Final Report

UPDATED MINIMUM RETROREFLECTIVITY LEVELS FOR TRAFFIC SIGNS

June 2003

Foreword

Report FHWA-RD-03-081 presents the results of a study that updated the minimum levels of traffic sign retroreflectivity for regulatory, guide, and warning signs which had been generated in 1993. The research team identified the need to update the basic input parameters for headlight illumination patterns and intensity, the effects of larger vehicles in the and the associated changes in driver eye height and headlight positions, the new legibility requirements of the MUTCD, the needs of older drivers, and the performance features of new sign materials. A new analysis tool was developed that computed retroreflectivity needs considering the relative illumination provided by each headlight for traffic signs in various positions (right-side, left-side, and overhead) relative to the roadway. Detailed tables of minimum levels of traffic sign retroreflectivity were produced to allow analysis of the sensitivity of factors such as speed, driver accommodation levels, the features of available materials, sign legend, and other factors. The detailed tables were subsequently collapsed to address AASHTO concerns about the requirements being too complicated. The end result of these efforts was that the three tables from the 1993 research and the three tables from the recent research on overhead guide and street names signs were collapsed into a single table. This single table is described in this report.

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Director, Office of Safety R&D

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16. Abstract

The development of minimum retroreflectivity (MR) levels for traffic signs has been going on for more than two decades, but it was significantly accelerated in 1984 when the Center for Auto Safety petitioned the Federal Highway Administration (FHWA) to establish retroreflectivity standards. During the past decade, several sets of recommended MR levels for traffic signs have been proposed. However, these preliminary recommendations have been based on a headlamp-beam pattern that represents vehicle design from the mid- to late-1980s. Vehicle headlamps have changed significantly since then. Other significant changes also have prompted the need to update the recommended MR levels for traffic signs before FHWA initiates the rule-making process.

This report includes an updated set of recommended MR levels for traffic signs based on recent developments in vehicle headlamps, vehicle types/sizes, nighttime driver needs, and newer sheeting materials. The updated MR levels are also based on more robust computer modeling of retroreflective sheeting performance.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: volumes greater than 1000 L shall be shown in m^3			
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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SUMMARY

The development of minimum levels of retroreflectivity (end-of-service-life values) for traffic signs is one of the latest steps in the evolution of providing a safe and efficient road transportation system. The progression of this concept in the United States was significantly accelerated in 1984 when the Center for Auto Safety petitioned the Federal Highway Administration (FHWA) to establish retroreflectivity standards for signs and markings.(1) In 1993, Congress required the Secretary of Transportation to revise the *Manual on Uniform Traffic Control Devices* (MUTCD) to include "a standard for a minimum level of retroreflectivity that must be maintained for pavement markings and signs that apply to all roads open to public travel."(2) In 2000, when FHWA revised the MUTCD, a new section (Section 2A.09) was introduced in Part 2, which stands as a placeholder for minimum retroreflectivity (MR) standards for traffic signs.(3)

MR levels help increase nighttime safety because they are a measurable surrogate for providing and maintaining adequate nighttime visibility. MR levels account for such factors as vehicle type, headlamp design, drivers' visual capabilities, roadway type, traffic speed, and the necessary maneuver as dictated by a sign message.

For at least the past two decades, FHWA has been working toward the development of MR levels for traffic signs.(4-8) Recommended MR levels for warning, regulatory, and guide signs were first published in 1993; they were revised in 1998, and then expanded to include overhead guide signs and street-name signs in 2001.(9-13) The development of these previously recommended levels has been based on a headlamp-beam pattern that represents vehicle designs from the mid- to late-1980s. Vehicle headlamps have changed significantly since then. There have also been other significant changes that have prompted the need to update the MR levels for traffic signs before FHWA initiates rule making.

This report includes an updated set of MR levels for traffic signs based on recent developments in vehicle headlamps, vehicle types/sizes, drivers' nighttime needs, and newer sheeting materials. The updated MR levels are also based on more robust computer modeling of retroreflective sheeting performance. The MR levels presented in table 1 represent the result of these updates and the results of various decisions made regarding American Association of State Highway and Transportation Officials' (AASHTO's) policy resolution on MR levels (appendix A). The MR levels presented in table 1 also represent the input from the participants of the four national MR workshops.(14) Although the levels presented in table 1 are subject to change, they represent the most current research recommendations.

Table 1. Research Recommendations for Updated MR Levels

Sign Color	Criteria	Sheeting Type (American Society for Testing and Materials (ASTM) D4956-01a)					
		I	II	III	VII	VIII	IX
White on Red	See Note Î	35 * 7					
Black on Orange or Yellow	See Note Ï	(	50				
	See Note Ð	(	75				
Black on White		50					
White on Green	Overhead	(* 7	(* 15	(* 25	250 * 25		
	Shoulder	(* 7	120 * 15				

NOTE: Levels in cells represent legend retroreflectivity * background retroreflectivity (for positive contrast signs). Units are $cd/lx/m^2$ measured at an observation angle of 0.2E and an entrance angle of -4.0E.
Î Minimum Contrast Ratio $ 3:1 (white retroreflectivity ÷ red retroreflectivity).
Ï For all bold symbol signs and text signs measuring 48 inches or more.
Ð For all fine symbol signs and text signs measuring less than 48 inches.
(Sheeting Type should not be used.

Bold Symbol Signs

- W1-1 – Turn
- W1-2 – Curve
- W1-3 – Reverse Turn
- W1-4 – Reverse Curve
- W1-5 – Winding Road
- W1-6 – Large Arrow (One direction)
- W1-7 – Large Arrow (Two directions)
- W1-8 – Chevron
- W1-9 – Turn & Advisory Speed
- W1-10 – Horizontal Alignment & Intersection
- W2-1 – Cross Road
- W2-2, W2-3 – Side Road
- W2-4 – T Intersection
- W2-5 – Y Intersection
- W2-6 – Circular Intersection
- W3-1a – STOP Ahead
- W3-2a – Yield Ahead
- W3-3 – Signal Ahead
- W4-3 – Added Lane
- W6-1 – Divided Highway Begins
- W6-2 – Divided Highway Ends
- W6-3 – Two-Way Traffic
- W10-1, -2, -3, -4 – Highway-Railroad Intersection Advance Warning
- W11-2 – Pedestrian Crossing
- W11-3 – Deer Crossing
- W11-4 – Cattle Crossing
- W11-5 – Farm Equipment
- W11-5p, -6p, -7p – Pointing Arrow Plaques
- W11-8 – Fire Station
- W11-10 – Truck Crossing
- W12-1 – Double Arrow

All symbol signs not listed in the bold category are considered fine symbol signs.

Special Case Signs

- W3-1a – Stop Ahead
- Red retroreflectivity $ 7, White retroreflectivity $ 35
- W3-2a – Yield Ahead
- Red retroreflectivity $ 7, White retroreflectivity $ 35
- W3-3 – Signal Ahead
- Red retroreflectivity $ 7, Green retroreflectivity $ 7
- W14-3 – No Passing Zone, W4-4p – Cross Traffic Does Not Stop, or
- W13-2, -3, -1, -5 – Ramp & Curve Speed Advisory Plaques
- Use largest dimension

CHAPTER 1. INTRODUCTION

The purpose of traffic control devices, as well as the principles for their use, is to promote highway safety and efficiency by providing for the orderly movement of all road users on streets and highways. Traffic control devices, which include traffic signs, pavement markings, and traffic signals, notify road users of regulations and provide warning and guidance needed for the safe, uniform, and efficient operation of all elements of the traffic stream. Arguably, traffic signs make up the most effective category of traffic control devices.

Traffic signs use many techniques to inform drivers: for example color, shape, and location. However, there is little doubt that to be effective traffic signs must be visible. The MUTCD establishes guidelines for traffic-control devices in the United States, including traffic signs.[3] Portions of Parts 1 and 2 of the most recent version of the MUTCD address traffic sign visibility. Sign retroreflectivity is specifically addressed in Section 2A.08, which states that, *"Regulatory, warning, and guide signs shall be retroreflective or illuminated to show the same shape and similar color by both day and night, unless specifically stated otherwise in the text discussion in this Manual of a particular sign or group of sign*s."[3] It is important to note that at least some form of retroreflectivity has been required for traffic signs since the first version of the MUTCD, published in 1935. It is just as important to note that no minimum criteria have ever been established in the MUTCD for maintenance purposes. However, in publishing the 2000 MUTCD, FHWA added Section 2A.09 to reserve a section for future guidelines on MR levels.

Sign retroreflectivity is a property of the sheeting material, which redirects incident light back toward the source. Sign retroreflectivity cannot be seen or observed, but when combined with a light source (such as a vehicle headlamp), the results of sign retroreflectivity can be seen during nighttime conditions as the appearance of brightness, or more specifically, luminance, which can be measured.

Visibility research is usually reported in terms of luminance and from a theoretical perspective; luminance is the most important metric of nighttime sign visibility. In other words, the relative brightness of a specific sign is what really matters, not the features or properties of the sign (such as the crashworthiness or the substrate material, or even the retroreflectivity of the sheeting material). However, when it comes to the luminance of a retroreflective sign at night, luminance becomes a function of the viewing geometry, the retroreflective sheeting performance, and the light source. Unfortunately, traffic sign luminance is nearly impossible to accurately measure without closing a roadway to traffic, and even then the measurement is time consuming and impractical. For many reasons, researchers have had difficulty pinpointing a precise level of luminance needed to accommodate a given proportion of nighttime drivers. Therefore, until technology can provide a means of measuring luminance more efficiently or a new type of sign material is introduced that relies on something other than retroreflectivity to provide nighttime visibility, the measurement of retroreflectivity is the most practical metric to assess for providing and maintaining nighttime traffic sign visibility.

BACKGROUND

The initial set of MR levels was published in 1993 and derived from a theoretical computer model called Computer Analysis of Retroreflectance of Traffic Signs (CARTS).[9] CARTS comprises several submodels that work in series to determine retroreflectivity needs based on user-selected inputs. The first submodel determines the minimum distance at which a sign must be legible in order for a motorist to respond appropriately and safely. This distance is termed the Minimum Required Visibility Distance (MRVD), and is the sum of distances associated with the following factors: detecting the sign, recognizing or reading the sign, deciding on the appropriate action, initiating the response, and completing the required maneuver (depending on the sign message, the latter factors may not be needed).

Using the computed MRVD value, the next submodel estimates the threshold legibility luminance needed for the sign. The heart and soul of this submodel is a visibility model called PCDETECT.[15] PCDETECT is based on data from the classical Blackwell experiments of the 1940s where subjects were tasked with the identification of circular targets against uniform backgrounds.[16] The last submodel takes the MRVD and estimated threshold legibility luminance and back-calculates the retroreflectivity needed at the standard measurement geometry of 0.2 and -4.0 degrees for the observation and entrance angles, respectively.[17]

Because of the infinite number of possible scenarios in terms of the combination of sign types, sign locations, driver needs, headlamp performance variations, and the like, several scenarios were selected to represent typical or design conditions. For instance, the driver was assumed to be 47 years old and the dimensions of the vehicle approximated a large passenger sedan. The assumed headlamp was a composite headlamp representing the median value of 26 headlamps from passenger cars ranging from model year 1985 to 1990.

The results of this initial work were summarized in four tables of MR levels, distinguished by the color of sign: a table for white signs, one for yellow and orange signs, one for green signs, and one for red signs. Depending on which of the four tables was considered, the MR levels also depended on at least some of the following factors: roadway speed, sign size, type of retroreflective sheeting, sign location for green signs, and type of legend (symbol versus text). There was also a minimum contrast ratio of 4:1 required for white-on-red and white-on-green signs. Because this research was conducted in the early 1990s, the only types of microprismatic sheeting included in the recommendations were ASTM Types IV and VII (but Type IV is no longer made).

After the 1993 values were published, the developers of CARTS received many comments indicating that the modeling was incorrect in that it assumed one headlamp with the driver directly above the headlamp (also called cyclops modeling). In reality, this modeling represents a motorcycle rather than a four-wheeled vehicle. Because of retroreflective sheeting materials' sensitivity to observation angle, a cyclops modeling assumption can produce significantly different values than a model with the proper positioning of the headlamps in respect to the driver's eye. In July 1994, the developers of CARTS provided a refined version that accounted for the effect of two headlamps on observation angle.[18]

Shortly thereafter, FHWA sponsored two research projects to determine the adequacy of the initial minimum in-service retroreflectivity values.(19,20) During the same period, FHWA sponsored three national workshops to solicit input on the initial minimum in-service retroreflectivity values for signs. In 1998, McGee and colleagues authored two related reports, one addressing various implementation strategies for transportation agencies and another investigating the impacts of the recommended values on transportation agencies. (11,12) These reports also included revised minimum in-service retroreflectivity values. McGee and Paniati listed the following reasons for revising the minimum in-service retroreflectivity values: (11)

- The results from research that utilized a human factors and mathematical modeling approach to consider the range of visual, cognitive, and psychomotor capabilities of the driving population and the complexity of the relationships among the driver, the vehicle, the roadway environment, and the sign (in other words, the second version of CARTS).
- The results of human factors research to evaluate the percent of drivers that would be accommodated by signs with varying levels of retroreflectivity (in other words, the Mercier et al. research).(18,19)
- The results from measurements made on more than 20,000 in-service signs in the 50 States and many local jurisdictions (data from three different reports).(12,21,22)
- Input received from the more than 40 State and local jurisdictions represented at the 1995 regional workshops in Baltimore, MD, Kansas City, MO, and Denver, CO.
- Input from public agency and private industry representatives received at numerous presentations given at such forums as the Transportation Research Board (TRB) Annual Meeting, the Institute of Transportation Engineers Annual Meeting, the American Traffic Safety Services Annual Meeting, the TRB Visibility Symposium, and State-sponsored safety and traffic engineering workshops.

The revisions in 1998 resulted in several changes, the most evident being the removal of all MR levels for overhead signs because of many unresolved issues with vehicle headlamp performance specification and the difficulty in measuring overhead sign retroreflectivity.(11) The MR levels for red, yellow, and orange signs were slightly reduced. Most MR levels for white signs were reduced, but a few were raised. The MR levels for ground-mounted green signs, which did not include street-name signs, stayed the same.

In March 1997, the National Highway Traffic Safety Administration (NHTSA) implemented a final rule that revised *FMVSS 108* to address the issue of headlamp misaim, which was believed to be a significant factor related to the amount of glare and the variability of headlamp luminous intensity directed toward overhead signs. The rule reflects the consensus of the negotiated rule making concerning the improvement of headlamp aimability performance and visual/optical headlamp aiming.

The new rule established improved headlamp aiming features that provide more reliable and accurate aiming, and help vehicle operators to more easily determine the need for correcting aim. The rule introduced Visually/Optically Aimed (VOA) headlamps to the United States. The term "VOA" generically describes two types of visually/optically aimed headlamps: VOL and VOR. The VOL headlamp is a low beam with a horizontal cutoff to the **L**eft side of the beam. The VOR is a low beam with a horizontal cutoff to the **R**ight side of the beam. VOL headlamps can reduce glare to oncoming drivers compared to conventional U.S. low beams. VOR headlamps have less ability to reduce oncoming glare but produce luminous intensity distributions more similar to conventional U.S. low beams.

As a result of NHTSA's revision to *FMVSS 108* in 1997, FHWA sponsored a research project focused on the development of MR values for overhead signs. To complete the initial set of MR recommendations, FHWA also included MR levels for street-name signs in the scope of the project.

Researchers at Texas Transportation Institute (TTI) were awarded the research contract, which was completed in early 2001. The research included the development of an analytical process to determine MR levels from a host of factors including demand luminance. To determine the adequate demand luminance values, researchers performed a legibility study with full-scale guide signs and street-name signs. Special emphasis was devoted to accommodating older drivers. The results of the study were used to determine a set of MR levels for overhead and street-name signs.(13)

Besides providing recommendations for MR levels for overhead and street-name signs, the researchers also performed sensitivity analyses to determine the relative impact of factors such as the assumed design driver capabilities, the headlamp type, and the vehicle type. This research identified a need to update some key assumptions of the initial 1993 and revised 1998 MR levels. In addition, there was a need to develop MR levels for the various types of retroreflective sheeting introduced after the earlier work was completed.

Validation Efforts

At least seven studies have been either completely or partially focused on determining the adequacy of the initial 1993 and/or the revised 1998 minimum in-service retroreflectivity levels. These studies are summarized below.

The first review of the minimum values came from Mercier et al. in 1995.(18,19) In this study, the researchers concluded that 85 percent or more of all drivers would be accommodated by the initial 1993 levels for nearly all signs tested. They also concluded that the 1993 MR levels were fairly conservative, allowing a margin for safety.

However, it is important to note that the study did not specifically evaluate the retroreflectivity levels or the CARTS modeling techniques. Rather, it focused on a static laboratory study that resulted in the determination of luminance thresholds needed to read or recognize 25 different signs (comprising a mix of sign types (symbol and text warning signs, regulatory signs, and guide signs) and sign sizes). The ambient light conditions were approximately 0.01 to 0.1 cd/m^2, which represents typical rural environments.

Using a 50-percent scale, the researchers simulated CARTS' MRVD for each of the 25 signs (which were also scaled to 50 percent). For each sign, the researchers systematically increased the sign luminance until subjects were able to correctly read or recognize the sign.

Scatter plots included the luminance thresholds by subject's age. The minimum luminance (ML) from CARTS was then superimposed on the scatter plots. Figure 1 shows an example of the reported findings for one specific sign. (All data from Mercier et al. are shown in appendix B.)

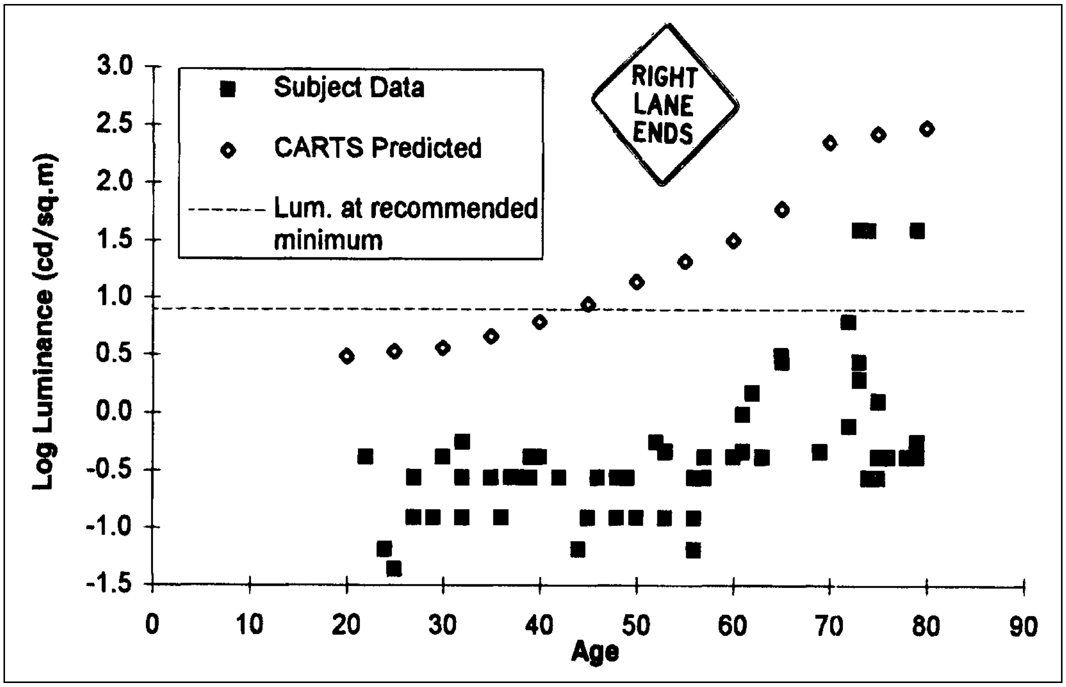


Figure 1. Minimum Luminance Data for Warning Signs [18]

Figure 1 indicates that the ML levels from CARTS are substantially higher than the study findings, which means that the MR values generated from the CARTS ML levels should be higher than what is actually needed. It is important to emphasize that the researchers' conclusions stating that the MR levels are fairly conservative is based on luminance threshold data and *not* retroreflectivity values.

Also in 1995, Zwahlen published possibly one of the only documented criticisms of the CARTS modeling technique.[23] Zwahlen argues that the theoretical approach of using the MRVD concept to determine the distance at which signs need to be read or recognized does not correlate well with distances associated with actual driver performance as measured by first and last look glances. Zwahlen concludes that the MRVD values for bold warning signs (which were the only types of signs he tested) are on the order of 30 to more than 150 feet too short. In contrast, Zwahlen's recommended approach is to provide drivers a 3-second preview distance plus the time needed to absorb the information on the sign.[23] Unfortunately, the 3-second preview criterion is not strongly supported with data or a tie to safety. The reported source of the 3-second preview criterion is reports from the International Commission on Illumination (CIE); these also provide little justification for the criterion of 3 seconds.[24] Using his time-dependent approach, Zwahlen developed recommended MR levels for pavement markings using a preview time of 3.65 seconds.[25]

In 2001, a long-awaited report documenting a follow-up study to the Mercier et al. study was finally published.[20] This laboratory study was conducted to determine the adequacy of the initial 1993 MR values in situations of varying visual complexity and environmental illumination (because the retroreflectivity values were developed for a dark environment with a medium-complexity background). Subjects completed a target search-and-recognition task on a set of 11 traffic signs presented at four different background complexities and three different luminance levels, including luminance levels produced by CARTS and used to generate the initial 1993 guidelines. A recognition response frequency of 90.3 percent (across all treatments) at the CARTS luminance levels was enough for the researchers to conclude that the 1993 guidelines were adequate for the general driving public.

While both of these validation studies concluded that the initial 1993 values were adequate, both used the CARTS luminance values as their benchmark and compared measured luminance at threshold conditions. Consequently, both validation studies assumed that CARTS' calculation from luminance to retroreflectivity at the standard measurement geometries were correct. Instead, these studies only validated that the threshold legibility luminance values produced by CARTS adequately accommodated nighttime motorists. They did not validate the MR values.

Another examination of the MR levels was published in 2001 by Hawkins and Carlson.[26] In this study, State Department of Transportation (DOT) maintenance personnel subjectively evaluated the nighttime adequacy of 49 different roadside signs in a controlled environment with no distracting traffic or fixed lighting. The subjective results were compared to the signs' measured retroreflectivity levels. The findings showed that while only one sign failed to meet the revised 1998 levels, the maintenance personnel rejected more than half of the signs (26 of 49). However, the study also showed that factors other than retroreflectivity were associated with maintenance personnels' opinions regarding the signs' adequacy (including uniformity of the sign face and sheeting type). The research concluded that the revised 1998 levels were lower than Texas DOT's (TxDOT) maintenance personnels' subjective opinions.

Three additional research studies have assessed the reliability of subjective nighttime visual inspections.[6,27,28] This report also includes a new evaluation of subjective sign ratings as a function of retroreflectivity. These new data will be discussed and presented in a later section of this report.

Mace et al. had knowledgeable subjects (traffic engineers, township managers, a retroreflective sheeting sales representative, and highway researchers) drive a test route, evaluate signs, and decide whether the signs needed to be replaced.[6] The results were compared to various strategies being considered for flagging signs to be replaced using a sign-management program. The researchers concluded that considering all factors that might be influential in judging the need for sign replacement, the relationship between the subjective ratings and the strategy that depended on retroreflectivity levels was reasonable.

The main objective of Lagergran's research was to assess the accuracy of using human observers to evaluate traffic sign retroreflectivity.[27] Observers were trained to rate warning and STOP sign retroreflectivity. After training, the observers evaluated signs on two highway courses. The observer sign ratings and the sign rating calculated using a retroreflectometer were incorporated into a decision model to replace or not replace a sign based on the sign condition and environment. The individual observers made correct decisions on 74 percent of the warning signs and 75 percent of the STOP signs.

More subjective evaluations were reported by Ziskind et al. in 1991.[28] The objective of this effort was to validate the CARTS modeling of sign legibility and recognition distances. Subjects in a moving vehicle reported when they could recognize and then read traffic signs of varying retroreflectivity levels. The findings show good correlation to the results of the CARTS legibility and recognition distances, which contrasts Zwahlen's arguments summarized above.

IDENTIFYING THE NEEDS FOR AN UPDATE

The studies summarized above provide reasonable support for the MR concept, but they do not fully support the MR levels recommended in the 1990s. Furthermore, there have been at least three responses to FHWA regarding the technical validity of the MR levels recommended in the 1990s.[23,29,30] The 1990s saw significant changes that affect the criteria used to establish MR levels. For instance, some of the more noticeable changes have been vehicle headlamp design (which has affected the distribution of light) and vehicle type (which has affected the inherent observation angle associated with sign viewing geometrics). By today's standards, all three sets of recommended MR levels have been based on an outdated headlamp and an outdated vehicle type.[9,11,13] Furthermore, the 1993 and 1998 recommendations were based on crude retroreflectivity performance curves and did not include or have a way to evaluate and determine MR levels for new sheeting products. These early efforts were also based on assumptions that represented a 47-year-old driver.

Because of these demonstrated limitations, in March 2002, an effort was initiated to provide updated MR levels based on new research related to factors such as the assumed design driver capabilities, the headlamp type, and the vehicle type. It should be noted that this effort did not include additional research related to determining demand luminance levels for various signs or other issues related to visual or human factors demands. Rather, the work was focused on the synthesis of current information such as headlamp candela profiles, vehicle sales information, and luminance demand literature.

In July 2002, preliminary recommended MR levels were developed and submitted to FHWA.[31] The recommended MR levels were based on the findings from early tasks, including an investigation of new headlamps, updated vehicle dimensions representing the most recent trends in vehicle sales in the United States, more robust techniques to model retroreflectivity performance, and assumptions that included older drivers. The preliminary minimum levels were also derived using a minimum demand luminance of 1.0 cd/m^2 and a driver accommodation level that represented the 50^{th} percentile performance level of drivers aged 55 and older. Four separate tables were provided that were based on the sign color: one for white-on-red signs, one for yellow and orange signs, one for white-on-green signs, and one for white signs.

Since then, the research team has met with and discussed the preliminary recommendations with FHWA's Retroreflectivity Technical Working Group. Special emphasis has been focused on consolidating the preliminary recommendations into a simple and unambiguous format to help assure that they can be easily and properly applied. The preliminary results have also been presented at professional meetings including TRB's Visibility Symposium (Iowa City, IA, June

2002), TRB's Annual Meeting (Washington, DC, January 2003), the National Committee on Uniform Traffic Control Device's Research Committee Meeting (Washington, DC, January 2003), and the American Traffic Safety Services Association's Annual Traffic Expo (New Orleans, LA, February 2003). As the work on the MR levels progressed, a second round of national MR workshops was being conducted during the late summer of 2002. The most current recommendations were presented to each group of workshop participants and feedback was solicited. The recommendations shown in table 1 represent the collective efforts from all of these activities, and more. The remainder of this report provides the details that have led to the updated MR levels presented in table 1.

The remainder of this report follows the organizational list below.

- Chapter 2. Fundamental Concepts.
- Chapter 3. Updated Factors.
- Chapter 4. Updated MR Levels.
- Chapter 5. Assumptions and Limitations.
- References.
- Appendix A. AASHTO Policy Resolutions.
- Appendix B. Raw Data from Mercier et al.
- Appendix C. Subjective Results from National MR Workshops.

This report contains references to data and dimensions using both the SI and English units. The units are presented using the common terminology among practicing traffic engineers and visibility experts. The photometric terms are expressed in SI units, as that is the standard in the industry. Sign size, letter height, and other sign-related dimensions (including legibility index) are expressed in English units because that is still the preferred practice by the transportation profession. The conversion table shown on Page iv should be used when it is necessary to convert the units from one system to the other.

CHAPTER 2. FUNDAMENTAL CONCEPTS

In reality, the concept of MR is nearly impossible to specify for each combination of sign type, sign location, driver capability, vehicle type, headlamp type and aim, and viewing geometry that exists on public roads. At a minimum, there can be large differences between sign luminance conspicuity, recognition, and legibility requirements. Regardless of which type of visibility measure one uses, drivers will have different demand levels. For instance, older drivers will generally need higher levels of luminance than younger ones. Vehicles have various dimensions and headlamp performance capabilities that affect nighttime sign visibility. Signs will also have different retroreflective sheeting materials, which redirect light back to the driver at various rates depending on many factors such as the type of retroreflective element, the age of the sheeting, and the orientation with respect to the vehicle and roadway. A number of other issues also can affect the required MR. Therefore, to develop a simple and easy-to-use set of MR recommendations, the research team studied and developed representative levels that were based on the most current information and provided the most reasonable amount of accommodation. It should be noted, however, that no new human performance studies were done during this effort. Rather, the human factors element of updating the MR levels for traffic signs relied on previous literature. Ideally, additional research would be performed to address the assumptions and limitations discussed in this report. A list of recommended research topics is included later.

RETROREFLECTIVITY METRIC

Sign luminance is the visibility metric that provides the most fundamental groundwork for the establishment of MR levels. Overall, the concept used to establish MR levels results in ML levels needed to read or recognize different signs in different viewing scenarios. Because luminance is the product of the headlamp illuminance and the retroreflective characteristics of the sign material, it is important to have reliable and accurate demand luminance data, headlamp candela profiles, and retroreflective sheeting performance information.

The ML needed to read or recognize a traffic sign is often termed the demand luminance. Demand luminance is dependent on the driver's visual capabilities, the design of the sign legend, and the distance between the driver and the sign. The demand luminance is what researchers try to determine when they study how bright signs need to be before test subjects can read or recognize them.

Illuminance is the amount of energy emitted from the vehicle’s headlamp and falling on the signs. Illuminance depends on the headlamp type, the headlamp aim, and the geometry of the particular scenario under consideration.

As mentioned, luminance is the product of the headlamp illuminance and the retroreflectivity of the traffic sign material; this is the supplied luminance. If a particular type of retroreflective sheeting cannot produce a supply luminance at least equal to the demand luminance, it should not be used. If the supply luminance is greater than the demand luminance, then MR levels can be determined. The resulting MR levels represent the point where the demand and supply luminance are equal.

