distance. Also shown are the minimum luminances expected for each ASTM (2013) sign material type. Different symbol shapes/colors represent different sessions and sheeting materials.

It can be seen that most of the luminance measurements in these figures exceed the minimum values expected of most of the sign material types. One sign in the second measurement session had a relatively low luminance (0.1 cd/m²).

Using the RVP model (Rea and Ouellette, 1991), the RVP values corresponding to the visual performance of 16-in. characters on the sign by 60-year-old drivers at the measured distances were calculated. Figure 32 shows the measured RVP alongside the AASHTO (2010) sign material types and Figure 33 shows them alongside the ASTM (2013) types.

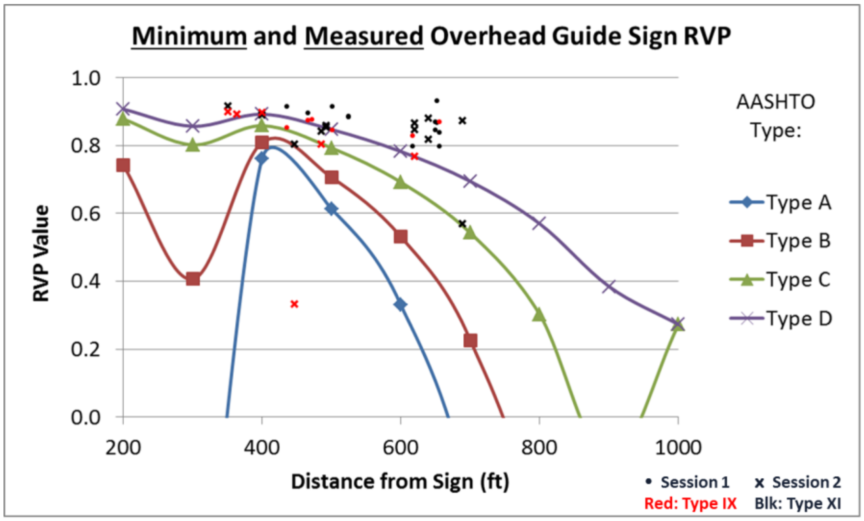


Figure 32. RVP values corresponding to the measured luminances and distances, compared with the minimum RVP values expected for each AASHTO (2010) material type. Different symbol shapes/colors represent different sessions and sheeting materials.

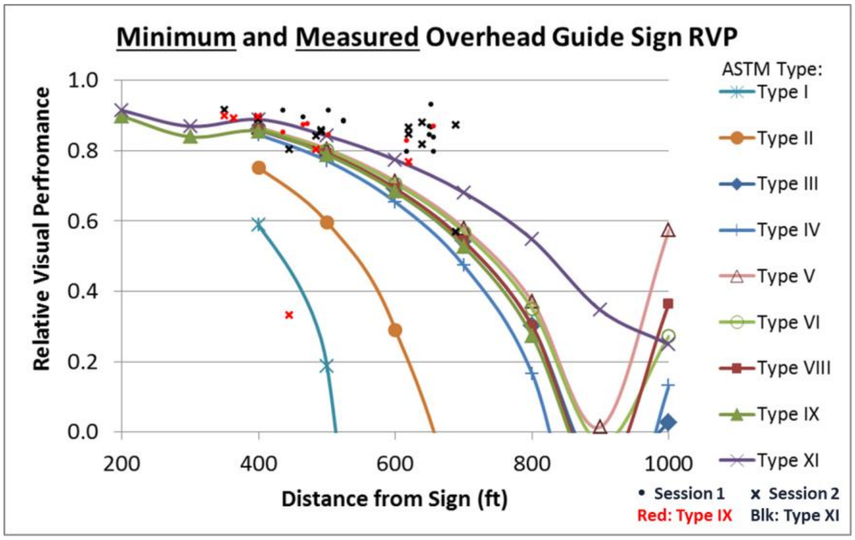


Figure 33. RVP values corresponding to the measured luminances and distances, compared with the minimum RVP values expected for each ASTM (2013) material type. Different symbol shapes/colors represent different sessions and sheeting materials.

The data in Figures 32 and 33 clearly illustrate the plateau nature of RVP (Rea and Ouellette, 1991). Despite a very large variation in measured luminance values shown by the spread of data points in Figures 30 and 31, the RVP data points in the latter two figures are much more tightly packed together. Almost all of them, with the exception of the one sign from the second measurement session with the very low (0.1 cd/m^2) measured luminance, are near or above the curves corresponding to the highest material types (e.g., AASHTO types C and D, and ASTM types XIII, IX and XI). The lowest measured luminance value in the second measurement set could have been extraneous light sources in the scene when the headlights-off measurement was made, or by a slight misorientation of the measurement vehicle away from the signs for this particular measurement (the measured luminance of the sign adjacent to the lowest-luminance sign was also relatively low, 0.5 cd/m^2, which is consistent with a possible difference in vehicle orientation for this pair of measurements).

