Impact Assessment of Revised Retroreflectivity Requirements for Highway Signs in Montana

Phase I - Final Report

by

John M. Mounce, P.E.
Principal Investigator

and

Matthew A. Ulberg
Research Assistant

of the

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Civil Engineering Department
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Prepared for the
STATE OF MONTANA
DEPARTMENT of TRANSPORTATION
RESEARCH & DEVELOPMENT PROGRAM
in cooperation with the
U.S. DEPARTMENT of TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

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16. Abstract

The objective of this report is to give a preliminary assessment of the impact that revised retroreflectivity requirements will have on the State of Montana. Conclusions and recommendations are made for Montana's future management and handling of sign inventory data. This objective is addressed through the following tasks:

- **Task A: Review, assimilation and analyses of current literature available on a nation-wide basis.**
- **Task B: Discussion of results from a multi-state phone solicitation regarding state sign management practices and policies.**
- **Task C: An assessment of sign reflectivity inspection equipment and sampling methodology.**
- **Task D: Evaluation of Montana's sign inventory on the basis of current practices and condition of a limited sampling of signs.**

Recommendations of this report include upgrading of, or improvements to Montana Department of Transportation's sign management system and multi-district state-wide retroreflective sampling to better determine the impacts revised standards may have.

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Implementation Statement

This study is sponsored by the Montana Department of Transportation in cooperation with the Federal Highway Administration. The major objective of the study is to conduct an impact assessment of implementing the proposed revised retroreflectivity requirements for traffic signs utilized on the State Highway System in Montana. Recommendations from this study will allow an effective implementation strategy to be determined based on cost, compliance, and sign management.

Disclaimer

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Abstract

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Task B: Discussion of results from a multi-state phone solicitation regarding state sign management practices and policies.

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Table of Contents

List of Tables

List of Figures

Background

The goal with the placement of any traffic control device is to effectively communicate to motorists the appropriate positive or prohibitive actions necessary to allow safe traversal of any section of public roadway. Signs, especially, are designed and placed to be easily and quickly visible, recognizable, and understood with information, guidance, and warning information.

Adequate sign reflectivity, or retroreflectivity, is essential for nighttime visibility of these traffic control devices. The extent of nighttime visibility of signs must be such that motorists have sufficient time and distance to detect, interpret (read), and respond as needed.

Research (1,2) in recent years has demonstrated the need to upgrade the previous requirements for sign retroreflectivity to enhance nighttime visibility. For many states, such as Montana, this will mean replacing a substantial portion or eventually all of the signs currently utilized on the State highway system.

New retroreflectivity standards are being proposed by the Federal Highway Administration for adoption by the national Committee on Uniform Traffic Control Devices. Tentative target date for implementation to begin is in 1997.

Scope of Work

The overall objective of this study is to conduct an impact assessment of implementing the proposed new retroreflectivity requirements for traffic signs utilized on the State highway system in Montana. This objective is to be accomplished through a two phase project covering a period of 18-months from March 15, 1995 to September 15, 1996.

This interim report discusses work activity in Phase I of the project which consists of the following tasks:

Task A - Literature Assimilation, Review and Analysis

Task B - Multi-State Phone Solicitation of Policy/Strategies

Task C - Assess Equipment Methodology for Sign Reflectivity Inspection

Task D - Evaluation/Modification of Current Sign Inventory

Task E - Interim Report Recommendations for Impact Assessment/Implementation

The remainder of this interim report details and discusses completion of these tasks in Phase I with recommendations for impact assessment and implementation to follow in Phase II of the study.

Task A - Literature Assimilation/Review/Analysis

All available research or technical literature on sign retroreflectivity published in the last ten (10) years was accessed and assimilated from the National Technical Information Service (NTIS) and Research Management Unit of the Montana Department of Transportation. Approximately thirty (30) articles and reports were deemed relevant to the study research. These publications were reviewed and summarized by annotation. A bibliography of these annotations are presented in the appendix to this interim report.

From an analysis of this information, selected topics of technical merit have been categorized and are discussed in the following paragraphs.

Retroreflective Sign Sheeting Types and Specifications

Sign sheeting materials are specified by class and/or type (1,3). Each material is referred to somewhat differently according to the agency involved. Table 1 clearly identifies the materials and specifications involved.

Table 1: Sign sheeting material designations.

Class Designation	D4956 ASTM Designation	FP-85 FHWA Designation	M268 AASHTO Designation	Field Designation
—	—	—	Type I	Utility
Class I	Type I	Type II	Type II	Engineering Grade (EG)
Class Ia	Type II	Type IIA	--	Super Engineering Grade (SEG)
Class II	Type III	Type III A, B	Type III, IV*	High Performance (HP)
Class III	Type IV	--	—	Diamond Grade

*Denotes vinyl sheeting

Sign Legibility

There seems to be some disagreement in the field as to which combinations of sign sheeting grades and backgrounds produce the brightest and most legible signs. McNees, (4) recommends that High Intensity stick-on copy, opaque background with button copy, and Engineering Grade with button copy are the three best sign options for legibility. He based this recommendation upon extensive research including different lighting conditions and different entrance angles. McNees also found that standard specifications concerning letter height and stroke may need to be reviewed, as legibility of standard signs was not sufficient in areas of high vehicle speeds.

Economy and Use of Sign Sheeting Materials

Research sponsored by the Kansas Department of Transportation (5), found that through investigation of selected other States' practices, life-cycle cost analysis, and previous sheeting studies, that the trends are toward high-performance sheeting on all traffic sings, and high-performance sheeting on traffic control devices in the construction work zone. Increased use of the high-performance materials is also consistent with the increasing amount of older drivers on the roads today. Also, there is a growing movement to use sheeting with three times the retroreflective values for current high-performance materials for critical locations, such as construction work zones, and areas of high visual complexity. Review of recent bids also shows high performance signs have a lower life-cycle cost than materials with less inherent reflectivity. These findings are supported by other studies done for the Arizona Department of Transportation (6) and the Florida Department of Transportation (7)

E.R. Russell's report (8) suggests that there are many possible economic analysis methods that could be used, but the Equivalent Uniform Annual Cost (EUAC) method is best suited for cost-effective analysis of sheeting. Cost of fabrication, installation, service life of the sign, and benefits are all part of the analysis, giving the most precise results of all the methods. Based on Kansas' sign costs and bid prices, their policy of using high-performance sheeting for key highway signs is cost-effective. The life-cycle cost analysis is a very good tool for states that have *appropriate* data. It would ensure that the most cost-effective of the materials currently available were being used, as well as developing base data to evaluate and make economic decisions on new materials becoming available. The appropriate data needed for such an analysis, is expected life of the sign, date installed, weathering factors, present worth of sign and remaining life, and cost of new materials.

In 1991, the Oklahoma Department of Transportation (ODOT) adopted a policy that required the use of high-intensity, encapsulated glass-bead sheeting on all red and yellow signs, as well as green and blue signs on interstate highways. The policy also called for use of super-engineering grade sheeting on all other signs. S.A. Ahmed (9) performed research to evaluate this policy, and found that their policy to use Type-IIIA, high intensity (HI),. sheeting on all red and yellow, as well as green and blue signs on interstate highways was sound and defensible. Ahmed also found that ODOT requirement to use Type-IIA (SEG) sheeting on all other signs needed to be reviewed. Although the initial cost of fabrication of Type-IIIA (HI) signs was higher, life-cycle analysis indicates that HI sheeting is more cost-effective than Type-IIA. This shows that a policy of using HI sheeting on all signs is economically defensible, and overall good practice due to its increased reflectivity.

Deterioration of Sign Sheeting Materials

Deterioration is a problem with retroreflective sign materials. Deterioration factors include solar irradiation, high temperatures and moisture effects, photo oxidation, industrial pollution, wind erosion, sand abrasion, and sign vandalism. Black (10) suggests that the best way to deal with sign deterioration is to fully develop a Sign Management System (SMS). A thorough review of current sign management procedures should be considered before making any major changes. FHWA projects include improving their SMS to provide local agencies with a microcomputer-based predictive tool for use in managing a sign inventory. There are many ways in which computers and scanners could aid in this process while performing field inspections of the sign inventory. Also, after the SMS is in effect and all of the signs are on the data base, quantitative sample measurements of the retroreflective signs of similar age populations could be used to represent the population of signs in any given area. This would provide a real service life check for the life-cycle analysis being performed by the computer SMS.