The fundamental concept used to establish MR can be expressed as an equation shown below.

$$\text{Minimum } R_A = \text{New } R_{A,SG} \times \left(\frac{\text{Demand } R_{A,NSG}}{\text{Supply } R_{A,NSG}} \right) \quad [1]$$

Where:

Where:	Minimum R_A	=	MR at standard measurement geometry (α = 0.2E, β = -4.0E) needed to produce demand luminance, cd/lx/m^2
	New $R_{A, SG}$	=	Averaged retroreflectivity of new sheeting at **s**tandard **g**eometry, cd/lx/m^2
	Demand $R_{A, NSG}$	=	Retroreflectivity needed to produce the demand luminance at the **n**on**s**tandard **g**eometry (back-calculated and determined for each scenario), cd/lx/m^2
	Supply $R_{A, NSG}$	=	Retroreflectivity of new sheeting at nonstandard geometry (determined for each scenario), cd/lx/m^2

If the Demand $R_{A, NSG}$ is greater than the New $R_{A, NSG}$, then the material cannot provide the threshold luminance for the given scenario. As shown below, the demand $R_{A, NSG}$ is determined from the illuminance falling on the sign, the viewing geometry (where the Greek letter *Nu* is the viewing angle for the sign, using the driver as the observation point), and the assumed threshold luminance needed for legibility.

$$\text{Demand } R_{A,NSG} = \frac{\text{Minimum Luminance} \times \cos(\upsilon)}{\text{Illuminance}} \quad [2]$$

The supply-and-demand concept presented above requires certain assumptions related to both the supply and demand sides of the concept. For instance, on the demand luminance side it is important to have valid luminance threshold data and know what the data represent. Factors such as the subjects' age and the specific research task(s) can have significant impacts on the results of research studies. It is also important to understand the relative distances associated with reported luminance threshold data. Factors that affect the supply luminance side of the overall concept include the viewing geometry, the vehicle headlamps, and the vehicle size, to list a few. The remainder of this chapter discusses the elements of demand-and-supply luminance.

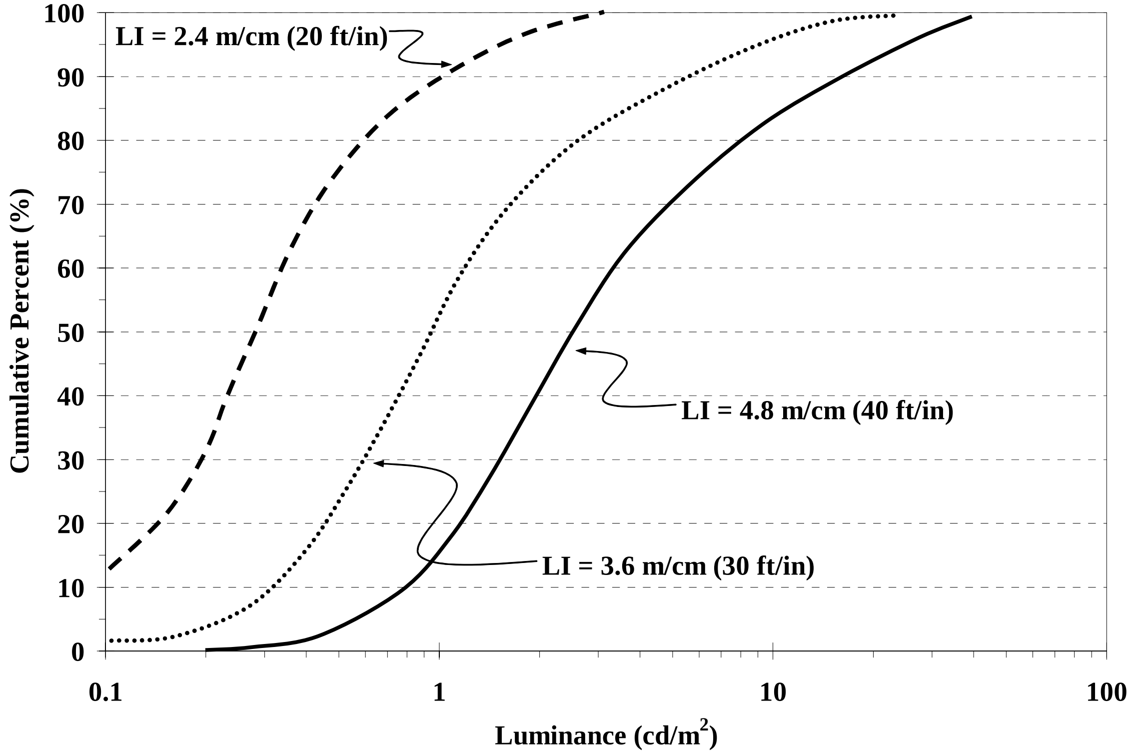
DEMAND LUMINANCE

It is important first to recognize that luminance is but one of several measures of sign visibility, and various methods have been used to determine luminance requirements (or demand luminance, as used herein). First, there is the demand luminance measured by, for example, glance legibility, pure legibility, and recognition. Then there are several ways to measure or determine demand luminance criteria. For instance, some researchers have used the orientation of a Landolt C or the letter E; some have used random letters; some have used familiar names; and others have used unfamiliar names. Furthermore, some have used laboratory-based studies with internally illuminated signs or computer monitors; controlled field tests with fixed lighting;

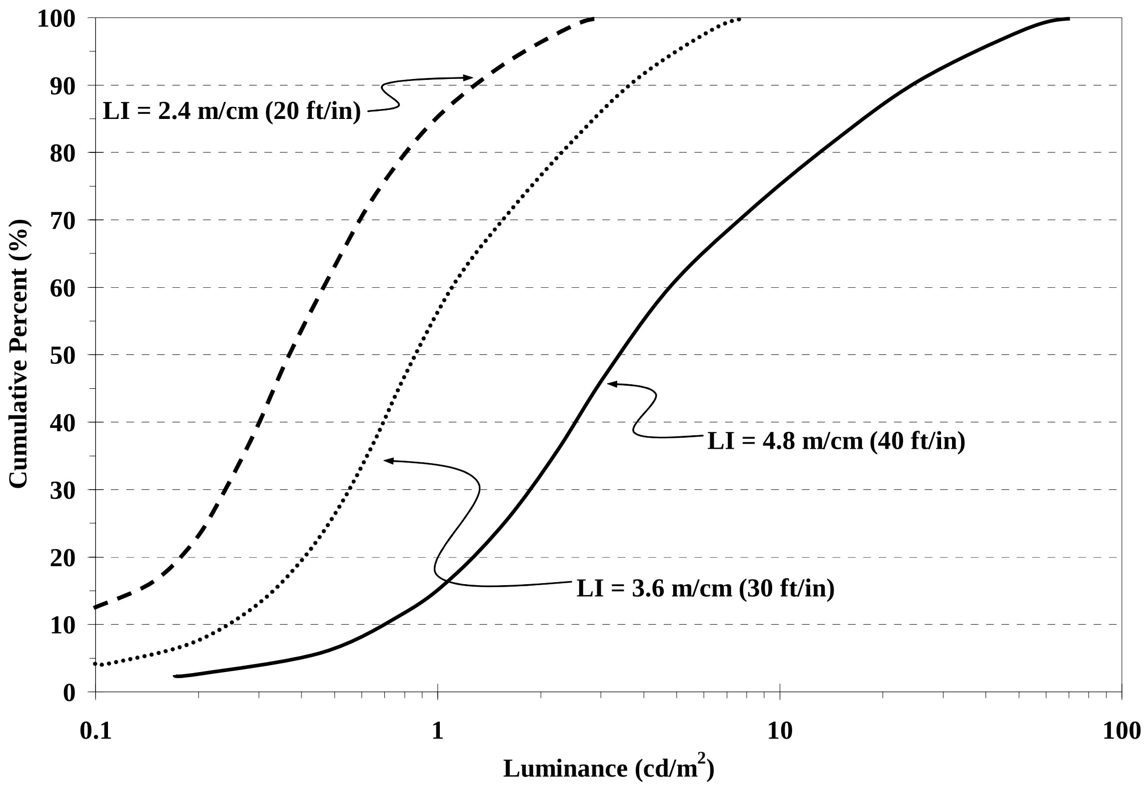
or controlled field tests with retroreflected light. There are other important differences as well, but two worth noting are static versus dynamic evaluations and evaluations focused on the general driving population versus the older driving population.

Given these possible bias-generating variations, researchers have wanted to use threshold luminance data derived from actual signs rather than arbitrary targets such as discs used in the Blackwell data, which most visibility models use as their basis. Therefore, the demand luminance work recently completed for white-on-green guide and street-name signs were used at the benchmark to select and study other demand luminance work.(13) The TTI study included 30 drivers aged 55 years or older. The study was performed with full-scale signs in a controlled outdoor environment with retroreflected luminance.

Summed, there were 534 overhead sign observations and 270 street-name sign observations. The results are shown in figure 2 for the legend luminance on a green background (the internal sign contrast ratio during the study was 5:1). Using the results shown in figure 2, ML (or demand luminance) values were generated, as shown in table 2.



a. Overhead Guide Signs



b. Street Name Signs

Figures 2 a and b. Minimum Luminance Requirements

Table 2. Threshold Luminance Values by Accommodation Level (cd/m^2)

Accommodation Level (percent)	Overhead Signs Î			Street Name Signs Ï		
	Legibility Index (ft/in)			Legibility Index (ft/in)		
	20	30	40	20	30	40
10	0.1	0.3	0.8	0.1	0.2	0.8
25	0.1	0.5	1.2	0.3	0.5	1.8
50	0.3	0.9	2.3	0.4	1.0	3.9
75	0.5	1.9	5.7	0.7	1.8	14.1
85	0.8	3.8	11.7	1.0	2.5	20.0
95	1.6	11.7	19.2	1.6	4.7	32.7
98	1.7	16.5	31.5	1.9	5.8	38.0

Î For white Series E (Modified), 16/12-inch uppercase/lowercase (16" uppercase and 12" lowercase letters) words on a green background
Ï For white Series C, 6-inch uppercase words on a green background

These findings were compared to Sivak and Olson's 1985 work related to demand luminance.[32] Their work included geometric means of various luminance studies that had been previously published. They assumed legibility indices (LI) of 50 and 40 feet per inch of letter height for younger and older drivers, respectively. Their recommended demand luminance criteria are shown in table 3 with the LI = 40 ft/in results of the TTI study.

Table 3. Replacement Luminance Values

Replacement Level	Sign Luminance (cd/m^2)		
	Sivak & Olson	TTI Guide Sign	TTI Street Name Sign
85^{th} percentile	16.8	11.7	20.0
75^{th} percentile	7.2	5.7	14.4
50^{th} percentile	2.4	2.3	3.9

Sivak and Olson's results compare well to the findings presented here. For all three replacement levels, the Sivak and Olson luminance criteria fall between the overhead and street name criteria found as a result of the field studies. It should be noted, however, that the comparison presented here should be interpreted carefully, as the Sivak and Olsen data are based on studies that are not necessarily relevant to today's typical sign design practice, which includes fully retroreflectorized legends on retroreflectorized backgrounds.

Interestingly, for street-name signs, the results of the study are generally higher than for overhead signs or what Sivak and Olson have recommended. One possible explanation for this was that many subjects repeatedly commented on the difficulty they had reading the street-name signs because they perceived that letter spacing was too close. They also commented that the all-uppercase design of the street-name signs made it more difficult to read because of the similarity in word footprints. Had the street-name signs been made with an initial uppercase letter followed by lowercase letters, the threshold luminance values may have been lower.

Unfortunately, the TTI demand luminance data were generated with white-on-green signs and therefore are limited to such signs. Consequently, because of limited time and insufficient funding to support additional human performance research related to sign visibility, the researchers scoured the literature related to demand luminance work. The pertinent literature was critically reviewed to determine how well it compared with the TTI white-on-green data. If strong correlations were found between the demand luminance data found through the literature review and the TTI demand luminance data, then the researchers felt safe generalizing the data for other colors.

For white-on-green signs, the demand luminance work performed by Mercier et al. at FHWA provided a strong correlation to the TTI demand luminance data. Therefore, the Mercier et al. data were used for sign colors other than white on green. A comparison of the TTI and Mercier et al. demand luminance data is shown in figure 3.

Figure 3. Scatterplot of Data from Mercier et al. and TTI

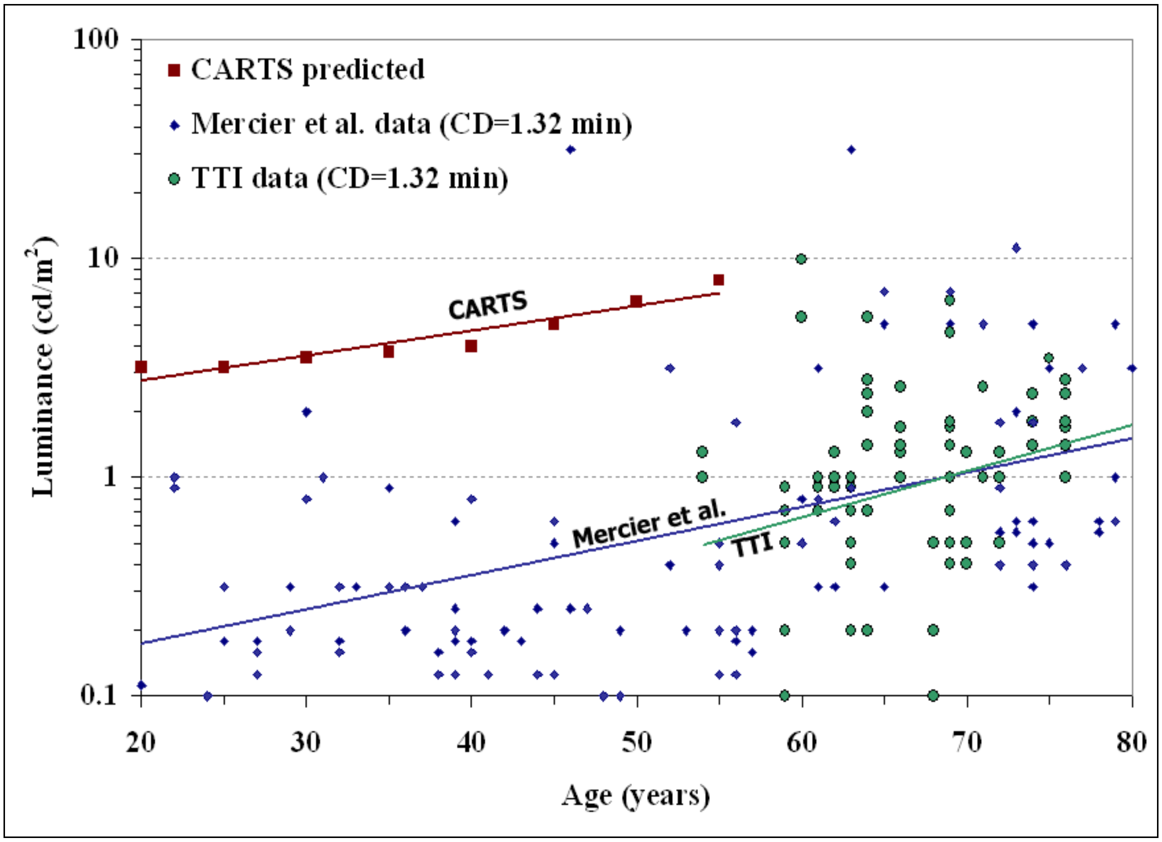


Figure 3 shows that the Mercier et al. data collected for white-on-green signs at distances resulting in a critical detail of 1.32 minutes show nearly identical patterns as the corresponding TTI data (1.32 minutes of critical detail is equivalent to a LI equal to 38 feet per inch for a Series E letter). The TTI study only included subjects 55 and older and therefore no TTI data points are shown for subjects less than 55 years old. The lines shown in figure 3 are best-fit regression lines, which are shown to make relative comparisons of the data sets. It is obvious that a large amount of variation exists in both data sets. However, figure 3 shows that the minimum threshold is much less than that predicted by CARTS. The slope of the Mercier et al. best-fit line is flatter than for the TTI data, but that can possibly be explained by the larger range in subject age and the tendency for luminance demand to become practically asymptotic as driver age increases.

To better compare the two data sets, all subjects younger than 55 were excluded from the Mercier et al. data set. Then, using data representing critical detail levels in addition to 1.32 minutes, cumulative distribution plots were generated to compare the spread in the data sets. Figure 4 shows these cumulative distribution curves.

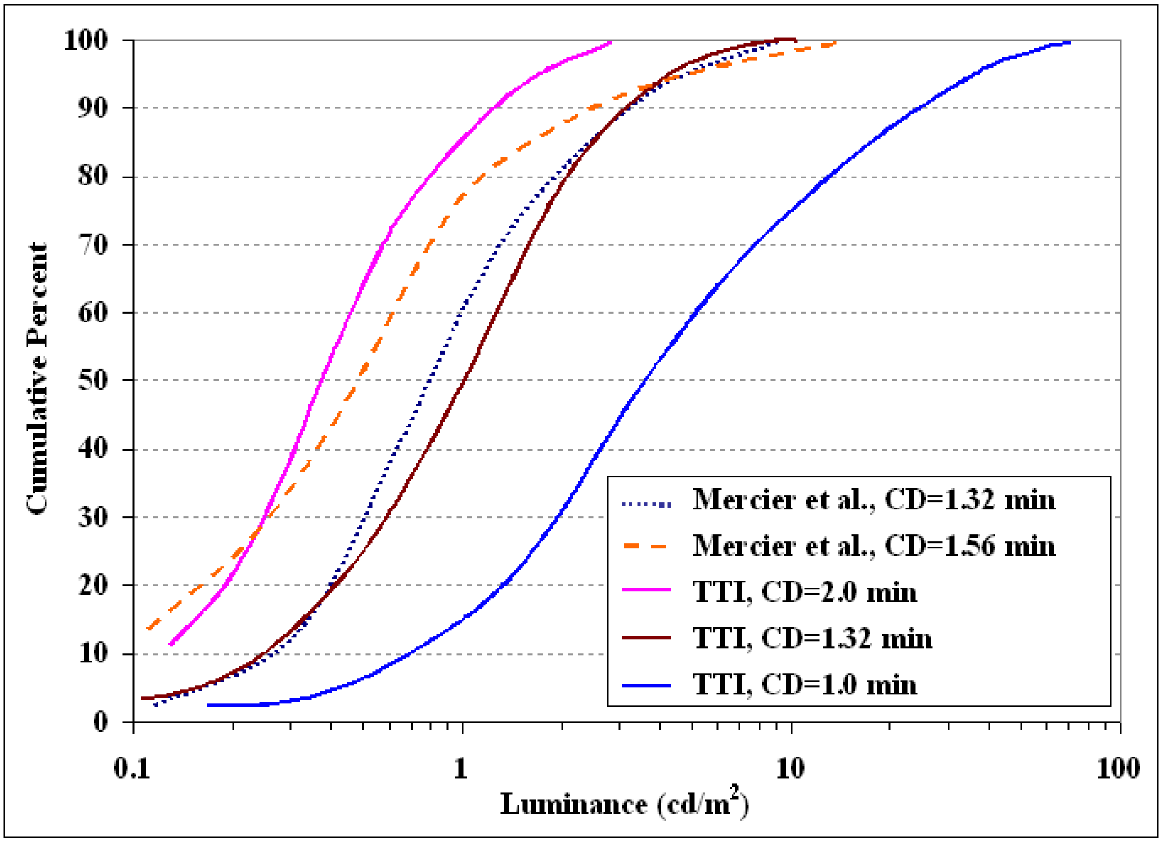


Figure 4. Comparison of Data for Older Drivers Only

Figure 4 shows that the smaller the critical detail, the more luminance is needed. The TTI data represent Series C legends and the Mercier et al. data represent Series D legends. There is good correlation in this figure as well. Consequently, the researchers felt comfortable using the Mercier et al. data for sign colors other than white on green.

The subsequent analyses of the Mercier et al. data (reported in appendix B) revealed that demand luminance was very low* for certain signs. For instance, for STOP signs, the demand luminance values* were almost always less than 1.0 cd/m^2. Therefore, to maintain reasonable levels of conspicuity for iconic signs such as the STOP sign, the demand luminance for all sign types considered was assigned a minimum value of 1.0 cd/m^2. This concept is based on comments received at TRB's Visibility Symposium following a project briefing to TRB's Visibility Committee and other participants of the symposium (June 2002, Iowa City, IA). Subsequent discussions among the participants of the symposium, which included many members of the TRB Visibility Committee, revealed that the concept was reasonable in light of the lack of research focused on the subject.

It should be noted, however, that the Mercier et al. data set does not include demand luminance curves for white-on-blue and white-on-brown signs. Additional work is needed to determine appropriate demand luminance data for these colors.

Critical Distance

The updated MR levels for traffic signs were derived at distances associated with an LI of 40 feet per inch of letter height (corresponding to the *Millennium MUTCD*), which results in various distances depending on the assumed letter height. At distances associated with a LI of 40 feet per inch of letter height, Series E letters subtend 1.25 minutes and Series D letters subtend 1.13 minutes of critical detail.

For signs that require maneuvers before reaching the sign (e.g., speed reduction or STOP), the distance provided by an LI of 40 feet per inch is not always valid, especially at higher speeds. In such cases, the distance associated with perception, reaction, and braking time can be greater than the distance provided by using a constant value of LI. For these types of signs (STOP signs), the minimum required visibility distance (MRVD) values from CARTS were used. The MRVD distances comprise a 5-step serial process that includes the distance to:[(9)]

1. Detect the sign.
2. Recognize or read its message.
3. Decide an appropriate course of action.
4. Initiate a control response.
5. Complete the required maneuver.

By using the LI concept, the burden of providing adequate visibility is appropriately placed upon the choice of the proper sign size. The substitution of the CARTS distance introduces the

* Findings in foot lamberts (ft-L) were converted to cd/m^2 (1 ft-L = 3.426 cd/m^2).
* Findings in foot lamberts (ft-L) were converted to cd/m^2 (1 ft-L = 3.426 cd/m^2).

possibility that the sign may be too small for recognition at MRVD. The distance determined by the legibility index is a measure of the critical detail supplied, while the distance determined by CARTS is a measure of the critical detail required. Because signs like the STOP sign often have iconic value, recognition may be accomplished without legibility, so that the critical detail supplied at MRVD is as great as that required. Fortunately, this concept coincides with demand luminance for iconic signs. In the Mercier et al. work, subjects were asked to identify the sign, not necessarily read it. Therefore, for iconic signs such as STOP signs, the demand luminance threshold criteria were likely too low for a driver to actually read the word "stop," but they were high enough to determine that the target was a STOP sign.

Contrast Ratio Issues

The two fundamental elements of traffic signs that allow drivers to understand their intended message are the background and legend, which are designed and manufactured in prescribed color combinations. Drivers rely on the contrast between the background and legend elements of traffic signs to provide legibility. New traffic signs fabricated in accordance with national standards and practices are intended to provide adequate contrast.[3,17,33,34] However, the films and inks used on the face of signs degrade over time, especially when exposed to weather. The degradation rate can vary depending on several factors such as the type of retroreflective film, the color of the film, the compatibility of ink with the retroreflective film, the geographical locale, the direction the sign is facing, and the fabrication techniques. One of the possibly life-ending results of sign degradation is contrast. As the sign degrades, the contrast can reach a point where legibility is unreasonably sacrificed; this level depends on the sign type and the necessary driver actions.

Although contrast can be a problem for a variety of sign types, contrast issues are most relevant to white-on-red signs such as STOP signs, DO NOT ENTER signs, YIELD signs, and WRONG WAY signs. These types of signs are generally made with a process referred to as reverse screening: the sign blank starts with white retroreflective sheeting and then a semi-transparent red film is screened over the white sheeting. The red-screened ink can and usually does fade causing a pinkish to near white appearance. This lightening of the color of red (toward the white region of the color domain) causes the color to become more transparent. Therefore, less of the entering and retroreflected light is absorbed by the color. In other words, the retroreflectivity actually increases (because the sign is able to return more light to the source now that the absorbing dark red color has diminished to a pinkish white color). The end result is that as the sign ages, the contrast between the white legend and red background continues to decrease, eventually approaching a value of one.

A key need related to contrast is the establishment of a criterion that defines the minimum acceptable contrast. The initial set of recommended MR levels for traffic signs required that a contrast of 4:1 be maintained for white-on-red and white-on-green signs. When the recommendations were revised in 1998, the criterion for white-on-green signs was dropped.

The 1993 minimum contrast criterion of 4:1 was chosen based on a review of the literature. Specifically, four sources are referenced in the 1993 report and shown in table 4.

Table 4. Minimum Internal Contrast Criteria[9]

Source	Minimum Contrast
Smyth	3.3:1
Hills and Freeman	6:1 to 10:1
Forbes et al.	3:1 to 7:1
Hahn et al.	3.85:1

The four studies listed in table 4 were conducted to determine the contrast needed to maintain a prescribed threshold of legibility for unknown words or letter orientations. Other studies have also focused on the effect of sign contrast on legibility. For instance, the data plotted in figure 5 are from three studies[35] that tested the orientation of the letter E. The results support the acceptance of a contrast range of at least 3:1, but preferably 4:1 to 50:1.

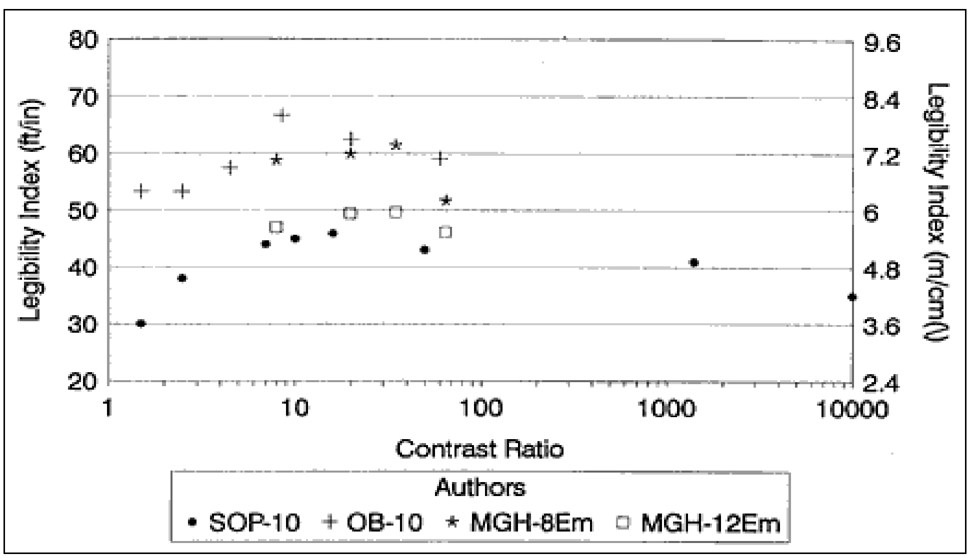


Figure 5. Effect of Contrast Ratio on Legibility

However, some traffic signs need not necessarily to be read to effectively communicate their message. For instance, STOP signs have a unique octagonal shape and color combination that provides recognition distances much longer than the actual legibility of the legend. Therefore, for such signs, the minimum contrast needed may not be as high as recommended in the initial set of MR levels or in the referenced studies, which focus more on the legibility of a word or orientation of a specific letter.

Recent research conducted at TTI has shown that a STOP sign with a contrast of 3:1 was rated unacceptable by only 4 of 29 State DOT maintenance personnel during a subjective evaluation of 49 different signs on a 5-mile closed-course facility.(26) Although the amount of data is limited, it is not unreasonable to expect that STOP signs and other similar signs with a unique shape and/or color combination require a minimum contrast somewhat less than what is needed to maintain nighttime legibility of unknown words.

Further evidence of the effectiveness of the sign shape and color-coding designs was discussed as early as 1957 when Robinson reported how the National Joint Committee on Uniform Traffic Control Devices (now called the National Committee on Uniform Traffic Control Devices) determined and selected its 12 unique colors.(36) In this article, Robinson demonstrates that color is perhaps the most important element in the code through which traffic control devices convey meaning to drivers. Birren proved how valuable the sign shape and color-coding can be in his work published in 1957.(37) In this study, Birren rearranged the legend of a STOP sign and reported that 86 percent of the subjects passing the sign overlooked the rearranged legend.

It should be noted that other legibility research also supports contrast criteria less than 4:1. For instance, after completing a series of legibility studies in 1976, Forbes et al. concluded that minimum contrast levels of at least 65 percent (2.85:1) are needed to maintain a minimum level of nighttime sign visibility.(38,39) The authors also report that legibility typically levels off at a contrast level of about 80 percent, or 5:1.

The latest version of the British standard for the testing and performance of microprismatic materials includes a range of contrast values depending on sign color combinations.(40) For white-on-red signs, where recognition outweighs the actual legibility of the legend, the minimum is 2.8:1. For white-on-blue and white-on-green, where the predominant visual task is legibility of the legend rather than recognition of the sign, the minimum value is set much higher, at 6.7:1.

There is at least one more reason for using a minimum contrast ratio of 3:1 for white-on-red signs. Based on recent retroreflectivity measurements of Type III (encapsulated) traffic signs in Indiana, Nuber and Bullock present data indicating that the contrast ratio of new white-on-red signs is just above 4:1.(41) Interestingly, their data indicate that the contrast ratio actually increases the longer the signs are weathered. For instance, using the data supplied in their paper, at 2 years the contrast ratio of unwiped white-on-red signs would be approximately 4.7:1. Based on the Nuber and Bullock data, it would not be uncommon to measure a contrast ratio less than 4:1 on new, unweathered white-on-red signs. This is apparently a feature of the screening ink, which has undergone various formulae changes designed to provide more durability in terms of maintaining an acceptable amount of red over time.

One of the only documented and supported arguments against a minimum contrast ratio of 4:1 was presented by Chalmers in 1999.(42) In his report to the Arizona DOT, Chalmers makes a case for lowering the minimum contrast ratio below 4:1, although no recommendation is provided. Using retroreflectivity data from weathering racks in Arizona, Chalmers determined that maintaining a 4:1 contrast ratio for white-on-red signs fabricated with Type I or Type II sheeting would be difficult to do for more than 5 years.

Based on the information described, the contrast ratio can have an effect on demand luminance but the overall effect is small if the ratio is kept within a reasonable range. Provided that signs are made with the same type of retroreflective sheeting or at least logical combinations of retroreflective sheeting (i.e., more efficient materials used for the copy), then the proper color coding is provided and contrast ratio is only an issue for weathering. Therefore, a minimum contrast ratio of 3:1 was chosen as the most appropriate ratio of white-on-red signs (STOP, YIELD, DO NOT ENTER, and WRONG WAY). The designs of these signs produce unique shape and/or color cues that drivers use to recognize the sign before they can read the actual message. The only possible exception is the WRONG WAY sign, but even that is unique in that it is the only red rectangular sign used in the United States. The WRONG WAY sign is also a redundant sign that, by MUTCD standards, is used in conjunction with a DO NOT ENTER sign.

It is important to note that additional research aimed at determining the minimum contrast ratio would be extremely beneficial. This proposed research should be based primarily on the legibility requirements needed for signs with very effective color and shape coding (such as white-on-red signs).

