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Proceedings

Workshop on Field Inspection and Rehabilitation of Traffic Control Devices

Eastern United States	*Western United States*
February 5 to 7, 1990 *Reston, Virginia*	***February 21 to 23, 1990*** *Salt Lake City, Utah*

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Mr. Guenther Lerch, HRT-20, Highway Engineer (COTR), Federal Highway Administration

16. Abstract

The Federal Highway Administration (FHWA) has begun a number of initiatives to improve signing on the Nation's roadways. These include workshops to obtain input from experts across the country, a review of each State's highway sign replacement and refurbishing program, and a training course. This report documents the proceedings of the workshops, one held in the Western United States and one in the Eastern United States.

The workshops opened with a plenary session on Issues, Needs, and the FHWA Research Program, followed by a plenary session on Development of Minimum Requirements. The program continued with a panel discussion on Performance Standard Criteria, followed by a plenary session on Materials Selection. Breakout sessions on freeway signing, non-freeway signing, and motorist services and tourist-oriented signing completed the first day of the workshops. The second day opened with reports of the breakout sessions and continued with a plenary session on Field Assessment Techniques. A plenary session on Maintenance Procedures and Programs followed. The second day ended with breakout sessions on sign replacement methods, using contracting versus in-house and prison industries, and traffic control during sign replacement. The third day opened with reports on the previous day's breakout sessions, followed by a plenary session on Improved Inventory Techniques. The workshops closed with a Look to the Future plenary session.

This report details the remarks made by the panelists and the comments and concerns of the participants on each of these issues.

*P. Russell, J. Paniati, P. Olson, H. McGee, K. Black, D. Casner,
R. Moseley, E. Lagergren, C. Robert, R. Young, J. Lumia, C. Antle, R. Attaway,
R. Schwab, B. McCoola, L. Elts, R. Cunard, D. Holstetter, V. Liebe, S. Hearn.
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

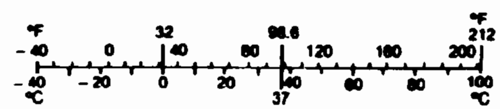
Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

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PREFACE

For several years, the Federal Highway Administration (FHWA) of the U.S. Department of Transportation has been concerned that highway signs and markings are not being replaced in a timely manner. Currently, the *Manual on Uniform Traffic Control Devices* (MUTCD) only requires that signs and pavement markings be retroreflectorized or illuminated. The MUTCD contains no minimum in-service retroreflective requirements for traffic control devices.

Accident statistics indicate that a nighttime driving problem exists. The fatality rate (fatalities/vehicle) for miles of travel is more than three times higher at night than during the day. Although factors such as fatigue and intoxication contribute to this disparity, they do not account of the total difference. Because of poor visibility, driver reliance on traffic control devices for the necessary warning, regulation, and guidance decreases at night, adding to the problem. The additions of inclement weather and glare from opposing vehicles compound the problem.

The FHWA recognized the need to determine the minimum in-service retroreflective requirements for traffic control devices and convened the Workshops on Field Inspection and Rehabilitation of Traffic Control Devices held in Reston, Virginia, from February 5 to 7, 1990 (the eastern workshop), and in Salt Lake City, Utah, from February 21 to 23, 1990 (the western workshop). Each workshop spanned two and a half days and comprised 22 presentations, 1 panel discussion with 4 panel presentations, and 2 breakout sessions of 3 simultaneous discussion groups.

The objective of the workshops was to obtain information from State and local officials to guide the development of national policy on minimum in-service retroreflectivity requirements for traffic control devices. Specifically, the purpose of the workshops was to:

- Disseminate results of research related to minimum visibility requirements.
- Disseminate information about various tools for maintaining adequate signs and markings.
- Encourage State and local officials to share their procedures and experience maintaining signs and markings.
- Obtain feedback from State and local operations organizations that would support decisions for a national policy on minimum in-service retroreflectivity requirements for traffic control devices.
- Advise FHWA regarding future research activities that could be inaugurated to support a program for better traffic signing.

The organization of this proceedings document mirrors the structure of the western workshop, which differed only slightly from the eastern workshop. The proceedings document begins with an executive summary, followed by presentation papers grouped into seven plenary sessions: Issues, Needs, and the FHWA Research Program; Development of Minimum Requirements; Materials Selection; Field Assessment Techniques; Maintenance Procedures and Programs; Improved Inventory Techniques; and Look to the Future. Where presentation topics were addressed by different speakers at the eastern and western workshops, papers by speakers at the eastern workshop precede those by speakers at the western workshop. Following the papers on Development of Minimum Requirements is a summary of the panel discussion on Performance Standard Criteria. A summary of the breakout sessions on freeway signing, non-freeway signing, motorist services and tourist oriented signing follows the papers on Materials Selection and a summary of the breakout sessions on sign replacement methods, using contracting versus in-house and prison industries, and traffic control during sign replacement follows the papers on Maintenance Procedures and Programs.

EXECUTIVE SUMMARY

This proceedings document describes the Workshops on Field Inspection and Rehabilitation of Traffic Control Devices (TCDs), convened by the Federal Highway Administration (FHWA) of the Department of Transportation to improve signing on the nation's streets and highways. The workshops comprise two regional workshops—one in the Eastern U.S., the other in the Western U.S.

To achieve improved signing on the nation's roadways, FHWA has begun a number of initiatives, including the two regional workshops, a review of each State's highway sign replacement and refurbishing program, and a training course entitled *The Road to Better Highway Signing*. In conjunction with this effort, the FHWA Retroreflectivity Research Program has begun efforts to obtain the information necessary to establish minimum retroreflectivity requirements and also to develop the tools (management programs and measurement devices) needed to implement these requirements.

Although the structure of the two workshops varied slightly, all sessions were the same. This document follows the pattern of the western workshop, which opened with a plenary session on Issues, Needs, and the FHWA Research Program, followed by a plenary session on Development of Minimum Requirements. The program continued with a panel discussion on Performance Standard Criteria, followed by a plenary session on Materials Selection. Breakout sessions on freeway signing, non-freeway signing, motorist services and tourist oriented signing completed the first day of the workshops. The second day opened with reports of the breakout sessions and continued with a plenary session on Field Assessment Techniques. A plenary session on Maintenance Procedures and Programs followed. The second day ended with breakout sessions on sign replacement methods, using contracting versus in-house and prison industries, and traffic control during sign replacement. The third day opened with reports on the previous day's breakout sessions, followed by a plenary session on Improved Inventory Techniques. The workshops closed with a Look to the Future plenary session.

Most plenary-session speakers made presentations to both workshops. In other instances, speakers participated in only one workshop. However, all topic areas were included in the two regional workshops.

DEVELOPMENT OF MINIMUM REQUIREMENTS

After opening remarks on the workshop goals and objectives by Philip Russell and an overview of the FHWA Retroreflectivity Research Program by Jeffrey Paniati, three speakers presented research information concerning the development of minimum requirements.

Research studies described by Paul Olson indicate that the most important variable affecting nighttime legibility is legend to background contrast. Background luminance is also a factor. These findings, coupled with more specific data from studies, offer specific recommendations for improving the performance of older drivers.

Jeffrey Paniati outlined research studies used to determine the level of visibility required by drivers (in order to respond safely to a TCD) and compared this level to the actual amount of visibility supplied by the TCD. As part of the research, FHWA developed a computer model, Computer Analysis of Retroreflective Traffic Signs (CARTS), using laboratory and field data to calibrate the model.

Hugh McGee reported on the status of a project funded by the National Cooperative Highway Research Program currently under way to determine the economic consequences of alternate standards for retroreflective traffic signs. The data from the project will be used to develop relationships that indicate how various retroreflectivity standards would affect, nationally and at State and local levels, the number of signs to be replaced, the replacement costs, and any other economic or management considerations.

PERFORMANCE STANDARD CRITERIA

The workshop panel discussion comprised four presentations on performance standard criteria. Each panelist presented the concerns of one of the following groups: State agencies, local agencies, industry, and the public.

The representatives from State agencies acknowledged that agencies need to make signs more visible to motorists. Concerning development of minimum retroreflectivity standards, they also emphasized specific issues to consider, including the variable factors that influence sign retroreflectivity, the needs of older drivers, and the need to prevent creating more tort liability problems. Representatives of local agencies also acknowledged the need for agencies to provide signs with adequate nighttime visibility. Concerns focused on preventing increased liability problems, ensuring flexibility of standards for various conditions, and consideration of economic impacts during the setting of minimum retroreflectivity standards. Two suggested methods for developing standards described by the representatives were phasing in standards on the freeway system only and setting the minimum standard as a service life limit.

Industry representatives considered minimum retroreflectivity standards essential for maintaining high quality signs and expressed strong support for tight standards. They also noted that standards could reduce tort liability costs by eliminating many of the subjective rulings of the court system. Regarding the establishment of minimum retroreflectivity standards, representatives of the public expressed their concern by emphasizing that minimum retroreflectivity standards must be established along with legibility standards, that older drivers must be considered when establishing the standards, and that economic considerations must not lower the standards.