Notwithstanding this single measurement, which corresponds to less than 3% of the entire number of field measurements made in Region 11 over the project period, the measured data and corresponding RVP analyses confirm that the measured signs meet or exceed the minimum performance requirements for the types of highly reflective sign sheeting materials used in the measurement location.

6. GUIDELINES FOR SPECIFICATION OF RETROREFLECTIVE SIGN PERFORMANCE

Calculation Tool

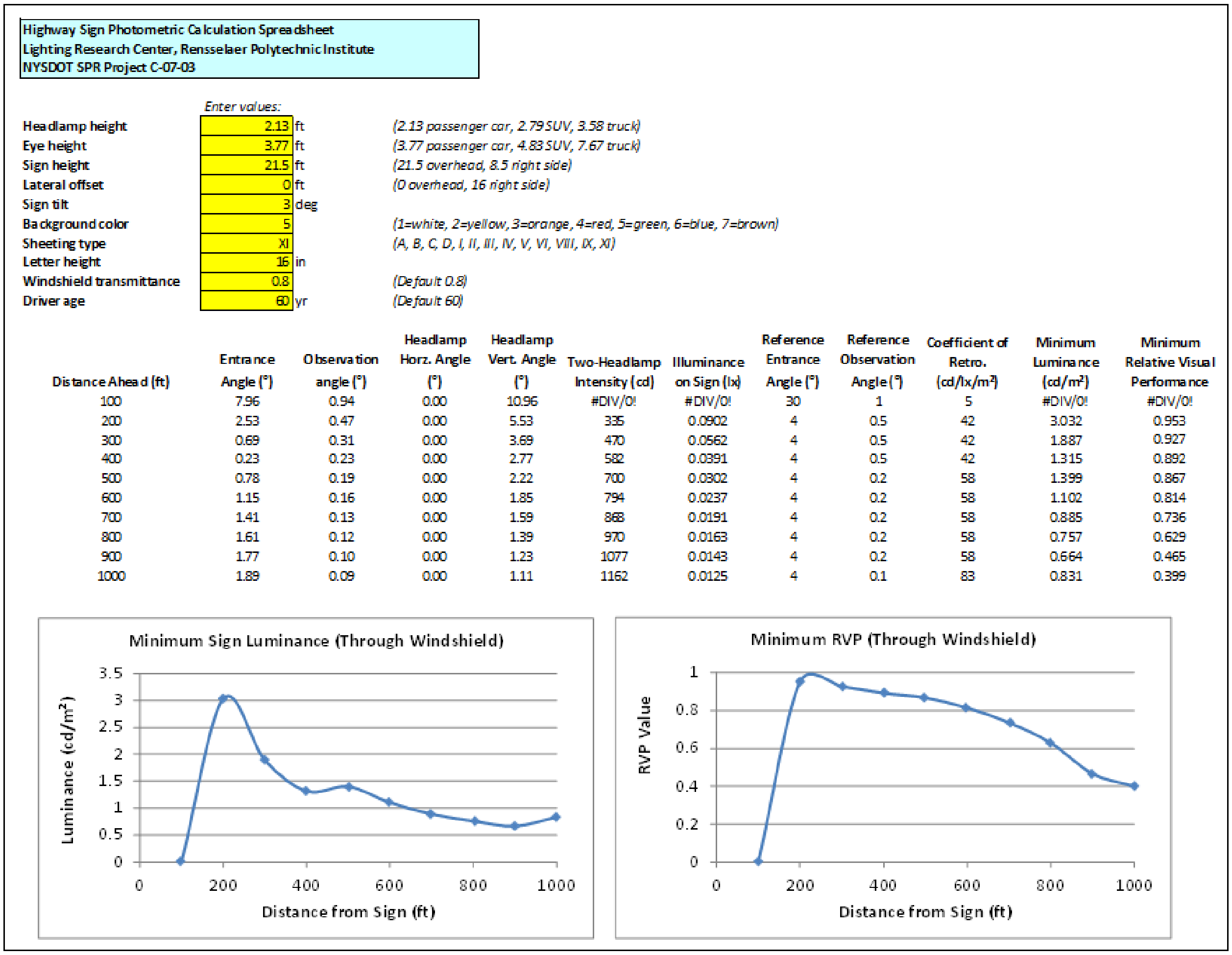
Using the methodology described in the previous chapter to estimate the luminance and visual performance for signs varying in geometry, color, and sign material type, a Microsoft Excel spreadsheet was developed to permit users to specify sign, driver and geometric characteristics.