SUPPLY LUMINANCE

The supply luminance (L) of a retroreflective sign, directed toward the driver, can be estimated as follows:

$$L = \frac{\left(R_A \times E\right)_{left} + \left(R_A \times E\right)_{right}}{\cos \upsilon} \qquad [3]$$

$R_{A,left}$ and $R_{A,right}$ are the coefficients of retroreflection of the sign corresponding to the vehicle's left and right headlamps (as source points) with the vehicle's driver as the observation point. E_{left} and E_{right} are the separate headlamp illuminance values falling on the sign, measured on planes perpendicular to the respective illumination axis. *Nu* is the viewing angle for the sign, using the driver as the observation point. Viewing angle (**<**) and all other retroreflection angles used to determine supply luminance are defined in ASTM E808.(43)

It should be noted, however, that adjustments are needed to account for factors that affect the amount of supply luminance directed from the sign. The luminance calculated from the equation presented above can be thought of as the luminance in a perfect environment with no obstacles between the sign and the observer. However, in a driving environment at least two factors should be considered. The first is the impact of the light scatter caused by the absorption and transmission of light through the windshield. This is called windshield transmissivity and typically reduces the ideal luminance by about 30 percent.(44) The second factor is the atmospheric transmissivity. As light passes through the air, it is scattered by dust particles, and thus the luminance is reduced. Atmospheric reduction factors are available in most physics books and depend on not only the weather conditions but also the viewing distance. An atmospheric transmissivity of 0.53 miles represents clear and dry conditions.(45) Dirty windshields or those that have a haze from cigarette smoke can impede the transmission of luminance even further.

(Veiling luminance due to backscatter can also have a significant impact, but is beyond the scope of this report.)

Ascertaining the values in the luminance supply equation involves a combination of photometric and geometric investigation. Most computer models take a systems approach, dividing the data collection into five enterprises, and then a calculation to join them into a single luminance value. The five enterprises are: sheeting photometrics, headlight photometrics, vehicle and driver geometry, sign geometry, and road geometry. The details of these enterprises are presented in a variety of reports and the reader is encouraged to study them for additional detail.[42,46-50]

SUMMARY

One way to think of the modeling process is the traditional supply-and-demand concept taught in freshman economics. The combination of the retroreflective sheeting performance data and headlamp performance data along with the associated viewing geometries (defined by the designated sign scenarios) can be used to estimate the supply luminance.

The demand luminance (or the threshold luminance needed by drivers) was based on, among other factors, driver visual capabilities and the required visibility distances. The required visibility distances depend on the designated sign scenario under study. Empirical studies performed in the field and in the laboratory were used to generate threshold demand luminance levels. These studies emphasized the accommodation of older drivers' nighttime needs.

The point of equilibrium between the supply and demand luminance curves can be thought of as the retroreflectivity measuring stick. When the distance associated with the point of equilibrium is less than the required visibility distance, the sign fails to perform at the designated level. When this distance is at least equal to the required visibility distance, a MR level can be generated. However, the viewing geometries of the designated sign scenarios do not correspond to the standard U.S. retroreflectivity measurement geometry of 0.2 and -4.0 degrees for the observation and entrance angles, respectively. Therefore, a conversion was made to change the MR levels at the nonstandard geometries to MR levels at the standard U.S. geometry.

One factor that can affect the MR levels is the viewing geometries associated with the designated sign scenarios. While parameters such as the vehicle dimensions, the vehicle position within the roadway, and the sign position with respect to the vehicle help to define the viewing geometries, one of the more critical parameters of the viewing geometries is the required visibility distance. For the updated MR levels, a modified approach for the required visibility distance was used as compared to the initial set of MR recommendations (published in 1993 and revised in 1998). It is important to note that this modification (i.e., the assignment of the required visibility distance) is only one of several that were implemented as researchers developed updated MR levels for traffic signs.

The updated MR levels were based on required visibility distances associated with a constant legibility index (LI) of 40 feet per inch of letter height (corresponding to the *Millennium MUTCD*), which results in various distances depending on the letter height of the primary text. At distances associated with a LI of 40 feet per inch of letter height, Series E letters subtend 1.25 minutes and Series D letters subtend 1.13 minutes of critical detail.

For signs that require maneuvers before reaching the sign (e.g., speed reduction or STOP), the required visibility distance provided by an LI of 40 feet per inch is not always valid, especially at higher speeds. In such cases, the distance associated with perception, reaction, and braking time can be greater than the required visibility distance provided by using a constant value of LI. For these types of signs, such as STOP signs, the MRVD values from CARTS were used. The MRVD distances comprise a 5-step serial process involving the distance to:

1. Detect the sign.
2. Recognize or read its message.
3. Decide an appropriate course of action.
4. Initiate a control response.
5. Complete the required maneuver.

By using the constant LI concept, the burden of providing adequate visibility is appropriately placed upon the choice of the proper sign size. In other words, the ideal situation would be that the sign size be determined from daytime legibility needs, as determined by the traffic engineer. The nighttime legibility would be maintained as long as the updated MR levels were satisfied. It should be noted, however, that the substitution of the CARTS MRVD distance introduces the possibility that sign size may not be sufficient for recognition at the MRVD. The distance determined by the constant LI is a measure of the critical detail supplied, while the distance determined by CARTS MRVD is a measure of the critical detail required. Because signs (like STOP) often have iconic value, recognition may be accomplished without legibility, so that the critical detail supplied at MRVD is as great as that required and therefore appropriate.

CHAPTER 3. UPDATED FACTORS

Several retroreflectivity-dependent factors were updated in this most recent research effort. These factors included the vehicle headlamps, the vehicle type (or size), the method used to predict retroreflective sheeting performance, the number of materials considered, and the driver's age and assumed accommodation level. This chapter summarizes the work that was completed to update these factors.

HEADLAMPS

In 2001, Carlson and Hawkins completed a sensitivity analysis of the then-available headlamp isocandela profiles.(46) They used typical guide sign and street-name sign placements to compare sign illuminance values at various distances. The results showed that headlamp output directed toward overhead signs decreased by about 30 to 40 percent between the mid-1980s and mid-1990s. For street-name signs, the drop was not as severe but still substantial at 20 to 30 percent.

Carlson and Hawkins also benchmarked seven headlamp profiles against field illuminance measurements recorded in the mid 1990s along a flat tangent section of rural interstate in Kansas.(51) The results showed that the headlamp profile representing vehicles from the mid-1980s with halogen sealed-beam headlamps had the best correlation to the field measurements. Keeping in mind that the average age of U.S. vehicles is 9 years(52) and that the field measurements were recorded before the introduction of VOA headlamps in 1997, the results provide the earliest validation of the assumed correlation between the illuminance results of modeling headlamp isocandela data and actual field illuminance measurements. Chrysler et al. have recently provided additional confirmation of this modeling assumption.(53)

After Carlson and Hawkins completed their analyses, University of Michigan Transportation Research Institute (UMTRI) published headlamp isocandela data representing model year 2000 vehicles.(54) The UMTRI 2000 headlamp isocandela profiles were the first available that included a sample from VOA headlamp types. These headlamp types were studied by UMTRI and shown to produce even less light for nighttime sign visibility.(55) For example, compared to the conventional U.S. headlamps of the mid-1990s, the VOA headlamp (which generically describes two subclasses: VOR and VOL) reduces overhead illumination by 28 percent (VOL headlamp) and 18 percent (VOR). (The VOL headlamp is a low beam with a horizontal cutoff to the left side of the beam. The VOR has a horizontal cutoff to the right side of the beam. The VOL can reduce glare to oncoming drivers compared to conventional U.S. low beams. VOR headlamps have less ability to reduce oncoming glare but produce isocandela profiles more similar to conventional U.S. low beams.)

More recently, a newer style of headlamp has entered the U.S. market and its popularity is slowly growing. These headlamps, termed HID for High Intensity Discharge, use an arc capsule where an arc jumps between two electrodes. This arc is used as the light source, instead of the glowing filament in a conventional halogen headlamp. UMTRI's latest headlamp profile representing model-year 2000 vehicles does not include representation from HID headlamps. Therefore, as part of an earlier effort related to this project, the researchers purchased 6 HID headlamp profiles. The data from the 6 individual profiles were averaged into a composite HID profile, which was compared to various other headlamp profiles, including U.S. headlamps from the mid-1980s to 2000, and a European headlamp representing vehicles sold in Europe in model-year 2000 (see table 5 for a complete description). The researchers used three typical sign placements for the analysis: right shoulder, left shoulder, and overhead. The results were mixed. However, a consistent finding was that at distances greater than 500 ft, the composite HID headlamp profile consistently provided the least amount for traffic signs (of the five U.S. headlamp profiles).(56)

Table 5. Headlamp Descriptions

Name	**Description**	**Reference**
Pre-1985	Average of 2 halogen sealed beam headlamps (2A1).	TTI data
1985-1990	50th percentile low-beam headlamp derived from 26 U.S. headlamps from vehicle model years (MY) 1985-1990.	FHWA-RD-93-077(9)
1997-UMTRI	50th percentile market-weighted low-beam headlamps from 35 headlamps from 23 best-selling vehicles for model year 1997. Does not include VOAs or HIDs.	UMTRI-97-37(57)
2000-UMTRI	50th percentile market-weighted low-beam headlamps from 20 headlamps from 20 best-selling vehicles for model year 2000. Does not include HIDs.	UMTRI-2001-19(54)
2000-Euro	50th percentile market-weighted low-beam headlamps from 20 headlamps from 20 best-selling vehicles in 17 countries for model year 2000.	
2000-HID	50th percentile of HID headlamps from 6 MY 2000 passenger cars.	TTI data(56)

To further investigate the distance-related differences, the 2000-HID profile was compared to the 2000-UMTRI profile. Considering signs with 5-inch tall letters mounted on the left- and right-mounted shoulders and a legibility threshold defined by assuming 40 ft per inch of letter height (i.e., 200 ft), the 2000-HID profile provided illumination levels of 84 and 110 percent of 2000-UMTRI profile, respectively. For overhead signs at 650 ft, the 2000-HID profile provided an illumination level of 78 percent of the 2000-UMTRI headlamp profile.

Based on the results reported above, the 2000-UMTRI profile was selected for establishing MR levels for traffic signs. However, it is important to note that as technologies, specifications, and the vehicle fleet composition evolve, there will be a need to revisit the headlamp issues associated with MR development.

VEHICLE TYPE/SIZE

All three previous sets of recommended MR values have been based on dimensions of a vehicle that represents a large passenger car.(9,11,13) While the passenger car has traditionally been the best-selling vehicle type in the United States, for the 1999 model year, new trucks (defined as pickups, sport-utility vehicles, and minivans) outsold new cars for the first time; trucks had about

50.1 percent of the new-vehicles market versus 49.9 percent for cars.[58] This trend continued for the year 2000. Furthermore, over the past decade the number of registered passenger cars decreased by 0.1 percent, while the percent of trucks has increased over 60 percent.[52]

In November 2001, researchers measured the pertinent dimensions of the top-ten-selling light trucks, minivans, and sport utility vehicles for model year 2000. The results were averaged to develop a set of dimensions representing a typical light truck/minivan/sport utility vehicle that could be used to develop MR values (see table 6). The overall impact of this change is a larger observation angle associated with the vehicle dimensions. The larger observation angle will result in higher levels of MR values.

Table 6. Vehicle Dimensions for MR Calculations

Top-10 Passenger Vehicles Sold in U.S. in 2000	**Number of Units Sold**	**Headlamp Height (in)**	**Eye Height (in)**	**Headlamp Separation (in)**	**Eye Setback (in)**	**Eye Offset (in)**
1 Ford F Series	877,000	35.5	60.0	51.0	91.5	16.0
2 Chevrolet Silverado	645,000	34.0	60.0	59.0	89.0	17.0
3 Ford Explorer	445,000	35.0	57.5	51.0	86.5	15.5
4 Toyota Camry	423,000	27.5	47.5	44.0	84.5	14.6
5 Honda Accord	406,000	25.2	47.0	48.0	87.0	14.0
6 Ford Taurus	382,000	26.5	46.5	46.0	86.5	13.5
7 Honda Civic	325,000	25.0	47.0	43.0	79.0	12.5
8 Ford Focus	286,000	26.5	48.0	46.0	80.0	12.5
9 Dodge Caravan	286,000	29.0	56.5	47.5	81.0	16.0
10 Jeep Grand Cherokee	272,000	34.0	55.5	54.5	84.0	14.5
Average Passenger Car Dimensions		26.2	47.2	45.4	83.4	13.4
Average Truck/SUV Dimensions		**33.5**	**58.1**	**52.6**	**86.4**	**15.8**
CARTS Passenger Car Dimensions[9]		24.0	42.0	48.0	54.0	18.0
NOTE: Measurements made in November 2001. One inch is equal to 2.5 cm.						

RETROREFLECTIVE SHEETING PERFORMANCE

When the first set of recommended MR levels was published in 1993, traffic engineers did not fully understand the way retroreflectivity performed. Since then, traffic engineers have learned much about retroreflectivity and, as a result, more data are available in the public domain and many new computer tools have been developed to analyze retroreflective sheeting performance (such as Exact Roadway Geometry Output (ERGO) and TarVIP).

The first set of MR levels recommended for traffic signs used rather crude regression functions to predict the performance of retroreflectivity sheeting.(9,11) The impacts of both the orientation and rotation angles were completely neglected.

The updated retroreflectivity values use look-up functions to extract a subset of retroreflectivity values from four-dimensional matrices (observation angle, entrance angle, orientation angle, and rotation angle) that include over 250,000 data points. Retroreflectivity data come from the computer program called ERGO.(50)

Interpolation algorithms are then executed on the subset of retroreflectivity values to account for the potential nonlinearity of the data. This process results in an accurate estimate of retroreflectivity for any given geometry, as long as it is represented within the initial four-dimensional matrix.

As long as traffic signs continue to use retroreflectivity to increase nighttime visibility, the procedure described above can be used to assess the MR levels needed. As new materials are produced, the manufacturer should provide a full matrix of retroreflectivity values, similar to those in the ERGO program. A subset of the provided matrix should be validated at FHWA's photometric range.

DRIVER ACCOMMODATION LEVEL

The initial set of MR recommendations was based on the visual capabilities of a 47-year-old driver. The first field research using full-scale signs to address older drivers' needs in terms of MR levels was done by Carlson and Hawkins in 2001.(13) The effort described in this report includes further explorations of accommodating nighttime driver needs using findings from the literature and empirically derived relationships.

Using their data from an earlier effort, the researchers initially developed demand luminance curves for drivers aged 55 and older.(13) Using a subset of this data set, the researchers also considered demand luminance curves derived with the lower bound set at 65 years and older. Using these two data sets, the researchers analyzed the relative sensitivity of visual capabilities using age as a surrogate for all other visual metrics.

For either set of legibility luminance threshold curves, an accommodation level had to be established that could be used to determine the demand luminance (i.e., the percent of drivers assumed to be accommodated). Initially, sensitivity analyses were performed on various accommodation levels using just the 55-year-old driver data set.(46) When both the 55- and 65-year-old driver data sets were studied, the 50th percentile level was used. However, the researchers quickly realized that the levels under consideration did not represent the actual nighttime driving population.

Data from the National Personal Transportation Survey of 1995 were used to estimate the actual nighttime levels of driver accommodation represented by the 50th percentile levels. According to figure 6, approximately 89 percent of the nighttime drivers are under 55 years and almost 96 percent are under 65 years. If one assumes that visibility is directly correlated with age and as age increases visibility decreases, then a 50th percentile level of accommodation of drivers 55 years and older actually corresponds to nighttime accommodation levels well above 90 percent. Therefore, the 50th percentile levels were maintained for the development of the MR levels.

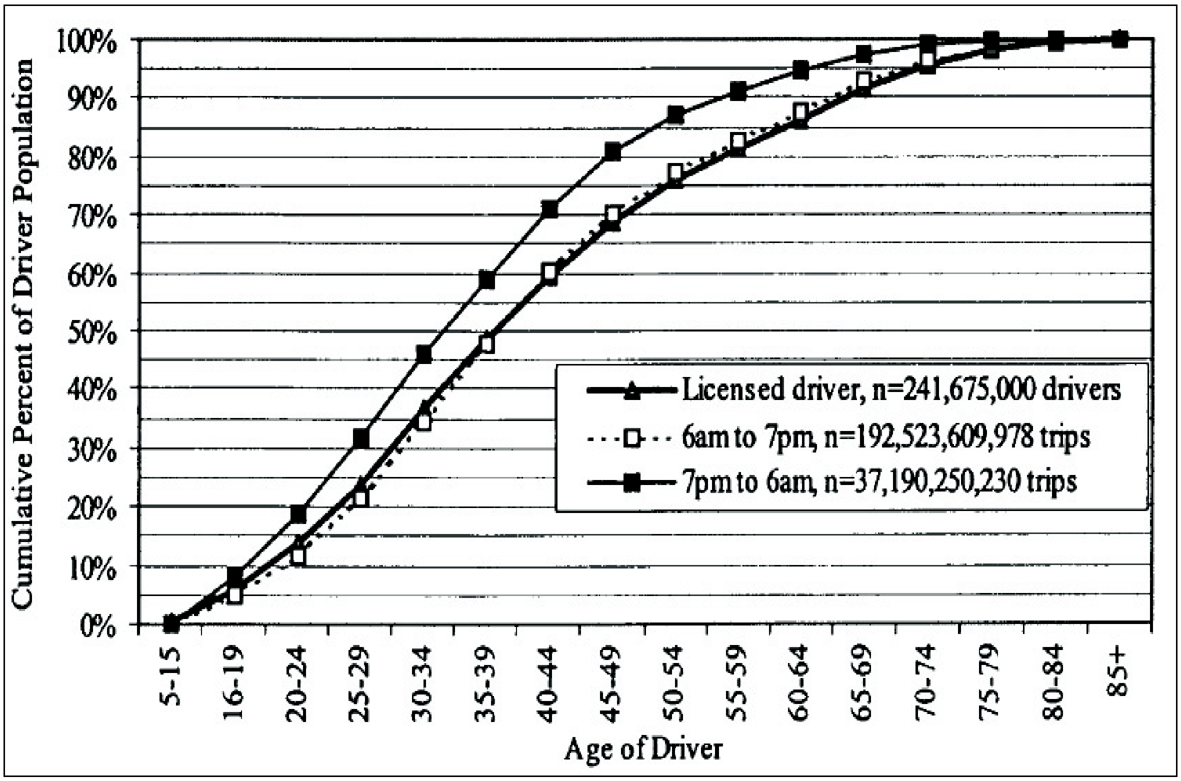


Figure 6. Cumulative Percentage of Driver Population as a Function of Driver Age for Trips at Different Times of Day (Source: National Personal Transportation Survey, 1995)

CHAPTER 4. UPDATED MR LEVELS

This chapter describes analyses conducted to develop a set of preliminary updated MR levels. It includes the demand luminance criteria and other related conditions used to establish MR levels. The discussion is divided into three sections corresponding to the type of sign: guide, warning, and regulatory.

GUIDE SIGNS

Several types of guide signs were considered for this analysis, all of which were assumed to have white legends on green backgrounds. Large and small guide signs and street-name signs were considered. This section describes how the updated MR levels were established for guide signs.

Large Guide Signs

The large guide sign category represents those used on freeways and expressways: used on high-speed facilities, have large letters, and are designed with redundancy. Overhead and right- and left-shoulder-mounted guide signs were considered.

A recent survey of transportation agencies showed that the combination of 16/12-inch uppercase/lowercase Series E (Modified) letters are the most commonly used legends for large guide signs.[(46)] Using the MUTCD legibility index criterion of 40 ft/in of letter height, it was assumed that overhead and shoulder-mounted guide signs need to be legible at 640 feet.

The signs were assumed to be located at fixed positions corresponding to typical State DOT practices. The overhead sign was positioned with a centroid 25 ft above the pavement surface and offset 18 ft to the left of the travel lane right edge line (i.e., centered above the left adjacent lane). Both the right- and left-shoulder-mounted guide signs were positioned with a centroid height of 14 ft above the pavement surface. The offsets used for these signs were 30 ft to the right and 42 ft to the left of travel lane right edge line.

Using the TTI demand luminance data for guide signs, MR levels for overhead and shoulder-mounted guide signs were based on demand luminance values of 2.3 and 3.2 cd/m^2, for the 55-year-old and 65-year-old driver data sets, respectively (see figure 2). The corresponding MR levels needed to satisfy these demand luminance values are shown in table 7. The demand luminance values and therefore the MR levels shown in table 7 represent the white legend for white-on-green signs.

The MR levels for the green background were determined by first calculating the ratio of the levels shown in table 7 to the levels of ASTM D4956,[(17)] then multiplying the calculated ratio and the green levels of ASTM D4956. The white-to-green ratios of ASTM D4956 change as a function of sheeting type designation. Therefore, this process was completed by sheeting type. This was the same process that was used for all positive contrast signs.

Table 7. Initial MR Levels for Large Guide Signs

Position	Speed	Luminance Level	ASTM Sheeting Type					
			I	II	III	VII	VIII	IX
Overhead	Any	55	–	–	290	290	250	230
		65	–	–		400	350	320
Right Shoulder		55	–	115	115	110	95	100
		65	–	160	160	155	135	140
Left Shoulder		55	–	–	210	210	190	160
		65	–	–	290	295	260	225

- Retroreflectivity (cd/lx/m^2) at observation angle = 0.2E and entrance angle = -4.0E.
- Represents only the white legend of white-on-green signs.
- Blank cells indicate that new sheeting will not provide sufficient levels of supply luminance to meet the demand luminance levels.

Small Guide Signs

The small guide sign category of white-on-green signs was developed for guide signs much smaller than one would typically find on freeways; an example is destination and distance signs found along conventional highways. Only right-shoulder-mounted signs were included in this analysis.

These signs were assumed to have a legend made of Series D with letter heights of 8 inches. Therefore, using the MUTCD legibility index criterion of 40 ft/in of letter height, it was assumed that small guide signs need to be legible at 320 feet.

As with the large guide signs, the signs were assumed to be located at fixed positions corresponding to typical State DOT practices. The centroid height was assumed to be 8 ft above the pavement surface and offset 10 ft from the travel lane right edge line.

The TTI demand luminance data for street name signs was used to determine the initial MR levels for small guide signs. The street-name sign data were used instead of the guide sign data because the legends were assumed to be Series D, which is all uppercase letters, as is Series C, which was used on the street-name signs. To account for the legibility differences between Series C and D (because of the wider stroke width of Series D), the TTI demand luminance was lowered by 10 percent. Therefore, the demand luminance values for small guide signs were 3.5 and 6.2 cd/m^2, for the 55-year-old and 65-year-old driver data sets, respectively. The MR levels associated with these demand luminance criteria are shown in table 8.

Table 8. Initial MR Levels for Small Guide Signs

Position	Speed	Luminance Level	ASTM Sheeting Type					
			I	II	III	VII	VIII	IX
Right Shoulder	Any	55	–	125	130	165	130	60
		65	–	–	235	290	225	105

- Retroreflectivity (cd/lx/m^2) at observation angle = 0.2E and entrance angle = -4.0E.
- Represents only the white legend of white-on-green signs.
- Blank cells indicate that new sheeting will not provide sufficient levels of supply luminance to meet the demand luminance levels.

Street-Name Signs

Because street-name signs are installed in somewhat unusual positions compared to other white-on-green signs, the researchers felt they warranted a dedicated analysis. Two street-name sign positions were analyzed. One was a right shoulder mounting and the other was an overhead mounting.

The size of the legends of the street-name signs varied depending on the speed limit on the roadway under consideration. In general, FHWA's proposed recommendations for Revision #2 of the *Millennium MUTCD* were used to select letter height as a function of speed. Table 9 provides a summary of the letter heights used for different speed ranges and the distances resulting from the application of the 40 ft/inch of letter height legibility concept.

Table 9. Assumed Characteristics and Criteria for Street Name Signs

Position	Ground	Ground	Ground	Overhead
Speed (mph)	> 40	30–40	# 25	Any
Letter height (in)	8	6	4	12
MRVD (ft)	320	240	160	480

Both types of street name signs were assumed to be located at positions corresponding to typical practices. The centroid height of the ground-mounted street-name sign was assumed to be 9 ft above the pavement surface (which is based on the assumption that it is located on top of a STOP sign) with an offset of 6 ft from the travel lane right edge line. The overhead street-name sign was assumed to be located on a signal mast arm or span wire and was therefore positioned 18 ft above the pavement surface and centered above the travel lane.

The TTI demand luminance data for street-name signs was used to determine the initial MR levels for these signs. Therefore, the demand luminance values were 3.9 and 6.9 cd/m^2, for the 55-year-old and 65-year-old driver data sets, respectively. Table 10 shows the set of preliminary updated MR levels associated with these criteria.

Table 10. Initial MR Levels for Street Name Signs

Position	Speed	Luminance Level	ASTM Sheeting Type					
			I	II	III	VII	VIII	IX
Ground	> 40	55	–	140	145	180	140	70
		65	–	–	255	315	245	120
	30–40	55	–	–	240	290	285	80
		65	–	170	210	255	250	70
	# 25	55	–	–	–	710	660	135
		65	–	–	–	–	–	240
Overhead	Any	55	–	–	265	290	225	195
		65	–	–	–	510	400	340

- Retroreflectivity (cd/lx/m^2) at observation angle = 0.2E and entrance angle = -4.0E.
- Represents only the white legend of white-on-green signs.
- Blank cells indicate that new sheeting will not provide sufficient levels of supply luminance to meet the demand luminance levels.

WARNING SIGNS

Warning signs include both black-on-yellow and black-on-orange signs. The analyses included two types of sign legends: symbol and text. For the symbol legends, a binary subclass was defined based on the symbol design, which included “fine” and “bold” classes. Symbol signs were initially categorized into these classes based on the initial analysis of Mercier et al. data. However, not all signs types were studied by Mercier et al. Therefore, Paniati’s work on symbol sign legibility distances was used to classify the remainder of the symbol signs.(59)

For warning signs with text legends, an inventory of the *Standard Highway Signs* was completed where the sign size, letter size, and letter type were recorded.(33) The results of this inventory are shown in table 11.

Table 11. Inventory of Standard Size Warning Signs

Letter Height (in)	FHWA Alphabet (Primary Legend) N = 178 signs			Row Percent	Cumulative Percent
	Series C	Series D	Series E		
3	4	0	0	2.2	2.2
4	11	21	0	18.0	20.2
5	30	38	0	38.2	58.4
6	17	15	4	20.2	78.7
7	8	6	0	7.9	86.5
8	7	8	7	12.4	98.9
9	0	0	0	0.0	98.9
10	0	0	2	1.1	100.0
Column Percent	43.3	49.4	7.3	–	–

Based on the inventory shown in table 11, the researchers selected a 6-inch letter to represent warning signs 36 inches or less. When the size of warning signs is increased to 48 inches, the legend size typically increases by 2 inches. Therefore, for warning signs larger than 36 inches, an 8-inch-tall letter was used.

Based on Mercier et al.'s study, (x) demand luminance curves were developed for Series C and Series D letters. However, because there is almost a 50-50 split between these two alphabet types (see table 11), the average results of both curves were used to establish a specific demand luminance requirement for the basis of MR. The criteria used to establish MR levels for text-based warning signs are shown in table 12. Table 13 shows the set of preliminary updated MR levels associated with these criteria.

Table 12. Criteria for Text-Based Warning Signs

Sign Size (in) [measured along an edge of the diamond]	# 36	> 36
Letter Height (inch)	6	8
Critical Distance (ft)	240	240
Effective LI (ft/inch)	40	30
Demand Luminance - 55 (cd/m^2)	1.4	1.0
Demand Luminance - 65 (cd/m^2)	1.9	1.0
Sign centroid height = 8.5 ft and offset from right edge line = 10 ft. One foot equals .31 meters.		

Table 13. Initial Retroreflectivity Levels for Text Warning Signs

Position	Sign Size (inch)	Luminance Level	ASTM Sheeting Type					
			I	II	III	VII	VIII	IX
Right Shoulder	# 36	55	48	66	84	107	98	28
		65	65	89	114	145	133	37
	> 36	55	29	40	51	65	60	17
		65	34	47	60	76	70	20

- Retroreflectivity (cd/lx/m^2) at observation angle = 0.2E and entrance angle = -4.0E.

For the bold symbol warning signs, a legibility distance of 240 ft was assumed, regardless of size or class of symbol. However, the analysis of Mercier et al.'s data showed a distinct demand luminance difference between fine and bold symbol signs. Further comparisons to Paniati's work related to symbol sign legibility distances confirmed this distinction.[59] Therefore, symbol signs were classified into the bold and fine classes, whose demand luminance values were 1.0 and 3.2 cd/m^2, respectively. Table 14 shows the set of preliminary updated MR levels associated with these criteria.

Table 14. Initial Retroreflectivity Levels for Symbol Warning Signs

Position	Sign Size (inch)	Luminance Level	ASTM Sheeting Type					
			I	II	III	VII	VIII	IX
Right Shoulder	Any	Bold Symbol	34	47	60	76	70	20
		Fine Symbol	–	151	192	244	224	65

- Retroreflectivity (cd/lx/m^2) at observation angle = 0.2E and entrance angle = -4.0E.
- A blank cell indicates that new sheeting will not provide sufficient levels of supply luminance to meet the demand luminance levels.

A sensitivity analysis based on sign position indicated that warning signs installed on the left side of a roadway require approximately 50 percent more retroreflectivity than warning signs located on the right side of a roadway. This increase is also evident in table 7, which presents the initial set of updated MR levels for large guide signs.

REGULATORY SIGNS

There are two general types of regulatory signs with significant differences, so the analysis was split into two main headings: black-on-white and white-on-red regulatory signs. This section describes the analyses for each type.

Black-on-White Signs

Regulatory signs are almost always installed at the location where the specific regulation to which they refer begins. As described earlier, this practice can create a problem when using the legibility index of 40 feet per inch of letter height at high speeds. Therefore, the MRVD distances from CARTS were used for regulatory signs. By using the MRVD criteria, the updated MR levels consider the distance traveled from an initial speed to a final speed (depending on the sign) by serially summing the time required to detect a sign, recognize the message, decide an appropriate maneuver, initiate the response, and complete the response.

Four different black-on-white regulatory signs were analyzed. The SPEED LIMIT sign was analyzed to determine the MR levels needed to read the numbers on the sign. A KEEP RIGHT sign, ONE WAY sign, and a NO RIGHT TURN sign were also analyzed to determine the MR levels needed for the signs' symbolic message to be recognized.

The criteria used to establish the updated MR levels for SPEED LIMIT signs are shown in table 15. Table 16 shows the resulting updated MR levels.

Table 15. Criteria for Speed Limit Signs

Sign Size (width)	Luminance Level	Speed (mph)				
		70	55	45	35	25
		MRVD (ft)				
		513	393	308	227	145
24"	55	1.7	1.5	1.3	1.0	1.0
	65	3.8	3.5	3.1	2.5	1.7
36"	55	1.4	1.2	1.0	1.0	1.0
	65	3.4	2.9	2.5	1.9	1.1
48"	55	1.3	1.0	1.0	1.0	1.0
	65	3.2	2.7	2.2	1.6	1.0
Sign centroid height = 8 ft and offset from right edge line = 10 ft.						