MATERIALS SELECTION

Hugh McGee discussed the principal factors—driver visibility needs, durability and economics, and practicality—involved in selecting sign material. Because agencies prioritize each of these factors differently, depending upon agency policy, location, and method of operation, definitive recommendations cannot be made for selecting from among the many types of materials.

Preliminary results of the FHWA-sponsored project on "Service Life of Retroreflective Traffic Signs," presented by Kent Black, determined that sheeting age, solar radiation levels, and general area climate were reasonable predictors of in-service specific intensity per unit area (SIA). The study also revealed that sign SIA increased by nearly 10 percent after sign washing, based on approximately 600 samples. In addition, the project uncovered several key issues that reduce researchers' ability to model in-service SIA: variability in SIA values for new sheeting, errors in computerized sign inventories, and the limited number of sites surveyed.

The Northeastern Association of State Highway and Transportation Officials (NASHTO) initiated a Regional Testing Program, which will enable member States to pool material evaluation and testing of common materials. The process of developing the program, described by Donald Casner[*], began with the formation of a NASHTO ad hoc committee to evaluate striping materials. More recently, the program expanded to cover other materials and products, including geotextiles and geocomposites, anti-graffiti coatings, reflective sheeting, flexible delineators, coatings for structural steel, plastic pipe and culverts, raised pavement markers, tubular markers, and concrete admixtures.

Richard Young[+] reported on the development of the Southeastern Association of State Highway and Transportation Officials (SASHTO) Regional Test Facilities for Robert Moseley. The facilities perform required research and testing, but do not approve or disapprove products. Each SASHTO State receives a report for a product, reviews the information, and then makes its own determination of acceptable products.

BREAKOUT SESSION ON SIGN MATERIALS

Workshop participants attended breakout sessions to discuss one of three topics: freeway signing materials, non-freeway signing materials, or motorist services and tourist oriented destination signing. Following the breakout sessions, group moderators presented short summaries of the discussions to the entire workshop.

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[*] Presented at eastern workshop only.
[+] Presented at western workshop only.

FIELD ASSESSMENT TECHNIQUES

To begin the session on field assessment techniques, Edwin Lagergren presented the findings of an investigation of the current methodology used to evaluate traffic sign retroreflectivity under actual highway conditions. The investigation, comprising a literature survey, a questionnaire sent to all States, and the training and analysis of human observers to rate traffic sign retroreflectivity, revealed that at present, for a large sign inventory, no method of sign review is more suitable than using a trained observer.

Calvin Roberts* described the Michigan Department of Transportation sign evaluation process, which used a team to subjectively evaluate the performance and condition of individual signs and a computerized method to determine overall signing needs for various segments of freeways. Using the review, evaluation, and rating data, the computer program generated a prioritized listing of sign segments to be upgraded.

Citing the fact that more than 55 percent of all fatal accidents occur at night, Richard Young+ emphasized the need to identify nighttime problem signs, particularly those that appear without problems in the daytime. Although nighttime inspections are the ideal, most signing budgets do not enable the necessary nighttime inspections. Mr. Young detailed a method that uses a 200,000 candle-power spotlight available for $15 to determine during the daytime signs with problems.

John Lumia outlined another practical system for evaluating the nighttime visibility of existing signs and providing data for decisions on sign replacement or refurbishment. The system uses a charge coupled device (CCD) video camera to acquire sign images, a xenon flash as a source of light, and a portable personal computer to analyze the retroreflected sign images and can be operated during daylight from a moving vehicle. The results of experiments and analyses indicate that such a system is feasible, well suited for making measurements from a moving vehicle, and can be built from commercially available components.

A study of service life of pavement markings, reported on by Charles Antle, compared four different types of reflectometers and found that the Mirolux, Ecolux, and the Erichsen are about equally useful for determining reflectivity levels. The study used a panel of human observers to calibrate actual test readings using the reflectometers; the results indicate a reading of 100 from either the Erichsen or the Mirolux to be failure level.

Robert Attaway described the procedures, which included using portable retroreflectometers, and results for two pavement marking evaluations, one of thermoplastic longitudinal markings and a second of special markings. The first evaluation, performed on 350 miles of thermoplastic edgelines, lanelines, centerlines, and barrier lines, indicated that thermoplastic is a durable and reflective pavement marking. The second evaluation of

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*Presented at eastern workshop only.
+Presented at western workshop only.

approximately 200 tape arrows and symbols indicated that pavement marking tapes, as measured by reflectivity, performed poorly.

Reporting on the development of a new laser retroreflectometer that evaluates pavement marking retroreflectivity from a vehicle moving at highway speeds during normal working hours, Richard Schwab noted that the method more closely simulates the typical driver's viewing geometry. The equipment is capable of sampling from 200 to 500 data points on each scan of the line as frequently as every 3 feet (.9 meters), while the truck is traveling at 55 mph (88 kph). Because this device offers too much data to store and interpret, research is currently under way to determine meaningful sampling procedures.

MAINTENANCE PROCEDURES AND PROGRAMS

The session on maintenance procedures and programs included presentations on State and/or local maintenance procedures, strategies for managing sign replacement, and the role of industry for better signing.

The Pennsylvania Department of Transportation's (PennDOT) major initiative to upgrade and improve statewide traffic signing, described by Brian McCoola[*], began in 1987. At the end of December 1989, some 17,258 miles or 42 percent of the State highway system was successfully corrected and improved. Other PennDOT initiatives include supervising a growing logo signing program, upgrading welcome center and rest area signing, evaluating signing and safety improvements at nearly 120 long, steep-grade "truck" hills, and implementing an "Adopt-A-Highway" litter control program.

Leonard Eilts[+] described the State of Minnesota's program to help local governments improve their sign compliance with the *Manual on Uniform Traffic Control Devices (MUTCD)* and reduce liability. Of the 87 counties in Minnesota, 68 presently participate in this local sign upgrade program.

While presenting a number of sign maintenance strategies and techniques, Richard Cunard[*] emphasized that developing a systematic approach to maintenance, no matter which specific system, is the key to offsetting the simultaneous increasing need for sign replacement and decreasing availability of funds for sign maintenance.

Oregon's program for interstate sign rehabilitation, as described by Dwayne Hofstetter[+], focuses on improved project scoping, reducing the contracts to a more manageable size, and opting for complete sign replacement as opposed to overlay. This approach has assisted in producing an upgraded interstate freeway signing system and producing improved target value, daytime and nighttime visibility, and legibility of signs that will last until the updating process must be repeated.

[+]Presented at western workshop only.

[*]Presented at eastern workshop only.

Victor Liebe[*] and Robert Garrett[+] outlined the role that industry plays in an agency's .affic control system for streets and highways. For industry to provide effective service, the public agency should have an inventory system in place for tracking purposes, as well as clear contractual guidelines.

BREAKOUT SESSION ON SIGN REPLACEMENT

A second group of breakout sessions offered participants a choice of one of three discussion topics: sign replacement methods, contracting versus in-house and prison industry, or traffic control during sign replacement. Group moderators presented short summaries of the breakout session discussions to the entire workshop.

IMPROVED INVENTORY TECHNIQUES

The sessions on improved inventory techniques covered computerized sign inventories at both the State and local levels, video disc technology, and the FHWA sign management system.

Robert Feldman[*] (presenting for Steven Hearn) described a microcomputer-based sign inventory system for all interstate routes in the Richmond District of the Virginia Department of Transportation. During development of the inventory, the objectives expanded to meet additional information needs and eliminate duplicate records. The inventory, which was completed in 18 months, is easily updated and provides the information needed for sound decisions on traffic engineering studies, budgets, and future planning.

Reporting on the Highway and Traffic Records Management Information System (HTRIS), Fred Small[*] detailed one component in particular, the Traffic Control Device System. The Traffic Control Device System incorporates an inventory that includes all traffic control and safety devices that the State is responsible for maintaining.

Idaho's recently implemented sign inventory system, described by Dan McComb[+], codes individual signs, storing information such as size, material, color, location, and orientation. The system is easily accessed via District computer terminals and may soon be augmented by using a laptop computer in the field.

Richard Butula[*] described the process and procedures used to initiate the City of Milwaukee's computerized sign inventory. Designed to provide accurate information to courts, attorneys, and the police department, to provide statistical information necessary for scheduled replacement of aged signs and to budget for such activities, to identify locations of non-standard signs, and to provide a listing of locations that have a high frequency of damage reports, the inventory accomplished all of the city's goals.

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[*]Presented at eastern workshop only.
[+]Presented at western workshop only.

While detailing a highway sign inventory system that computerizes both the inventory itself and the generation of the field information gathering system, Thomas Pickford* noted that the system has the capability to monitor and inventory completely signs and pavement markings in Shawnee County, Kansas, and will pay for itself in approximately 3 years.