Construction Work Zone (CWZ) Signing

Use of reflective sign materials that are brighter and last longer has become the trend in recent years, and CWZ signing materials are no exception. The benefits of increased use of High-Performance reflective materials (SEG,HP,HI) has been demonstrated by increases in detection and recognition distances of CWZ devices. However, the benefit of using high-intensity sheeting was offset by the cost, loss of durability, and problems with handling and fabrication (11). It should be noted that these problems with handling, durability, and fabrication have since been effectively addressed and minimized by the manufacturers of the products. Use of fluorescent sheeting on CWZ signs is once again gaining popularity. In the past fluorescent CWZ signing materials did not last for more than a year, and sometimes only three weeks, which prevented it from gaining widespread acceptance. Durable fluorescent sign materials are now available that are well suited to both day and nighttime visibility, and have service life and durability that is comparable to other CWZ signing materials. Diamond Grade sheeting is another alternative for use in CWZs, or where it is desirable to have a higher target value and reflectiveness than High Intensity sheeting. The cost of the diamond grade sheeting would limit it to use in areas where brighter, wide angle reflective sheeting is warranted, and the cost could be justified. It would be best used in areas of high ambient lighting, work zones with a cluttered roadway environment, and high accident locations with nighttime accident problems. Another good alternative would be to use this material where an increased viewing angle cannot be avoided, such as urban overhead signs or intersections.

Task B - Phone Interviews for State Policies/Strategies

Phone interviews were conducted to ascertain strategies and policy decisions being implemented by other states in response to proposed changes in sign retroreflectivity requirements. Four (4) geographically separate states were contacted in this regard. A summary of each discussion is given as follows.

Texas

A meeting was held with Mr. Lewis Rhodes of the Texas Department of Transportation (TxDOT) in Austin, Texas on March 13, 1995. Mr. Rhodes indicated that TxDOT does not currently have a consistent or user friendly system on sign inventory or responsive sign management. He indicated a complete, statewide sign inventory evaluation in the near future was felt to be too labor intensive and cost prohibitive. He stated that with an expected sign reflectivity performance life of 8-10 years, it was anticipated that TxDOT would attempt a sign conversion to high performance sheeting at an annual rate of 10-12 percent.

California

Mr. Richard Hickman, Senior Engineer in Testing and Technology Services, with the California Department of Transportation (Caltrans), was contacted by phone regarding sign retroreflectivity issues. Mr. Hickman indicated that Caltrans had recently completed a statewide survey on the condition of reflective signs (12). A representative sample of signs were evaluated by reflectivity measurements using an ART Model 920L retroreflectometer. Sign measurements were taken at widely separated interchanges on sections of roadways not recently reconstructed and with no signs less than 2 years old. Various sheeting grades were measured. In summary of this work, Mr. Hickman stated that of the total 1000 miles sample, 95 percent of the signs measured would meet the proposed revised sign retroreflectivity requirements. Mr. Hickman verified that current Caltrans policy was that all new signs were either SEG or HP sheeting.

Kansas

Mr. Kenneth Gudenkauf of the Kansas Department of Transportation (KDOT) was contacted by phone and engaged in an interview discussion concerning policies and strategies by KDOT on sign reflectivity requirements. Mr. Gudenkauf indicated that extensive research had been initiated by KDOT focusing on both sign inventory systems (13) and sign replacement assessment (14). He stated that KDOT was implementing a statewide sign inventory program to begin in 1996 and was adopting a statewide policy of sign replacement to meet the proposed minimum retroreflectivity requirements. The sign upgrade program was to be completed over a ten (10) year period with major routes to be done first and entire routes completed at a time. This encompasses 10,000 miles of rural highway and over 800 miles of Interstate Highways. All replacement signs will be High Performance (High Intensity with a ten (10) year life from manufacture).

Pennsylvania

Ms. Eileen Collins in Traffic Engineering and Operations of the Pennsylvania Department of Transportation (PennDOT) was contacted concerning sign retroreflectivity requirements. Ms. Collins stated that the current PennDOT sign replacement policy was based on a seven (7) year sign life with an inventory change out of 15 percent a year. She further said that within the last year all signs produced have been high intensity with exclusive application of this sign grade on freeways, expressways, and other "critical" signs. She indicated that this implementation strategy was also influenced by PennDOT's concern for the increasing elderly driving population. This was confirmed also by Mr. Arthur Breneman in later correspondence and report findings (15).

Montana

Mr. Pat Brannon in Maintenance Division of the Montana Department of Transportation (MDT) was contacted concerning MDT's sign inventory practices, and retroreflectivity requirements. Mr. Brannon stated that MDT uses a biannual sign inventory gathered in the field, reporting sign appearance and condition. Mr. Brannon stated that this inventory is the current replacement tool for installed signs. MDT expects a seven (7) to ten (10) year sign life, and replacement is based primarily on functionality, physical condition, and appearance of the sign as is reported in the sign inventory. Field maintenance personnel hold primary responsibility for maintenance and inspection of the signs for completion of the sign inventory. He also indicated that MDT is currently using high intensity sheeting materials on all new signs installed on the interstate system.

Mr. Jeff Paniati was also contacted and discussions held by phone concerning Federal Highway Administration (FHWA) sponsored research (1, 16) resulting in the proposed minimum retroreflectivity requirements for traffic signs. Mr. Paniati discussed an on-going survey of approximately forty (40) states to establish the replacement impact of these revised requirements. Montana was not a participant and the results of that study are currently not available. Mr. Paniati also elaborated on a prototype van being developed by FHWA to assist with measurements of sign retroreflectivity. He was hopeful that several of these units would be produced and available for state demonstration use in 1996.

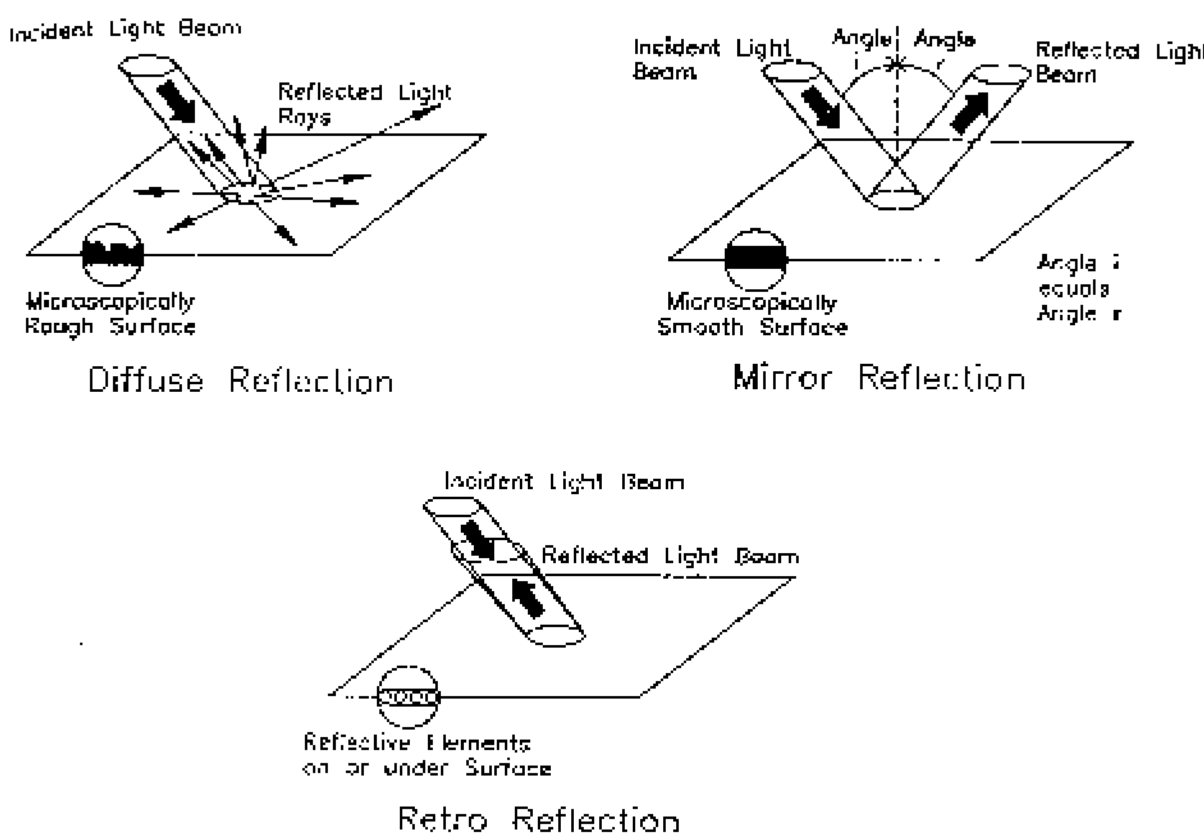
Finally, information was also drawn from reports on sign retroreflectivity by the Colorado Department of Transportation (17) and the Kentucky Department of Transportation (18).