Using the data provided by the user, the main sheet of the spreadsheet tool provides a summary graph of the sign luminance and of the RVP values associated with the minimum performance specifications for the given material. The user inputs the following information:

- Vehicle headlamp height, in ft
- Driver eye height, in ft
- Sign height, in ft
- Lateral offset of the sign (distance to the right or left of straight ahead – right is positive and left is negative), in ft
- Sign tilt, in degrees
- Background color (white, yellow, orange, red, green, blue or brown)
- Sheeting type (AASHTO type A, B, C or D; or ASTM type I, II, III, IV, V, VI, VIII, IX or XI)
- Letter height, in inches
- Windshield transmittance, a unitless quantity from 0 to 1
- Driver age, in years

Based on the measured data from Bullough et al. (2010) it is assumed that the luminance contrast of the letters against the background is always high (0.8) by design. Default values for common situations (vehicle types, sign locations) are provided. For 100-ft intervals from the sign ranging from 100 to 1000 ft, the spreadsheet displays the entrance and observation angles corresponding to the geometry, the luminous intensity from market-weighted median U.S. low beam headlamps (Schoettle et al., 2004) in the direction of the sign, the coefficient of retroreflection for the geometric configuration (if applicable; some distances might result in angles outside the defined boundaries for some material specifications), and the resulting luminance and RVP curves for these distances. When data are outside the range the spreadsheet returns a blank or "N/A" value.

Individual tabs within the spreadsheet tool contain the interim calculations for interpolating the headlamp intensity for each geometry, for identifying the retroreflection coefficient for each material, color and entrance/observation angles (using a lookup table), and for calculating visibility using the RVP model. Figures 34 and 35 show examples of the main screen for two different sign calculation scenarios, Figure 34 for a green overhead sign viewed by the driver of an SUV, and Figure 35 for a white post-mounted sign on the right side of the highway viewed by the driver of a truck.



Highway Sign Photometric Calculation Spreadsheet
Lighting Research Center, Rensselaer Polytechnic Institute
NYSDOT SPR Project C-07-03

	Enter values:		
Headlamp height	2.13	ft	*(2.13 passenger car, 2.79 SUV, 3.58 truck)*
Eye height	3.77	ft	*(3.77 passenger car, 4.83 SUV, 7.67 truck)*
Sign height	21.5	ft	*(21.5 overhead, 8.5 right side)*
Lateral offset	0	ft	*(0 overhead, 16 right side)*
Sign tilt	3	deg	
Background color	5		*(1=white, 2=yellow, 3=orange, 4=red, 5=green, 6=blue, 7=brown)*
Sheeting type	XI		*(A, B, C, D, I, II, III, IV, V, VI, VIII, IX, XI)*
Letter height	16	in	
Windshield transmittance	0.8		*(Default 0.8)*
Driver age	60	yr	*(Default 60)*

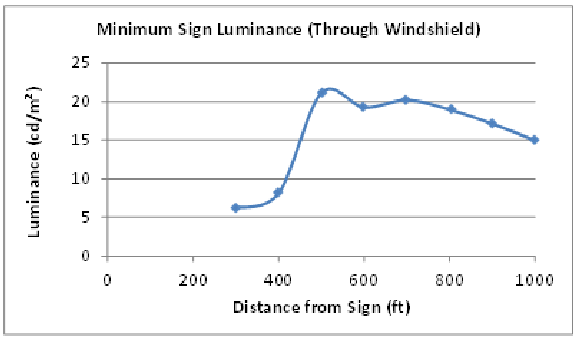
Distance Ahead (ft)	Entrance Angle (°)	Observation angle (°)	Headlamp Horz. Angle (°)	Headlamp Vert. Angle (°)	Two-Headlamp Intensity (cd)	Illuminance on Sign (lx)	Reference Entrance Angle (°)	Reference Observation Angle (°)	Coefficient of Retro. (cd/lx/m²)	Minimum Luminance (cd/m²)	Minimum Relative Visual Performance
100	7.96	0.94	0.00	10.96	#DIV/0!	#DIV/0!	30	1	5	#DIV/0!	#DIV/0!
200	2.53	0.47	0.00	5.53	335	0.0902	4	0.5	42	3.032	0.953
300	0.69	0.31	0.00	3.69	470	0.0562	4	0.5	42	1.887	0.927
400	0.23	0.23	0.00	2.77	582	0.0391	4	0.5	42	1.315	0.892
500	0.78	0.19	0.00	2.22	700	0.0302	4	0.2	58	1.399	0.867
600	1.15	0.16	0.00	1.85	794	0.0237	4	0.2	58	1.102	0.814
700	1.41	0.13	0.00	1.59	868	0.0191	4	0.2	58	0.885	0.736
800	1.61	0.12	0.00	1.39	970	0.0163	4	0.2	58	0.757	0.629
900	1.77	0.10	0.00	1.23	1077	0.0143	4	0.2	58	0.664	0.465
1000	1.89	0.09	0.00	1.11	1162	0.0125	4	0.1	83	0.831	0.399

Figure 34. Main screen of the spreadsheet tool showing calculated luminances and RVP values for a green overhead sign using ASTM type XI material.