To illustrate how videodisc technology has emerged as a viable inventory tool among State Departments of Transportation, William Baker detailed several that use a video disc system to store data for various highway files, including photologs, signs, and pavement conditions. As an additional feature of the technology, the Iowa Department of Transportation has recently demonstrated the ability to use an electronically shuttered video camera that can record images directly onto a laser optical disc. This enables video disc technology to be used for capturing as well as for storing data.

Jeffrey Paniati reported on the Sign Management System (SMS) that FHWA is developing. In its current form, this microcomputer-based system can be used to assemble and maintain a sign inventory. However, the final version of the SMS will go beyond a simple inventory by using models to predict when a sign is likely to need replacement.

LOOK TO THE FUTURE

Jeffrey Paniati presented the future research plans of FHWA. While FHWA has not completed budgeting funds for individual studies, future work will most likely fall into the following four areas: refining research results, testing and evaluating management and measurement tools, demonstrating results and training users, and preparing technical handbooks and guides.

PARTICIPANT FEEDBACK

At the close of the workshop, participants asked lingering questions and made final comments concerning the workshop during a planned feedback period. At the eastern workshop feedback session, participants suggested ways for FHWA to improve signing and pavement markings, expressed concerns and hopes related to liability and the establishment of minimum standards of retroreflectivity, and noted that an upper limit to useful sign brightness may exist. At the western workshop, participants voiced concern about the problems related to varying observation angles and about new headlight designs that eliminate the ability to see signs and pavement markings, requested guidance on vision requirements of older drivers, and questioned the conditions under which retroreflectivity standards would be applied.

SESSION 1

ISSUES, NEEDS, AND

THE FHWA RESEARCH PROGRAM

INTRODUCTION

Philip O. Russell
Chief, Traffic Control Development Applications Branch
Federal Highway Administration
400 Seventh Street, S.W.
Washington, DC 20590

This workshop is one of two workshops that are part of the Federal Highway Administration's initiative to improve signing on the Nation's streets and highways. This initiative also includes a review of each State's highway sign replacement and refurbishing program, and a training course entitled "The Road to Better Highway Signing."

Motorists depend almost exclusively on traffic control devices to delineate the roadway and to instruct, warn and guide them to their destination. Yet, the FHWA is convinced that perhaps as many as one half of the signs on our streets and highways are not serving the motorists' needs. Increases in travel, new drivers, and the increasing percentage of older drivers will place even greater dependency on delineation and motorist information systems in the future.

The need for conspicuous and legible traffic control devices is especially critical at night. Over half of the Nation's fatalities occur at night while only one-third of vehicle miles of travel occur at night. Because the *Road to Better Pavement Markings* program initiated in 1986 proved successful, on October 3, 1989 the Executive Director, Mr. Dean Carlson, sent memorandums to all Regional Federal Highway Administrators announcing FHWA's *Road to Better Highway Signing program*. The purpose of this program is to promote good signing practices along with the dissemination of information on the availability of a variety of signing materials and technology. The program itself will focus on three essential elements:

- **Inventories** - States should have statewide computerized sign inventories in order to improve the quality and maintenance of their signs.

- **Orderly Approach** - Each State's sign replacement and refurbishment program should set forth specific goals and objectives, assure the timely progress of the program, and provide for meaningful performance evaluations.

- **Performance Evaluations** - Each State's program should provide for internal reviews of the program's effectiveness and for the adequacy of sign performance through the use of instruments and day/night field observations.

The program will consist of reviewing the procedures of all the State highway agencies, conducting a training course on the subject program, and conducting two workshops on field inspection and highway sign rehabilitation and refurbishment. The field reviews and training are planned for completion by December 31, 1990. The information from the workshops and field reviews will be used to develop a Technical Advisory on improved highway signing.

The workshops will include discussions and reports on procedures and practices for implementing all the elements necessary for a successful sign replacement and refurbishing program. Specific discussions will be directed to contracting provisions and procedures, specifications, overlay techniques, and traffic control during sign replacement construction projects. Contract provisions must include plans for disposal of salvaged sign blanks and the removal of the retroreflective sheeting. The use of chemicals is of concern because of environmental issues and disposal. Freeway guide sign removal and replacement must be coordinated to insure the motorist is not left without necessary guidance information. This involves removing signs one or two at a time and immediate installation of the new signs. Traffic control is particularly critical during sign replacement. Special provisions must provide for worker and driver safety. The FHWA will use much of the information from these workshops in completing the development of the training course.

Projects for the replacement of worn out signs are eligible for Federal-aid funds. These provision are contained in the Federal Highway Program Manual 6-8-3-1 and CFR 655 Subpart F. Also, agencies can use Federal-aid funds at the 100 percent participation ratio if they so desire for the sign replacing and refurbishing projects.

The FHWA is concerned with compliance with the *Manual on Uniform Traffic Control Devices* (MUTCD). We are urging our Division Offices to work closely with the States during the development of replacement and refurbishment sign projects. We ask that the selection of destinations, supplemental guide signs, sign format, alphabets, layouts, are selected and designed in accordance with the MUTCD. This is an ideal opportunity to eliminate non-compliance items, update selection of destinations and improve the overall appearance of signing displays, messages and format.

It is clear that many of the signs on our streets and highways need replacing. Much of the Interstate highway system is 20 years or even older. Many of these signs have never been replaced. Projects to replace and refurbish signs are complicated, labor intensive, and expensive. The FHWA expects to develop standards for minimum maintained levels of retroreflectivity. These standards will require well maintained signs and detailed plans to manage an ongoing effective program.

By continuing to promote improvements in pavement markings along with this new safety initiative to improve highway signing, we will be supporting President Bush's safety goal to decrease the highway fatality rate of 2.2 deaths per 100 million vehicle miles of travel by 1992.

All participants are encouraged to participate in discussions in this workshop. Clearly, the need to identify better ways of doing things is essential and timely.

THE FEDERAL HIGHWAY ADMINISTRATION RETROREFLECTIVITY RESEARCH PROGRAM

Jeffrey F. Paniati
Highway Research Engineer
Federal Highway Administration
6300 Georgetown Pike, T-210
McLean, VA 22101-2296

INTRODUCTION

The Federal Highway Administration (FHWA) has been concerned for some time that highway signs, markings, and other traffic control devices are not being replaced in a timely manner. Studies of in-service traffic signs have shown that signs that are acceptable during daylight can have a markedly different appearance at night. One property of traffic control devices that requires further study is retroreflection.

Retroreflection occurs when light rays from an automobile strike the surface of a traffic control device and are redirected back toward the driver. Retroreflective traffic control devices are used to provide the driver with the necessary warnings, regulation, and guidance at night.

Accident statistics indicate that there is a nighttime driving problem. The fatality rate (fatalities/vehicle miles of travel) is more than three times higher at night than during the day. A variety of factors contribute to this disparity (fatigue, intoxication, etc.), but driver reliance on traffic control devices increases as visibility decreases. Many of the cues (curbs and sidewalks) used by the driver for visual guidance by day disappear at night. Inclement weather and glare from opposing vehicles only serve to compound the nighttime driving problem. Improving the visibility of traffic control devices can decrease the demands on the driver. Good traffic signs and roadway delineation reduce the need to search for information and allow increased attention to the driving task.

Over time, retroreflective materials deteriorate and their ability to return light to the driver diminishes. The current *Manual on Uniform Traffic Control Devices* (MUTCD) contains no minimum performance requirements to specify when retroreflective traffic control devices should be replaced. The practicing traffic engineer must rely solely on engineering judgment and a subjective assessment of the sign's condition.

RETROREFLECTIVITY RESEARCH PROGRAM

The FHWA recognizes that minimum retroreflective requirements for traffic control devices must be determined. These requirements will be based on the driver's need to detect and respond to traffic control devices safely and efficiently. To develop performance specifications for retroreflective traffic control devices, FHWA established the High Priority National Program Area (HPNPA), which is part of a larger program that falls under the 1986 Nationally Coordinated Program (NCP) of Highway Research, Development, and Technology.

The FHWA Office of Safety and Traffic Operations Research and Development is coordinating a research program on minimum in-service retroreflective requirements. The FHWA Office of Traffic Operations has provided technical guidance in the development of this program and will be responsible for directing implementation of the results.

Numerous funding sources are involved in the cooperative program, including FHWA research contracts, the National Cooperative Highway Research Program (NCHRP), FHWA staff studies, the Grants for Research Fellowship (GRF) program, Small Business Innovation Research (SBIR) efforts, and Highway Planning and Research (HP&R) studies.

Several major topics are included in the retroreflectivity research program as explained in the following paragraphs and shown in figure 1.