Task C - Assessment of Sign Reflectivity Inspection Equipment/Methodology

Reflection of light occurs when the light illuminating an object is reflected back from the object. The brightness of the reflected light is directly related to the intensity of the light source and the type of diffuse, mirror, and retroreflection. Diffuse reflection results when light strikes an object that has a microscopically rough surface. The light scatters in all directions, and only a small amount of light is reflected back to the light source. Because only a small amount of light is returned along the path of the incident (incoming) light beam, diffuse reflection materials have poor nighttime visibility to drivers (9).

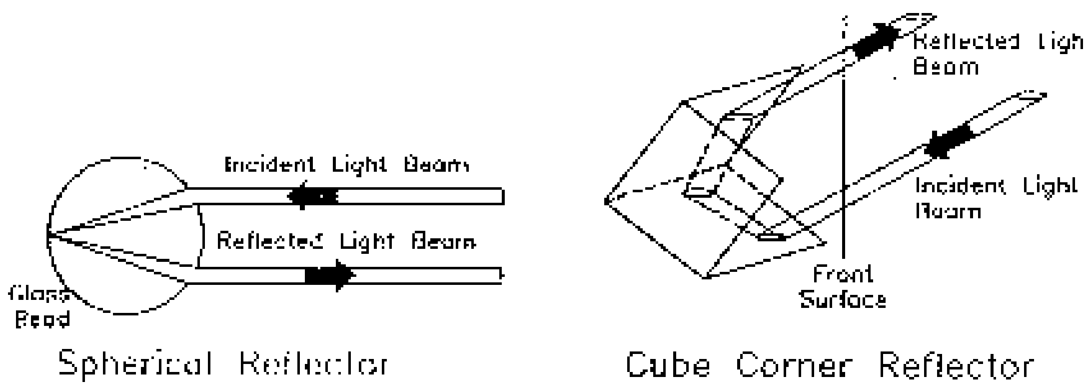
Mirror reflection takes place when light strikes a microscopically smooth surface. The light is reflected from the surface at an equal, but opposite, angle from that of the incident light beam. Light is returned directly to the source only when the light beam is exactly perpendicular to the surface. This is shown in Figure 1.

Figure 1: Types of Reflection



Retroreflection occurs when light strikes an object and is reflected directly back to the source of light. Because a relatively large amount of light is returned, retroreflective materials appear brightest to an observer located near the light source. It is the principle of retroreflection that is applied to traffic control devices. As shown in Figure 2, there are two basic types of retoreflectors: a spherical lens and a cube corner reflector. A spherical lens reflector uses microscopic glass beads and a reflecting surface placed at the focal point to return light to its source. In cube-corner reflectors, light is reflected successively from the three back faces of the cube and is redirected to the source (9).

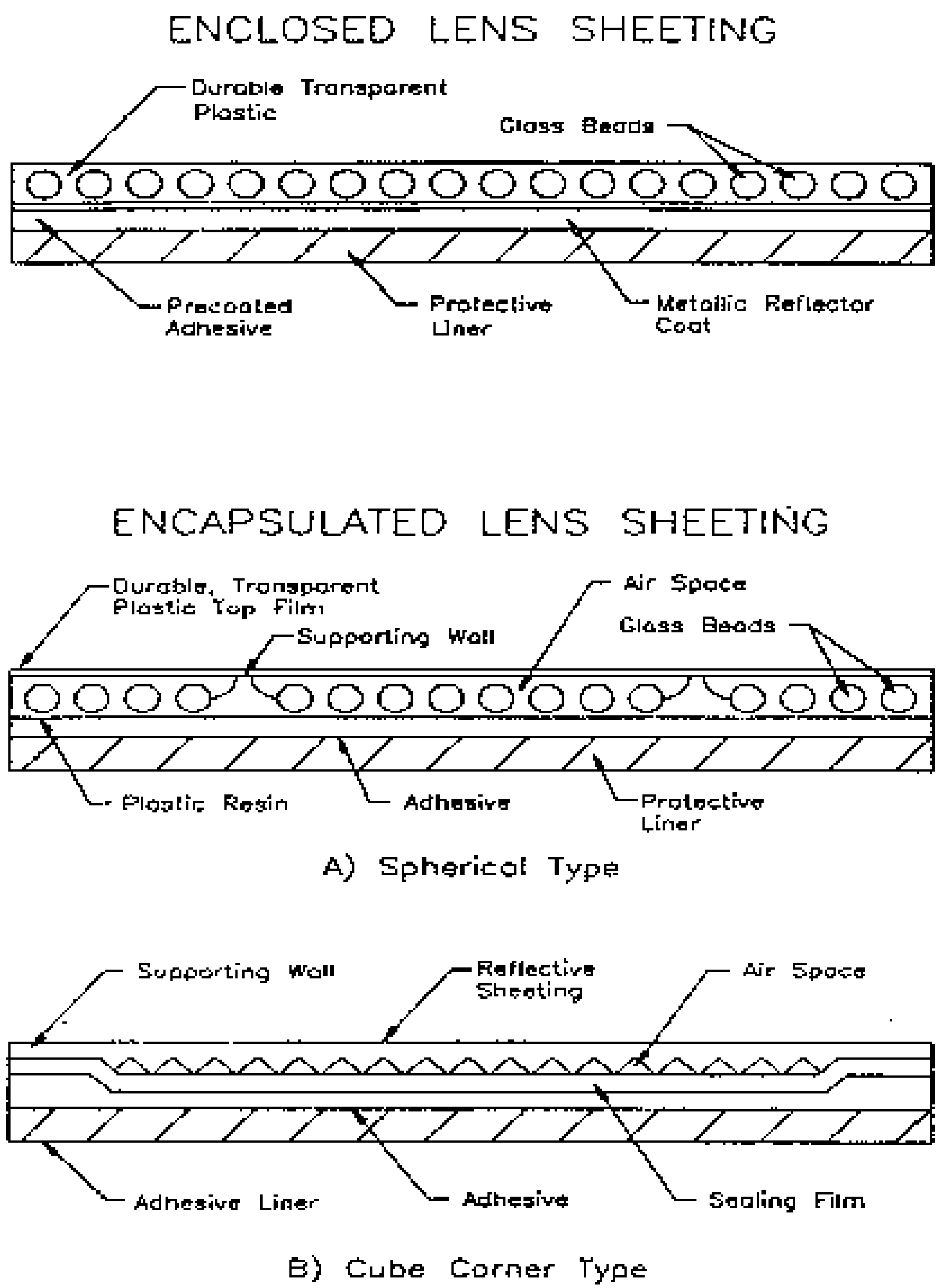
Figure 2: Types of Retroreflectors



A retroreflective sheeting is a flexible sheet that consists of very large number of spherical lens or cube-corner retroreflective elements embedded in a weather resistant transparent film. To reflect color, pigment or dye is inserted into the film or onto the reflective surface behind the retroreflective elements. Although there are a number of variations, as previously discussed, the three common types of sheetings used on traffic control devices are: 1) *engineering grade*, 2) *super-engineering grade*, and 3) *high-intensity grade* sheetings.

Both the engineering and super-engineering grades are of *enclosed lens* type sheeting with the main distinction between the two being a higher quality glass bead in the super-engineering grade sheeting. As shown in Figure 3, an enclosed lens sheeting consists of a layer of transparent plastic of the appropriate color in which microscopic glass beads are embedded. The plastic covering enables the sheeting to be equally bright under dry and wet conditions. A metallic reflector shield is provided behind the plastic, plus a layer of adhesive and a protective liner that is removed during the fabrication of a traffic control device (9).

Figure 3: Schematic of Retroreflective Sheeting Composition



High-intensity grade sheetings are of the *encapsulated lens* type. The glass beads are protected by a transparent top film that is sealed in a mesh pattern and is supported slightly above the beads by walls leaving an air filled compartment. The back of the beads is covered with a reflective coat. Because an air cushion is provided in front of the beads, this type of sheeting is more reflective than the enclosed lens sheeting. Microprismatic reflectors are sometimes used instead of the glass beads with the air cushion being behind the cubes.

The overall performance of a retroreflective sheeting depends not only on the optical properties of the material used but also on distances, angles, alignments, and specific vehicle and ambient lighting encountered on the roadway. Nevertheless, the luminance properties of retroreflective sheetings are usually specified in terms of their brightness.