Highway Sign Photometric Calculation Spreadsheet
Lighting Research Center, Rensselaer Polytechnic Institute
NYSDOT SPR Project C-07-03

	Enter values:		
Headlamp height	3.58	ft	(2.13 passenger car, 2.79 SUV, 3.58 truck)
Eye height	7.67	ft	(3.77 passenger car, 4.83 SUV, 7.67 truck)
Sign height	8.5	ft	(21.5 overhead, 8.5 right side)
Lateral offset	16	ft	(0 overhead, 16 right side)
Sign tilt	0	deg	
Background color	1		(1=white, 2=yellow, 3=orange, 4=red, 5=green, 6=blue, 7=brown)
Sheeting type	B		(A, B, C, D, I, II, III, IV, V, VI, VIII, IX, XI)
Letter height	12	in	
Windshield transmittance	0.8		(Default 0.8)
Driver age	60	yr	(Default 60)

Distance Ahead (ft)	Entrance Angle (°)	Observation angle (°)	Headlamp Horz. Angle (°)	Headlamp Vert. Angle (°)	Two-Headlamp Intensity (cd)	Illuminance on Sign (lx)	Reference Entrance Angle (°)	Reference Observation Angle (°)	Coefficient of Retro. (cd/lx/m²)	Minimum Luminance (cd/m²)	Minimum Relative Visual Performance
100	2.82	2.34	9.09	2.82	382	0.4109	4		#N/A	#N/A	#N/A
200	1.41	1.17	4.57	1.41	971	0.2612	4		#N/A	#N/A	#N/A
300	0.94	0.78	3.05	0.94	1579	0.1889	4	1	41	6.194	0.943
400	0.70	0.59	2.29	0.70	3681	0.2476	4	1	41	8.122	0.930
500	0.56	0.47	1.83	0.56	4538	0.1954	4	0.5	135	21.102	0.932
600	0.47	0.39	1.53	0.47	5956	0.1781	4	0.5	135	19.232	0.909
700	0.40	0.33	1.31	0.40	8504	0.1868	4	0.5	135	20.175	0.884
800	0.35	0.29	1.15	0.35	10430	0.1754	4	0.5	135	18.945	0.848
900	0.31	0.26	1.02	0.31	11926	0.1585	4	0.5	135	17.116	0.799
1000	0.28	0.23	0.92	0.28	12858	0.1384	4	0.5	135	14.947	0.726



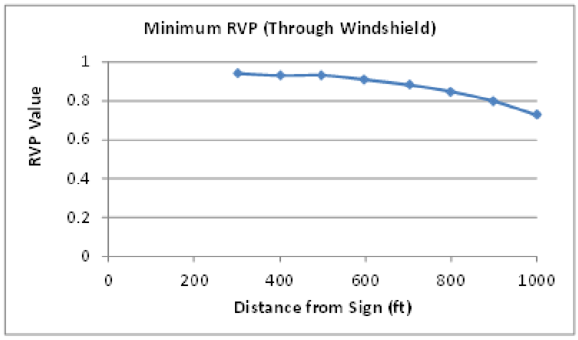


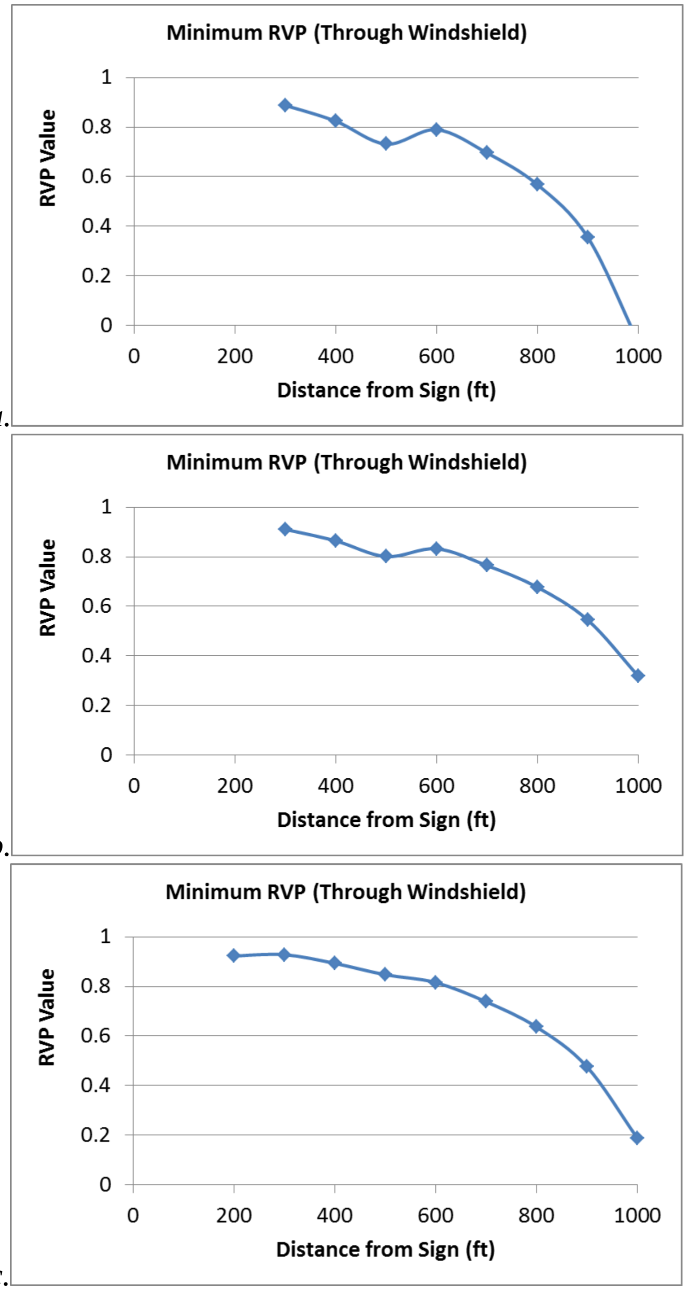
Figure 35. Main screen of the spreadsheet tool showing calculated luminances and RVP values for a white post-mounted sign along the right side of the road, using AASHTO type B material.