Table 16. Initial Retroreflectivity Levels for Speed Limit Signs

Sign Size	Speed	Luminance Level	ASTM Sheeting Type					
			I	II	III	VII	VIII	IX
24" Sign 10" E	70	55	33	33	33	34	28	25
		65	73	74	73	76	62	56
	55	55	39	43	43	52	38	26
		65	90	100	101	121	88	61
	45	55	63	80	84	107	84	38
		65	–	–	200	255	200	91
	35	55	31	45	62	77	74	19
		65	78	113	155	192	185	48
	25	55	42	46	88	337	200	41
		65	72	78	150	574	340	69
36" Sign 12"E	70	55	27	27	27	28	23	21
		65	65	66	65	68	56	50
	55	55	31	34	35	41	30	21
		65	75	83	83	100	73	50
	45	55	49	61	65	82	64	29
		65	–	153	161	205	161	73
	35	55	31	45	62	77	74	19
		65	59	86	118	146	140	36
	25	55	42	46	88	337	200	41
		65	46	50	97	371	220	45
48" Sign 16"E	70	55	25	25	25	26	21	19
		65	61	62	61	64	52	47
	55	55	26	29	29	34	25	17
		65	69	77	78	93	68	47
	45	55	49	61	65	82	64	29
		65	–	135	142	181	142	65
	35	55	31	45	62	77	74	19
		65	50	72	99	123	118	31
	25	55	42	46	88	337	200	41
		65	42	46	88	337	200	41

- Retroreflectivity (cd/lx/m^2) at observation angle = 0.2E and entrance angle = -4.0E.
- Blank cells indicate that new sheeting will not provide sufficient levels of supply luminance to meet the demand luminance levels.

The criteria used to establish the updated MR levels for the three symbol-based regulatory signs are shown in tables 17 through 19. The resulting updated MR levels are shown in tables 20 through 21.

Table 17. Criteria for KEEP RIGHT Signs

Sign Size (width)	**Luminance Level**	**Speed (mph)**				
		70	**55**	**45**	**35**	**25**
		MRVD (ft)				
		273	**245**	**218**	**196**	**174**
24"	55	1.00	1.00	1.00	1.00	1.00
	65	1.73	1.32	1.06	1.00	1.00
36"	55	1.00	1.00	1.00	1.00	1.00
	65	1.00	1.00	1.00	1.00	1.00
Sign centroid height = 8 ft and offset from right edge line = 10 ft.						

Table 18. Criteria for ONE WAY Signs

Sign Size (width)	**Luminance Level**	**Speed (mph)**				
		70	**55**	**45**	**35**	**25**
		MRVD (ft)				
		225	**203**	**188**	**173**	**159**
36"	55	1.10	1.00	1.00	1.00	1.00
	65	3.00	2.40	2.10	1.70	1.30
54"	55	1.00	1.00	1.00	1.00	1.00
	65	1.10	1.00	1.00	1.00	1.00
Sign centroid height = 9 ft and offset from right edge line = 10 ft.						

Table 19. Criteria for NO RIGHT TURN Signs

Sign Size (width)	Luminance Level	Speed (mph)				
		70	**55**	**45**	**35**	**25**
		MRVD (ft)				
		273	**245**	**218**	**196**	**174**
24"	55	1.00	1.00	1.00	1.00	1.00
	65	2.30	2.10	1.70	1.50	1.20
36"	55	1.00	1.00	1.00	1.00	1.00
	65	1.10	1.00	1.00	1.00	1.00
Sign centroid height = 8 ft and offset from right edge line = 10 ft.						

Table 20. Initial MR Levels for KEEP RIGHT Signs

Sign Size (width)	Speed (mph)	Luminance Level	ASTM Sheeting Type					
			I	II	III	VII	VIII	IX
24"	70	55	24	33	37	46	38	14
		65	41	57	65	80	66	25
	55	55	29	40	49	63	57	22
		65	38	52	65	83	75	20
	45	55	33	48	69	93	81	20
		65	33	48	69	93	81	20
	35	55	35	47	77	127	93	22
		65	35	47	77	127	93	22
	25	55	38	48	89	165	130	28
		65	38	48	89	165	130	28
36"	70	55	24	33	37	46	38	15
		65	24	33	37	46	38	15
	55	55	29	40	49	63	57	17
		65	29	40	49	63	57	17
	45	55	33	48	69	93	81	20
		65	33	48	69	93	81	20
	35	55	35	47	77	127	93	22
		65	35	47	77	127	93	22
	25	55	38	48	89	165	130	28
		65	38	48	89	165	130	28

- Retroreflectivity (cd/lx/m^2) at observation angle = 0.2E and entrance angle = -4.0E.

Table 21. Initial MR Levels for ONE WAY Signs

Sign Size	Speed (mph)	Luminance Level	ASTM Sheeting Type					
			I	II	III	VII	VIII	IX
36" Sign 4" D	70	55	39	55	78	96	91	23
		65	–	151	212	263	247	64
	55	55	40	56	89	138	103	24
		65	96	134	214	331	247	58
	45	55	43	58	101	190	128	29
		65	91	122	213	400	270	61
	35	55	45	57	107	200	162	34
		65	76	97	182	340	275	58
	25	55	48	56	107	275	200	40
		65	62	73	140	358	260	52
54" Sign 6" D	70	55	35	50	71	88	82	21
		65	39	55	78	96	91	23
	55	55	40	56	89	138	103	24
		65	40	56	89	138	103	24
	45	55	43	58	101	190	128	29
		65	43	58	101	190	128	29
	35	55	45	57	107	200	162	34
		65	45	57	107	200	162	34
	25	55	48	56	107	275	200	40
		65	48	56	107	275	200	40

- Retroreflectivity (cd/lx/m^2) at observation angle = 0.2E and entrance angle = -4.0E.
- A blank cell indicates that new sheeting will not provide sufficient levels of supply luminance to meet the demand luminance levels.

Table 22. Initial MR Levels for NO RIGHT TURN Signs

Sign Size (width)	Speed (mph)	Luminance Level	ASTM Sheeting Type					
			I	II	III	VII	VIII	IX
24"	70	55	24	33	37	46	38	14
		65	54	76	86	107	88	33
	55	55	29	40	49	63	57	17
		65	60	83	103	132	120	35
	45	55	33	48	69	93	81	20
		65	57	82	117	158	138	35
	35	55	35	47	77	127	93	22
		65	52	70	116	191	139	33
	25	55	38	48	89	165	130	28
		65	45	58	107	198	156	33
36"	70	55	24	33	37	46	38	14
		65	26	36	41	51	42	16
	55	55	29	40	49	63	57	17
		65	29	40	49	63	57	17
	45	55	33	48	69	93	81	20
		65	33	48	69	93	81	20
	35	55	35	47	77	127	93	22
		65	35	47	77	127	93	22
	25	55	38	48	89	165	130	28
		65	38	48	89	165	130	28

- Retroreflectivity ($cd/lx/m^2$) at observation angle = 0.2E and entrance angle = -4.0E.

White-on-Red Signs

Two sets of preliminary updated MR levels were developed for white-on-red signs. One set was for STOP signs and the other was for DO NOT ENTER signs. Again, it was assumed that the legends of these types of signs are not actually read but the signs are recognized through their unique design characteristics.[37]

The criteria used to establish the updated MR levels for STOP signs are shown in table 23. The resulting updated MR levels are shown in table 24. Tables 25 and 26 show the criteria and resulting updated MR levels, respectively for the DO NOT ENTER sign.

Table 23. Criteria for STOP Signs

Sign Size (width)	Luminance Level	Speed (mph)				
		70	55	45	35	25
		MRVD (ft)				
		915	608	437	293	176
30"	55	1.40	1.00	1.00	1.00	1.00
	65	11.50	6.80	3.70	1.30	1.00
36"	55	1.20	1.00	1.00	1.00	1.00
	65	9.30	5.00	2.40	1.00	1.00
48"	55	1.00	1.00	1.00	1.00	1.00
	65	6.20	2.70	1.00	1.00	1.00
Sign centroid height = 8 ft and offset from right edge line = 10 ft.						

Table 24. Initial MR Levels for STOP Signs

Sign Size (width)	Speed (mph)	Luminance Level	ASTM Sheeting Type					
			I	II	III	VII	VIII	IX
30" Sign 10" C	70	55	56	53	52	52	43	46
		65	–	–	–	424	352	376
	55	55	40	39	38	37	33	31
		65	–	–	261	254	224	211
	45	55	22	23	23	28	20	16
		65	80	86	85	99	73	59
	35	55	22	30	32	42	33	14
		65	28	37	40	51	40	17
	25	55 and 65	38	48	88	163	125	27
36" Sign 12" C	70	55	48	46	45	44	37	39
		65	–	–	–	343	284	304
	55	55	40	39	38	37	33	31
		65	–	–	192	187	164	155
	45	55	22	23	23	28	20	16
		65	52	56	55	64	48	39
	35	55 and 65	22	30	32	42	33	14
	25	55 and 65	38	48	88	163	125	27
48" Sign 16" C	70	55	38	36	36	35	29	32
		65	–	–	232	228	190	203
	55	55	40	39	38	37	33	31
		65	–	106	104	101	89	84
	45	55 and 65	22	23	23	28	20	16
	35	55 and 65	22	30	32	42	33	14
	25	55 and 65	38	48	88	163	125	27

- Retroreflectivity (cd/lx/m^2) at observation angle = 0.2E and entrance angle = -4.0E.
- Represents only the white legend of white-on-red signs.
- Blank cells indicate that new sheeting will not provide sufficient levels of supply luminance to meet the demand luminance levels.

Table 25. Criteria for DO NOT ENTER Signs

Sign Size (width)	Luminance Level	Speed (mph)			
		70	55	35	25
		MRVD (ft)			
		915	608	293	176
30"	55	3.10	2.20	1.00	1.00
	65	16.70	11.30	3.20	1.00
36"	55	2.6	1.70	1.00	1.00
	65	13.80	8.40	1.70	1.00
Sign centroid height = 8 ft and offset from right edge line = 10 ft.					

Table 26. Initial Retroreflectivity Levels for DO NOT ENTER Signs

Sign Size (width)	Speed (mph)	Luminance Level	ASTM Sheeting Type					
			I	II	III	VII	VIII	IX
30" Sign 4" D	70	55	–	118	116	114	95	101
		65	–	–	–	615	511	
	55	55	87	86	84	82	72	68
		65	–	–	–	422	372	351
	35	55	22	30	32	42	33	14
		65	17	23	25	31	25	11
	25	55	38	48	88	163	125	27
		65	38	48	88	163	125	27
36" Sign 5" D	70	55	–	99	97	96	79	85
		65	–	–	–	508	422	
	55	55	67	67	65	63	56	53
		65	–	–	–	314	276	261
	35	55	22	30	32	42	33	14
		65	37	48	52	66	53	22
	25	55	38	48	88	163	125	27
		65	38	48	88	163	125	27

- Retroreflectivity (cd/lx/m^2) at observation angle = 0.2E and entrance angle = -4.0E.
- Represents only the white legend of white-on-red signs.
- Blank cells indicate that new sheeting will not provide sufficient levels of supply luminance to meet the demand luminance levels.

CONSOLIDATION

At least in theory, nearly every individual driver may need a unique set of MR levels that address the different signs she or he may encounter. In addition to covering all the various signs, each set of driver-specific minimum levels would vary depending on factors such as the vehicle and even the driving environment (i.e., rural, suburban, and urban). However, from a practical point of view, the MR levels need to be easy to manage and implement, and thus be consolidated into a straightforward format. This was one of the most consistent and frequently heard comments during the four national MR workshops held over the summer of 2002.(14) To consolidate the MR levels, certain decisions were made regarding the resolution of the levels. The consolidation efforts ultimately resulted in some degree of compromise between the precision of the minimum levels and their brevity.

The research team proposed the first step toward consolidation by suggesting the elimination of MR levels associated with the demand luminance levels representing the 50th percentile of drivers 65 and older. This early decision reduced the total number of specific numeric values by 50 percent, leaving only MR levels associated with demand luminance levels representing the 50th percentile of drivers 55 and older (i.e., a 62-year-old driver). The researchers based this suggestion on several factors, including:

- It is very possible to preselect conditions that, once analyzed, reveal that no current retroreflective sheeting material can produce supply luminance levels at least equal to the assumed demand luminance levels. For instance, it is possible to consider a 65-year-old driving an 18-wheeler in the right lane of an 8-lane freeway (4 lanes per direction). If the sign position is assumed to be left-mounted and overhead and the headlamps are VOL style, then it is quite possible that no amount of retroreflectivity would result in enough sign luminance for that driver's legibility at an adequate distance. In other words, while the criteria associated with the worst-case scenario ensure that all other conditions are satisfied, they also can produce unrealistic demands.
- The researchers compared the preliminary sets of updated MR levels to the levels found in ASTM D4956, which represents the minimum levels for new retroreflective sheeting materials.(17) This comparison revealed that many updated minimum retroreflective levels were actually higher than the minimum levels for new sheeting, especially when the higher luminance demand criteria were used. Based on their engineering judgment, and the lack of a scientific link between higher grades of retroreflective sheeting and safety, the researchers felt that the minimum levels based on the lower of the two luminance demand-based levels were the most reasonable in terms of practicality and acceptability.
- It is possible that modeling parameters could be selected so that the luminance demand criteria are so high that only microprismatic retroreflective sheeting materials would meet the assumed luminance demand. However, while this may not be reasonable, it may also unnecessarily eliminate some retroreflective sheeting materials that perform well.

The suggestions were submitted to FHWA as Working Paper #2.(31) The researchers then met with the Retroreflectivity Technical Working Group (RTWG) of FHWA to discuss the recommendation of eliminating MR levels associated with demand luminance levels representing the 50th percentile of drivers 65 and older. The group reached a consensus to drop the higher levels. To receive additional feedback regarding this decision, the RTWG of FHWA decided to present the preliminary levels to the participants of the first of four national MR workshops, which was held in Lakewood, CO, in July 2002 (the handout materials, including the then-current research recommendations regarding MR levels, are available on the Web at http://tcd.tamu.edu).

In general, the comments received from the Colorado participants were positive. They noted that retroreflectivity alone would not define nighttime sign visibility. Other factors such as color, uniformity, and sight distance are also important. The participants were also concerned about the precision of the MR levels. For instance, if a sign has a measured retroreflectivity of 38 cd/lx/m^2 and the minimum level for that sign is 40 cd/lx/m^2, then the sign would technically fail to meet the minimum levels although the difference would not likely be noticeable from a driver's perspective. An example of a resolution was to use a band of retroreflectivity levels representing desired and minimums.

After the Colorado workshop, the RTWG and the researchers met several times throughout the summer of 2002 to discuss additional consolidation efforts. During the remaining three workshops, the most current form of the MR levels was presented so that researchers could receive outside feedback (again, the levels presented to each workshop are available on the Web at http://tcd.tamu.edu).

During the consolidation process, the RTWG and the researchers made several assumptions regarding the amount of consolidation that could be performed without compromising the use of any one particular type of retroreflective sheeting material. The assumptions were based on various data and information that either FHWA or the researchers had available. For instance, for the majority of the minimum levels proposed herein (i.e., 25 - 75 cd/lx/m^2),[*] it was assumed that there is no perceivable difference in sign luminance when retroreflectivity values are within 15 cd/lx/m^2. It was also assumed that for microprismatic retroreflective sheeting materials the practical difference between relatively low retroreflectivity levels (at least in terms of the typical levels represented by microprismatic retroreflective sheeting materials) such as 100 cd/lx/m^2 and 50 cd/lx/m^2 is insignificant. This assumption was based on currently available weathering data, which indicate that it is doubtful that these types of sheeting materials will ever reach such low levels without catastrophic failure (such as delaminating).

There were also some exceptions. For instance, using the similar ratio method to determine MR levels for backgrounds would have eliminated all sheeting materials except microprismatic materials for overhead guide signs. However, several States are using a combination of microprismatic sheeting materials for the legends of white-on-green signs with beaded sheeting materials for the background. This practice appears to be catching on well. Therefore, exceptions were made to allow any type of retroreflective sheeting to be used for the background, as long as it was maintained to a level that produced enough luminance for adequate color coding at night.

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[*] Retroreflectivity levels discussed without reference to a specific measurement geometry should be assumed to have the standard measurement geometry, which includes an observation angle of 0.2 degrees and an entrance angle of -4.0 degrees.

The results of the consolidation efforts are presented in table 27. The MR levels represent the most current research recommendations, but are subject to change as additional research is performed and implemented. A list of research needs is presented later in this report.

It is important to note that the level of complexity of the MR levels of 1993 and 1998 was a particularly significant issue as seen by the AASHTO Retroreflectivity Task Force. As the research to update the MR levels was nearing completion, the researchers focused on consolidating the recommendations into an easy-to-use format. In consolidating the MR levels, certain decisions were made as described above. The consolidation efforts ultimately resulted in some degree of compromise between the precision and the brevity of the MR levels.

Table 27. Updated MR Levels for Traffic Signs

Sign Color	Criteria	Sheeting Type (ASTM D4956-01a)					
		I	II	III	VII	VIII	IX
White on Red	See note Î	35 * 7					
Black on Orange or Yellow	See note Ï	(	50				
	See note Ð	(	75				
Black on White		50					
White on Green	Overhead	(* 7	(* 15	(* 25	250 * 25		
	Shoulder	(* 7	120 * 15				

NOTE: Levels in cells represent legend retroreflectivity * background retroreflectivity (for positive contrast signs). Units are cd/lx/m^2 measured at an observation angle of 0.2E and an entrance angle of -4.0E.
Î Minimum Contrast Ratio $ 3:1 (white retroreflectivity ÷ red retroreflectivity).
Ï For all bold symbol signs and text signs measuring 48 inches or more.
Ð For all fine symbol signs and text signs measuring less than 48 inches.
(Sheeting Type should not be used.

Bold Symbol Signs

- W1-1 – Turn
- W1-2 – Curve
- W1-3 – Reverse Turn
- W1-4 – Reverse Curve
- W1-5 – Winding Road
- W1-6 – Large Arrow (One direction)
- W1-7 – Large Arrow (Two directions)
- W1-8 – Chevron
- W1-9 – Turn & Advisory Speed
- W1-10 – Horizontal Alignment & Intersection
- W2-1 – Cross Road
- W2-2, W2-3 – Side Road
- W2-4 – T Intersection
- W2-5 – Y Intersection
- W2-6 – Circular Intersection
- W3-1a – Stop Ahead
- W3-2a – Yield Ahead
- W3-3 – Signal Ahead
- W4-3 – Added Lane
- W6-1 – Divided Highway Begins
- W6-2 – Divided Highway Ends
- W6-3 – Two-Way Traffic
- W10-1, -2, -3, -4 – Highway-Railroad Intersection Advance Warning
- W11-2 – Pedestrian Crossing
- W11-3 – Deer Crossing
- W11-4 – Cattle Crossing
- W11-5 – Farm Equipment
- W11-5p, -6p, -7p – Pointing Arrow Plaques
- W11-8 – Fire Station
- W11-10 – Truck Crossing
- W12-1 – Double Arrow

All symbol signs not listed in the bold category are considered fine symbol signs.

Special Case Signs

- W3-1a – Stop Ahead
- Red retroreflectivity $ 7, White retroreflectivity $ 35
- W3-2a – Yield Ahead
- Red retroreflectivity $ 7, White retroreflectivity $ 35
- W3-3 – Signal Ahead
- Red retroreflectivity $ 7, Green retroreflectivity $ 7
- W14-3 – No Passing Zone, W4-4p – Cross Traffic Does Not Stop, or
- W13-2, -3, -1, -5 – Ramp & Curve Speed Advisory Plaques
- Use largest dimension

CHAPTER 5. ASSUMPTIONS AND LIMITATIONS

The recommended updated MR levels presented in this report represent the most recent results of dedicated research studies undertaken over the past two decades. They also represent the latest efforts in a long series of safety considerations related to providing safe and efficient roadways. FHWA will initiate MR rule making soon and it is likely that the recommendations presented here will accompany the rule. While it is impossible to predict the outcome of the rule-making process, it is possible and important to summarize the assumptions and limitations of the updated MR levels.

ASSUMPTIONS

The key assumptions associated with the updated MR levels are described below.

Demand Luminance

- Based on field data from TTI and laboratory data from Mercier et al.,[13,18] studies performed in environments representing dark rural conditions with essentially no ambient lighting, no glare except from the vehicle instrument panel, and no visual complexity.
- Assumed threshold levels equivalent to accommodating legibility or recognition for 50 percent of drivers over age 55.
- Required legibility distances based on a legibility index of 40 feet per inch of letter height.
- Required recognition distances based on CARTS MRVD values.
- Required sign contrast ratio criterion based on sign recognition rather than legibility and set at a minimum of 3:1 for white-on-red signs.
- In conditions where the required threshold luminance levels were below 1.0 cd/m^2, a minimum of 1.0 cd/m^2 was assumed for maintenance of sign conspicuity.

Supply Luminance

- The supply luminance was modeled assuming that the only contribution of illuminance originated from the design vehicle. In other words, no contribution from other vehicles in the proximity of the design vehicle was considered. There also was no consideration of pavement reflection adding to the luminance of the sign.[64]
- The supply luminance did consider windshield transmissivity (72 percent) and atmospheric transmissivity (0.53 miles).
- The headlamp luminous intensity matrix used for developing the MR levels represented a market-weighted model-year 2000 passenger car. The data are derived from measurements made with perfect aim, no scattering of light caused by lens wear or dirt, and a voltage of 12.8 v.
- The retroreflectivity data used for the analysis and modeling were the same as those included in the ERGO2001 program. While the retroreflective sheeting materials mentioned throughout this paper are classified using the ASTM D-4956-01a classification scheme, it is important to note that the retroreflectivity data from the

EGRO2001 model do not necessarily represent all manufacturers' sheeting performance within each ASTM Type designation. For instance, several manufacturers produce high-intensity retroreflective material (ASTM Type III), and each brand performs differently. However, the retroreflectivity data from the ERGO2001 program represent only one manufacturer's retroreflective sheeting performance. It is also important to note that the retroreflectivity data in ERGO2001, while comprehensive in nature, are about 5 years old. There is a need to provide an updated set of retroreflectivity data for modeling purposes.

- Other key modeling factors related to the supply luminance were straight and flat roadways (i.e., no curves), vehicle dimensions representing a contemporary sport utility vehicle, and signs installed normal to the roadway.

STANDARDS AND SPECIFICATIONS

The recommended updated MR levels are a function of the type of retroreflective sheeting material used on the sign face. Moreover, they depend on the ASTM classification scheme described in D-4956.(17) Several issues are created by referencing the ASTM classification scheme in the MR levels.

One issue is that the committee in charge of maintaining ASTM D-4956 is currently debating the reorganization of the classification scheme. Much debate and controversy surrounded the initial development of the current scheme. Since the current scheme was approved, multiple proposals have been presented to ASTM suggesting different schemes. ASTM is currently considering the latest of these, which proposes that Types IV, VII, and VIII would no longer be described. A new type, Type X, would include Types VII and VIII. Type IV is no longer manufactured, so its removal is more maintenance than reclassification, although some DOT specifications still include Type IV as an approved material. It is likely that ASTM will develop a new classification scheme or at least modify the current one. The MR levels then will need to be modified to be current.

Another issue associated with the reference of the ASTM classification scheme is that it is based on measurement geometries that do not represent actual driving scenarios and therefore may not be the best criterion to use as a scheme. Perhaps the most revealing research related to actual viewing geometries versus standard specification geometries was completed by Brich in 2001.(60) In this research, Brich demonstrated the need to classify retroreflective sheeting materials on geometries that actually represent typical driving scenarios. Other countries are currently developing retroreflective sheeting material classification schemes based on such scenarios.(40) Fortunately, research is currently underway through the National Cooperative Highway Research Program in the United States that may provide a more practical classification scheme (Project 4-29).

Also, by using an ASTM Type designation rather than specific manufacturer and brand names, an assumption is introduced that inherently indicates that all manufacturer/brand products meeting a certain ASTM Type designation performance similarly. For example, according to FHWA’s retroreflective sheeting material identification guide, at least nine products can be classified as ASTM Type III materials.(61) Not all of these perform equally, and a certain amount of error is introduced by collapsing them into one classification category. The amount of error is unknown but depends on various factors such as:

- The performance of various products versus the retroreflectivity data used to generate the updated MR levels,
- The degradation rates and characteristics of the various products falling into a specific classification category, and
- The changes the manufacturers inevitably make in the raw materials and construction processes used to make the sheeting materials.

MEASURING RETROREFLECTIVITY

Several unresolved issues are associated with the measurement of retroreflectivity. This section describes these issues and indicates what is being done to address them.

Measurement Error

One of the largest unknowns in terms of measuring retroreflective sheeting material is the repeatability and reproducibility of the equipment used to measure retroreflectivity. Several devices currently are available to make measurements; they can be described as either contact or non-contact devices. Some are portable and some are not. Regardless of which specific device is used to make retroreflectivity measurements, no information is currently available that describes the expected error associated with measurements.

One specific source of measurement error should be ASTM E-1709, *Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer*. However, the precision and bias statement of E-1709 has not been completed. Preliminary estimates indicate error rates approaching 20 percent at the 95-percent confidence level. Fortunately, research is currently underway that will provide repeatability and reproducibility statistics for most currently available retroreflectometers.

Measurement Variability

According to ASTM E-1709, at least four measurements should be averaged when determining retroreflectivity of a specific sign. In a recent study, researchers measured retroreflective traffic signs in accordance with ASTM E-1709.[62] The signs had been removed from service by TxDOT maintenance personnel. Up to six retroreflectivity measurements were made on each sign. The retroreflective sheeting materials were limited to Type I and Type III (although most were Type I, because TxDOT switched from Type I to Type III in 1993). The results of the retroreflectivity measurements are summarized in table 28.

Table 28. Summary of Variability Across Sign Faces

Color	Sample Size (signs)	Average Retroreflectivity	Average Standard Deviation	Coefficient of Variation
Yellow	12	90.3	12.6	0.167
White	23	83.1	7.6	0.111
Red	9	22.1	2.5	0.122
Green	5	27.0	2.1	0.100

While the data used to generate the variability values shown in table 28 were not meant for such purposes and therefore are not statistically valid, they do indicate the level of imprecision that exists when measuring retroreflectivity on signs that have been in the field for a considerable length of time. Additional information is needed in standards, specifications, and practices in terms of how to measure retroreflectivity of used signs and how to use the data to get a representative retroreflectivity value.

Standardization

Establishing a national standard for minimum levels of retroreflectivity as instructed by Congress requires accurate methods to measure retroreflectivity. Instruments are commercially available for these measures, and documented standards establish procedures for such measurements. However, there can be significant variability among instruments measuring the same object, and the standards do not ensure accuracy of the instruments. There are currently no traceable methods in the United States to determine the accuracy of measurements, because national calibration standards for retroreflectivity do not exist.

Research currently underway by the National Cooperative Highway Research Program is devoted to the development of a dedicated reference instrumentation suitable for calibration and characterization of retroreflective reference materials. This research is being performed by the National Institute of Standards and Technology, and will be complete in 2004.

Rotational Sensitivity

ASTM E-1709 specifies two general types of sign retroreflectometers: point instruments and annular instruments,(62) and defines them as follows:

> *The instrument may be either a "point instrument" or an "annular instrument," depending on the shape of the receiver aperture. Point and annular instruments make geometrically different measurements of retroreflectivity, which may produce values differing on the order of 10 percent. Both measurements are valid for most purposes, but the user should learn the type of his instrument from its specifications sheet and be aware of certain differences in operation and interpretation. For both instrument types, the "up" position should be known. The point instrument makes a measurement virtually identical to a measurement made on a range instrument following the procedure of Test Method E 810…The annular instrument*

makes a measurement similar to an average of a great number of measurements on a range instrument with presentation angle (γ) varying between -180E and 180E.

Additionally, ASTM E-1709 includes the following information regarding rotational sensitivity. Glass bead sheetings tend to be rotationally insensitive. Therefore, point and annular instruments should produce similar retroreflectivity values for these sheetings. The values for prismatic sheeting are rotationally sensitive, and the values produced by point and annular instruments can differ on the order of 10 percent, with differences of up to 25 percent possible. Neither the magnitude nor the direction of difference can be predicted for unknown samples. Annular instruments cannot accurately gauge how the retroreflectivity of prismatic sheeting varies with rotation angle. Most prismatic retroreflectors are rotationally sensitive, having retroreflectivity values that vary significantly with rotation angle, even at small entrance angles.

A point instrument can gage the variation of retroreflectivity with rotation angle by placing it with different angular positions upon the sign face; variation of 5 percent for 5 degrees rotation is not unusual. Accordingly, repeatable retroreflectivity measurement of prismatic signs with a point instrument requires care in angular positioning.

To demonstrate the impacts of rotational sensitivity, consider the retroreflectivity measurements shown in figure 7. Here, retroreflectivity measurements were made with an annular retroreflectometer in 15-degree intervals from 0 degrees to 360 degrees. The measurements were made on various prismatic sheetings and on one beaded sheeting. Additionally, measurements were made on an unweathered control sample and a sample that had weathered approximately 3 years at a 45-degree orientation and facing south.

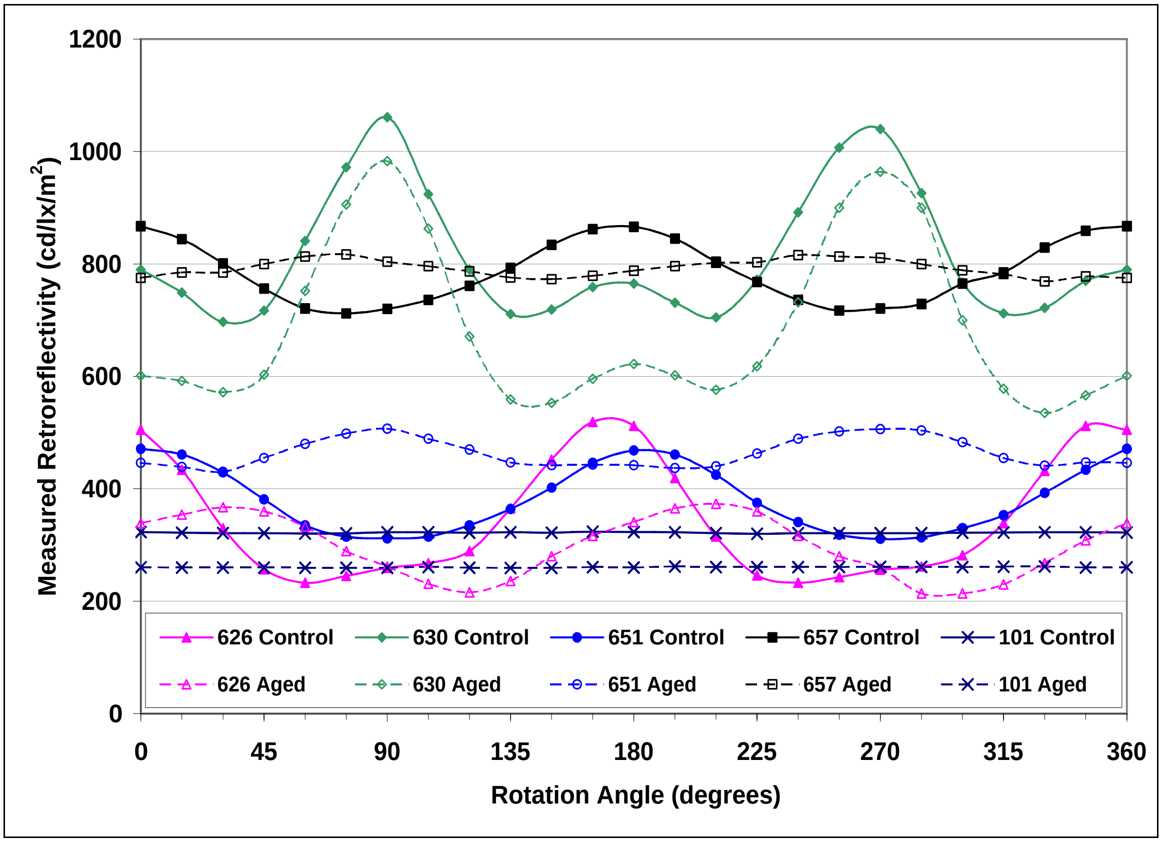


Figure 7. Rotational Sensitivity of Four Types of Retroreflective Sheeting Materials

Figure 7 clearly demonstrates the rotational sensitivity of certain microprismatic retroreflectivity sheeting materials. The sample labeled 101 is beaded sheeting (white Type III encapsulated). The other materials are all microprismatic. Tables 29 and 30 were developed with the data from figure 7 to better demonstrate the actual rotational sensitivity of these materials.