Brightness is a measure of the retroreflector's ability to return light. In the case of small reflectors, brightness is measured by the coefficient of luminous intensity, R, in candela per lux (cd/lx) or candela per foot-candle (cd/fc). Because traffic control devices have a relatively large area, the *coefficient of retroreflection*, R', has been adopted as a measure of brightness. It is merely the coefficient of luminous intensity divided by the area of the retroreflector. The units of R' are candela per lux per square meter (cd/lx/m) or candela per foot-candle per square foot (cd/fc/ft). Usually, the term R' is referred to as *Specific Intensity Per Unit Area*, SIA. It is important to note that the human subjective perception of brightness is not linear with instrument readings of R or R'. A tenfold increase in brightness, as measured by instruments, may be perceived as only two to three times brighter.

The brightness of sheeting materials is always described in context of another important property, is angularity which is defined by the *entrance angle* of the light and the *observation angle* of the motorist. These two angles change with the viewing distance between the vehicle and the control device. The observation angle depends on the height of the driver's eye with respect to the vehicle headlights, whereas the entrance angle depends on the location of the vehicle with respect to the device. The term "angularity" refers to the range of angles at which a retroreflective sheeting on a control device will remain retroreflective (2).

Tables 2-5 present the minimum Retroreflectivity guidelines as proposed by FHWA (19). These guidelines are represented in a matrix framework for legend-background color combinations of black-on-yellow/black-on-orange warning signs, white-on-red regulatory signs, black-on-white regulatory and guide signs, and white-on-green guide signs. All retroreflectivity values are given in R' units of $cd/lx/m^2$ and categorized by material type, size, traffic speed, and mounting position.

Measurements must be taken of retroreflectivity on a representative sample of signs statewide to establish comparative loss of reflectance and compliance with the proposed minimum FHWA requirements. Currently, these type of measurements are taken with a portable reflectometer. To effectively asses both equipment and methodology, field measurements were made.

Table 2: Minimum retroreflectivity guidelines for black-on-yellow and black-on-orange warning signs.

Legend Color: Black
Background Color: Yellow or Orange

	Sign Size:	> = 48 - in	36 - in	< 30 - in
Legend	Material Type			
Bold Symbol	ALL	15	20	25
Fine Symbol	I	20	30	45
& Word	II	25	40	60
	III	30	50	80
	IV & VII	40	70	120

Table 3: Minimum retroreflectivity guidelines for white on red regulatory signs.

Legend Color: White
Background Color: Red

Traffic Speed:	45 mi/h or greater						40 mi/h or less					
Sign Size:	> = 48 - in		36 - in		< = 30 - in		> = 48 - in		36 - in		< = 30 - in	
	W	R	W	R	W	R	W	R	W	R	W	R
All Signs	50	10	60	12	70	14	30	6	35	7	40	8

Table 4: Minimum retroreflectivity guidelines for white-on-green guide signs.

Legend color: White
Background Color: Green

Traffic Speed:	45 mi/h or greater		40 mi/h or less	
	White	Green	White	Green
Ground-mounted	35	7	25	5
Overhead-mounted	110	22	80	16

Table 5: Minimum retroreflectivity guidelines for black on white regulatory and guide signs.

Legend Color: Black and/or Black and Red
Background Color: White

	Traffic Speed:	45 mi/h or greater			40 mi/h or less		
	Sign Size:	>=48 -in	30-36 -in	<=24 -in	>=48 -in	30-36 -in	<=24 -in
	Material						
Ground-mounted	I	20	35	50	15	20	35
	II	25	45	70	20	30	55
	III	30	60	90	25	45	75
	IV & VII	40	80	120	35	60	100
Overhead-mounted	I				40	50	100
	II				50	75	135
	III				65	115	185
	IV & VII				90	150	250

Advanced Retro Technology manufactures a portable retroreflectometer that is commonly used by State Department's of Transportation. An ART 920 reflectometer was obtained from MDT to evaluate and training was received on the care, use, and necessary calibration of the instrument (20). The highly sensitive nature of the measurement geometry made calibration necessary on a sign-by-sign basis. Problems were encountered during sampling with power chord durability, and function of the 'trigger' to hold readings on the LCD display. Obtaining readings on signs taller than 7 ft. From ground elevation required the use of a step-ladder, and measurements were not attainable on signs taller than 10 feet. Use of the extension rod available from ART would be helpful in such instances, but access to one of these rods was not possible.

An alternative way to asses sign reflectivity in the field is the use of a spotlight during daylight hours. This practice is very likely to have originated from a FHWA publication, FHWA-RT-90-002, Maintenance of Small Traffic Signs (21). This booklet outlines the use of a spotlight for sign reflectivity checks, and states that this technique is valid under the following procedure. The 200,000 to 400,000 candlepower light is to be flashed from a maintenance vehicle approximately 100-200 feet away, during daylight hours. If the sign lights up or flashes back, then it is a good sign. Many variations of this technique are used by state transportation agencies.

Two variations were presented through interviews with MDT employees, and also through the review of a film developed by Mississippi DOT for review by State Department of Transportation Maintenance Bureaus (22, 23). Mississippi's spotlight technique involved the use of a 300,000 candle-power spotlight from within a maintenance vehicle. The method was very similar to the FHWA's method with the exception that the sign is flashed from 50-100 feet away instead of 100-200 feet as laid out by FHWA (23). MDT's spotlight technique has some variations, but is based on shining a large candlepower spotlight on the sign/during daylight hours from a short distance away. Variations of this technique include the use of headlights from employee's vehicles at night. Both directly aimed headlights, and passing by the sign slowly with the vehicles' headlights directed in a normal fashion, are common methods for this variation.

To test the validity and qualify these variations of the MDT spotlight technique, a test was performed on five signs that were near Bozeman. The signs were carefully selected to obtain values above, below, and near the minimum specified reflectivity value. These signs had a range of reflectivity values, varying from 1.2 to 85. Two of these signs were near the minimum required reflectivity; one being just higher, and on being just lower. After the initial ART 920 retroreflectometer measurements were taken, qualitative tests were performed using vehicle headlights in the same manner that was described by MDT maintenance personnel (MDT spotlight technique). These five signs were all warning signs with a yellow background in a 55 mph zone and 30 inches or less on the long dimension. The minimum retroreflectivity for these signs is 25. The first sign was a curve warning sign. This sign had a retroreflectometer reading of 1.2, and had a very crazed and faded appearance. At night, the reaction to low beam headlights using the 'pass by' version of the technique, was non existent. High beam lights drew a limited response. Positioning the vehicle perpendicular to the sign, the directed low beams elicited no response, and directly aimed high beams got little to no response. The other signs in the control group were tested in the same way, all of which had very good appearance in daylight. The signs were then tested with a spotlight in daylight hours, and the results are included in Table 6.

Table 6: Evaluation results of MDT Spotlight Techniques.

Sign	Reflectivity Reading	Passing by Low beam	Passing by High beam	Directly aimed From ~ 150 ft. Low beam	Directly aimed From ~ 150 ft. High beam	Spotlight in Daylight
1	1.2	none	very poor	none	very poor	poor
2	15	fair	good	good	good	fair
3	30	fair	good	good	very good	good
4*	38	poor	fair	good	very good	good
5	85	very good	excellent	excellent	excellent	good

Minimum Accepted Value for Yellow background, size: 30 inches or less, 55 mph min Ra Value = 25 cd/lx/m^2

*This sign was turned out of the correct alignment with respect to the roadway.

These results show that the alignment of the sign to the roadway, position of the light with respect to the sign, and intensity of the light source are all big factors affecting the response of the sign. The conclusions that can be drawn from this are: 1) This technique is highly dependent on correct alignment of the sign. 2) Signs that have slightly low or borderline reflectivity values do not give the correct results when this technique is used. 3) The results can be as inaccurate as the technique. 4) These techniques are a good basis for a replacement oriented program, given sign alignment is correct.

Signs examined in the process of evaluating the spotlight technique and the ART 920 were included in our limited sample in the Bozeman Area in the Butte District. The sampling schedule was modeled to obtain a wide variety of sign types and sizes, while conforming to the highway functional classifications present in Montana.

Based on this limited sample in the Butte District. Characteristic values from percentage of signs <u>not</u> meeting the FHWA proposed Retroreflectivity Criteria are tabulated in Table 7. These limited sample results are based on the FHWA proposed retroreflectivity standards previously presented in Tables 2-5.