The spreadsheet screen is formatted to print the main screen on a single landscape-formatted page to facilitate comparisons among different material types. Users can also view the worksheet tabs for the headlamp intensity interpolation, determining the coefficients of retroreflection and calculating RVP values.

Proposed Specification Procedure

An objective of sign material selection is to ensure high levels of visibility and legibility of the signs, without using materials that might produce excessively high brightness, or luminances much higher than needed for adequate visibility. An RVP level of 0.8 is considered (Rea, 1989) to be one that ensures a high level of visual performance. In multiple studies of nighttime driver visibility, this level of performance has been found to be associated with consistent detection and identification of objects and potential hazards along the roadway (Bullough and Radetsky, 2014).

Carlson et al. (2010) suggest that based on driver eye-movement data, that viewing distances between 320 ft from the sign out to 640 ft from the sign are those at which most sign reading is likely to occur. Given these considerations, a possible performance specification could be to achieve a minimum RVP value of 0.8 for distances from the sign between 320 and 640 ft. Figure 36a shows the RVP profile for a green overhead sign (21.5 ft above the ground with a 3^{o} tilt, with 16-in. characters, as viewed by a 60-year old driver of an SUV) using ASTM type III material; the minimum RVP values drop below 0.8 between 320 and 640 ft. If the ASTM material type is changed to type VIII (Figure 36b) or XI (Figure 36c), the RVP values remain at or above 0.8 between these distances.



a.

b.

c.

Figure 36. RVP values for a green overhead sign at different distances: a. ASTM type III material, b. ASTM type VIII material, c. ASTM type XI material.

For a white, post-mounted sign located along the right side of the road (8.5 ft high and 16 ft to the right of the driver, with no tilt and with 12-in. characters), Figure 37 shows the RVP profiles for three different materials.