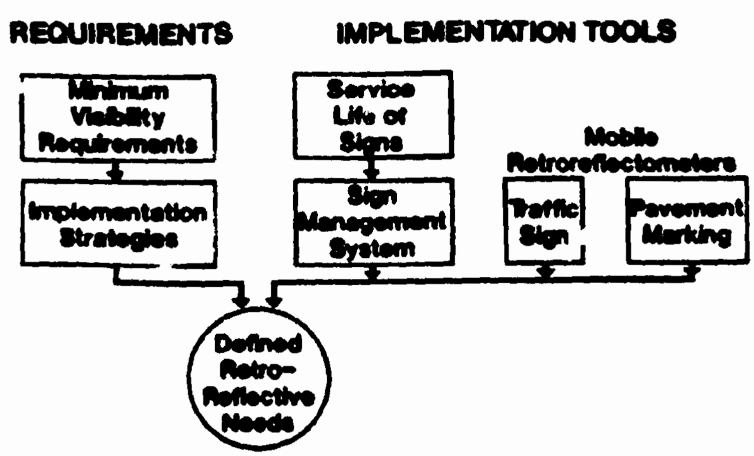

Figure 1. Flow diagram for retroreflectivity program.

The goal of the HPNPA is not just to obtain the information necessary to determine minimum retroreflectivity requirements, but also to develop management programs and measurement devices necessary to effectively implement these requirements.

Minimum Visibility Requirements

The first question that had to be answered in the development of performance requirements for in-service traffic signs was "Does a relationship exist between driver visibility and sign retroreflectivity measurements?" In a 1986 FHWA in-house research study, "Retroreflective Requirements for Traffic Signs—A Stop Sign Case Study," a relationship between the distance at which a STOP sign can be recognized by the driver and its measured retroreflectivity level was identified. Through this effort the feasibility of determining retroreflectivity requirements for control devices was established.

In 1987, a much larger FHWA study, "Minimum Visibility Requirements for Traffic Control Devices," was initiated to determine (a) the minimum distances at which traffic control devices should be visible to the driver and (b) the level of retroreflectivity required to satisfy these visibility requirements. As part of this study, a series of laboratory and controlled vehicle studies were conducted to fill gaps in the current state of knowledge. These studies included the time required by drivers to complete typical driving maneuvers (stop, speed reduction, lane change) and the distances at which drivers can perceive and recognize signs.

Computer models have been developed to study the impacts on the required visibility distances of sign placement, glare from opposing vehicles, and changes in alignment. The retroreflectivity requirements output by this model will be validated as part of this study. This project is scheduled to be completed in November 1990.

Implementation Strategies

Before any widespread implementation of retroreflectivity requirements can be made, their potential economic impact must be assessed. The desire for increased driver safety must be balanced with the economic constraints of the highway agencies that must implement the requirements. A 1989 NCHRP research project scheduled to be completed in mid-1991, "Implementation Strategies for Sign Retroreflectivity Standards," will provide this type of assessment.

As part of this study, a representative sample of retroreflectivity data will be collected from in-service traffic signs. Data-collection sites will include a variety of geographic locations, roadway classes (Interstate, primary, urban), and jurisdictional levels (State, county, city). These data will be used to estimate the effect of establishing minimum retroreflectivity levels and to develop economic-based priorities for sign maintenance budgets.

The data collected will help answer questions on how to maximize the benefit obtained from limited sign maintenance dollars. For example, should a highway agency spend its limited sign maintenance funds to upgrade the most critical signs (e.g. STOP, YIELD) on all roadways or should it concentrate on upgrading all signs on heavily traveled roadways? Guidelines for staging the implementation of retroreflectivity requirements and an estimate of their effects on highway jurisdiction will be provided.

Service Life of Signs

One of the problems of managing retroreflectorized traffic signs is identifying signs that need to be replaced because of loss of retroreflectivity. Sign replacement practices vary. Some agencies replace traffic signs based only on driver complaints, whereas others conduct subjective visual inspections. Still others arbitrarily replace signs every 5 to 7 years. Thus, signs with several years of service life remaining may be removed, resulting in a waste of money, and signs with insufficient retroreflectivity may remain. If not replaced, these deficient signs could lead to an accident for the motorist and a tort liability case for the highway agency.

An FHWA GRF program study, "Prediction of the Service Life of Warning Signs," examined the feasibility of predicting when a sign is likely to need replacement. Retroreflectivity data for signs with known dates of installation were collected and a model of the deterioration of sign retroreflectivity was developed. Although this model is applicable only to symbol warning signs, it has laid the groundwork for developing additional models. Under a 1988 FHWA study, "Service Life of Retroreflective Traffic Signs," this research will be expanded to include other types of signs and a range of climatic conditions. This study is scheduled to be completed in July 1990.

Sign Management System

As part of an FHWA in-house effort, the Sign Management System (SMS) is being developed to provide State and local highway agencies with a predictive tool for use in managing a sign inventory. This microcomputer-based system allows creation of a sign inventory and tracking of the age and condition of signs. The goal of the system surpasses the development of a simple inventory; computer models developed as part of the FHWA "Service Life" contract will be used to predict when a sign is likely to need replacement. This will assist highway agencies in locating deficient signs, using limited maintenance funds more efficiently, and projecting future budget needs.

An IBM-PC-compatible version of the data base management portion of the software is currently available and runs under MS-DOS. It is a menu-driven system that can be used to create an inventory and track the performance of signs. The predictive software is expected to be operational in 1991.

Traffic Sign Retroreflectometer

If minimum retroreflectivity levels are to replace the subjective replacement methods currently used, then a practical system for measuring the condition of existing signs must be available. A portable measuring device is available; however, it is not suitable for rapid measurement of numerous signs; the user must place the instrument against the sign face. Its value is limited to spot checks and acceptance testing. An ongoing NCHRP (Project 5-10) research project, "A Mobile System for Measuring Retroreflectance of Traffic Signs," is being conducted to assess the feasibility of developing a practical, safe, cost-effective instrument for measuring sign retroreflectivity in daylight from a moving vehicle.

The system concept, which has been developed in Phase I of Project 5-10, consists of a video camera to collect sign images and a microcomputer to analyze images and a microcomputer to analyze the image and output retroreflectivity information. The construction and testing of a laboratory proof-or-concept model has been completed. Development of a field prototype is now underway and is scheduled for completion in August 1990.

Pavement Marking Retroreflectometer

The limitations of existing devices for measuring the retroreflectivity of pavement markings are similar to those for traffic signs. Portable instrumentation is available for spot measurements, but it must be placed directly on the marking. This does not allow for rapid assessment of retroreflectivity. Through an SBIR study, "Measuring Retroreflectivity of Pavement Markings," a laser technique for the measurement of pavement marking retroreflectivity from a moving vehicle has been developed.

Field testing of the prototype instrument is under way. In its final form, this instrument will be suitable for acceptance testing of new markings when mounted directly on the marking equipment or as an inspection tool to check the performance of long-term markings.

GUIDE TO RETROREFLECTION

Although the results from the majority of the research studies on retroreflectivity are not yet available, a manual has been developed to provide highway personnel with a better understanding of the subject. This manual, *Retroreflectivity of Roadway Signs for Adequate Visibility: A Guide* (FHWA-DF-88-001), was developed as an aid for those who use the *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (FP-85)* but can be used by State and local highway personnel responsible for traffic signs.

This manual covers the principles of retroreflection; the selection of proper material type; specifications and testing procedures; fabrication methods, installation, handling, and stockpiling techniques; alternative inspection methods; and sign inventory, maintenance, and replacement guidelines.

CONCLUSION

The retroreflectivity research program described here has been developed as a cooperative effort. It demonstrates how technical expertise and funding from a wide variety of sources can be brought together to improve the safety and efficiency of the highway system. Although this research effort has been guided by FHWA, the input of State and local highway officials has been sought throughout the program. Two of the major topics, Implementation Strategies and Traffic Sign Retroreflectometer, have been included in the NCHRP, and frequent contact with practicing engineers has been made.

The FHWA will continue to work with organizations such as the NCHRP, National Committee on Uniform Traffic Control Devices, American Association of State Highway And Transportation Officials, Institute of Transportation Engineers, and others to ensure that the results of this research program are implemented reasonably and prudently.

DISCUSSION AT EASTERN WORKSHOP

Q: What type of time frame are you talking about with this research?

A: The studies are at various levels. They're all under way and most of them are more than half completed or in the second phase of research. Research will be completed by the end of 1991; the results will be given to Office of Traffic Operations and they will make a decision on implementation and any minimum requirements to be set.

SESSION 2

DEVELOPMENT OF MINIMUM REQUIREMENTS

BRIGHTNESS/CONTRAST REQUIREMENTS FOR SIGNS

Paul L. Olson
Human Factors
The University of Michigan Transportation Research Institute
2901 Baxter Road
Ann Arbor, MI 48109-2150

INTRODUCTION

Signs are the most important form of communication between those who design and operate the highway system and those who use it. In order to adequately fulfill that function signs must come to the attention of approaching drivers and convey their message in time to permit the driver to act on the information they contain. Thus, there are two relevant topics to be considered, i.e., conspicuity (the likelihood that something will come to the attention of someone who is not looking for it) and legibility. A number of factors influence both conspicuity and legibility. Among these are the reflective materials with which the sign is made, surround complexity, sign position, ambient illumination, and observer age. This paper will discuss research on both sign conspicuity and legibility that has been carried out at our Institute in recent years. Particular attention will be paid to the issue of older drivers, which has been somewhat neglected in the past.