Table 7: Percentage of signs in cell **not** meeting proposed reflectivity standards

<table>
<tr><th></th><th colspan="3">Sign Size</th></tr>
<tr><th>Type Sign/Color</th><th>24 inches</th><th>30 inches</th><th>36 inches</th></tr>
<tr><td>Legend: Black
Background: Yellow</td><td colspan="2">41.2%</td><td>4%</td></tr>
<tr><td>Legend: White
Background: Red</td><td colspan="2">44%</td><td>20%</td></tr>
<tr><td>Legend: Black, or Black and Red
Background: White</td><td>24%</td><td colspan="2">12%</td></tr>
<tr><td>Legend: White
Background: Green</td><td colspan="3">46.4%</td></tr>
</table>

Task D - Evaluation/Modification of Current Sign Inventory

With almost 4 million miles of highways and an estimated 60 million signs used by highway agencies to assist drivers, the task to monitor the condition of signs is immense to say the least. Several problems with assembling and maintaining an adequate and complete sign inventory stem from the labor-intensive nature of annual or biannual data collection. Ideally, several data-collection items could be effectively eliminated by maintaining a computer database containing the full inventory, reducing the repetitive collection of data such as sign position, location, orientation, and code designation as given in the Manual on Uniform Traffic Control Devices (MUTCD).

One of the problems of managing retroreflectorized traffic signs, is identification of signs that need to be replaced because of loss of retroreflectivity. Sign replacement practices vary greatly between agencies. Some agencies replace traffic signs on the basis of driver complaints, whereas others conduct subjective visual inspections at night. Still others arbitrarily replace signs every 5 to 7 years, which may result in removal of signs with several years of service life remaining or non-removal of signs with insufficient retroreflectivity, resulting in a waste of money. If not replaced, deficient signs could lead to an accident for the motorist and a tort liability case for the highway agency. A study of tort liability cases in Pennsylvania found that signing deficiencies were cited as a primary factor in 20 percent of their tort actions, second only to pavement deficiencies. When only highway accidents in which a fatality or serious injury occurred are considered, signing deficiencies rank as the primary factor most often cited - 41 percent (24).

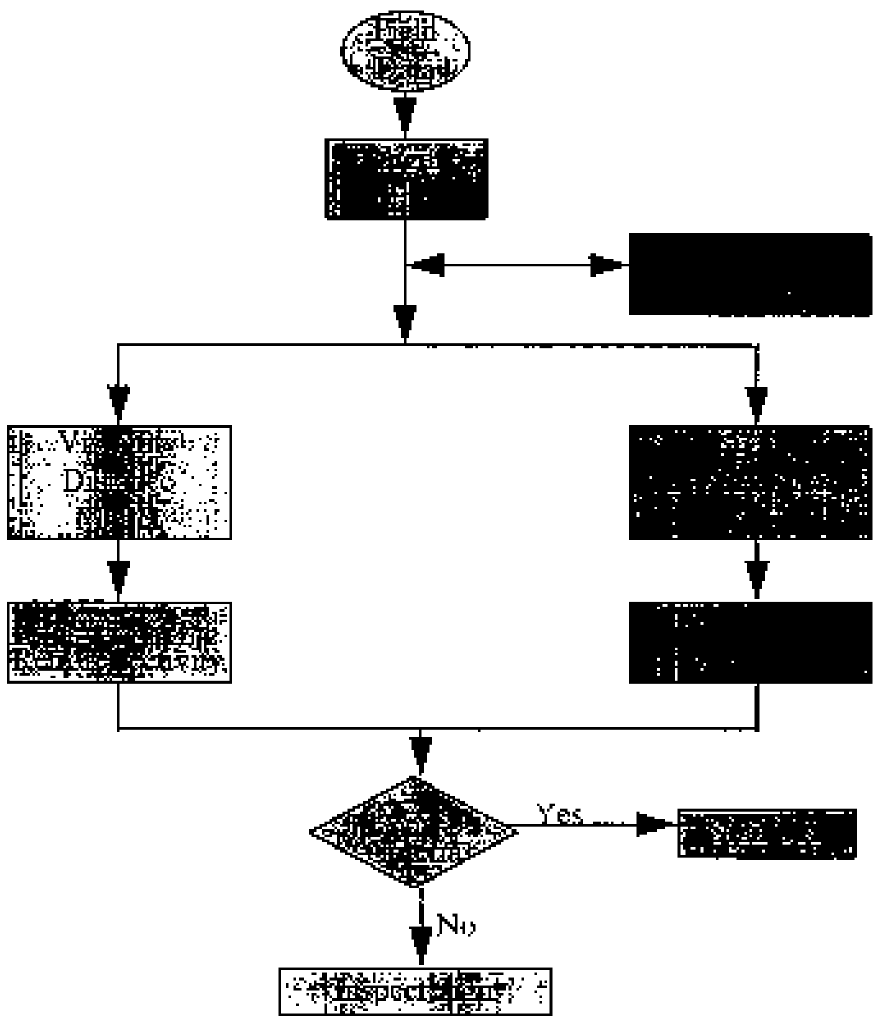
A review of MDT sign inventory data made available by Pat Brannon of MDT reveals many problems and strengths of current maintenance efforts in the inventory program. Subjective items, such as comments, and condition vary a great deal within the inventory. A more uniform, objective approach is needed to eliminate as much subjectivity as possible. The current inventory practices are also very replacement oriented, and are rarely complete, including only signs needing repair or replacement in any given area/section/route. The use of a computer-based management oriented system is necessary to adequately address the inventory as a unit. Incorporation of a Scantron form to facilitate data collection is a possibility, as has been suggested by MDT personnel (23).

The Federal Highway Administration has developed and is refining a Sign Management System (SMS). This SMS has been developed to provide state and local highway agencies with a predictive tool for use in managing a sign inventory. SMS is a microcomputer based system that allows a sign inventory to be created and the age and condition of signs to be tracked (24). Traffic engineers and others responsible for sign maintenance will find SMS very useful in determining which signs are likely to need replacement. Valuable tools within SMS include predictive models for sign deterioration for varying colors and types of sheeting materials, incorporating sheeting age, solar radiation levels, and general area climate as primary variables.

Currently, SMS is an IBM compatible, menu-driven system that makes assembling an maintaining a sign inventory very straight forward. Although the final version has not been released, current versions available are user friendly, and functional. A logic flow diagram is shown in Figure 4.

Final determination as to which signs need immediate replacement, and which ones could be left in service would require field verification. Proper use and verification of SMS models and data, prevent unnecessary sign replacement, assist highway agencies in locating deficient signs, use limited maintenance funds more efficiently, and aid in projecting future budgetary needs.

Figure 4: Logic flow diagram of SMS.



Data requirements for SMS are more extensive and detailed than current data contained within most inventory programs, but as mentioned before many data field will not change or need to be updated on a regular basis. A sample of the data-entry format for SMS is included in Table 8.

Table 8: Sample Data needs and format for SMS Program.

LOCATION

ID# ROUTE NAME/#
(<Alt-R> to see route names)

INTERSECT MILEPOINT DIRECTION

POSITION OFFSET HEIGHT ORIENTATION

DATA

MUTCD LEGEND
(<Alt-M> to see MUTCD codes)

SIZE: W H SHEETING MANUFACTURER BACKING POST

INSTALL DATE COMPLEXITY SPEED USER DEFINED

INSPECT DATE CONDITION ACTIVITY MEASRD Ra: L B
(<F9> Average Readings)

MAINT REQ'D COMMENTS

RESULTS

AVAILABLE Ra: L B

REPLACEMENT DATE

REQUIRED Ra: L B
(<F3> DISPLAY Special Keys)

Task E - Conclusions and Recommendations

Based upon the previously discussed work activity conducted in Phase I - i.e., meetings, correspondence, interviews, literature review, equipment utilization, reflectivity sample measurements, sign inventory evaluation, etc. - the following preliminary recommendations are offered:

1. The national trend by State DOT's in response to the proposed FHWA minimum sign retroreflectivity requirement is a multi-year plan for complete highway sign replacement with high performance (high intensity) sheeting. The Montana DOT should strongly consider the same. However, it may be prudent to delay full implementation of this decision as MUTCD adoption of requirements may be tabled as a "politically incorrect unfunded mandate".

2. Use of the portable reflectometer equipment (ART 920) in the field for strict measurements of sign reflectivity is cumbersome, time consuming, labor intensive, and thus costly unless incorporated with other sign inventory data collection. The utility of the FHWA Mobile Sign Reflectometer Van as an expedite measurement tool should still be investigated, possibly in Phase II of this study. Controlled spotlight assessment for sign replacement due to diminished reflectivity seems to be a workable alternative. Definite and viable procedures for this technique need to be established.