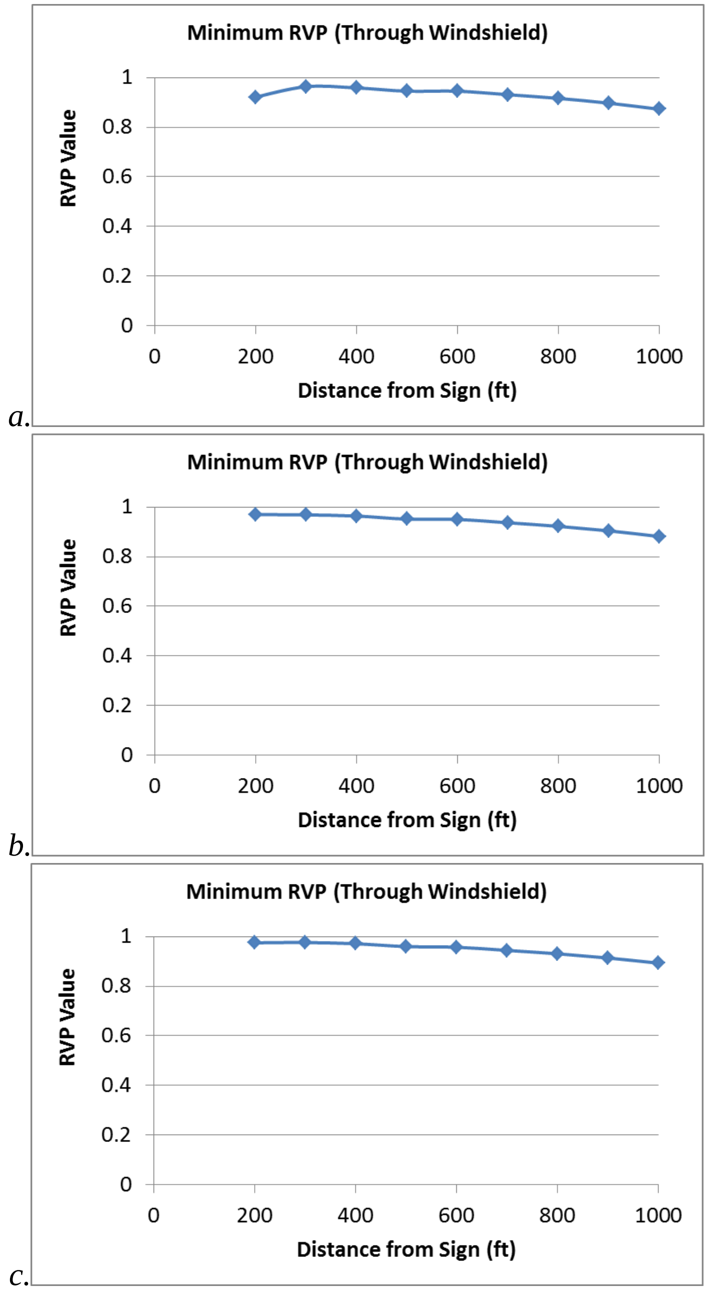


Figure 37. RVP values for a white post-mounted sign at different distances: a. AASHTO type A material, b. AASHTO type B material, c. AASHTO type C material.

It can be seen from Figure 37 that for each of the AASHTO material types A, B or C, the RVP values for all distances including those from 320 to 640 ft from the sign are high and relatively flat. In such a case, there is no meaningful advantage of higher-type material over materials of lower types.

The examples in Figures 36 and 37 show how it can be possible to compare materials and possibly make decisions about the selection of materials based on the minimum levels of performance that might be experienced. However, several caveats must be considered in interpreting these data:

- Based on the set of field measurements from Region 1, actual sign performance in terms of luminance and visual performance is usually higher than estimated from the minimum performance data included in the material specifications.
- Wide variations in road geometry, particularly changes in elevation, can result in actual luminances and RVP values that differ significantly from the values included in the spreadsheet tool calculations. In such conditions, if it is expected that a sign might be viewed well above the headlamp vertical cutoff line or to the far left of the vehicle's heading, the specifier might wish to consider using highly reflective material types or external sign illumination in order to ensure visibility.

Conclusions

The present study describes a series of investigations to identify a process for design that can help to ensure specified levels of performance in terms of a driver's ability to read and identify information on highway signage. The procedure uses published data on headlamp photometric performance in the past decade, and is based on present specifications for sign materials published by AASHTO (2010) and ASTM (2013). It also uses a visual performance model (Rea and Ouellette, 1991) that has been found to be related to visual response and identification times in simulated sign viewing conditions (Goodspeed and Rea, 1999; Schnell et al., 2009; and the human factors study in an earlier chapter of this report) as well as in outdoor field studies of visual object detection and identification (Bullough and Radetsky, 2014).

Human factors research undertaken as part of the present research effort demonstrate that although RVP is an essentially achromatic model that does not take into account differences in color between background and symbol sign elements, only small differences are found between response times predicted by RVP and those observed in human subjects. Further they are only found when the luminance contrast of sign symbols is low, resulting in improved performance that would be predicted by RVP. Therefore, RVP is a conservative estimate of visibility.

The present study also resulted in a useful procedure for conducting field measurements along busy highways at night with a minimum of disruption to traffic. Portable luminance meters like the one used in the Region 11 field measurements yielded consistent and reasonable measurement values based on the results of both sets of measurements, and can distinguish among different sign sheeting types (e.g., between ASTM Type IX and Type XI).

It should also be noted again that the luminances and visual performance values predicted by the spreadsheet calculation tool developed for this project are also conservative in that they are the minimum values expected. In comparison, the field measurements conducted in the present study nearly always show substantially higher luminances than predicted by the calculation procedure that was developed.

7. STATEMENT ON IMPLEMENTATION

The findings from the present project can be used by NYSDOT and other agencies in New York State to compare the photometric and visual performance of different sign materials used for different types of signs. While further field validation is necessary before performance specifications could be implemented using visual performance criteria as a basis for sign performance, the results in this study suggest that such criteria are practical, conservative and can be field-verified using available photometric tools and methods.

8. REFERENCES

AASHTO. 2010. Standard Specification for Retroreflective Sheeting for Flat and Vertical Traffic Control Applications, M 268-10. Washington: AASHTO.

Akagi Y et al. 1996. Influence of visual environments on visibility of traffic signs. Transp Res Rec 1553: 53.

ASTM. 2013. Standard Specification for Retroreflective Sheeting for Traffic Control, D4956-13. West Conshohocken: ASTM.

Bullough JD et al. 2010. Legibility of urban highway guide signs using new retroreflective materials. Transport 25: 229.

Bullough JD, Radetsky LC. 2014. Roadway lighting, relative visual performance and safety. Proc IES An Conf, Pittsburgh.