Table 29. Rotational Sensitivity of Unweathered Materials

Sample #	Description	Average R_A^*	Standard Deviation	Coef. of Variation	Minimum	Maximum	Ratio (Max/Min)
101	White Type III (Beaded)	322	1	0.003	320	324	1.01
626	Fluor. Orange Type VII	348	106	0.30	233	519	2.23
630	White Type VII	813	112	0.14	697	1061	1.52
651	Orange Type III (prismatic)	382	59	0.16	311	471	1.51
657	White Type VIII	788	56	0.07	712	867	1.22

Table 30. Rotational Sensitivity of Weathered Materials

Sample #	Description	Average RA	Standard Deviation	Coef. of Variation	Minimum	Maximum	Ratio (Max/Min)
101	White Type III (Beaded)	260	1	0.003	259	262	1.01
626	Fluor. Orange Type VII	298	54	0.18	214	373	1.74
630	White Type VII	686	145	0.21	535	983	1.84
651	Orange Type III (prismatic)	464	26	0.06	430	507	1.18
657	White Type VIII	792	15	0.02	769	817	1.06

The coefficient of variation (CV) is a measure of the dispersion and could be considered a method of normalizing the standard deviation. It is one of the best measures of rotational sensitivity. For example, a standard deviation of 50 could be considered small if the mean were 700 (CV = 0.07), but reasonably large if the mean were 250 (CV = 0.20). A low CV means that the material is rotational insensitive.

It is clear that, as indicated in ASTM E-1709, there is little rotational sensitivity with the beaded material (CV = 0.003). However, for the microprismatic materials, the CV value depends on the type of prismatic sheeting. Furthermore, the relative CV value changes depending on the type of microprismatic material and whether it was weathered. Additionally, the ratio between the minimum and maximum measured retroreflectivity is more than 200 percent for one of the samples. Obviously, this level of sensitivity will have implications when the updated MR levels are implemented.

From a practical point of view, researchers have demonstrated that the sensitivity of the orientation angle, ω_s, was prominent only when vehicles were located 100 ft from the microprismatic retroreflective targets.[63] At 100 ft, when the datum axis of the microprismatic materials was changed (ωs...0) via the orientation angle, the performance of the sheeting degraded, in some instances significantly. However, at further distances of 300, 500, and 800 ft the degradation was small to negligible.

The study mentioned above is currently analyzing the impacts of rotational sensitivity of the currently available retroreflectometers. This study is also investigating how rotational sensitivity depends on the various types of retroreflective sheeting materials.

Uniform Degradation

Figure 7 provides some early insight into the nonuniform degradation that some microprismatic retroreflective sheeting materials demonstrate. For instance, while there appears to be uniform degradation of samples 630 and 101, the other three samples show shifts in the peaks and valleys of the retroreflectivity measurements. One of the main assumptions related to the development of the updated MR levels is that all retroreflective sheeting materials degrade uniformly over time. In others, as a specific product weathers and becomes less efficient, its retroreflective properties degrade uniformly across a range of observation and entrance angles.

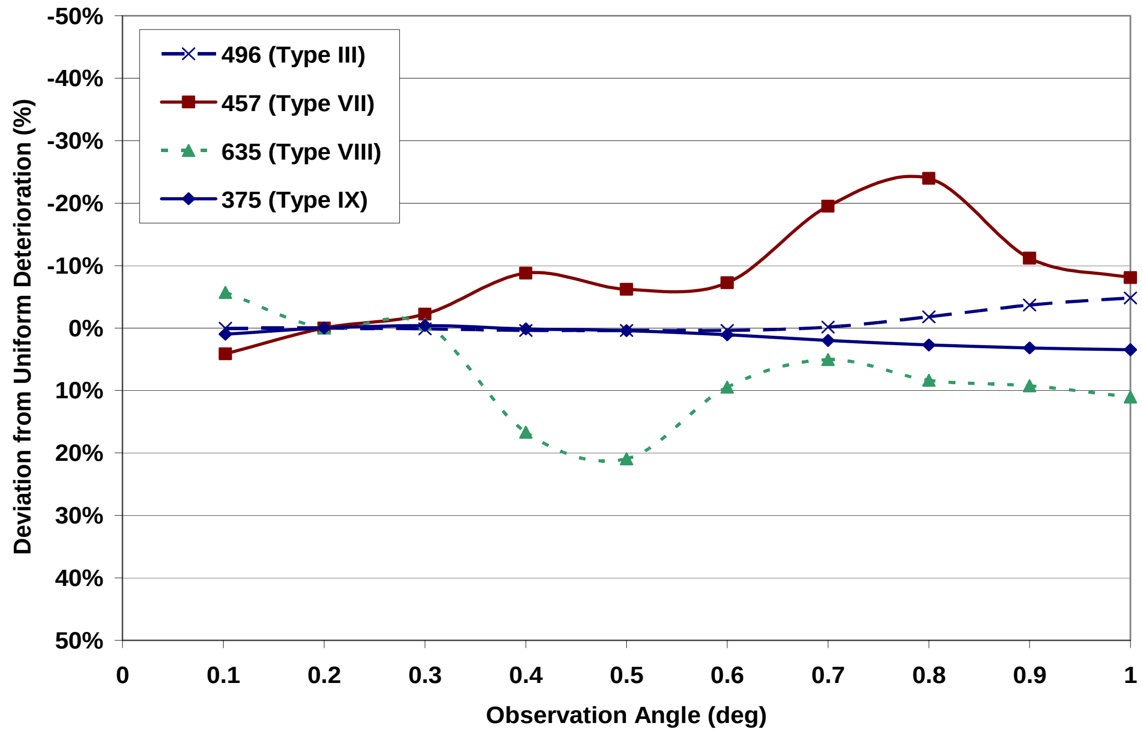
To test this assumption, the researchers obtained and measured 3-year Transportation Product Evaluation Program (NTPEP) panels (NTPEP weathers panels for a maximum of 3 years at a 45-degree orientation facing south). Table 31 includes a description of the panels and the measurements that were made at FHWA's Photometric/Visibility Lab.

Table 31. Description of NTPEP Panels Measured

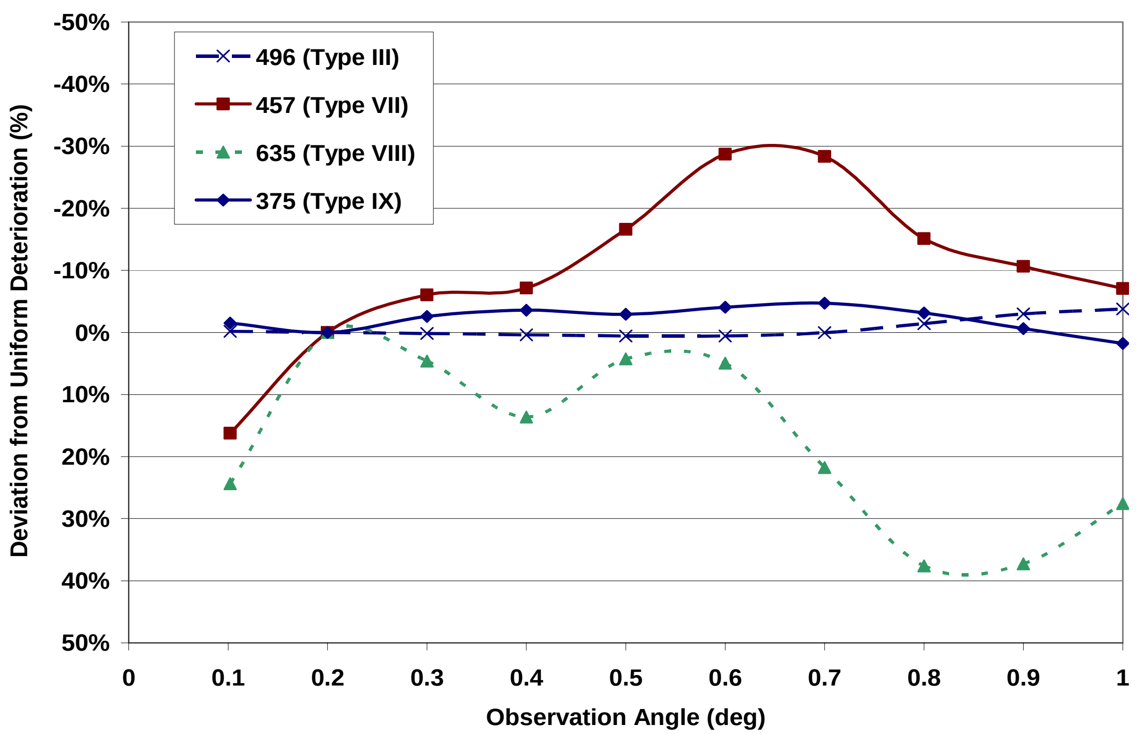
States	AZ, LA, VA
Color	White
Material	ASTM Types III, VII, VIII, IX
Control	Unweathered panels (one of each type)
Weathered	3 years facing south at 45 degrees (two of each type)
Measurements	Observation angle (α): 0.102, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0 Entrance angle (β2 = 0, β1): 4, 16, 30, 45 Epsilon (,): 0, 90

The practice of weathering panels at a southern orientation and at 45 degrees doubles the degradation rate compared to a standard vertically mounted sign. Therefore, the weathered panels have been effectively weathered for 6 years.

The results of the measurements and subsequent analyses showed that, as expected, the retroreflective sheeting made with glass beads degrades uniformly, but sheetings made with microsized prisms does not. Although the extent of the variations depends on the sheeting type and weathering location, for all sheetings the variation of degradation rate increases with increased observation and entrance angles. Figure 8 shows an example of the observation angle profiles obtained from the panels weathered in Louisiana.



a. Percent Degradation of Louisiana Panels, Beta = 4E



b. Percent Degradation of Louisiana Panels, Beta = 30E

Figures 8 a and b. Observation Angle Profiles as a Function of Weathering

Figure 8 shows that further weathering and subsequent analyses are needed. Because weathering takes time, an efficient way to obtain weathered data beyond 3 years would be to continue weathering the NTPEP panels (which have been stored in such a manner to prevent further degradation). However, several caveats are introduced by using the spent NTPEP samples. For instance, some panels may have been stored in ideal conditions while others may not. Because of the timing of when various materials were installed on the NTPEP panels, there may be a need to use some materials that have been in storage for a few years while other materials may be just coming off the NTPEP racks.

FUTURE WORK

While significant progress has been made in the past 20 years regarding the nighttime visibility requirements of traffic signs, there is a need for additional research. The following research topics, which are based on the assumptions and limitations associated with the proposed MR levels, are recommended by the research team.

- There is no direct link between MR levels and safety in terms of reduced crashes. There is even a void in the research related to identifying relationships between retroreflectivity and crash surrogates. Research is critically needed to develop a link between retroreflectivity and safety.
- Research is needed that identifies a set of retroreflective sheeting material measurement geometries that better represent the driving task. Such an effort would preferably lead to a more meaningful classification scheme than that used herein (the classification defined in ASTM D-4956-01a was used for this paper).
- A more recent study regarding the economic impacts of the MR levels needs to be completed. The last one was completed in 1998; however, many of the factors that were considered have either changed drastically or are no longer valid.(12)
- In order for transportation agencies to choose or design an efficient process that reasonably satisfies the MR levels, research needs to identify and develop methods to manage nighttime sign visibility. Research should also investigate new technologies or procedures to measure nighttime visibility such as the development of an on-the-fly sign luminance van.
- A carefully formulated study is needed to validate the MR levels from a driver's point of view; it would provide the first direct validation of the MR levels.
- Research is needed to better identify the contrast needed for iconic signs such as most white-on-red signs (STOP or DO NOT ENTER). Research is also needed to develop MR levels for other sign colors such as blue and brown.
- Research is needed to better understand the impacts of using different sized signs, horizontal and vertical curves, large trucks, glare source, various levels of ambient lighting, and various levels of background complexities.
- Research should address the implications of using various combinations of retroreflective sheeting materials on positive-contrast signs, for example, guide signs fabricated with legends made with microprismatic retroreflective materials on backgrounds made with high-intensity retroreflective materials.

Long-term weathering research is needed to determine the validity of the uniform degradation assumption (over a practical range of observation angles). This research should also address the performance of retroreflective sheeting relative to the rotational aspects of retroreflectivity measurements made with point-source instruments.

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APPENDIX A. AASHTO POLICY RESOLUTION

The following retroreflectivity resolution was passed by the AASHTO Board of Directors at its Annual Meeting in December 2000.

AASHTO POLICY RESOLUTION
MINIMUM LEVELS OF RETROREFLECTIVITY FOR SIGNS AND PAVEMENT MARKINGS

WHEREAS, the American Association of State Highway and Transportation Officials (AASHTO) is aware of the congressional mandate for the Secretary of Transportation to revise the Manual on Uniform Traffic Control Devices to include a standard for the minimum level of retroreflectivity that must be maintained for pavement markings and signs, which shall apply to all roads open to public travel, and

WHEREAS, AASHTO concurs that it is desirable to maintain an adequate level of retroreflectivity for both traffic signs and pavement markings to enhance safety for motorists during hours of darkness and during adverse weather conditions, and

WHEREAS, AASHTO is concerned about additional liability for transportation agencies if the Federal Highway Administration (FHWA) establishes the proposed minimum levels of retroreflectivity, and

WHEREAS, AASHTO greatly appreciates the opportunity afforded by FHWA to consider recommendations from AASHTO prior to publishing proposed rule making for MR for both signs and pavement markings;

THEREFORE, AASHTO established a “Task Force on Retroreflectivity Guidelines” composed of members from federal, state, and local transportation agencies, and from several transportation and industry associations, and has studied the various issues and produced a report with recommendations; and

THEREFORE, BE IT RESOLVED that based upon the findings and recommendations of the Task Force, AASHTO agrees that:

- It is desirable to assure adequate night visibility of traffic signs.
- Regular assessments of the adequacy of retroreflectivity or the planned replacements of signs to assure adequate night visibility is necessary.

BE IT FURTHER RESOLVED that efforts to assure adequate night visibility should not impose undue burdens on highway agencies, and to that end, AASHTO recommends that FHWA consider the following:

1. The minimum requirements need to be presented in a simple and unambiguous format to assure that they can be easily and properly applied.

2. Tables defining MR requirements should not appear in the MUTCD to help protect agencies from unnecessary tort liability.
3. Alternative methods to assess night visibility need to be fully developed.
4. Agencies should have the option to select the methods or combination of methods best suited to their needs and resources.
5. Agencies should have a 6-year period to implement methods.

FURTHER, it should be noted that the AASHTO Task Force on Retroreflectivity Guides will evaluate forthcoming FHWA findings and recommendations relative to MR values for additional types of signs and for pavement markings as they become available, and will provide comments at that time.

FHWA editorial note:

The four methods in Number 4 in the resolution are for evaluation processes and are briefly described as follows:

1. *Measure sign retroreflectivity with instruments and compare to numeric values in tables.*
2. *Conduct nighttime sign inspections and compare sign legibility distances to distance values in a table.*
3. *Conduct nighttime sign inspections by trained observers that would know how to subjectively evaluate signs.*
4. *Knowing how long certain retroreflective materials last in a certain geographic area, replace signs on a schedule to insure replacement prior to the sign reaching the end of its service life.*

APPENDIX B. RAW DATA FROM MERCIER ET AL.

This appendix summarizes all of the sign visibility data collected by Mercier et al.[9] The complete set of data was never published and therefore is included here for documentation purposes. Table 32 provides a summary of the signs used in the study. The demand luminance results are shown in order following table 32.

Table 32. Description of Signs Used in Visibility Study

Sign Description	MUTCD Code	Sign Size (in)	Scaled Size (in)	Viewing Distance for 30 mph in feet [graph code]	Viewing Distance for 50 mph in feet [graph code]
Right Curve	W1-2R	30	15	165 [E1]	201 [A1]
Right Intersection	W2-2	30 36	15 18	165 [E2] 166 [F3]	200 [A2] 203 [B3]
NARROW BRIDGE	W5-2	30	15	165 [E3]	201 [A3]
RIGHT LANE ENDS	W9-1	30 36	15 18	165 [E4] 166 [F4]	201 [A4] 203 [B4]
Bicycle	W11-1	30 36	15 18	165 [E5] 166 [F5]	201 [A5] 203 [B5]
Pedestrian	W11-2	30	15	165 [F1]	201 [B1]
EXIT 25 MPH	W13-2	24	12	163 [F2]	200 [B2]
DO NOT PASS	R4-1	24	12	163 [G2]	200 [C2]
KEEP RIGHT	R4-7	24	12	185 [G3]	240 [C3]
NO RIGHT TURN	R3-1	24	12	163 [G4]	200 [C4]
ONE WAY	R6-1	36	18	166 [G5]	203 [C5]
STOP	R1-1	36	13	231 [H1]	608 [D1]
DO NOT ENTER	R4-1	30	10	253 [H3]	608 [D3]
Corning	D2-1	18	9	169 [H2]	206 [D2]
Gravity	D2-2	60	30	172 [H4]	208 [D4]
SPEED LIMIT 50	R2-1	24	12	165 [G1]	–

FIGURES 9–45. Comparison of Human Subjects' Performance Against Demand Luminance Predicted by CARTS Using 15 Different Signs

The graphs that follow show the luminance demand data for the signs listed. The graphs can be matched with the data in table 32 using the graph code in the last two columns of the table and in the titles of the graphs. The graphs were scanned out of a draft final report and some information was lost in the conversion. The *x*-axis shows subject age in years. The *y*-axis shows the log luminance in cd/m^2. The solid data points represent the demand luminance predicted by CARTS. The open points represent the subjects' performance.

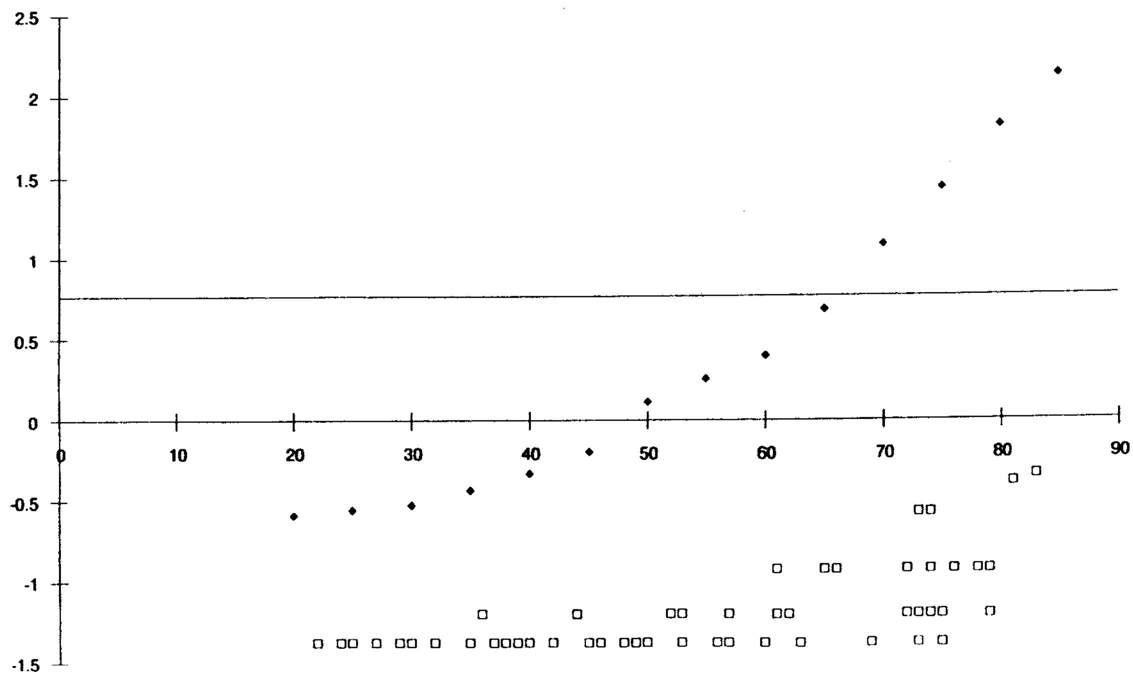

Figure 9. Right Curve (E1)

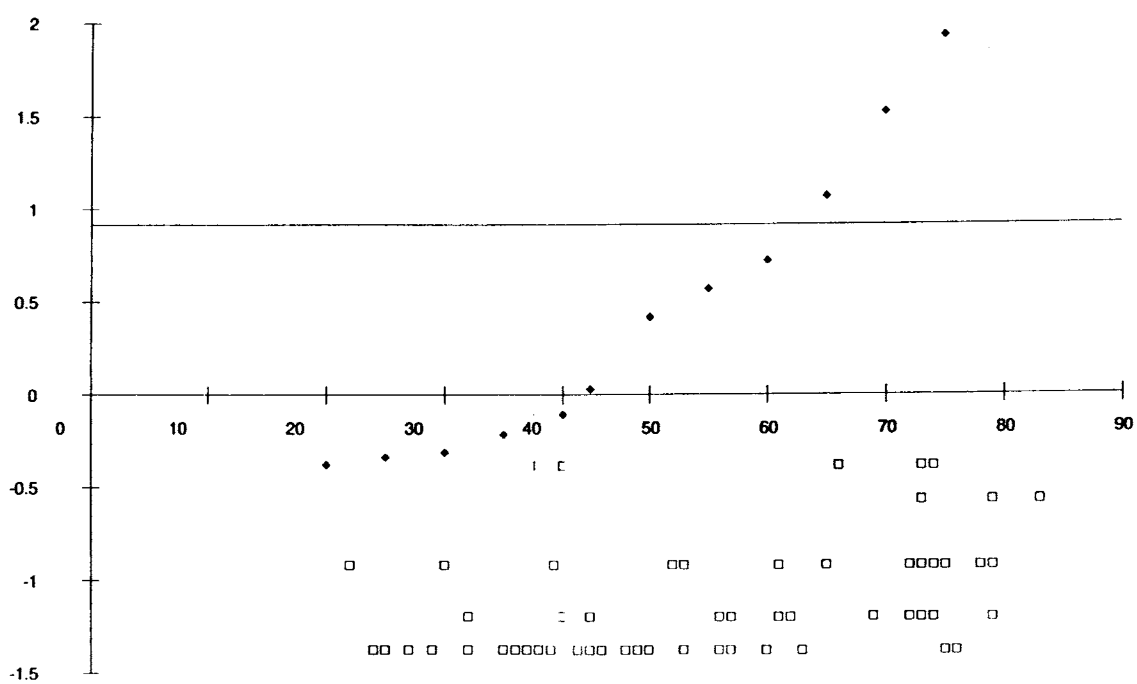

Figure 10. Right Curve (A1)

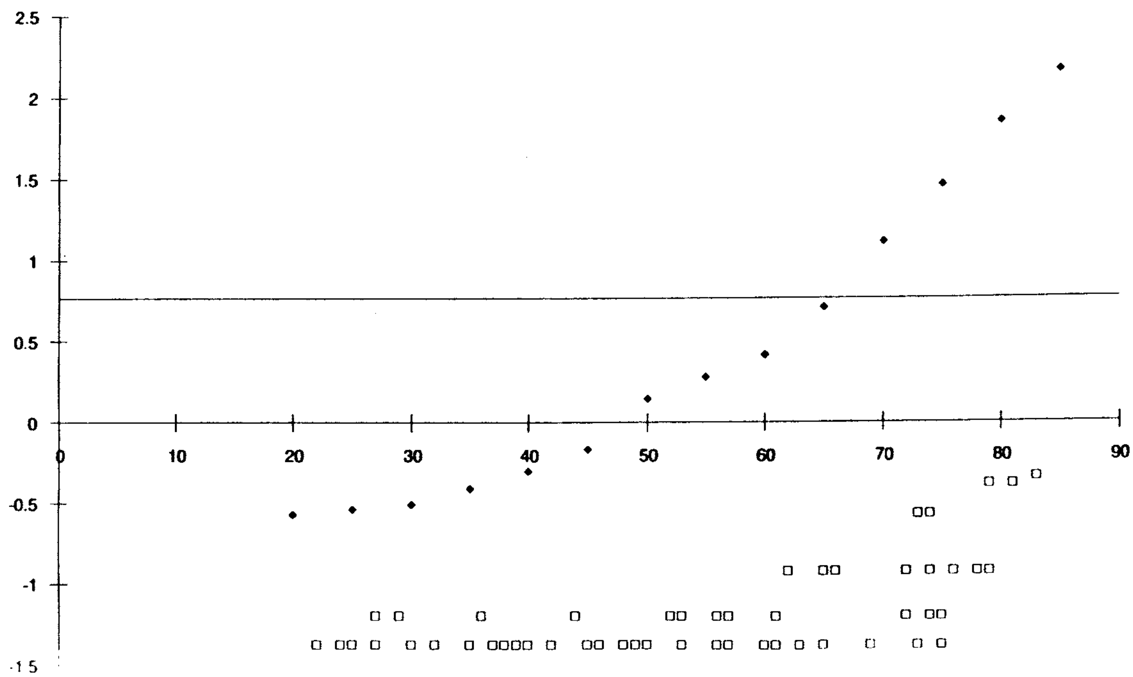

Figure 11. Right Intersection (E2)

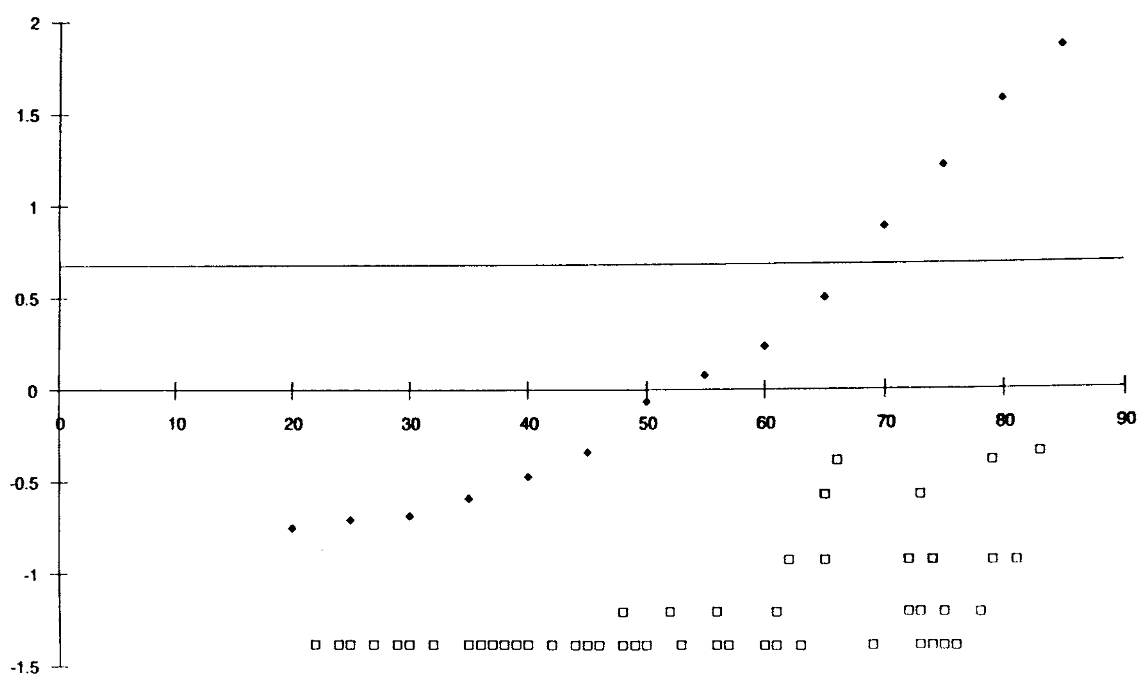

Figure 12. Right Intersection (F3)

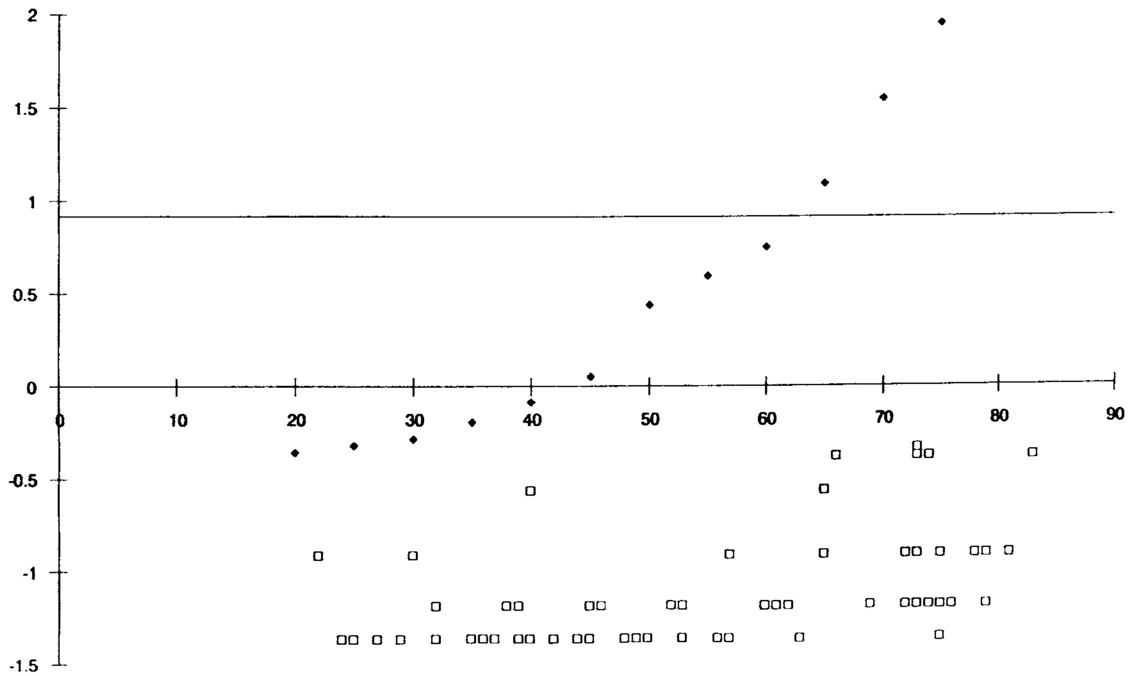

Figure 13. Right Intersection (A2)