THE OLDER DRIVER

If collision rates as a function of age are examined on a time basis the result is a function showing that young people (i.e., under age 20) have the highest rates, with the rates above about age 35 being relatively flat. Exposure is not constant across all age groups, however, so it is more appropriate to examine rates as a function of miles driven. This produces a plot having a very different appearance, with both young and older drivers showing higher involvement rates than those in the middle age group. (For a more complete treatment of this topic see the TRB report (1).) These data suggest that aging affects driving skills in a negative way. The traditional reaction to this kind of information has been, for example, to suggest that older persons be reexamined more frequently for driver licenses. That may not be a bad idea, but the possibility of utilizing technology to improve the performance of older persons has been largely ignored.

It is certainly true that aging is associated with many changes, some of which affect skills that would seem to be important in driving. Among these is night vision. For example, it is well documented that older persons detect and read highway signs at shorter distances than do young persons.[2,3] It is also clear that a significant portion of the problem of reduced visual performance at night is due to reduced pupil size (called senile myosis) and yellowing of the lens.[4] This suggests that if signs could be made brighter they would become more visible and legible to older drivers. This paper provides a brief overview of two research projects concerned with sign legibility and conspicuity. Each of these projects considered subject age as a variable, and the results show characteristic performance differences associated with age. The results also suggest methods by which the performance of older drivers in detecting and reading signs can be improved.

CONSPICUITY

Clearly, highway signs must have sufficient conspicuity to be able to compete successfully with other distractions in the environment for a driver's attention. Sign conspicuity has been studied under both day and night conditions. This paper will be concerned with nighttime conspicuity. The variables that were considered in this investigation were specific intensity per unit area (SIA), color, surround clutter, and subject age.

The study that was run to study this issue was carried out on public roads.[5] Subjects drove a car over a prescribed course on roads in dark-rural, residential, and busy downtown areas (which will be referred to as low, medium and high complexity areas respectively). Periodically they encountered a test sign panel along the right side of the road. The panels were 30 inches (76mm) square and faced with retroreflective material in various colors and grades (although most of the signs were yellow). Measures were made of the distance at which the subjects identified each sign and its color.

Sample results from this study are given in figure 2. This figure shows the distribution of identification distances as a function of sign SIA (which is listed in the box in the upper left-hand corner of each figure) and area complexity. The effect of area complexity, which was substantial, can be assessed by comparing the two graphs. Note, for example, that the performance of the SIA 77 sign in the low-complexity area is about equal to the SIA 750 sign in the high-complexity area.

Figure 3 illustrates the effect of observer age. Both these graphs show the effect on the performance of the older subjects that can be achieved by increasing the SIA of the sign material. In the two examples shown the performance of the older subjects could be made equal to that of the younger subjects by increasing the SIA by a factor of about three.

Significant differences were also found associated with color. Based on these results, and follow-up studies, it appears that the colors red and orange have greater conspicuity than white or yellow when SIA is held constant.[6]

In sum, the investigation, coupled with other studies that have been reported, shows that sign conspicuity depends very much on sign luminance, to some extent on sign color, and is much affected by observer age. The effects of observer age can be compensated for by the use of more highly reflective materials.

LEGIBILITY

Having detected the sign, the approaching driver must now assimilate the information it contains in time to take the required action. Legibility in the conventional sense is probably not an issue with certain signs. For example, stop and yield signs appear to convey the

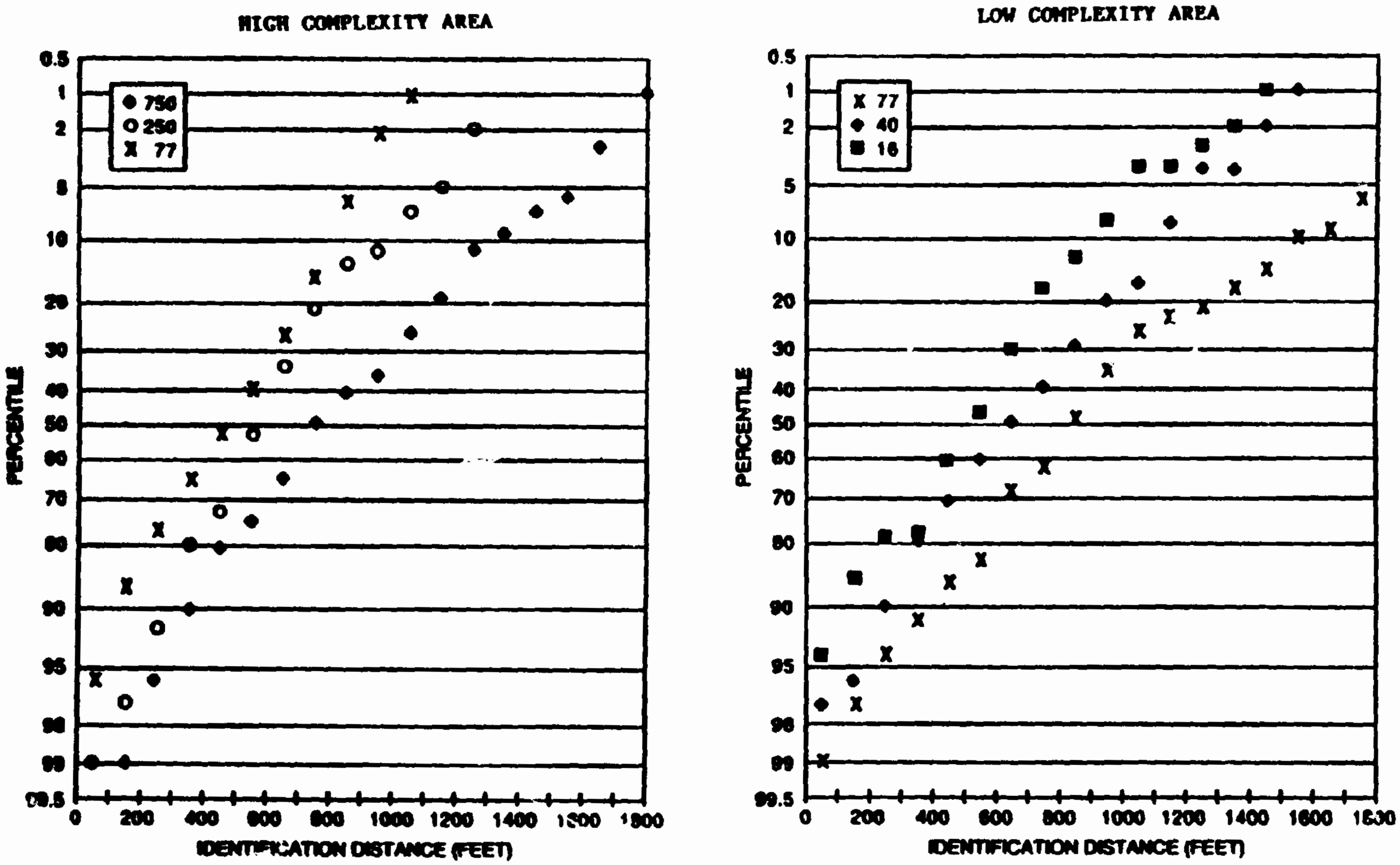

Figure 2. Normal probability distributions of sign identification distances in low- and high-complexity areas.