Bullough JD. 2009. Discussion of "Effect of luminance and text size on information acquisition time from traffic signs" by Schnell et al. Transp Res Rec 2122: 60.

Burns DM, Donahue TJ. 2001. Brightness and color of fluorescent yellow and fluorescent yellow green retroreflective signs: Comparison of laboratory and field measurements. Transp Res Rec 1754: 48.

Carlson PJ et al. 2010. Development of a Model Performance-Based Sign Sheeting Specification Based on the Evaluation of Nighttime Traffic Signs Using Legibility and Eye-Tracker Data. College Station: Texas A&M University.

Eastman AA. 1968. Color contrast versus luminance contrast. Illum Eng 63: 37.

Fontaine MD et al. 2000. Evaluation of Traffic Control Devices for Rural High-Speed Maintenance Work Zones: Second Year Activities and Final Recommendations. College Station: Texas Transportation Institute.

Forbes TW. 1972. Human Factors in Highway Traffic Safety Research. New York: Wiley.

Gates TJ et al. 2004. Field evaluations of warning and regulatory signs with enhanced conspicuity properties. Transp Res Rec 1862: 64.

Goodspeed C, Rea MS. 1999. The significance of surround conditions for roadway signs. J Illum Eng Soc 28: 164.

Gutierrez JA et al.. 2012. Dynamic measurement of traffic sign luminance as perceived by a driver. Lighting Res Technol 44: 350.

Hummer JE, Scheffler CR. 1999. Driver performance comparison of fluorescent orange to standard orange work zone traffic signs. Transp Res Rec 1657: 55.

Neale VL et al. 1999. Evaluation of unassigned sign colors for incident management trailblazing. Transp Res Rec 1692: 17.

Olson PL. 1988. Minimum Requirements for Adequate Nighttime Conspicuity of Highway Signs, UMTRI-88-8. Ann Arbor: University of Michigan.

Ré JM et al. 2011. analysis of in-service traffic sign retroreflectivity and deterioration rates in Texas. Transp Res Rec 2258: 88.

Rea MS, Jeffrey I. 1990. A new luminance and image analysis system for lighting and vision: I. Equipment and calibration. J Illum Eng Soc 19: 64.

Rea MS, Ouellette MJ. 1991. Relative visual performance: A basis for application. Lighting Res Technol 23: 133.

Schieber F, Goodspeed CH. 1997. Nighttime conspicuity of highway signs as a function of sign brightness, background complexity and age of observer. Proc Hum Fact Ergon Soc, p. 1362.

Schnell T et al. 2001. Legibility distances of fluorescent traffic signs and their normal color counterparts. Transp Res Rec 1754: 31.

Schnell T et al. 2009. Effect of luminance and text size on information acquisition time from traffic signs. Transp Res Rec 2122: 50.

Schoettle B et al. 2004. A Market-Weighted Description of Low-Beam Headlighting Patterns in the U.S.: 2004. Ann Arbor: University of Michigan.

Scialfa CT et al. 1999. Traffic sign conspicuity: The effects of clutter, luminance and age. Proc Hum Fact Ergon Soc, p. 108.

Simon L et al. 2007. A new paradign for the computation of conspicuity of traffic signs in road images. Proc CIE, p. D4-38.

Skinner NP et al. Survey of the present state of headlamp aim. TRB 89th Ann Mtg, Washington.

Takemoto A et al. 2008. Improving the nighttime visibility of signs and workers in road work zones in Japan. TRB Ann Mtg, Washington.

Zwahlen HT, Schnell T. 1997. Visual detection and recognition of fluorescent color targets versus nonfluorescent color targets as a function of peripheral viewing angle and target size. Transp Res Rec 1605: 28.

APPENDIX: RELATIVE VISUAL PERFORMANCE CALCULATION

This appendix provides the calculation methods for assessing the relative visual performance (RVP; Rea and Ouellette, 1991) of a target (e.g., a sign character) with a particular background luminance (L_b, in cd/m²), luminance contrast (C) and size (S, in steradians), for an observer of a particular age (A, in years):

Calculate the pupil radius P (in mm):

$$P = 2.39 - 1.22 \tanh(0.3 \log L_b)$$

Calculate the age-corrected retinal illuminance E_r [in trolands (Td)]:

$$E_r = \pi P^2 L_b[1 - 0.017(A - 20)]$$

Calculate five intermediate values x_1, x_2, x_3, x_4 and x_5:

$$x_1 = \log[\tanh(20{,}000\ S)]$$
$$x_2 = \log[\log(10\ E_r/\pi)]$$
$$x_3 = 1 + [0.0025(A - 20)]$$
$$x_4 = \log[\tanh(5000\ S)]$$
$$x_5 = \log[\tanh(0.04\ E_r/\pi)]$$

Calculate the threshold luminance contrast C_t (a dimensionless quantity):

$$C_t = x_3\ 10^{(-1.36 - 0.18x_1 - 0.81x_2 + 0.23x_1^2 - 0.077x_2^2 + 0.17x_1x_2)}$$