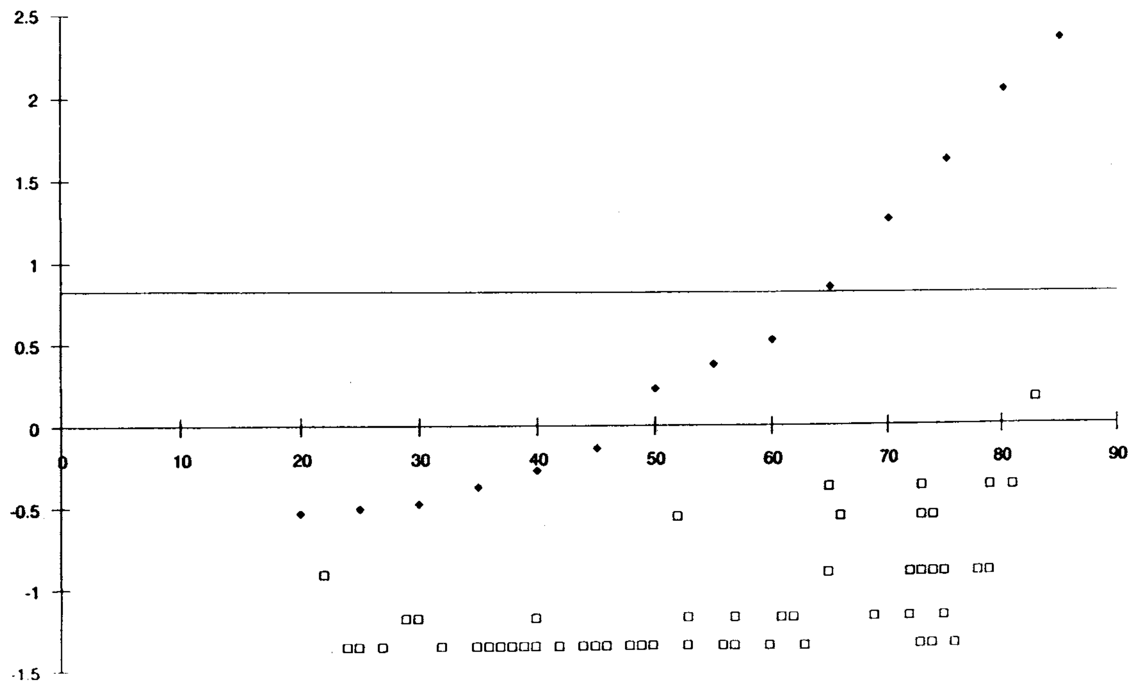

Figure 14. Right Intersection (B3)

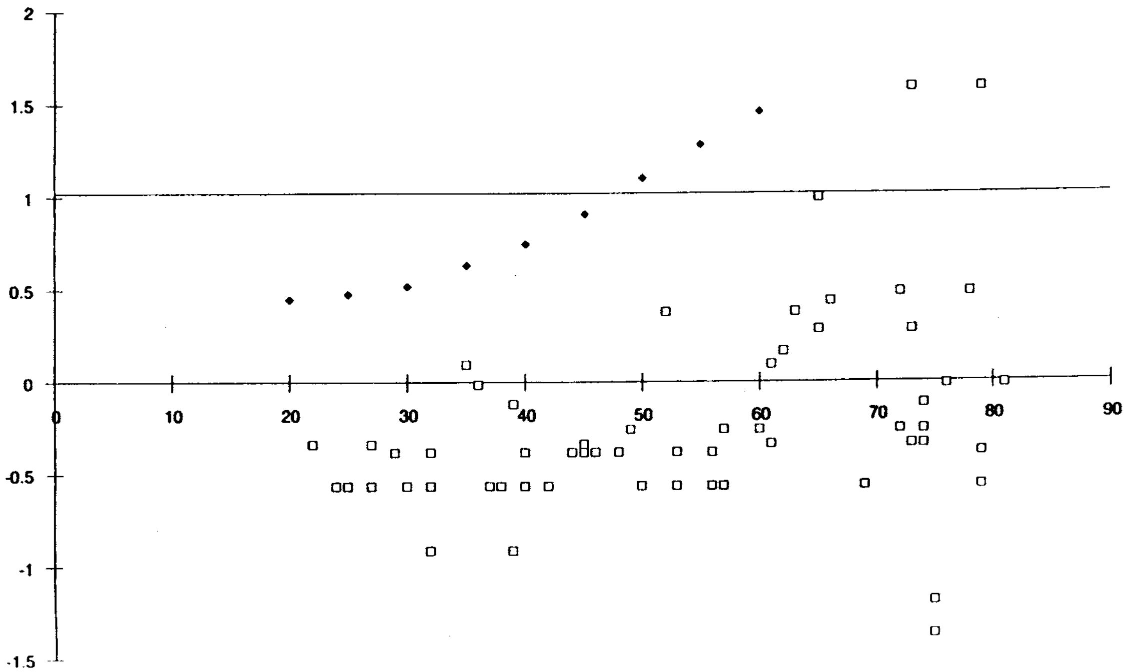

Figure 15. NARROW BRIDGE (E3)

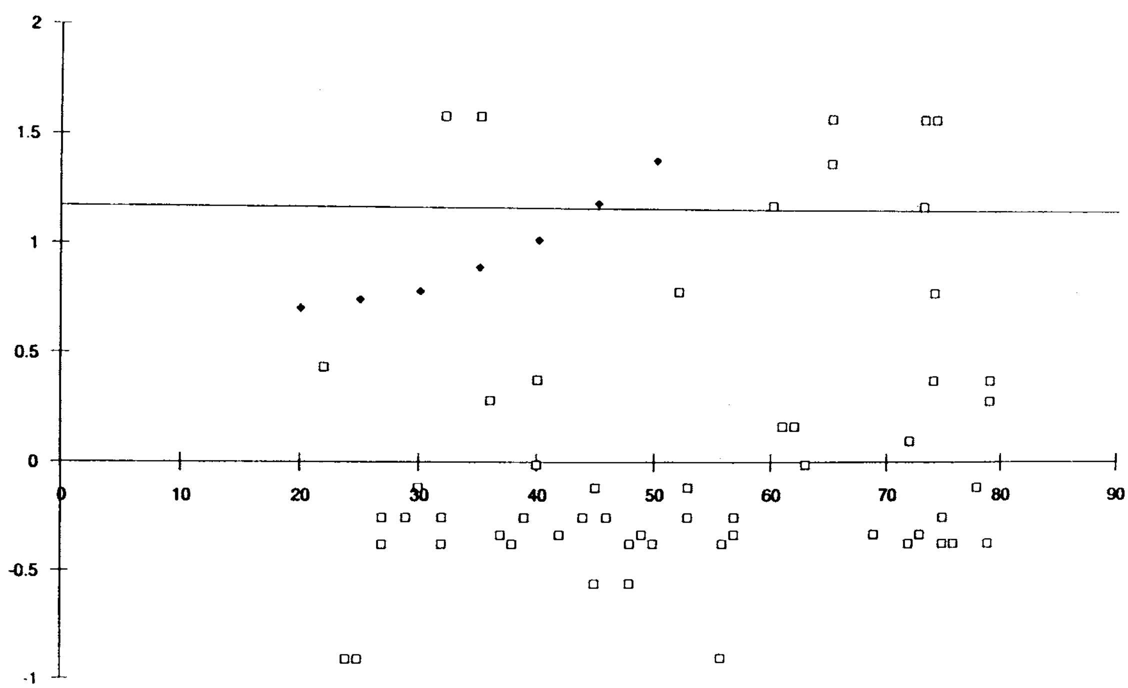

Figure 16. NARROW BRIDGE (A3)

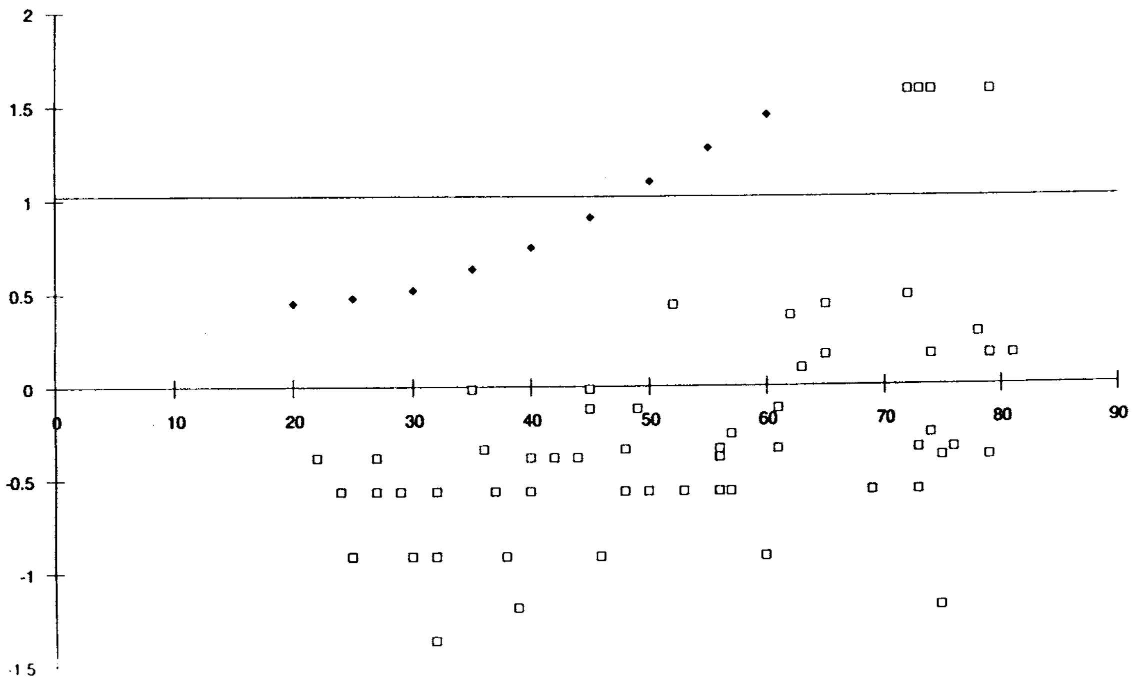

Figure 17. RIGHT LANE ENDS (E4)

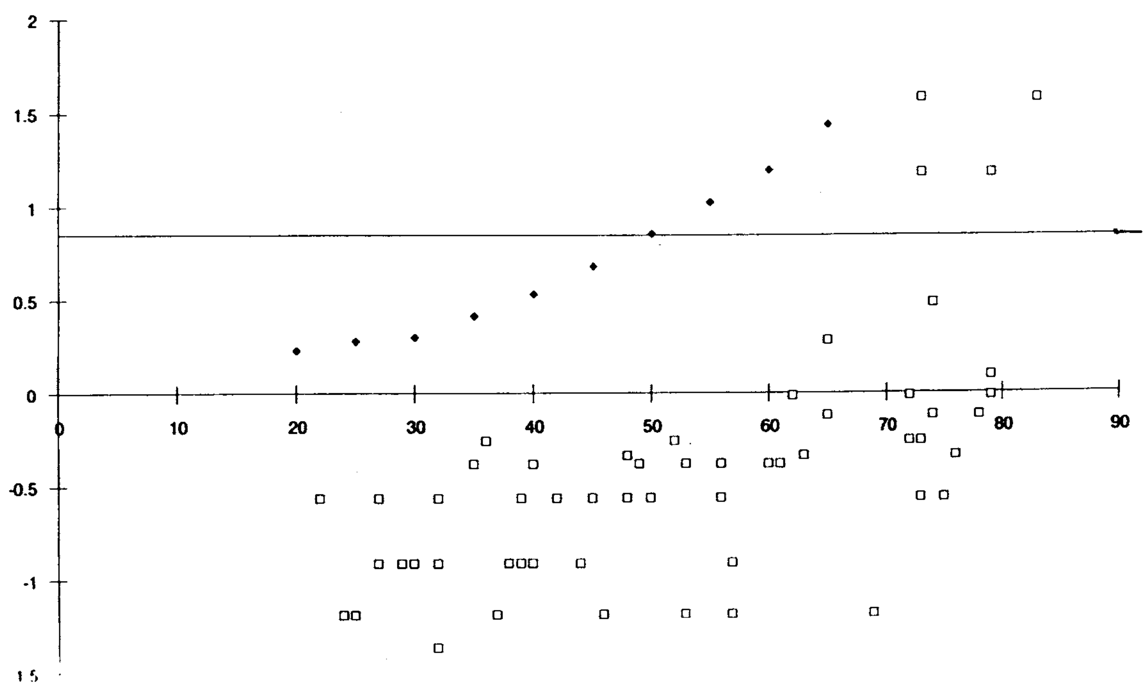

Figure 18. RIGHT LANE ENDS (F4)

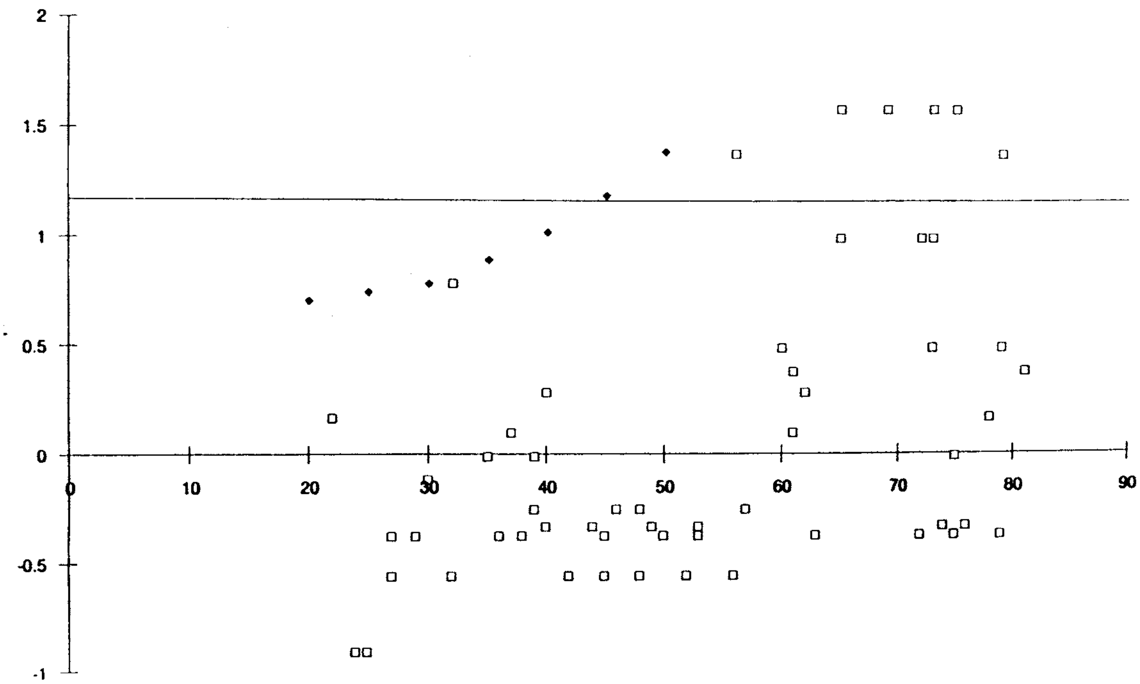

Figure 19. RIGHT LANE ENDS (A4)

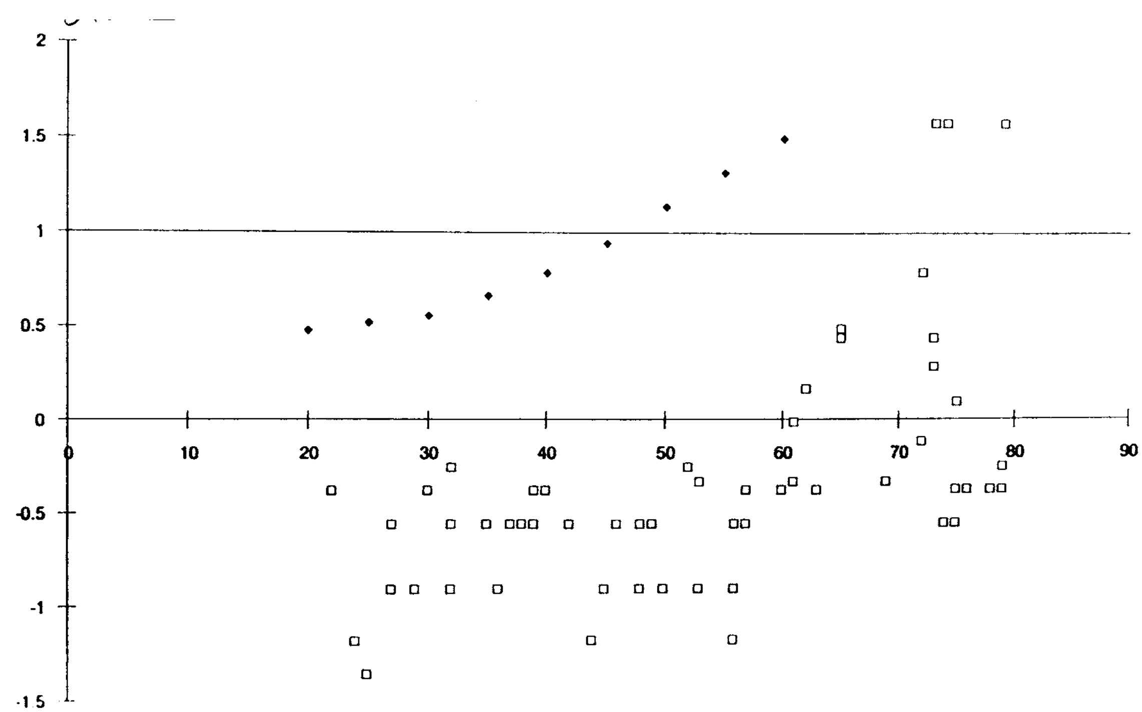

Figure 20. RIGHT LANE ENDS (B4)

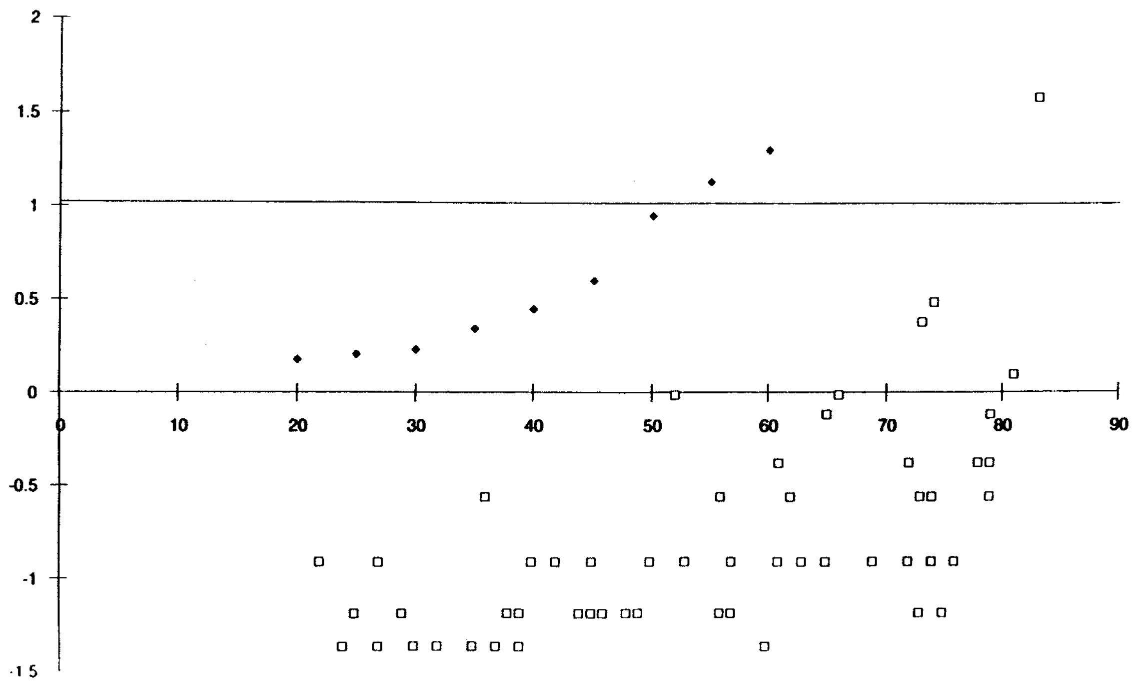

Figure 21. Bicycle (E5)

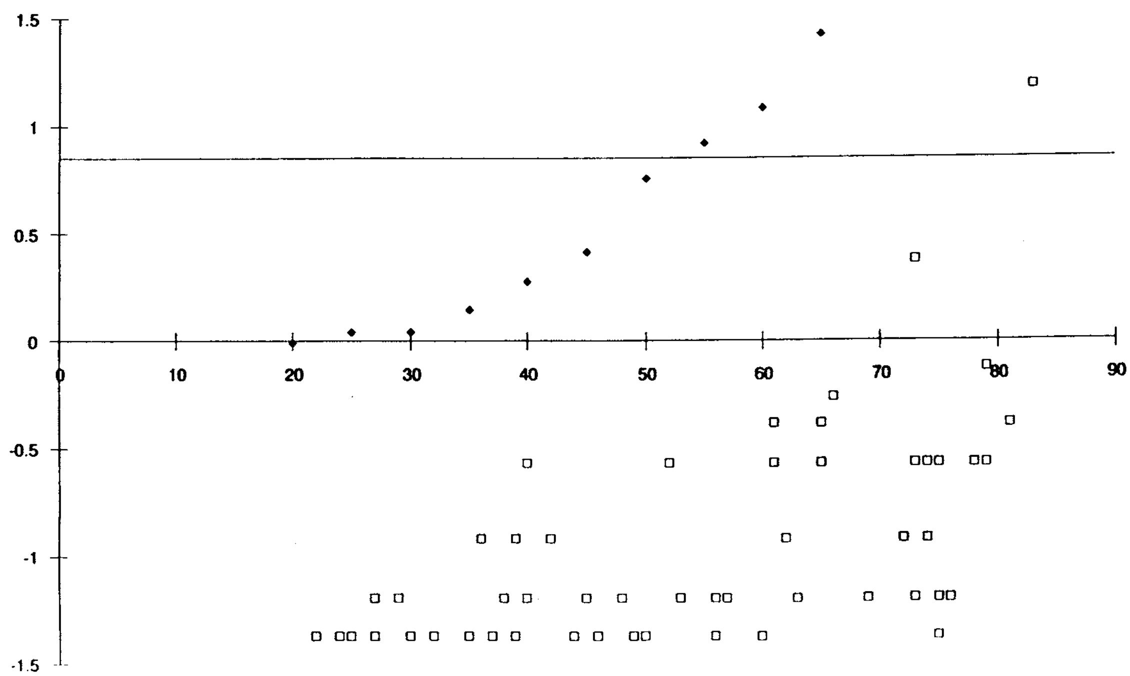

Figure 22. Bicycle (F5)

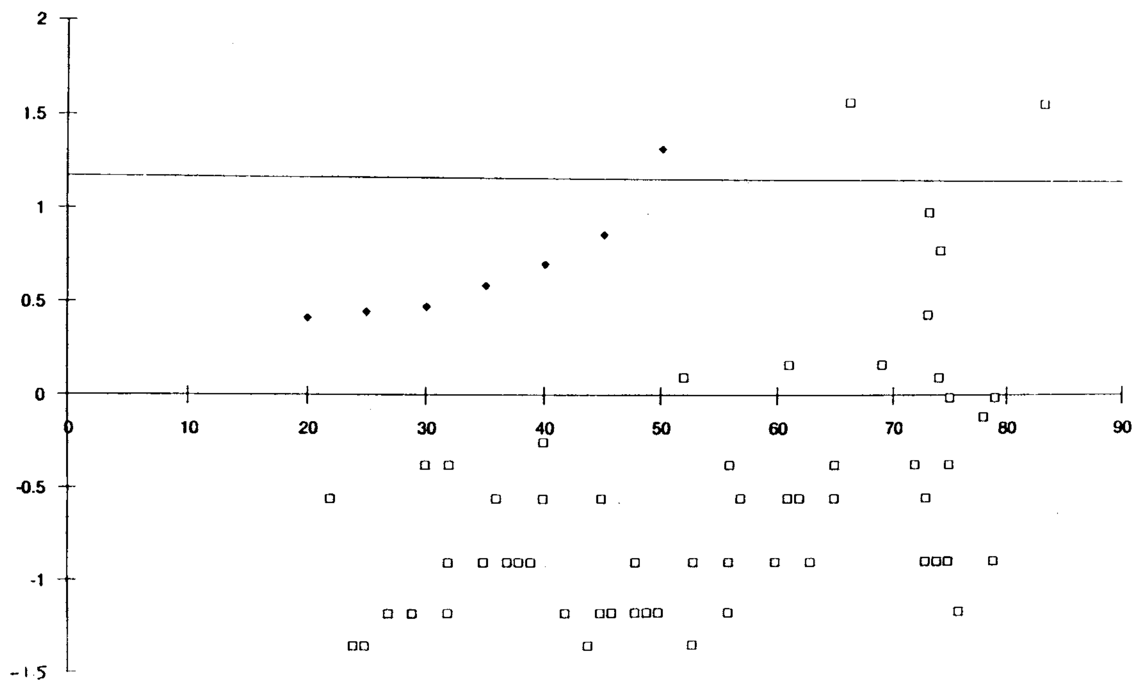

Figure 23. Bicycle (A5)

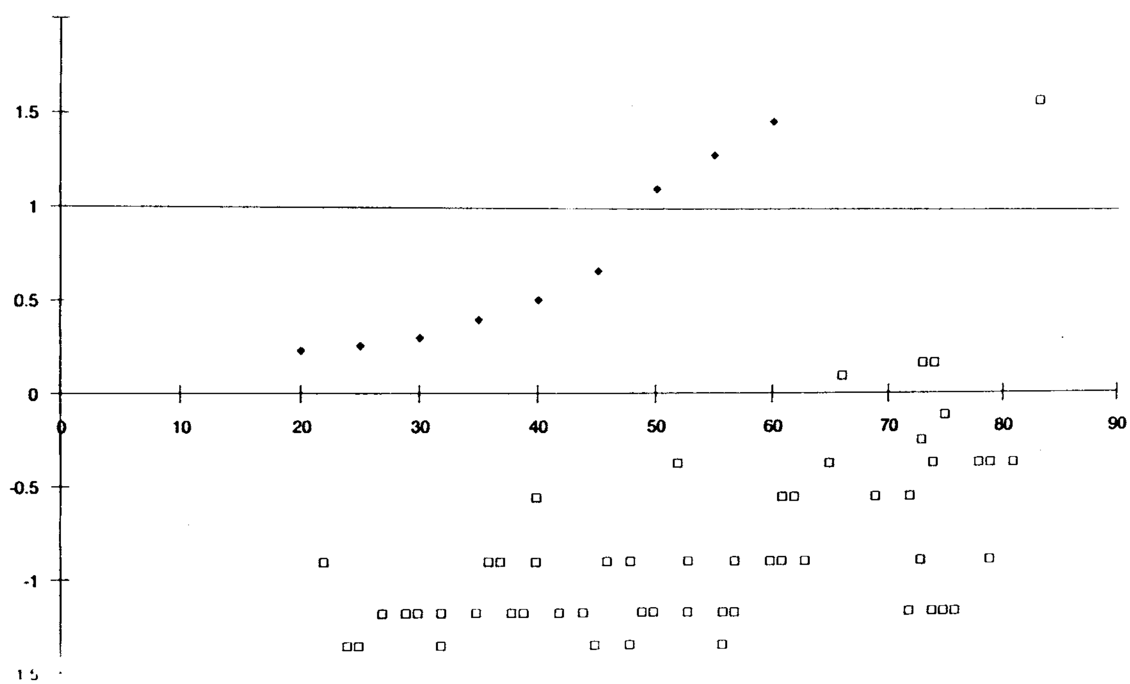

Figure 24. Bicycle (B5)

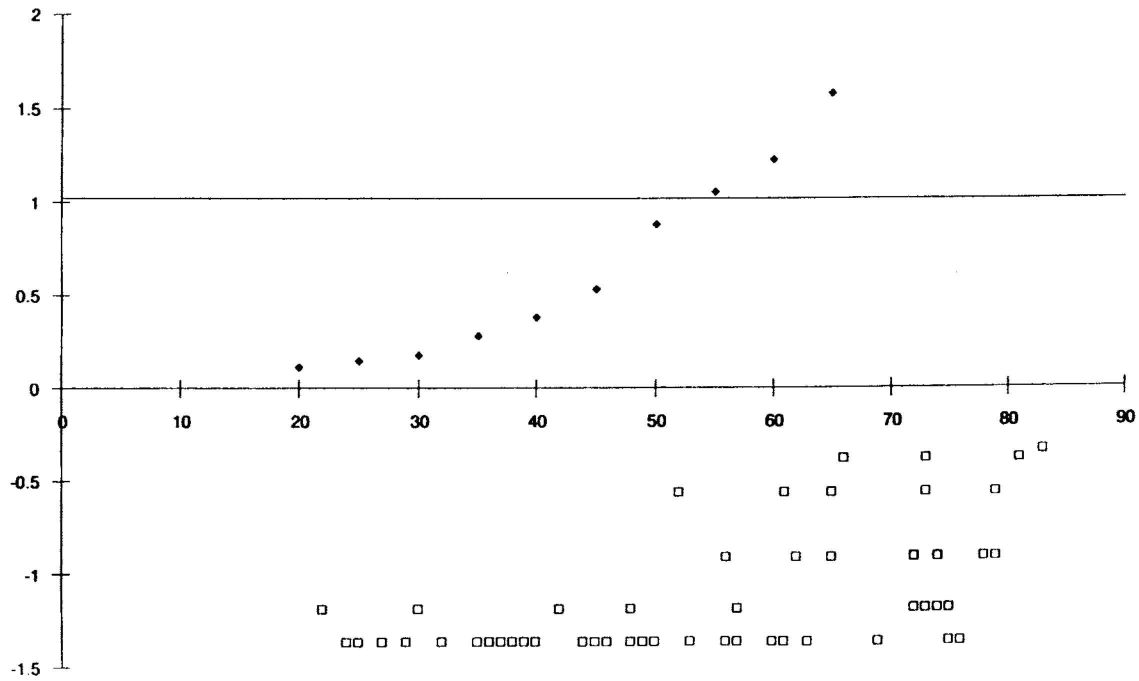

Figure 25. Pedestrian (F1)