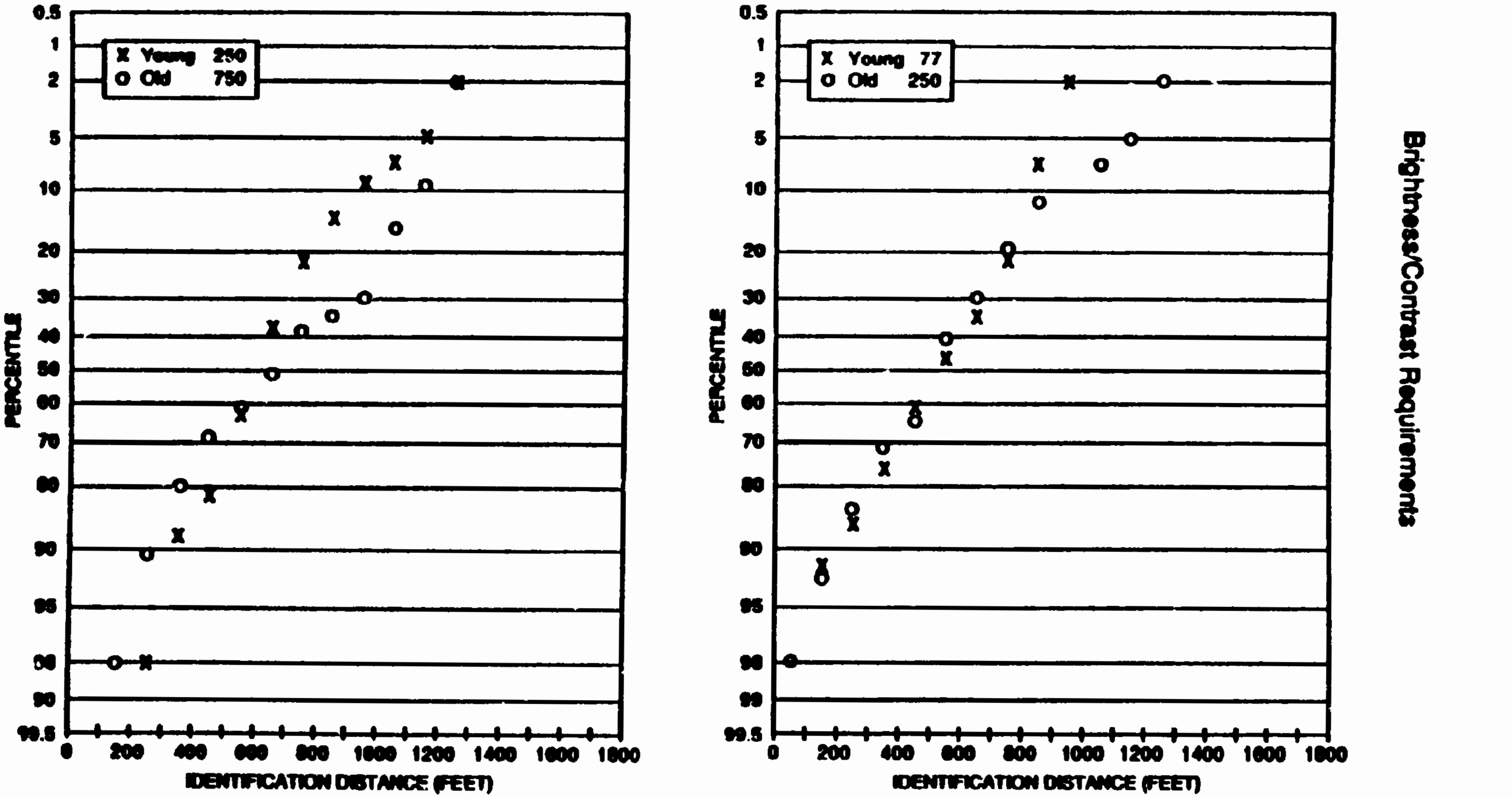

Figure 3. A comparison of sign identification performance of young and older subjects in high-complexity area.

intended message through a combination of color and shape coding. For many signs, however, words are the primary means of communication and legibility is of importance.

There have been a number of studies of sign legibility (see reference 7 for a review). Most of these investigations have concerned black and white signs only. There have been only a few studies of the legibility of signs in which both the legend and background are reflectorized, and their results of are not in good agreement. Hence, it was felt that there was a need for further data.

The legibility study that will be described here was carried out in two stages. The bulk of the data were collected in a laboratory setting using an optical device that presented a "sign" 12 inches (30.5 mm) square having a single-character legend consisting of a Landolt C (commonly used for acuity testing). The device provided independent control of color and luminance for both the background and legend, as well as legend size. The gap in the Landolt C legend could be placed in any of four positions. The task of the subject was to identify the position during a brief (1 second) exposure of the test configuration. These data were used to prepare a computer model of sign legibility that could be used to predict legibility distance under field conditions.

In the second stage two field studies were conducted to determine whether the results of the laboratory study could accurately predict legibility of signs in the field. One of these studies was run on a private road, using small signs with a single letter E legend. Subjects had to determine whether the arms of the E were facing right or left. In this study legend size was varied, as was background and legend luminance through the use of different retroreflective materials. The other field study was conducted on a freeway and used available signs. The correlation between measured and predicted legibility distances for both of the field tests was in excess of 0.90, indicating that the data from the laboratory study can do a good job of predicting field legibility.

The results from this study make it clear that the most important variable affecting sign legibility at night is legend-to-background luminance contrast. For any combination of materials there is a range of contrast values within which legibility is at or near maximum. Contrasts above or below that range will result in degraded legibility. In fully reflectorized signs the optimum contrast range depends on background luminance. The higher the background luminance, the lower the required contrast. Unlike conspicuity, legibility seems to be relatively unaffected by ambient illumination, environmental clutter or even glare.

Figure 4 shows results from the laboratory study that illustrate the points just outlined. This figure shows the percent correct identifications of the Landolt C target in a size equal to 50 ft/inch letter height (6m/cm) at four levels of sign background luminance (here given in cd/m^2). As an example, the background luminance of most fully reflectorized overhead signs probably falls between 3.8 and 0.41 cd/m^2, and such signs commonly have a contrast ratio of about 7:1. At the higher background luminance a 7:1 contrast would yield a legibility level of about 90 percent. At the lower background luminance it would yield a legibility level of about 70 percent. If the materials were left in place so that they degraded to lower levels, legibility could deteriorate markedly.

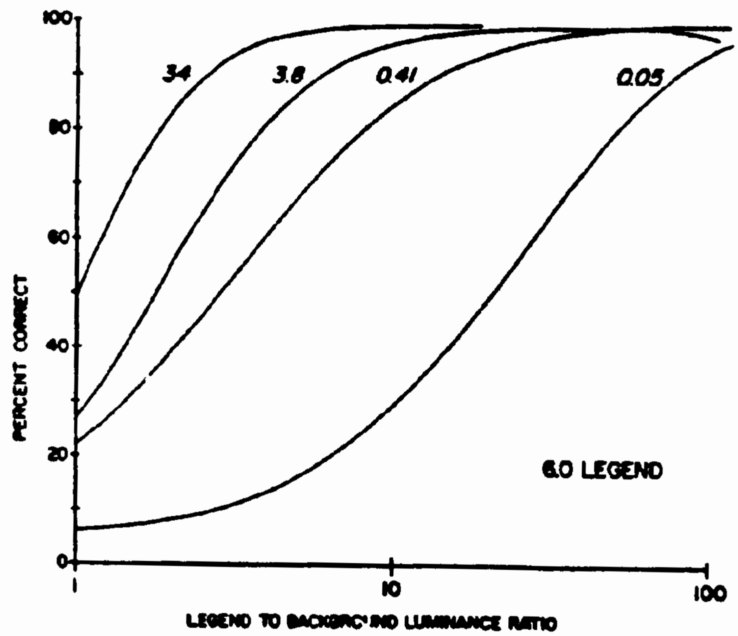

Figure 4. Percent correct identification of legibility target as a function of sign background luminance and legend to background luminance ratio. (Legend is 50 ft/in. (6 m/cm))

At any given level of legend size, background and legend luminance the performance of the older subjects was poorer than that of the younger subjects. An illustration of this is provided in figure 4, using the 50 ft/inch (6 m/cm) legend and a background luminance of 34 cd/m^2. At any contrast level shown, legibility is better for the young subjects, their peak legibility is better, and the older subjects show an effect of excessive contrast at levels above about 10:1.

If the results illustrate the problems that older drivers have in reading signs at night, they also suggest how matters might be improved. As in the case of conspicuity, the ability of older drivers to read reflectorized highway signs at night can be upgraded by use of more highly reflective materials. Once a decision has been made concerning a target level of legibility for a given signing application, material choices can be made to ensure that drivers of all ages will be able to meet it.

DISCUSSION

The results of these studies provide some guidance in the use of reflective materials for various signing applications to provide adequate visibility and legibility for all roadway users.

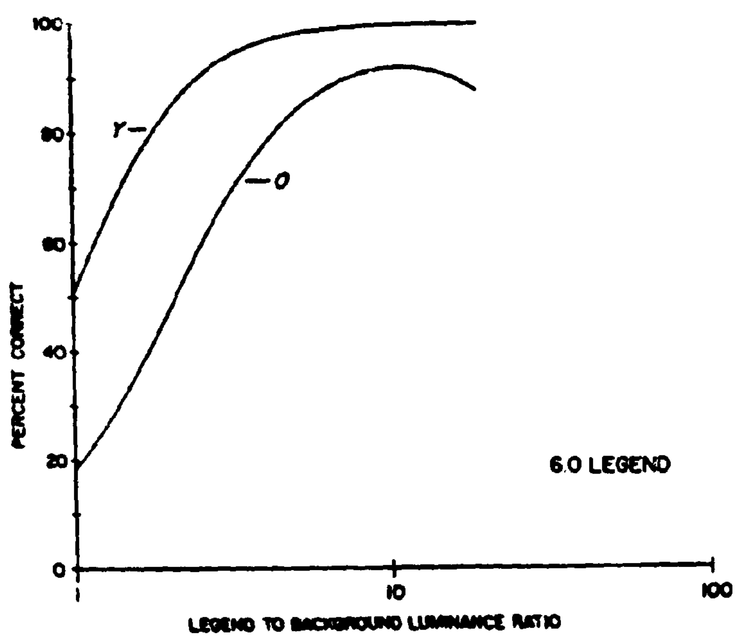

Figure 5. Percent correct identification of legibility target as a function of legend to background luminance and observer age. (Legend size 50 ft/in (6 m/cm))

It is clear that certain signs, particularly those in areas where there is a great deal of lighting and traffic, would benefit from the use of more highly reflective materials. It is also clear that older drivers in particular would benefit from the use of such materials, both from a point of view of detecting signs, and reading the message.