3. Preliminary sign retroreflectivity measurements taken in the Butte District has allowed the determination of a statewide sampling plan to be conducted in Phase II of the study. This sampling plan and methodology is based on minimum cell requirements for statistical extrapolation and is consistent with other similar sampling conducted by FHWA (25). It also can be accomplished within the time and budget constraints of the research contract. Table 9 details the minimum cell matrix projections for each of the five (5) MDT Districts. The total minimum statewide sample of estimated sign reflectivity measurements is 1000 or 200 per District, for both Interstate and non-interstate facilities. It is anticipated that the interstate sample requirement will be fulfilled by current work in progress by CH2M Hill for MDT.

4. Currently, there is no significant or consistent collection or maintenance of sign inventory data for wither tort liability documentation or replacement management. Studies by other states have emphasized that, while necessary, the institution of an effective sign management system with the associated data collection is a costly endeavor. Recognition of this has led FHWA to develop and offer a micro-computer based Sign Management System (SMS), with support and training, to State DOT's. It is recommended that MDT adopt this system for the stated purpose. It is further proposed that to assist MDT in implementation of the SMS, the research study conduct a pilot demonstration of this system utilizing sign

inventory data collected in the Butte District by student volunteers from the Institute of Transportation Engineers Student Chapter at Montana State University (MSU-ITE). The concept has been previously discussed and coordinated with Mr. Pat Brannon of MDT. Final details of this volunteer effort between MDT and MSU-ITE must still be negotiated.

Table 9: Proposed district sampling schedule for Montana sign reflectivity study.

Signs per Cell: Minimum of 25 (randomly selected to be representative of conditions jurisdiction-wide)

Interstate Designation: X
Non-Interstate Designation: Y
Legend Color: Black **Background Color: Yellow**

	Sign Size	> = 48 inches	36 inches	< = 30 inches
Legend	Material Type			
All Legends	I (E.G.)	X	Y	Y
	III (H.I.)	X	X	

Interstate Designation: X
Non-Interstate Designation: Y
Legend Color: White **Background Color: Red**

	Sign Size	> 48 inches	36 inches	< = 30 inches
Legend	Material Type			
All legends	I (E.G.)	X	X, Y	Y
	III (H.I.)			

Interstate Designation: X
Non-Interstate Designation: Y
Legend Color: Black and/or Black and Red **Background Color: White**

Sign size	> = 48 inches	36 inches	< = 30 inches
Material: All Types	X	Y	Y

Interstate Designation: X
Non-Interstate Designation: Y
Legend Color: White **Background Color: Green**

Material:	Sign Size	
All Types	All Sizes	X, Y

Minimum Total Number of signs to be sampled per District: 200

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A Review of Kansas Department of Transportation's Reflective Sheeting Policy, Final Report
By E.R. Russell and M. Rys, 1992
Report Number: K-TRAN: KSU-92-8

The main objective of this study was to determine the best, cost-effective policy, consistent with safety, for sign sheeting material to be used on signs and construction work zone traffic control devices on State highways in Kansas. The investigation consisted of reviewing literature, contacting knowledgeable traffic engineers and research, conducting a survey of selected States' practice, conducting a life-cycle cost analysis, and reviewing a previous reflective sheeting study conducted for the Kansas Department of Transportation (Bellomo-McGee Inc., 1988). Among the conclusions of this study are the following: (1) Kansas (or any State) should not change any policy on sign reflectivity at this time due to the extensive FHWA research program underway. (2) The trend is toward high-performance sheeting on all or most traffic signs. (3) For traffic control devices in construction work zones, the trend is also toward high-performance device. (4) There is a small but growing trend to use new reflective materials with three times the retro-reflective values of the present high-performance materials, at least for critical or special locations. (5) For high-speed highways, anywhere a critical vehicle maneuver is necessary and in areas of medium to high visual complexity, higher values of sign luminance are required for safety. (6) Older drivers are increasing in the US driving population and their visual needs are greater than those of younger drivers. The higher retro-reflective properties of high-performance materials enhance safety, particularly of older drivers, by providing greater conspicuity distances and slightly increased legibility distances for any given sign size. (7) An analysis of recent bid data from KDOT showed a lower annual life-cycle cost for high-performance signs. (8) The conclusions of the 1988 Bellomo-McGee Inc. Reflective sheeting study were valid and appropriately based on key available studies.

Comparing Sign Materials
Journal: Better Roads, July 1995

When comparing sign materials, consider cost, warranty, durability, visibility, reusability, and levels of performance. Even if your agency is just considering an upgrade in materials, all parameters must be covered. A discussion of funding concerns, cost and benefits associated with signage options, visibility requirements, and questions that need to be asked before making a sign sheeting material purchase.

Computerized Sign Inventory Feasibility Study
By C.E. Kurt, C.E. Thor, H.J. Melhelm, and R.W. Stokes, 1994
Report Number: K-TRAN: KU/KSU-94-3

> *The objectives of this study are to evaluate Kansas Department of Transportation's (KDOT) needs for sign inventory data and information; determine existing software, hardware, database, and video logging resources available in KDOT; and investigate available and potential sign inventory applications software which is compatible with KDOT's Geographic Information System (GIS) directives. This report summarizes findings and recommendations to KDOT for establishing a computerized statewide sign inventory system.*

Deterioration of Retroreflective Traffic Signs
By K. L. Black, S.F. Hussain, and J.F. Paniati, 1992
Journal: ITE Journal. Volume Number: 62, Issue Number: 7

> *The results are presented from the recently completed study, "Service Life of Retroreflective Signs", completed by the Federal Highway Administration, which investigated the factors that cause the deterioration of retroreflective sheeting and ultimately reduce the effective service life of signs. The study focused on the two most commonly used sheetings: Type II, engineering grade; and Type III-A, high-performance grade. The FHWA has developed a sign management system for managing sign replacement programs and for ultimately assisting in maintaining a minimum level of retroreflectivity. The ability to predict the service life of a traffic sign is essential to implementing the sign management system. To accomplish this, study objectives were established, the first of which focused on the factors that cause sign sheeting deterioration. To evaluate the deterioration factors, a national data collection effort was undertaken. This paper provides an overview of the data collection effort, and selected results from the sample data set.*

Devises at Construction Work Zones, Final Report
By S. A. Ahmed, 1991
Report Number: FHWA/OK 91(06).

> *The overall objective of this project was to evaluate the relative adequacy of the engineering grade, super-engineering grade, and high-intensity grade sheetings when used on traffic control devices at construction work zones. Evaluation criteria included driver visibility needs, durability and economics, and other practical considerations. To meet the objectives of this project, a research plan consisting of literature review, controlled field experiments, real-world field experiments, accelerated weathering tests, survey of Oklahoma traffic control contractors, and economic analysis was adopted. The results of these tasks formed the basis for the findings and conclusions of this study. While the high-intensity grade sheeting has the highest target value of the three sheeting*

grades, the tradeoff between detection and legibility of traffic control signs was interpreted to favor the use of the super-engineering grade on signs in both urban and rural construction projects. Durability, economics, and other practical issues emphasized by traffic control contractors support this conclusion. Nevertheless, use of the high-intensity grade sheeting in urban construction projects may be warranted at locations with visual clutter and excessive background lights. The beneficial effects of upgrading the type of sheeting used on barrels, barricades, and vertical panels from engineering grade to high-intensity grade or super engineering grade were demonstrated by the significant increase in both the detection and recognition distances of these devices. Yet, the benefits of upgrading to the high-intensity grade were found to be offset by the significant increase in cost, the less durability of the sheeting material, and the problems with fabrication and handling. Upgrading to super-engineering grade offers the most cost-effective and balanced solution.

Durable Florescent Materials for the Work Zone
By D. M. Burns., L.A. Pavelka, and R.L. Austin, 1993
Journal: Transportation Research Record, Issue Number 1409.

Construction work zones (CWZs) are a major cause of concern for highway and safety engineers. At any given time CWZs constitute only a small fraction of the total roadway miles. However, they are the site of an increasing number of roadway accidents each year. The traffic safety industry has attempted to respond to this problem by providing brighter retroreflective sign materials to increase the nighttime visibility of the CWZ. The equally important need for increase daytime visibility has prompted traffic engineers to experiment with fluorescent colors in the CWZ. Fluorescent colors have outstanding visibility under all daylight driving conditions. Even so, fluorescent colors have never achieved widespread acceptance in outdoor signing applications. The primary obstacle has been the very poor color stability of fluorescent signing maters. A typical fluorescent roadway sign has lost most, if not all, of its color within 1 year. Often it is only a matter of months or weeks. Recent developments have resulted in a redefinition of contribution that fluorescent colors can make toward improving traffic safety. A fluorescent retroreflective sheeting with color durability similar to existing CWZ sheetings is now available. A field study was run to compare the visibility performance of this fluorescent retroreflective sheeting that of conventional fluorescent films and ordinary retroreflective materials. The results of the study indicate that fluorescent retroreflective sheeting provides better daytime and nighttime visibility than do ordinary signing materials.