Calculate the half-saturation constant K:

$$K = 10^{(-1.76 - 0.18x_4 - 0.031x_5 + 0.11x_4^2 + 0.17x_5^2 + 0.062x_4x_5)}$$

Calculate the maximum response R_{max}:

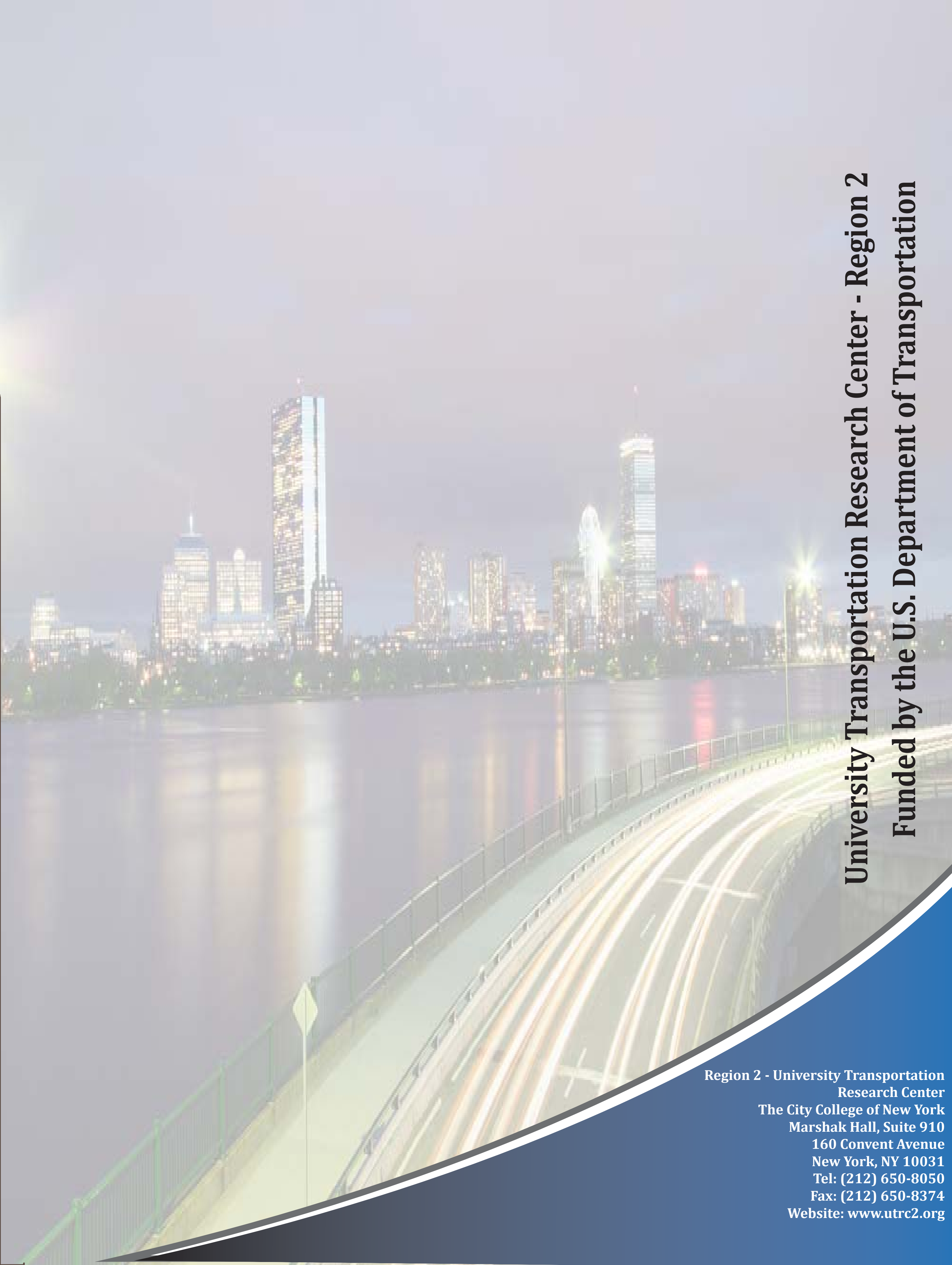
$$R_{max} = 0.0002 \log(E_r) + 0.0027$$

Calculate the visual response time V (in ms):

$$V = [(C - C_t)^{0.97} + K^{0.97}]/[(C - C_t)^{0.97}\ R_{max}]$$

Calculate the relative visual performance (RVP):

$$RVP = 1.42 - V/778.56$$



University Transportation Research Center - Region 2
Funded by the U.S. Department of Transportation

Region 2 - University Transportation
Research Center
The City College of New York
Marshak Hall, Suite 910
160 Convent Avenue
New York, NY 10031
Tel: (212) 650-8050
Fax: (212) 650-8374
Website: www.utrc2.org