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DISCUSSION AT EASTERN WORKSHOP

Q: Has there been any research done on engineering grade background signs with higher/brighter sheeting?

A: Based on the results of our study, it would be a good sign from the point of view of legibility. As I indicated, if you stay within the same family of materials, the available contrast is about six- or seven-to-one and that's not really enough for an engineering grade background. You would do better by putting, for example, high intensity on an engineering background in terms of legibility.

Q: When you say younger drivers and older drivers, what age range are you talking about?

A: In our studies young was defined as being between 35 and 40 or younger and 60 and up as older. The oldest drivers we had were 75, and they were not probably representative of older drivers. The older drivers who were willing to help us and drive at night were usually in good health and quite vigorous.

DISCUSSION AT WESTERN WORKSHOP

Q: What type of letters do you use with a high intensity background to enhance the contrast?

A: Try diamond grade material or button material.

Q: What if the background is already diamond grade material?

A: Diamond grade may be very useful for critical signs in urban areas where there is a lot of visual complexity, meaning there are many other competing light sources.

Q: What size sign panels were used?

A: In the legibility work, the sign simulator was a foot square. The field validation studies were run using artificial signs in a closed road environment that were three foot square, as well as a field study that was run with three-way guide signs, overhead and ground mounted.

Q: Regarding the 10 panel members, did you have their eyesight checked before they were tested?

A: Panel members were selected by screening about 50 people. We took a small number that were most representative of that group.

MINIMUM RETROREFLECTIVITY REQUIREMENTS FOR TRAFFIC CONTROL DEVICES

Jeffrey F. Paniati
Highway Research Engineer
Federal Highway Administration
6300 Georgetown Pike, T-210
McLean, VA 22101-2296

INTRODUCTION

The Federal Highway Administration (FHWA) has been concerned for some time that highway signs, markings, and other traffic control devices (TCDs) are not being replaced in a timely manner. Over time, retroreflective materials deteriorate and their ability to return light to the driver diminishes. The current *Manual on Uniform Traffic Control Devices* (MUTCD) contains no minimum performance requirements to specify when retroreflective traffic control devices should be replaced. The practicing traffic engineer must rely solely on engineering judgement and a subjective assessment of the sign's condition.

To provide the engineer with better information, the FHWA established a retroreflectivity research program. The goals of this program are to obtain the information necessary to establish performance specifications for retroreflective traffic control devices and to develop the management programs and measurement tools necessary to effectively implement these requirements. An overview of the entire retroreflectivity research program is presented in a paper titled, "The Federal Highway Administration Retroreflectivity Research Program," which is included elsewhere in these Proceedings.

This paper will describe one component of this research program, a study titled, "Minimum Visibility Requirements for Traffic Control Devices," being conducted by Ketron, Inc. The goal of this study is to obtain the information necessary to establish reasonable and prudent retroreflectivity requirements for traffic control devices.

STUDY OVERVIEW

The problem of determining when a traffic control device has reached the end of its useful life can be simply described as finding the point when the amount of luminance *supplied* by a sign of a given retroreflectivity level no longer exceeds the amount of luminance *demanded* by the driver (to respond safely to the TCD).

It was along this basic approach that this study was developed. The goals of the research were to define the demands of the driver, the sign luminance, and the sign retroreflectivity which provides the necessary luminance. This study combined the latest findings available in the literature with data collected as part of this research effort. A computer model, Computer Analysis of Retroreflective Traffic Signs (CARTS), was developed to allow the examination of a wide variety of parameters including sign types, roadway geometry, driver age and visual capabilities, and vehicle characteristics. Laboratory and controlled field data were collected to calibrate the CARTS model and to evaluate its reliability. Ultimately this model will be used to establish the relationship between sign retroreflectivity and the percent of drivers accommodated. This relationship will provide the information necessary to establish minimum retroreflectivity requirements.

Each of the major components of the research study is described in more detail in the following sections.

DRIVER DEMAND

The driver demands a certain amount of time (and distance) if he/she is to respond safely and efficiently to a traffic control device. This demand is dependent on the time which is required by the driver to: detect the TCD; recognize the message being provided by the device; decide on the proper course of action (if required); initiate the response (if required); and complete the maneuver (if required). As part of this study, a model of this process was developed. This model, the Minimum Required Visibility Distance (MRVD) Model, incorporates the best available information from the literature and uses results from research conducted as part of this contract to determine the requirements for a given TCD.

To supplement the existing literature, a controlled field study was conducted to collect data on driver lane change behavior. Data were collected for 79 subjects ranging in age from 16 to 80. The study was conducted using an instrumented vehicle on a closed section of Interstate highway in Pennsylvania. The study included three levels of speed (25 mi/h, 40 mi/h, 55 mi/h) and three simulated traffic volume levels (light, medium, heavy). The volume levels were simulated by replacing the rearview and sideview mirrors with small television monitors. Displayed on the monitors were videotaped images of vehicles following the driver at varying distances and speeds.

In conducting the experiment, the subject was instructed to attain a specified speed level and then wait for a "beep." Upon hearing this sound, the subject checked the mirrors to decide when it was safe to begin the maneuver and then performed the maneuver as if driving in an actual traffic situation. Through the use of distance measuring equipment and an on-board computer, the time and distance required for response and maneuver completion were recorded. The information from this experiment was used to refine the MRVD model.

From the MRVD model, the user can obtain the required conspicuity and legibility distances for a sign by inputting its MUTCD code (or describing a non-MUTCD sign) and site-specific information such as visual complexity, speed, and traffic volume.

SIGN SUPPLY

Having developed a model of the driver demand, the next step was to determine what level of luminance (and ultimately retroreflectivity) is required to satisfy this demand. This is a complex process which involves many factors including, the vehicle headlight characteristics, the size of the sign, the roadway geometry, and the presence of glare from oncoming vehicles. It is desirable to have a computer model that can be used to examine the effect of these variables on the required luminance levels.

A model of this process had been previously developed. This model, DETECT, is a seeing distance model that calculates the driver seeing distance given a target with a specified luminance level. What was needed for this research effort was to reverse the logic of the model. That is, for the required visibility distances specified by the MRVD model, what luminance level is needed? The conversion of the DETECT model was completed as part of this research effort.

The two models, the MRVD model and the reversed DETECT model, were then combined to form a new model, CARTS. With this model, the user is able to determine the minimum luminance required for a specified sign. A third component, the sign luminance model (SINLUM), was added to convert the specified luminance levels to retroreflectivity values at the standard measurement angle.

MODEL CALIBRATION

To evaluate the suitability of the CARTS model and to provide calibration information, laboratory and controlled field studies were conducted. These studies determined the conspicuity and legibility distances for TCDs as a function of the luminance of the TCD and the age and visual capabilities of the driver. The visual capabilities of the drivers were assessed through a series of visual tests, including both acuity and contrast sensitivity. Because it was not feasible to test all of the signs in the MUTCD, a classification scheme was developed to obtain a representative sample.

Laboratory Study

A laboratory study was conducted to obtain information from a large sample of drivers (184 subjects) and for a large number of TCDs (34) under controlled conditions. The subjects ranged in age from 16 to 80. The stimuli included signs, delineation, and channelizing devices. Each of the TCDs was studied at three luminance levels. These levels were selected to represent the brightness of 2 percent, 50 percent, and 100 percent of the luminance level of new Type II reflective sheeting, respectively. Each subject saw each of the stimuli at one of the three levels.

A 2 foot by 2 foot by 60 foot (.61 meters by .61 meters by 18.29 meters) visual tunnel was constructed to allow the presentation of the scale model TCDs at distances up to 3,000 feet (914.4 meters). A carriage containing a light source and the stimulus travelled back and forth on rails within the tunnel.

From a seated position, the subject controlled the movement of the carriage by depressing an "accelerator pedal" mounted on the floor. The carriage moved toward the subject at a constant rate as long as the pedal was depressed and ceased moving when the subject released the pedal. The subject was also given a subsidiary tracking task to simulate the demands required when driving a car. This task required the subject to use a joystick to keep a randomly left-right moving target as close to the center of the simulated roadway as possible.

From the laboratory studies, data were collected on the conspicuity and legibility of the TCDs. The stimuli began at the far end of the tunnel at a very small size. The subjects were instructed to move the stimuli toward them (using the foot pedal) until they could identify the shape and color of the TCD in the conspicuity study or identify the legend in the case of the legibility study.