Evaluation of Diamond Grade Reflective Sheeting. Final Report
By K. R. Agent, 1993
Report Number: KTC-93-8

The objective of this project was to monitor the performance of the diamond grade sheeting when used on both typical traffic signs and construction signs. The durability, *appearance, and reflectivity of the signs were monitored. Diamond grade sheetings used on typical traffic signs were evaluated over a two-year period with construction signs evaluated over an 18-month period. Diamond grade sheeting was found to provide increased reflectivity compared to high intensity sheeting with no problems noted related to durability or appearance. However, the cost of the diamond grade sheeting would limit its use to situations were brighter, wider-angle reflective sheeting is warranted and the increased cost can be justified. Locations where the use of diamond grade sheeting should be considered because of its higher reflectivity include the following: (1) signs in areas with high levels of ambient lighting; (2) work zones (especially in urban locations) where the roadway environment is visually cluttered; and (3) high accident locations involving a nighttime accident problem. A location where use of diamond grade sheeting could be considered because of the increased viewing angle would be for overhead signs in urban areas. These increased angles would only be a factor when the driver is attempting to view the sign at a location close to the sign which could be the situation at urban intersections.*

<u>Evaluation of Reflective Sheeting Grades</u>
By Commonwealth of Pennsylvania Department of Transportation, 1993
Report Number: 4700/AHB (7-3620)

New improved grades of reflective sheeting material became available during the past 20 years for use on traffic signs to provide better nighttime visibility under headlight illumination. These new grades are not only brighter during headlight illumination, but they are also more durable. This paper evaluates these materials to determine their respective cost-effectiveness.

A review and analysis of Pennsylvania Department of Transportation's use of retroreflective sheeting grades, comparison of the physical differences, cost effectiveness, and safety benefits between these grades of sheeting. The recommendations were to convert all warning signs that are currently made from engineering grade sheeting to high intensity reflective sheeting material. This conversion should be phased in as rapidly as the Department can upgrade the necessary handling/storage requirements.

<u>Evaluation of Retroreflective Sheetings for Use on Roadway Traffic Signs</u>
By S.A. Ahmed, 1994
Report Number: FHWA/OK 95(02)

The primary objectives of this research were to evaluate the Oklahoma Department of Transportation's (ODOT) policy on use of retroreflective sheeting products, and to identify any necessary changes to this policy based on driver visibility needs, durability of sheeting materials, life-cycle cost, and other practical considerations. The scope of the study included three types of retroreflective sheetings (engineering grade, super-

engineering grade, and encapsulated-lens high-intensity sheeting), five sheeting colors (white, red, yellow, green, and blue), and two sign fabrication methods (screening and overlay).

The findings in this study suggest that the specification of type III-A (high-intensity, encapsulated glass bead sheeting) on all red and yellow signs, as well as green and blue signs on interstate highways and freeways is sound and defensible. The requirement that type II-A (super-engineering grade sheeting) be used on all other traffic signs, except orange colored signs, needs to be examined. Although the initial cost of sign fabrication for type III-A sheeting is 25% to 65% higher than that of type II-A, life-cycle cost analysis indicates that type III-A is more cost-effective than type II-A. Evidence from visibility distance analyses and subjective evaluations made by the test subjects suggest that, in addition to upgrading sign materials to provide greater luminance, larger sign size and letter size are needed to satisfy the minimum required visibility distances, particularly at high speed, high traffic volume, and high visual complexity locations.

High-Intensity Reflective Materials for Signs
By R. L. Rizenbergs, 1974
Report Number: Research Report # 397

Field observations and laboratory tests and evaluations were conducted on High-Intensity and Engineering Grade materials (Scotchlite), manufactured by the Minnesota Mining and Manufacturing Company, and were compared in regard to reflectivity, durability, and cost. The High-Intensity Grade materials were found to have outstanding performance characteristics in comparison to Engineering Grade materials. The material significantly enhances sign legibility under low-beam illumination, and accelerated weathering tests showed superior durability.

Implementation Strategies for Sign Retroreflectivity Standards
By K.L. Black, H.W. McGee, and S.F. Hussain
Report Number: 346

Minimum retroreflectivity standards for traffic signs are currently being considered and indications are that standards will be instituted in the near future. Prior to the establishment of retroreflectivity standards two key issues must be addressed: (1) how will the standards be implemented and (2) how much will the standards cost jurisdictions for replacement and maintenance activities. Currently, only new purchase specifications exist for permanent and temporary traffic signs. The retroreflectivity specifications measured in terms of specific intensity per unit area (SIA) are related to manufacturer's warranties and were not established based on motorist needs for sign legibility. Minimum retroreflectivity standards for traffic signs based on legibility requirements are needed.

The research found that the economic impacts of standards will be hardest felt by city jurisdictions. This is because of the relatively poor condition of traffic signs on city roadways. In addition, deficient green signs accounted for a disproportionate share of replacement costs across all jurisdiction types. Green sheeting, especially engineering grade, has rather low retroreflective properties. One of the minimum standards tested here for green sheeting was actually higher than the delivered new specification prescribed by states and the FHWA for engineering grade sheeting. Ground-mounted guide signs also tend to be at least twice as large as standard warning and regulatory signs; therefore, the cost to replace ground-mounted guide signs is nearly double that of other traffic signs.

The research reported here tested two sets (i.e., lower and upper) of retroreflectivity standards. The lower standards should have minimal economic impacts on most jurisdictions. However, the upper standards would have an extreme impact on signing budgets. Maintenance to the upper standards could cost two to six times as much as current budgets. The establishment of retroreflectivity standards between the two sets of standards tested here would still burden some jurisdictions. However, the anticipated benefits of reduced liability and improved public safety could offset the additional maintenance costs.

Investigation of the Legibility of sign Letter and Background Type Combinations Under Various Conditions of Weather and Viewing and Durability of Reflective Sheeting, Final Report

By J. A. Wagner, 1989
Report Number: FL/DOT/SMO/357-89

This study investigated the durability of sign face materials through field surveys, the effect of weather conditions (dew, mists, fog, smoke, and rain) on sign performance, the effect of sign angular position on preventing the specular mirror problem, the effect of sign lateral position, the effect of material combinations on legibility and detection distances as measured by small sign elements and through a survey of large guide signs in three Florida cities. A part of the investigation set the level of specific intensity per unit of area marking the end of service life for reflective sheeting and acrylic button reflectors and the level of appearance for nonreflective porcelain enamel backgrounds. Recommendations are made for an updated specification for reflective sheeting, a design policy using certain material combinations for different weather and roadway situations, improved control over screened colors, use of Type II A sheeting, angular mounting of signs, and other issues.

Legibility of Freeway Guide Signs as Determined by Sign Materials
By R.W. McNees and H.D. Jones, 1987
Journal: Transportation Research Record 1149

In this paper, results of an operational study investigating the legibility distance of unlighted overhead guide signs are presented. Opaque sign backgrounds as well as engineer, super-engineer, and high-intensity reflective sheetings were used in combination with button-removable and high-intensity reflective copy. There was no significant difference between lighted and unlighted signs by sign material. Several sign combinations performed better than others. Engineer reflective sheeting was legible at more than 900 ft. Both on the lighted and on the unlighted routes, whereas engineer reflective sheeting with high-intensity stick-on copy was legible at 775 ft. (lighted) and 646 ft. (unlighted). The following combinations were visible at more than 800 ft: super-engineer/button, high-intensity/stick-on, and super-engineer/stick-on.

Methodology to Review Cost-Effective Highway Sign Retroreflective Sheeting Policy
By M. Rys and E.R. Russell, Sr., 1993
Journal: Journal of Transportation Engineering

Kansas State University conducted research for the Kansas Department of Transportation to evaluate their retroreflective sheeting policy. This paper presents a recommended methodology for conducting a life-cycle cost analysis using Kansas cost figures and bid prices for two sheeting types as an example. A 50-state survey uncovered only four states that had ever done an economic analysis of sign sheeting. All were old studies and none used life-cycle cost-analysis techniques. Three types of signs were analyzed. It was concluded that Kansas policy of using signs with high-performance sheeting was cost-effective. These conclusions are not necessarily valid in other states, and only two materials were used in the example because valid cost figures were available on only two materials. An analysis of life-cycle cost results made available by several states would result in a significant contribution to nationwide results on all materials used in the United States under actual conditions.