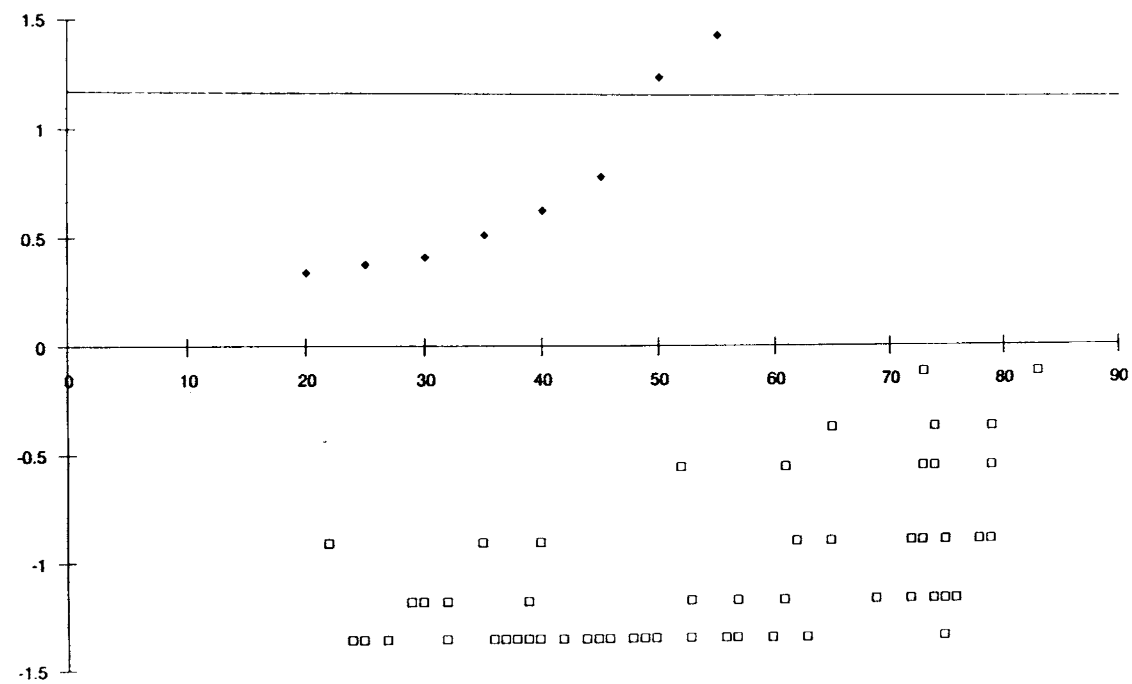

Figure 26. Pedestrian (B1)

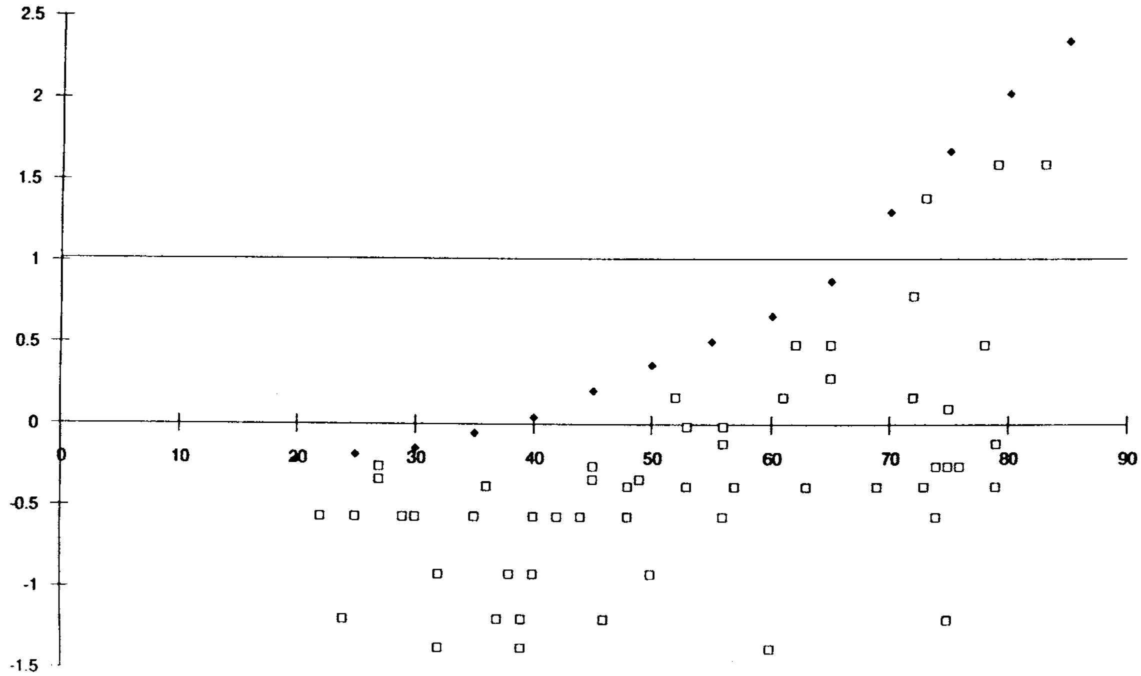

Figure 27. EXIT 25 MPH (F2)

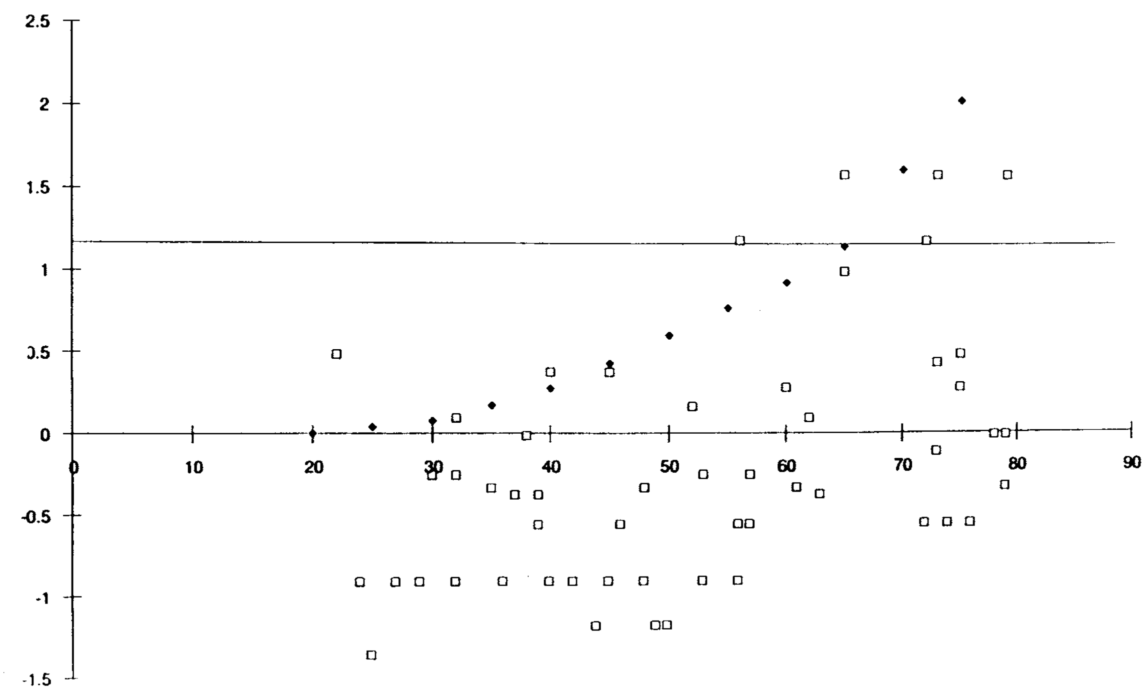

Figure 28. EXIT 25 MPH (B2)

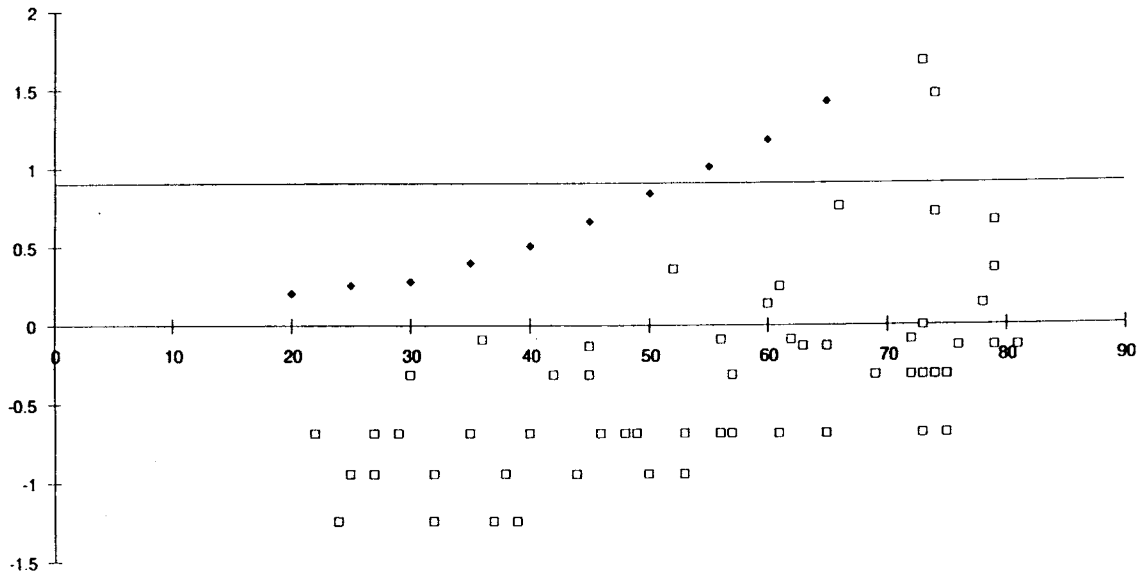

Figure 29. DO NOT PASS (G2)

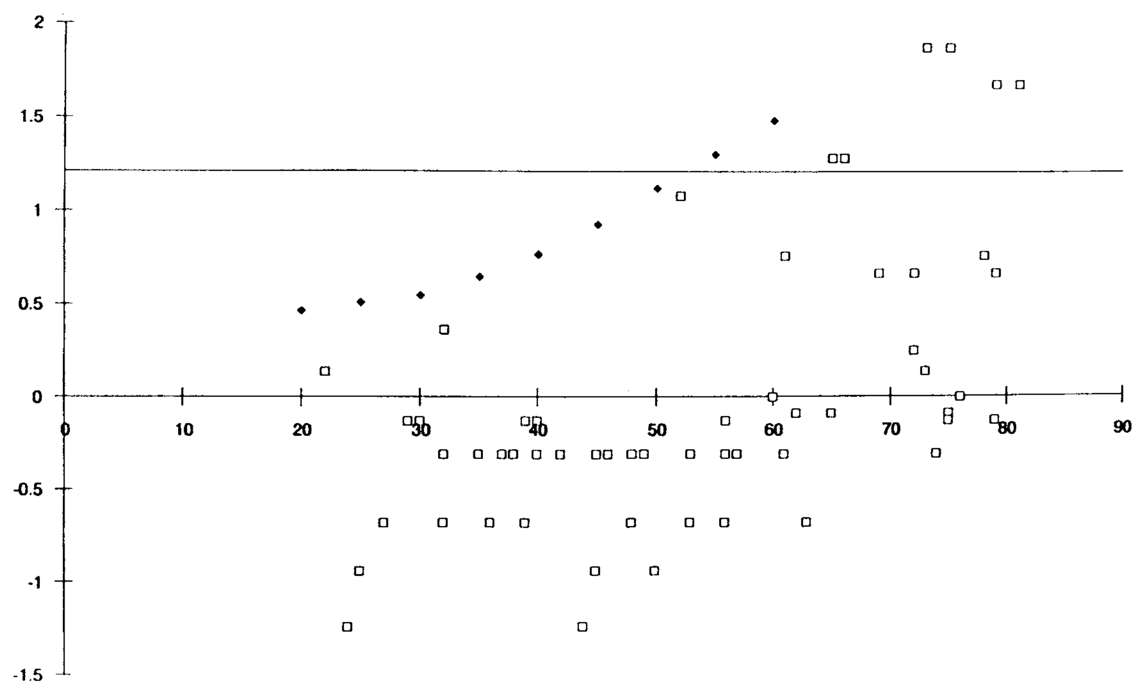

Figure 30. DO NOT PASS (C2)

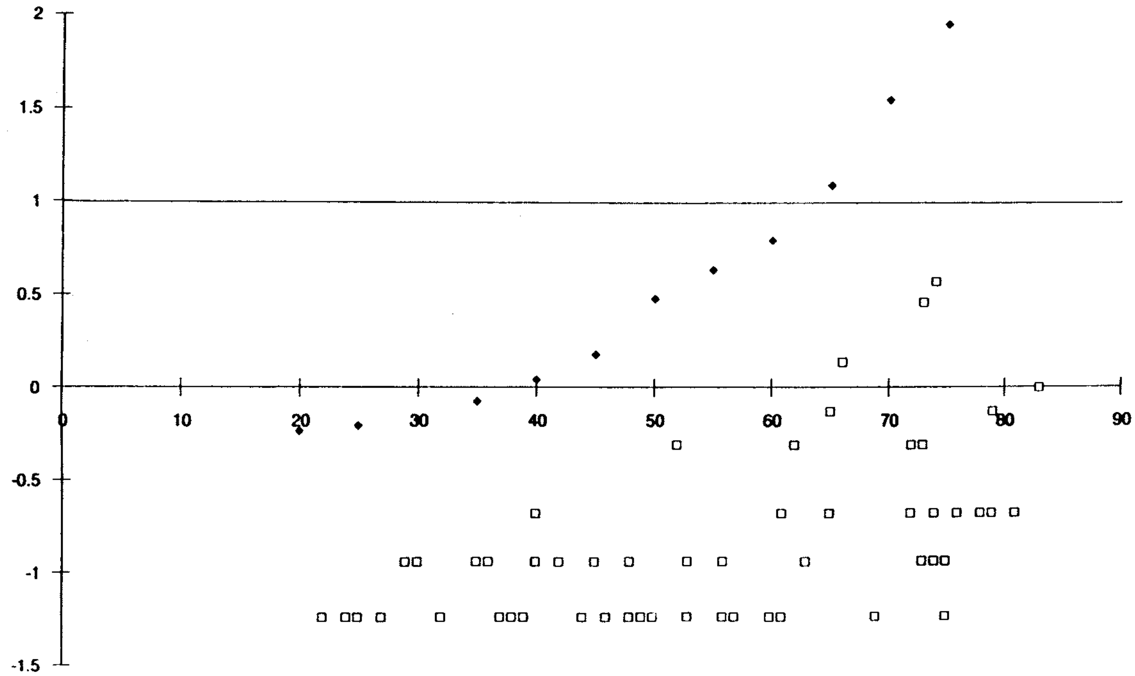

Figure 31. KEEP RIGHT (G3)

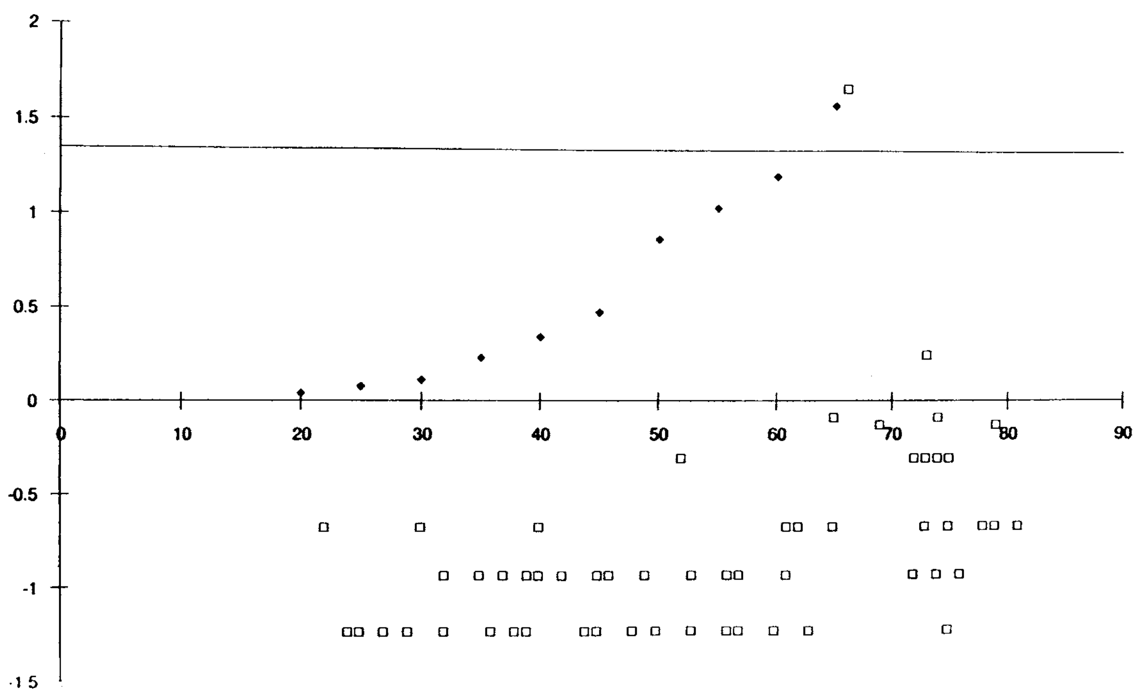

Figure 32. KEEP RIGHT (C3)

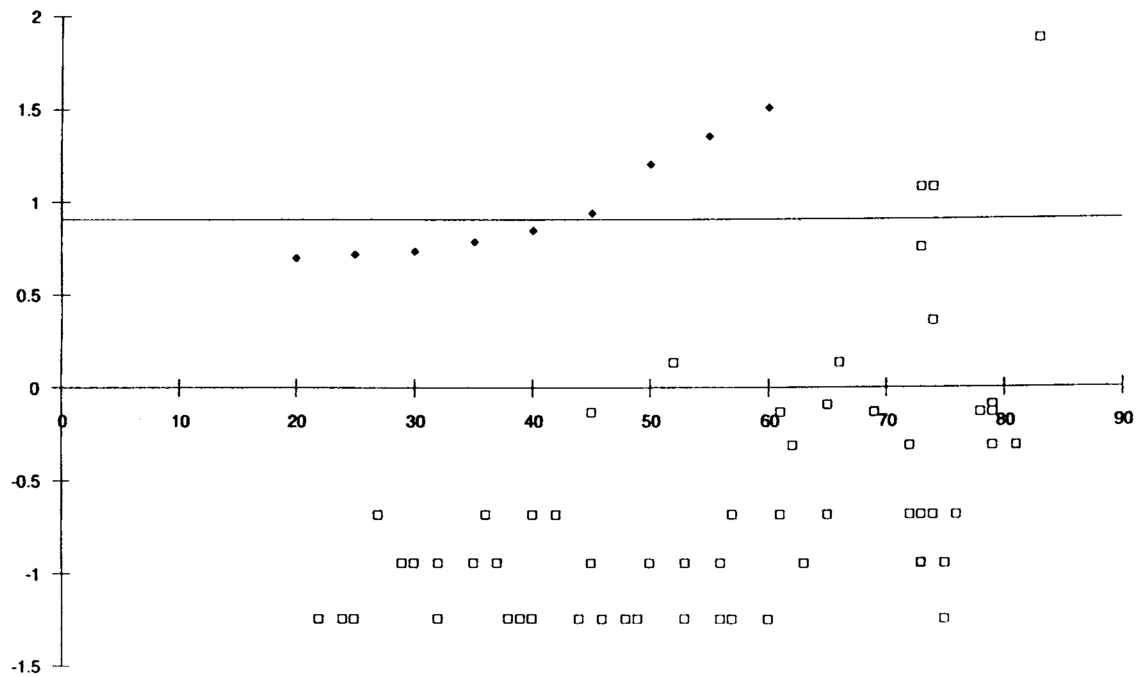

Figure 33. NO RIGHT TURN (G4)

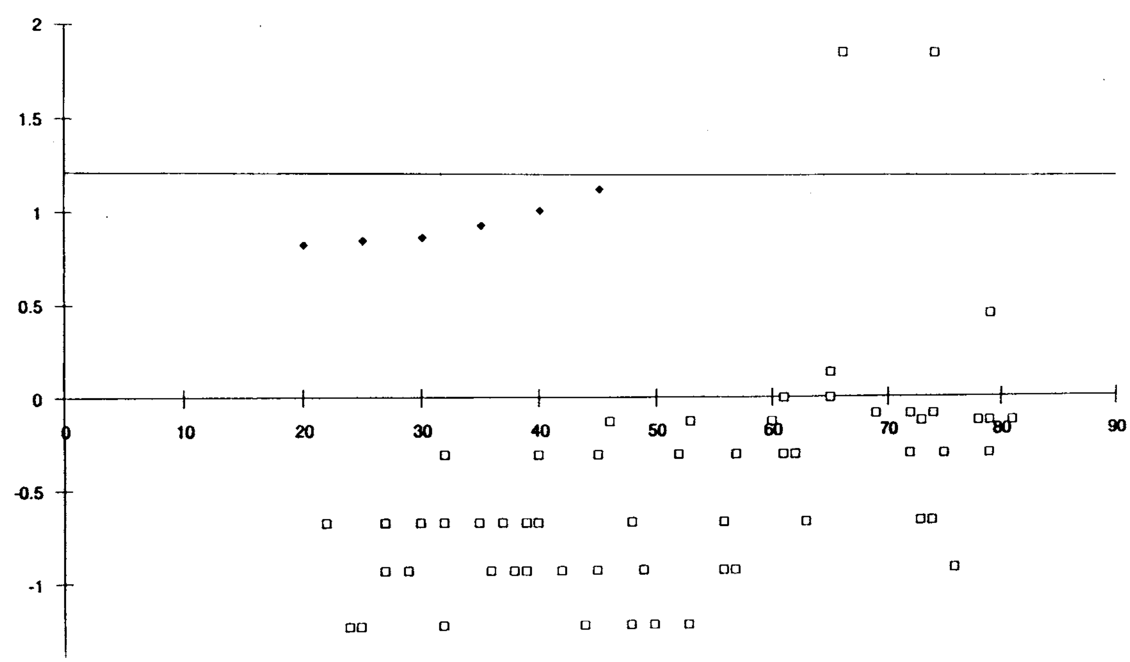

Figure 34. NO RIGHT TURN (C4)

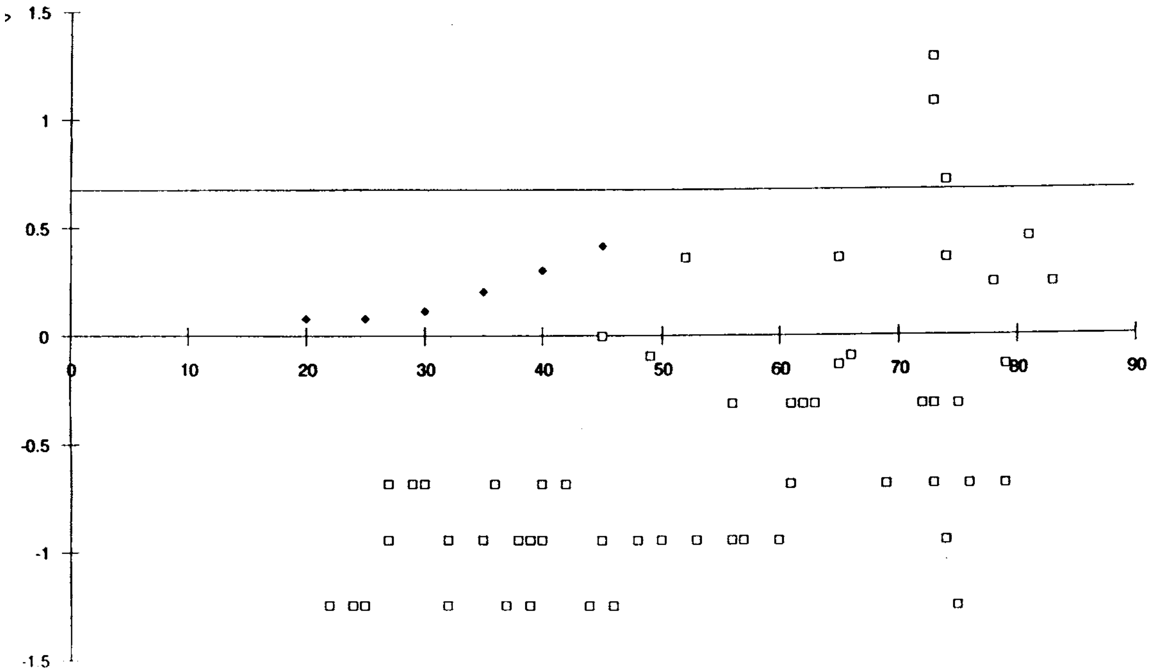

Figure 35. ONE WAY (G5)

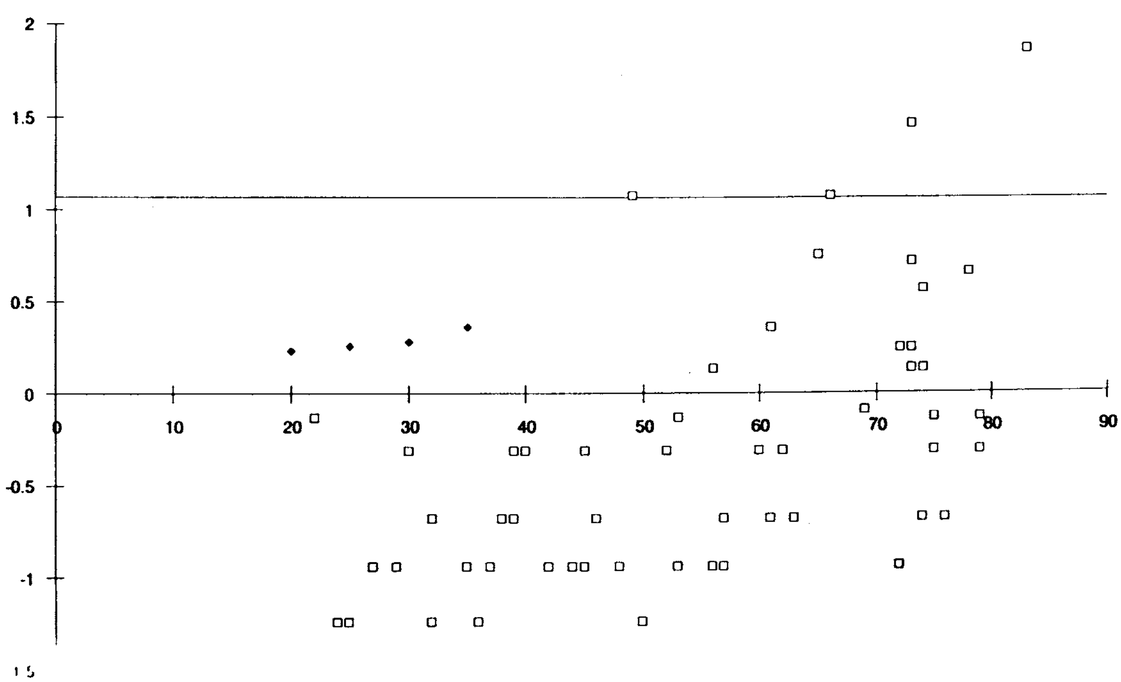

Figure 36. ONE WAY (C5)

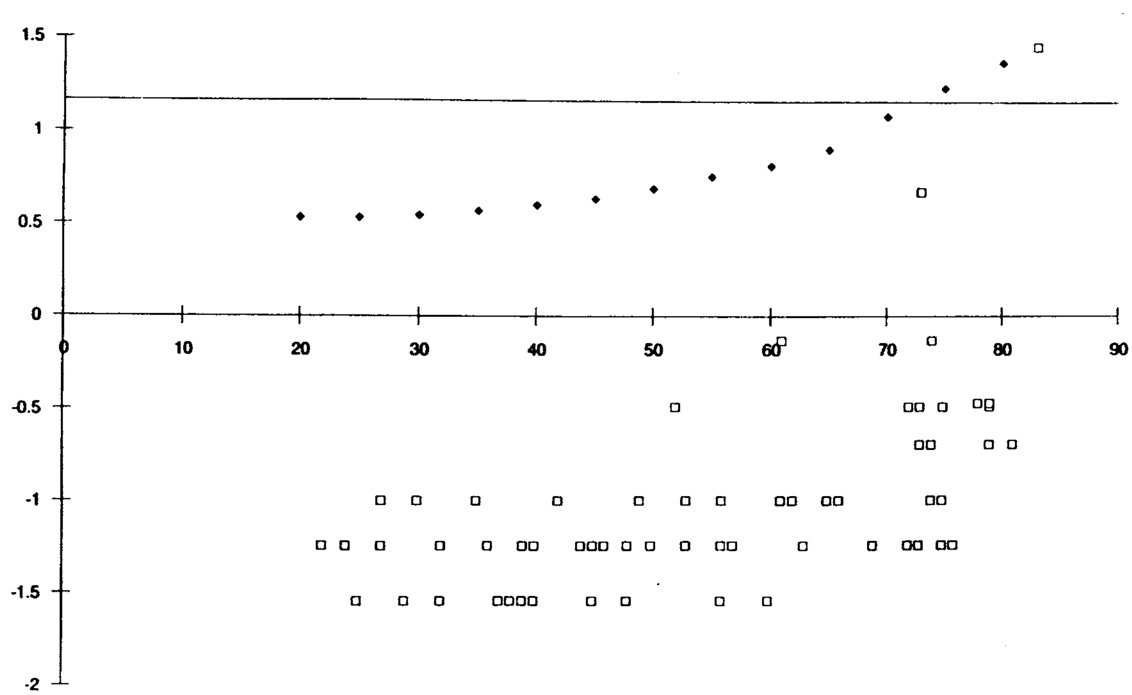

Figure 37. STOP (H1)

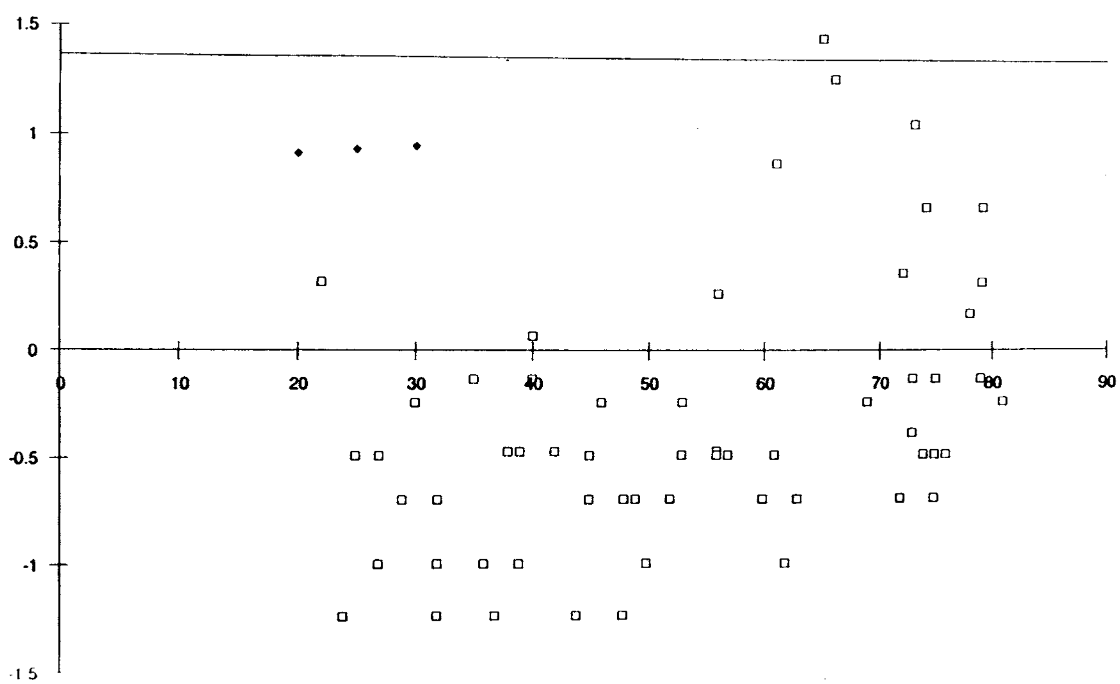

Figure 38. STOP (D1)