Minimum Retroreflectivity Requirements for Traffic Signs
By J.F. Paniati and D.J. Mace, 1993
Report Number: FHWA-RD-93-077

This summary report presents minimum retroreflectivity requirements for traffic signs by seeking to define the minimum nighttime visibility requirements for traffic control devices. Currently, national guidelines regarding the nighttime visibility of signs are limited to the stipulation in the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) that all warning and regulatory signs be illuminated or reflectorized to show the same color and shape by day or night. Given the wide range of visual, cognitive, and psychomotor capabilities of the driving population and the *complexity of the relationships between the driver, the vehicle, the sign and the roadway, a mathematical modeling approach was used.*

Minimum Retroreflectivity Requirements for Traffic Signs, Summary Report
By J.F. Paniati and D.J. Mace, 1993
Report Number: FHWA-RD-93-152

Currently, national guidelines regarding the nighttime visibility of signs are limited to the stipulation in the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) that all warning and regulatory signs be illuminated or reflectorized to show the same color and shape by day or night. Given the wide range of visual, cognitive, and psychomotor capabilities of the driving population and the complexity of the relationships between the driver, the vehicle, the sign and the roadway, a mathematical modeling approach was used. This model determines the distance at which a driver needs to see a sign, uses this distance to determine the luminance required, and then calculates the coefficient of retroreflection at standard measurement angles. This model is called Computer Analysis of Retroreflectance of Traffic Signs (CARTS).

Outdoor Testing of Reflective Sign Materials
By T.L. Nettleton, 1985
Report Number: HTO-21/10-85(2M) ENR

Some reflective signs on National Forest land are subjected to extreme temperatures and snow burial. Field units noted the reflective sheeting peeling from these signs after only one winter. In 1972 the Missoula Equipment Development Center (MEDC) began testing outdoor signs of various substrates, reflective sheeting, application techniques, and clear coatings. The goal was to find the right combination of materials and manufacturing processes to produce a reflective sign that would remain maintenance-free for 7 years.

The 3M Co. agreed to take part in the testing. In 1976 two other sheeting manufacturers, Avery International and Mitsubishi/Seibu International, joined the testing, and in 1979 Reflexite Corp. and Carsonite International began participating.

To date, outdoor testing has identified a number of combinations of substrate, reflective sheeting, application techniques, edge seal, and clear coatings that will extend the service life of outdoor reflective signs. These test findings are documented and the specific combinations recommended for manufacturing Forest Service signs are explained in detail.

Relative Visibility of Increased Legend Size vs. Brighter Materials for Traffic Signs
By The Last Resource, Inc., 1994
Report Number: FHWA-RD-94-035

> *The objective of this research was to determine the relative conspicuity and legibility of signs with different retroreflective materials containing legends using different stroke widths and other stylistic variations. With respect to legibility, the principal objective was to determine the font, stroke width, and spacing that would provide optimum legibility for each retroreflective material tested. With respect to conspicuity, the objective was to determine the detection/recognition distance under controlled and comparable visual surroundings for different materials and sizes of signs with optimum legend stroke width.*

Research on the End of Life for Retroreflective Materials: A Progress Report
By J. F. Paniati and R. N. Schwab, 1991
Journal: Transportation Research Record, Issue Number: 1316.

> *The status of the nationally coordinated program for retroreflectivity research is described. This program was developed under the guidance of the FHWA Office of Safety and Traffic Operations Research and Development. The goals of the program are to determine the end of life for retroreflective signs and markings and to develop the end of life for retroreflective signs and markings and to develop the necessary measurement and management tools. Included are discussions of the human factors research to determine the end of life of retroreflective materials, an economic analysis of the impact of deterioration of sign materials, the development of computer software to manage sign inventories, and the design of new instruments to measure the retroreflectivity of signs and makings from a moving vehicle during daylight.*

Review of Retroreflective Sign Sheeting Materials, Practices and Policies, Final Report
By G. W. Flintsch, 1993
Report Number: FHWA-AZ-SP-9304

> *The Arizona Department of Transportation (ADOT) is interested in establishing minimum retroreflectivity requirements for sign sheeting used on the State Highway System. This study consisted of a thorough literature review of minimum retroreflectivity needs and a nationwide survey which identified types of sheeting used and usage policies among the states. The distance at which a sign can be detected and recognized must be greater than the visibility distance required by the driver to make a decision and initiate and complete a maneuver, if necessary. Since at night visibility is heightened primarily by retro reflection, there must be a minimum retroreflectivity requirement that assures the visibility distance required by the driver. Forty-eight states were surveyed regarding sign sheeting and 35 states answered the questionnaire. The responses showed that most states have a policy that establishes the type of sheeting used for each sign class.*

However, minimum reflectivity requirements (SIA) are used only for purchase of new signs and new sign sheeting. The most recent study on SIA was performed by Olson at the University of Michigan. He conducted a field study of sign conspicuity and recommended minimum retroreflectivity requirements for several types of signs depending on the complexity of the surroundings and travel speed. Additionally, FHWA is sponsoring a project that will determine minimum visibility requirements and the level of retroreflectivity required to satisfy those requirements. The values determined by Olson appear to be high, especially for high complexity areas, but the study is the best currently available and Olson's SIA values were used in this study to estimate the minimum grade of sheeting necessary for each sign type. Considering the economic impact of using more retroreflective sheeting, it appears reasonable to wait for the results of the research sponsored by FHWA before recommending a retroreflective sheeting policy for ADOT.

Service Life of Retroreflective Traffic Signs, Draft Report.
By K.L. Black, H.W. McGee, S.F. Hussain, and J.J. Rennilson, 1991
Report Number: FHWA-RD-90-101; NCP 3A2A1122.

The ability to predict coefficient of retro reflection values for in service traffic signs is critical for the Federal Highway Administration's (FHWA's) Sign Management System (SMS). Within the SMS, tools for predicting in service retroreflective performance of traffic signs and for determining the motorist's visual needs are required. The research which focuses on the motorist's needs in terms of traffic sign luminance, legibility distance, conspicuity, etc., is on-going by others. The project reported on here evaluated the effects of climatological and geographic variables on sign sheeting deterioration. A national data collection effort was undertaken. Data samples from 6,275 traffic signs were collected across the country. The data collected included: sheeting retroreflectivity, ground elevation, orientation to the sun, data of installation, sheeting type, etc. Mathematical equations were developed using the key deterioration variables to predict in service coefficient of retroreflectivity and legend to background contrast ratios. The main difficulty in modeling sheeting deterioration was the result of the variation in the coefficient of retroreflectivity for new sheeting.

Sign Management System
By U.S. Department of Transportation, 1982

The Sign Management System (SMS) has been developed by the Federal Highway Administration Office of Safety and Traffic Operations Research and Development to provide State and local highway agencies with a tool for assembling a sign inventory and maintaining an integrated sign management program. The SMS allows for the tracking and systematic inspection of sign sheeting age and condition. The SMS will go beyond simply a sign inventory. Models to predict when a sign is likely to need replacement will be included to assist agencies with their maintenance and inspection programs. The key *results of recently completed research are being used to upgrade the current system into a predictive tool. The SMS will predict retroreflective levels for inservice signs and combined with minimum retroreflectivity guidelines provide an estimated replacement date. This will assist agencies with limited resources in locating, inspecting, and replacing those signs which are in the most serious need of maintenance.*

Specification for Retroreflective Sheeting and Process Inks for Traffic Control
By Pennsylvania Department of Transportation., 1995
Report Number: 470

This specification covers colored, adhesive-backed, retroreflective sheeting consisting of optical lens elements embedded or suspended within a transparent weatherproof outer surface and design to enhance nighttime visibility of signs. Transparent and opaque process inks for production application to reflective sheeting materials by a direct or reverse silk-screening process are also covered. Material classification, requirements, tests, test methods, color requirements, and quality assurance provisions are all included.

Summary Report of the Condition of Reflective Signs in California
By California Department of Transportation, 1995

A small number of representative signs at various places over a large area were examined. The findings show that although California requires sign contractors to stamp the year of manufacture on the signs with permanent ink, only an estimated 50% of the signs reviewed have readable dates. These dates are also manufacture dates of the signs, not install dates. Differences in performance between process ink performance, relationships between signs location and condition, and orientation are discussed. The signs were measured for reflectivity using a Model 920L Retroreflectometer from Advanced Retro-Technology (ART), Inc.