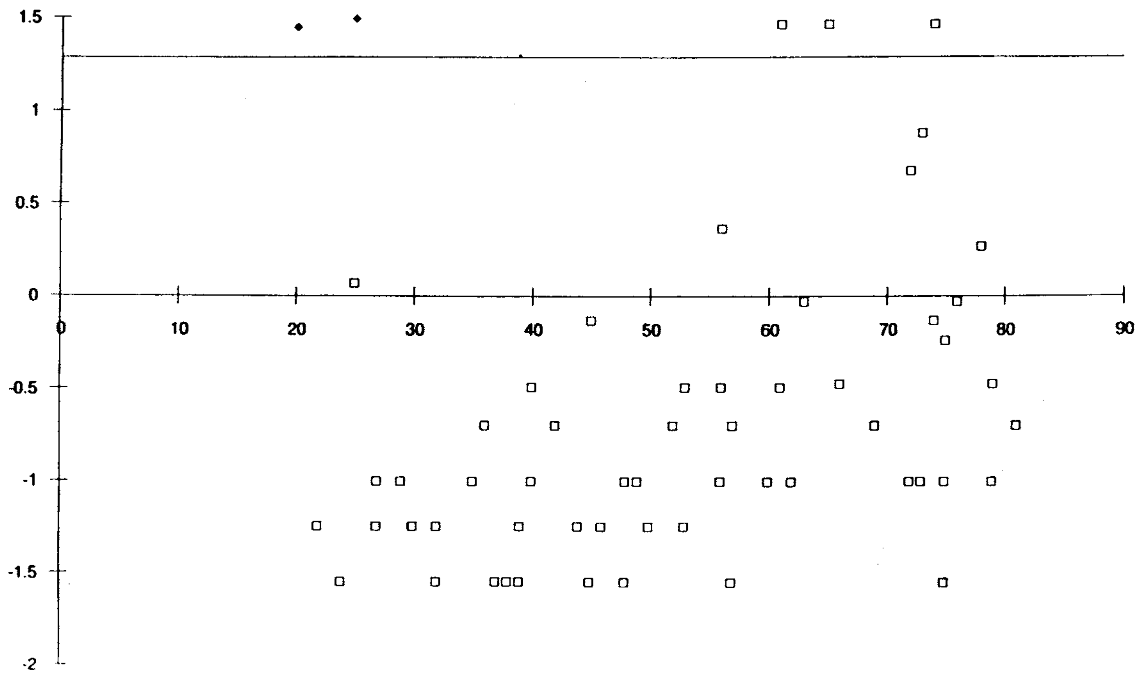

Figure 39. DO NOT ENTER (H3)

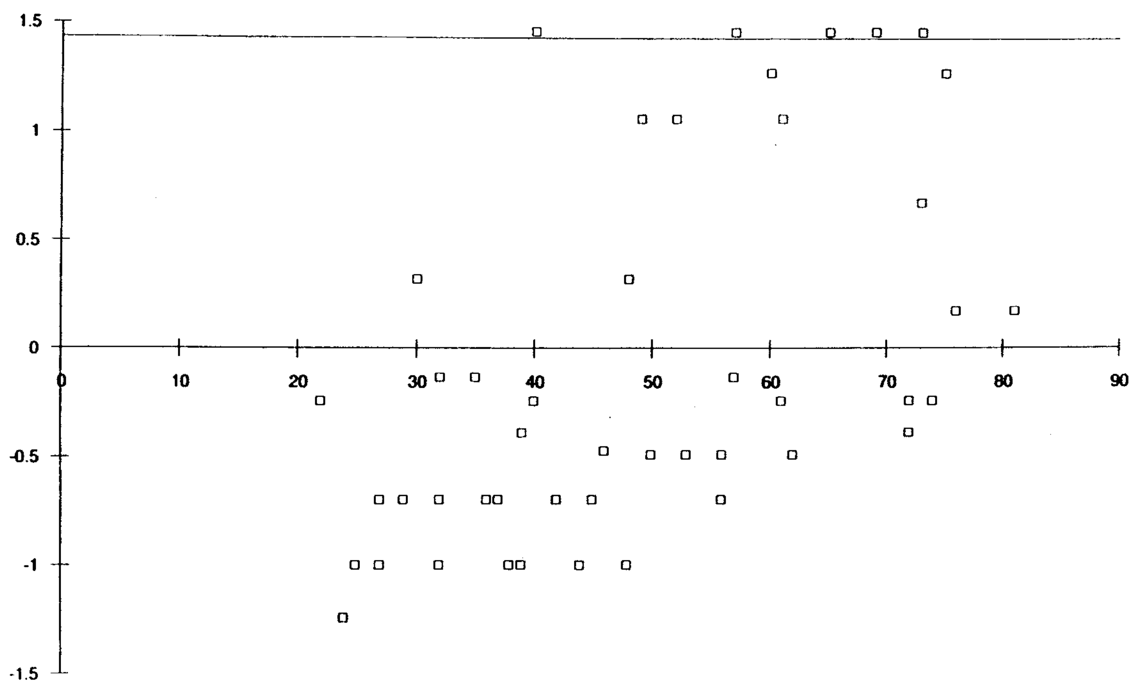

Figure 40. DO NOT ENTER (D3)

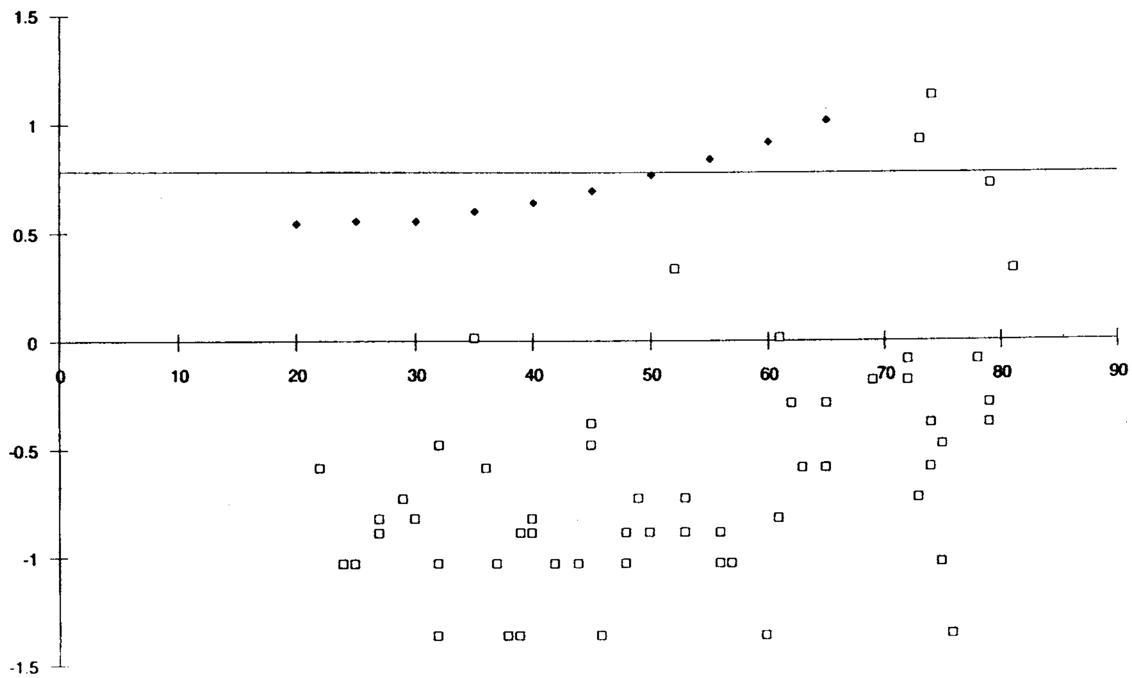

Figure 41. Corning 12 (H2)

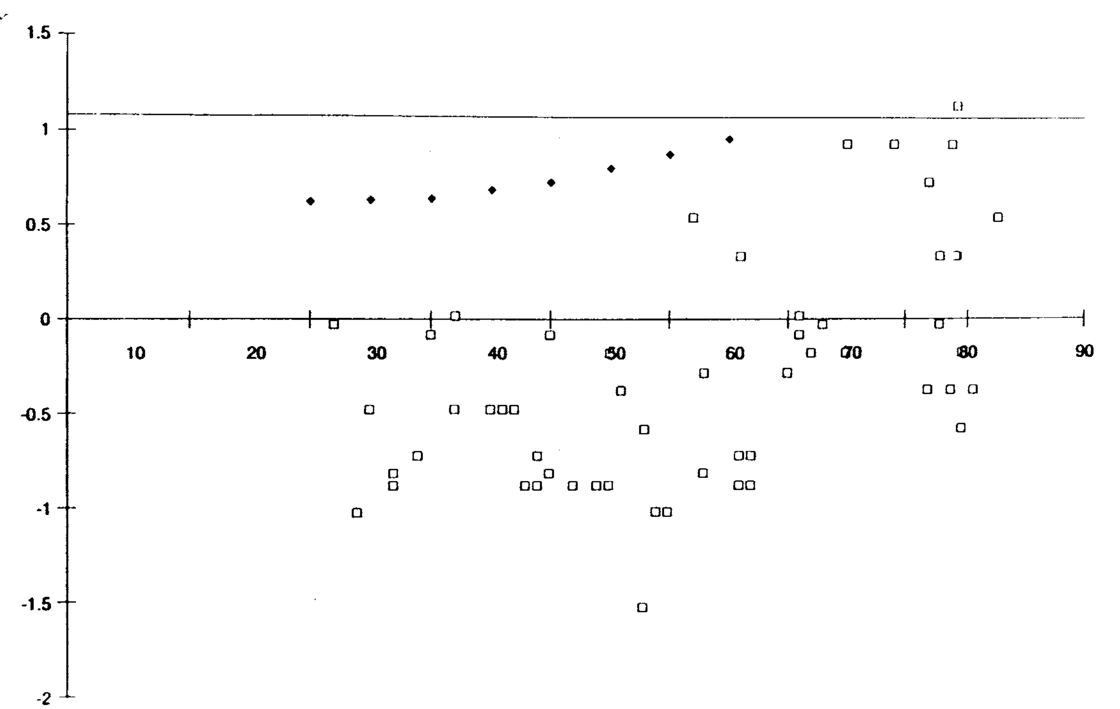

Figure 42. Corning 12 (D2)

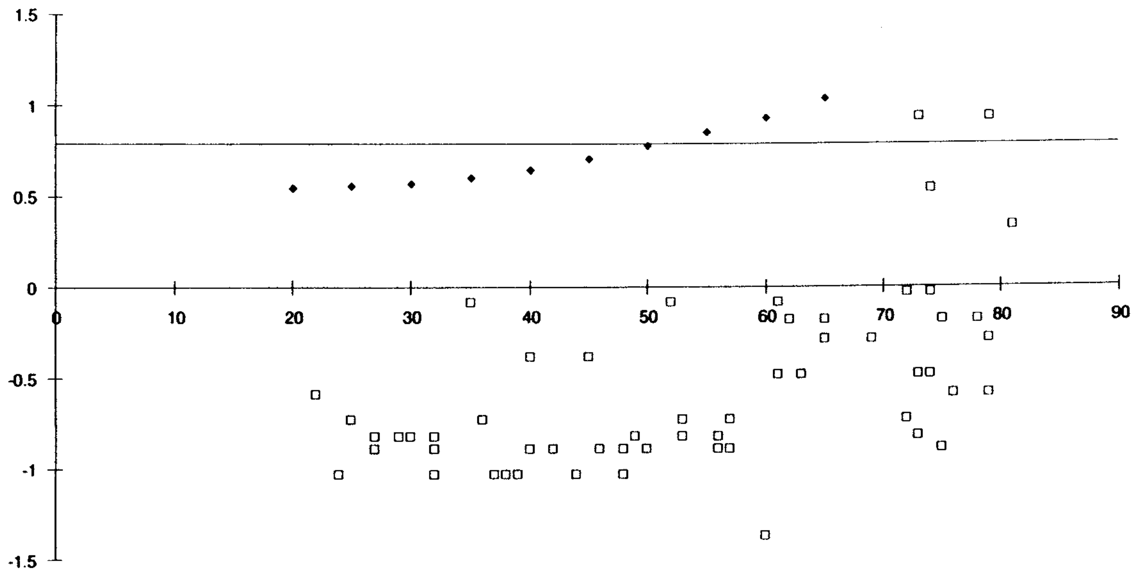

Figure 43. Gravity (H4)

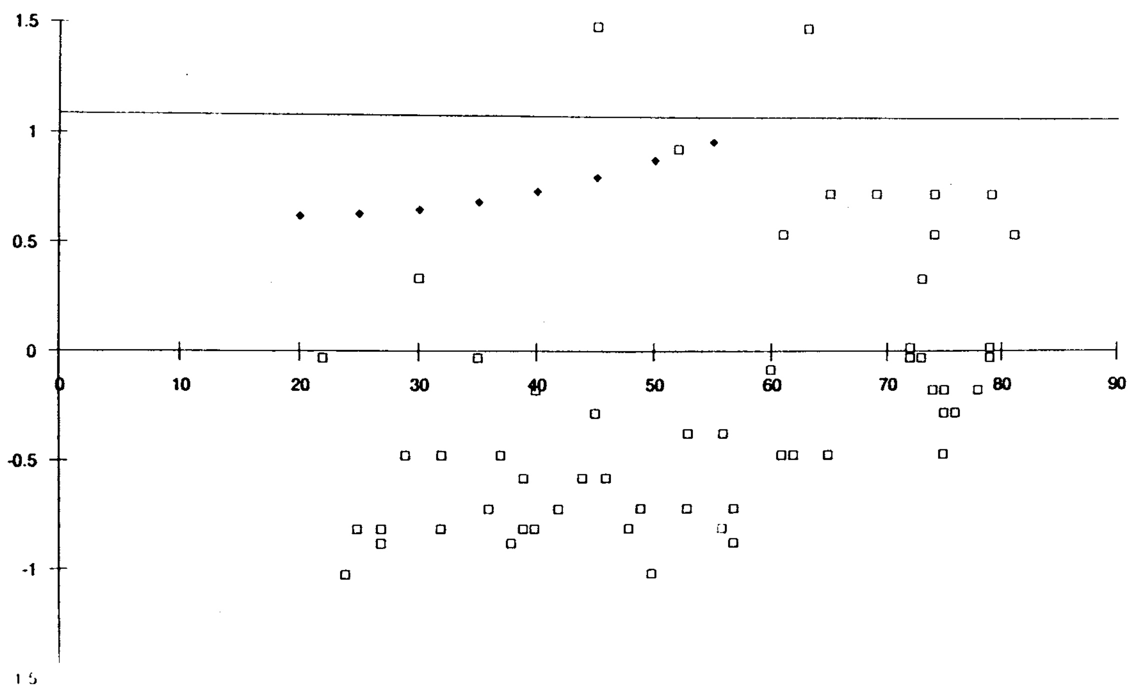

Figure 44. Gravity (D4)

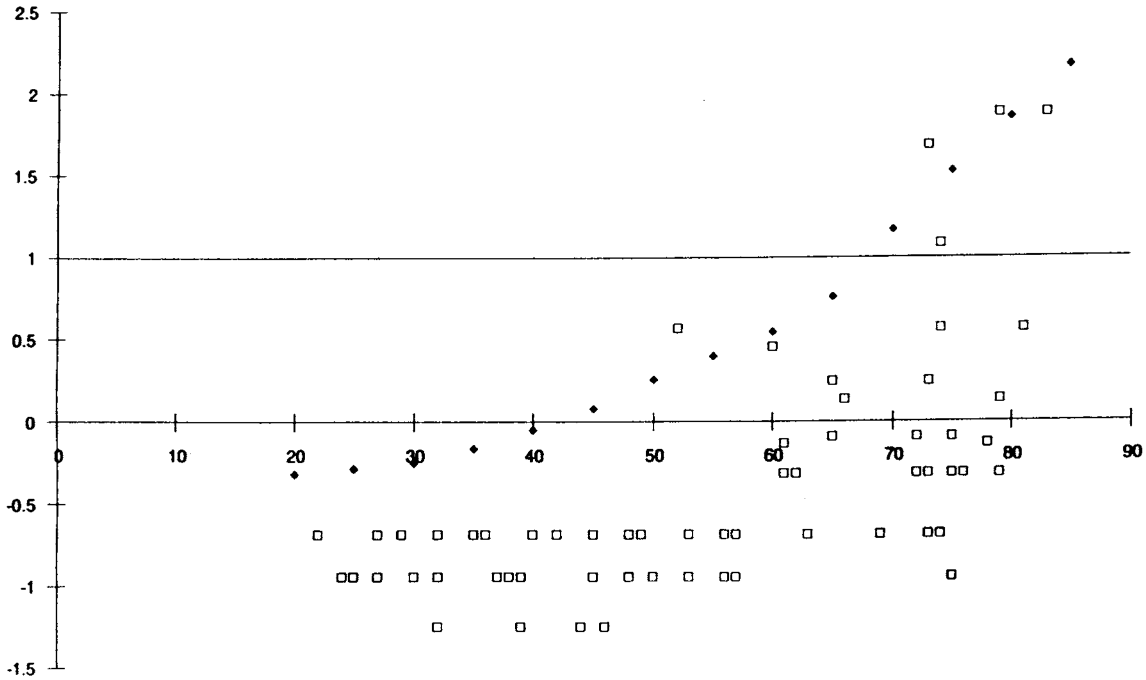

Figure 45. SPEED LIMIT 50 (G1)

APPENDIX C. SUBJECTIVE RESULTS FROM NATIONAL MR WORKSHOPS

Four workshops on MR were conducted in the summer of 2002.[14] Participation was by invitation only and included representatives from city, county, and State transportation agencies, professional organizations (including an industry group), agency attorneys, and FHWA staff. During the workshops, participants were presented with information on sign retroreflectivity, took part in a nighttime demonstration of sign retroreflectivity, and worked to develop recommendations regarding minimum levels of in-service retroreflectivity for signs.

The nighttime demonstrations of sign retroreflectivity were conducted to familiarize participants with the visual appearance of signs at various levels of retroreflectivity. They were not conducted to identify acceptable values for minimum levels of in-service retroreflectivity. However, their results can be used to provide a general impression of how the MR levels correspond to the participants' subjective opinions of the signs' visibility at night.

DESCRIPTION OF EVALUATIONS

During the evening of the first day of the workshops, participants drove through a demonstration course and rated various signs as acceptable or unacceptable. After completing the evaluation, participants were provided with retroreflectivity information for each sign and drove the course a second time, but were asked not to change their evaluations. The evaluation results were collected and presented to the workshop participants the following day.

The widely varying access to research facilities or similar areas where controlled nighttime sign evaluations could be performed resulted in four considerably different set-ups for the nighttime sign evaluation portion of the workshops. The first evaluation (Lakewood, CO) was performed on gated Federal property that resembled a business park. The speeds were low (approximately 25 mph) and the lighting in the area would best be defined as urban. In Hudson, WI, evaluations were performed on a frontage road with very low volumes and little ambient light except the headlamps from the adjacent freeway. The speeds at this site were approximately 40 mph. In College Station, TX, the demonstration was performed on the Texas A&M University's Riverside Campus. The environment was dark and the speeds were approximately 40 mph. In Hanover, MD, the nighttime sign evaluation course was set up in a business park. There was a considerable amount of ambient lighting from the buildings. The speeds were approximately 25 mph and there was more traffic at this site than at the other three.

EVALUATION OF SIGNS

The same signs were not used at all the study locations, although 12 signs were used consistently at the last three workshops. These signs were specially made to give a rough estimate of the correlation between the workshop participants' subjective ratings and the recommended updated MR levels. The idea for this technique originated from a participant in the Colorado workshop, so it was only used at the last three workshops.

The signs were a STOP sign (R1-1), a CURVE sign (W1-2), and a DIVIDED HIGHWAY ENDS sign (W6-2a). The signs were chosen to represent a white-on-red iconic sign that conveys its message primarily through shape and color, a bold symbol sign that should be easy to recognize, and a fine symbol sign that requires legibility as opposed to recognition. For each sign type, there were four duplicate signs. One sign was fabricated with beaded high-intensity sheeting (ASTM Type III). The other three were fabricated with engineering-grade sheeting (ASTM Type I). The retroreflectivity of two of the engineering-grade signs was degraded by applying varying levels of polyurethane to the sign. This technique resulted in four levels of retroreflectivity for each sign type. The objective of having four levels of retroreflectivity for each sign type was to evaluate the overall acceptance at various levels. For instance, the new beaded high-intensity signs were thought to be adequate for all conditions and that most, if not all, workshop participants would approve of these signs. On the other end of the scale, it was thought that by severely degrading a set of engineering signs to a relatively low level, most workshop participants would fail these signs. The middle grouping of retroreflectivity levels was established to be near the proposed minimum levels. Table 33 shows the retroreflectivity levels of the signs used in this evaluation.

Table 33. Description of Signs Used in Nighttime Evaluations

Background Retroreflectivity (cd/lx/m^2)			Retroreflective Sheeting	Condition
CURVE	DIVIDEND HIGHWAY ENDS	STOP		
246	250	45	Beaded High-Intensity (Type III)	New
70	63	18	Engineering Grade (Type I)	New
36	28	10	Engineering Grade (Type I)	Degraded
21	15	5	Engineering Grade (Type I)	Degraded

FINDINGS

A total of 71 workshop participants rated the 12 signs listed in table 33, resulting in a total of 851 observations. For each sign of each sign type, the results were plotted as shown in figures 45 through 47.

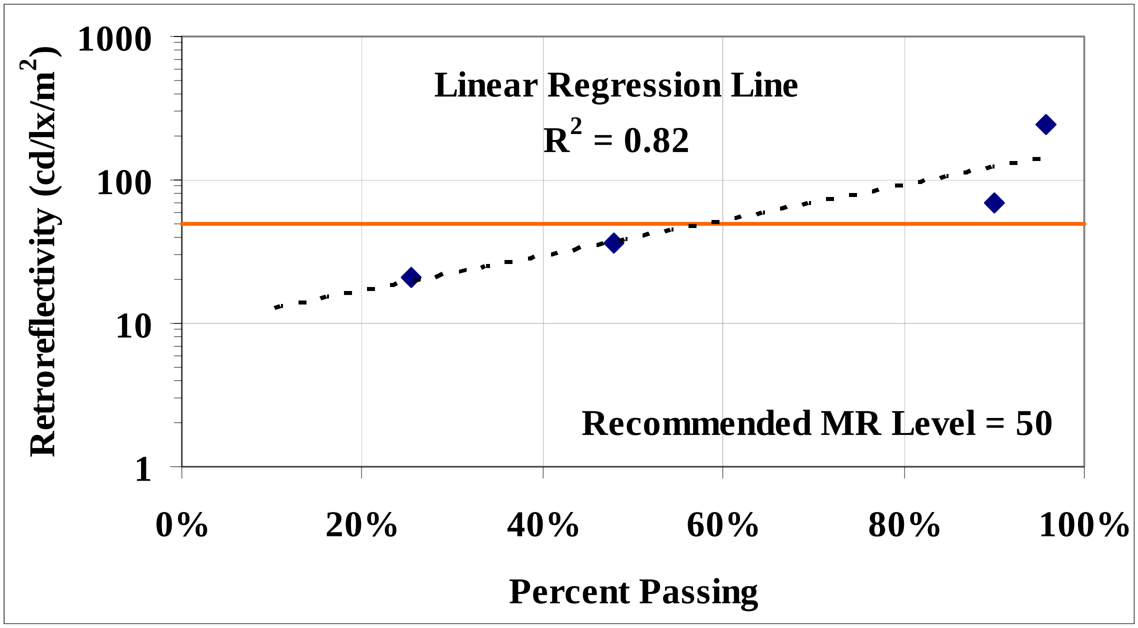

Figure 46. Results for the CURVE Sign (i.e., Bold Warning Sign)

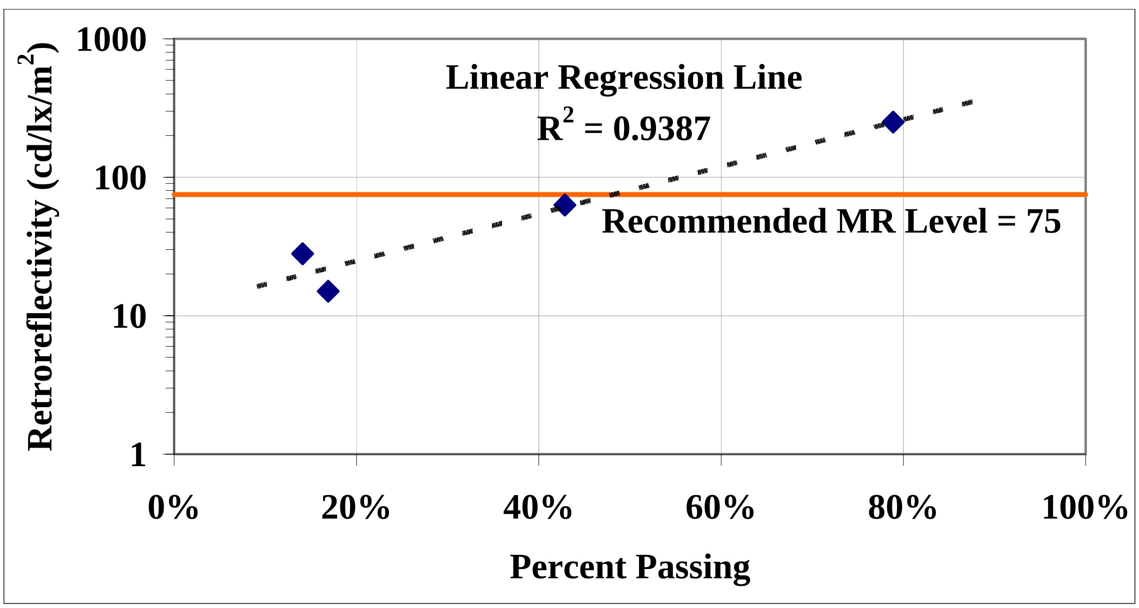

Figure 47. Results for the DIVIDED HIGHWAY ENDS Sign (i.e., Fine Warning Sign)

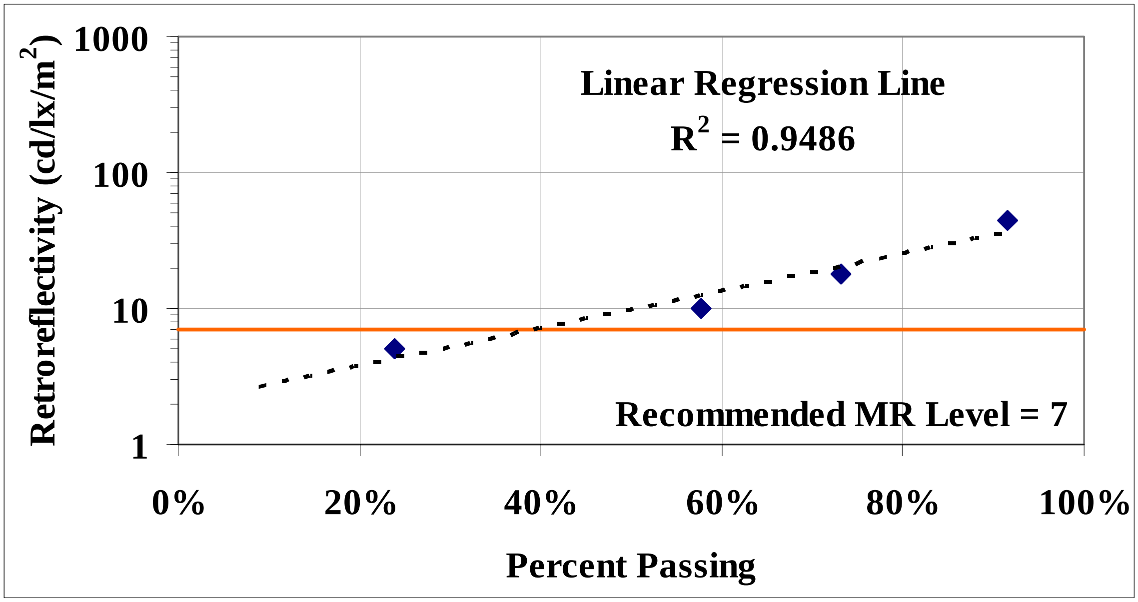

Figure 48. Results for STOP Sign (i.e., White-on-Red Iconic Sign)

The points where the best fit lines intersect the recommended updated MR levels range from 58 percent passing for the CURVE sign, to 48 percent passing for the DIVIDED HIGHWAY ENDS sign, to 39 percent passing for the STOP sign. In other words, 39 percent of the participants would have passed the STOP sign at a retroreflectivity level of 7 cd/lx/m^2 for the red background.

INTERPRETATION

It is important to restate that this evaluation was not scientifically designed or controlled. At each of the three workshops where they were shown, the signs were placed so that they were seen in various sequences and the distances between them was not equal from workshop to workshop. Participants were generally younger than the criteria at which the updated MR values were based on (age of the participants was not recorded). Participants drove and viewed the signs from a large variety of vehicles; participants were not exactly free of biases: It is probably not unreasonable to suspect that some may have had a predisposition concerning the development and implementation of MR levels for traffic signs. Therefore, in an effort to make the final levels so low that their impacts would be negligible, workshop participants may have passed signs that would have been normally judged inadequate.

Despite these caveats, the researchers feel that the results help to provide some confidence in the proposed minimum levels. Overall, 49 percent of the subjects would have passed the three signs at the proposed minimum levels. One of the key issues that needs to be remembered is that the workshop participants were generally younger than the criteria used to establish the proposed minimum levels. Had all the workshop participants been 55 years and older, as is the case for the criteria used to establish the proposed minimum levels, the percent passing the three test signs at the proposed minimum levels may well have been much lower. A target value in terms of percent passing, however, has not been established. While the 49 percent passing may be appropriate, others may feel that something much lower in terms of percent passing should be reached before the minimum level should be set. However, subjective visual inspections such as those performed and reported here will produce relatively large levels of variability and therefore it is difficult, if not impossible, to speculate about the most appropriate percent-passing level.