While the analysis of the laboratory study is still ongoing, figure 6 provides an example of the type of data which was collected in this experiment. This figure illustrates the relationship between sign luminance and legibility distance for yellow warning signs. An examination of the data reveals that the signs can be grouped by the characteristics of their legends. The "Crossroads" symbol, traditionally the symbol with the best legibility, had the longest legibility distance in this study. Following this symbol were a group of signs which can be characterized by their bold simple symbols ("Turn," "Divided Highway"). The next group of signs have much narrower symbols ("Bicycle," "Narrow Bridge") which result in lower legibility distances. Finally, the signs with word messages have the lowest legibility distance.

Field Study

To check the validity of the laboratory legibility and conspicuity data, a controlled field test was performed. This test was conducted in the parking lot and on the access roads for the Philadelphia Park racetrack in Bensalem, Pennsylvania. Thirty-six subjects ranging in age from 16 to 80 participated in the study. Nine TCDs were studied at the same three levels of retroreflectivity as were used in the laboratory study.

A test route containing all of the TCDs was developed. Data on sign conspicuity and legibility were collected as the subjects drove an instrumented vehicle along the test route. The conspicuity and legibility distances were recorded using distance measuring equipment and a laptop computer. The subjects were also given a secondary task which required them to occasionally look in the rearview mirror and report the number of lights illuminated on the rear dashboard (a small display with LED lights was used). The purpose of this task was to require the subjects to divert their attention from the sign to other tasks as commonly occurs in a real driving situation.

The data from the laboratory and field studies were compared and very few statistically significant differences were encountered. This indicated that the data collected in the laboratory closely approximated that collected in a field situation.

Based on the good agreement of the laboratory and field results, it was decided to use the laboratory results to calibrate the CARTS model. The conditions (dark, straight, level roadway, no glare, etc.) under which the laboratory data were collected will be replicated and

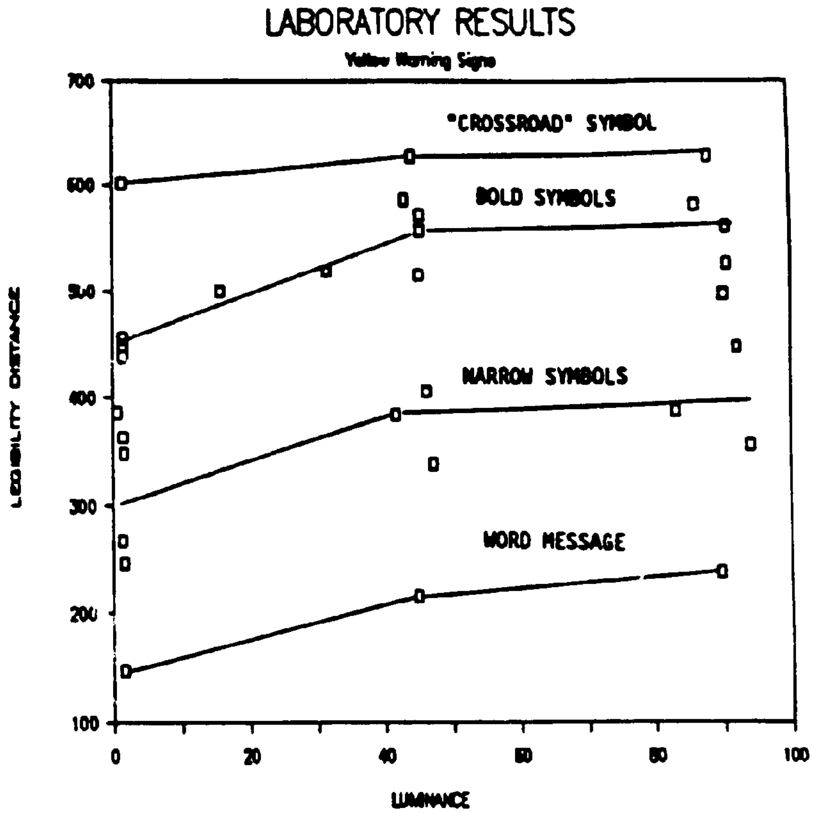

Figure 6. Legibility distance versus sign luminance.

the distance-luminance relationships found will be used to calibrate the model. This work is currently under way.

MODEL EXECUTION

Following the final calibration of the CARTS model it will be used to generate the necessary retroreflectivity data. A practical classification scheme is being developed to aid in the implementation. Figure 7 presents a concept of how the final results might be presented. This figure illustrates the relationship between the sign retroreflectivity level and the percent of drivers accommodated for one class of signs. It is anticipated that this type of relationship will be developed for each class of signs in the classification scheme. It is expected that the final report from this project will be available in October 1990.

CONCLUSION

The results from this study will be used by Bellomo-McGee, Inc., in their ongoing National Cooperative Highway Research Project, "Alternative Implementation Strategies," and by the FHWA in determining minimum retroreflectivity requirements for traffic control devices. The goal of the FHWA is to provide traffic control devices which satisfy the needs of all drivers under all conditions; however, given the limited resources available at the State and local levels, it is important that any minimum requirements balance both safety and economics. The FHWA will work in cooperation with organizations, such as the National Committee on Uniform Traffic Control Devices, the American Association of State Highway Transportation Officials, the Institute of Transportation Engineers, and others, to ensure that the results of this contract are implemented in a reasonable and prudent manner.

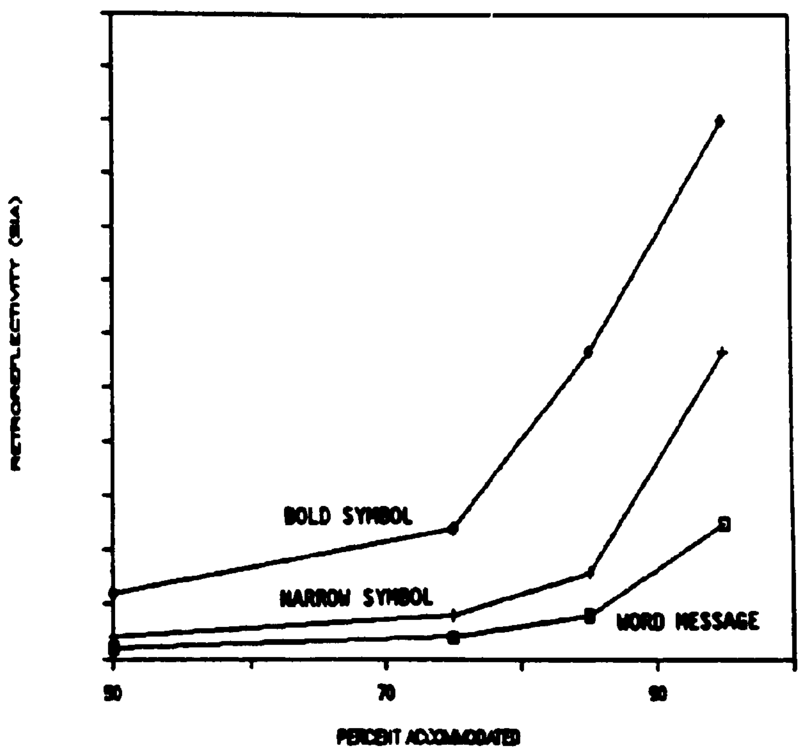

Figure 7. Retroreflectivity versus percent accommodated.

DISCUSSION AT WESTERN WORKSHOP

Q: Is there anything in the model about inclement weather conditions?

A: You can look at different visibility conditions and can simulate different conditions. I'm not sure how in depth we will go in terms of rainy weather and those kinds of situations. We will try to promote levels that are high enough in the field so that in practice we use signs that are substantially above those minimum levels established and that compensate for things like weather.

IMPLEMENTATION STRATEGIES FOR SIGN RETROREFLECTIVITY STANDARDS

Hugh McGee, Ph.D., P.E.
Principal
Bellomo-McGee, Inc.
8330 Boone Boulevard, Suite 700
Vienna, VA 22182

Traffic signing is a critical component of any road because it is the medium by which the highway agency communicates with the motorist, providing information related to regulations, warnings, and directional guidance. For signs to accomplish their intended purposes, they must be visible to motorists. Although sign visibility is generally not a problem during daylight, signs with inadequate retroreflectivity may not be sufficiently visible at night and can contribute to accidents.

In the *Manual on Uniform Traffic Control Devices* (MUTCD) it is stated that "All signs shall be reflectorized or illuminated to show the same shape and color both day and night." However, there is no performance standard for the level of retroreflectivity that must be maintained. The Federal Highway Administration is considering the establishment of such a standard. This required level presumably would be related to drivers' needs for minimum visibility. However, before retroreflectivity standards can be implemented, their potential impact must be assessed. Further, any adverse effects of such standards should be mitigated.

This paper provides a status of a project, funded by the National Cooperative Highway Research Program (NCHRP), which has the following objectives:

1. To determine the economic consequences of alternate standards for retroreflective traffic signs. In other words, what it will cost agencies to meet and maintain a minimum retroreflectivity performance standard?

2. To develop economic-based implementation strategies and recommend several options for system wide implementation. In other words, what are the alternative ways to have jurisdictions come into compliance considering their resources?

To meet these objectives, the following tasks are being pursued:

1. Literature dealing with retroreflective materials, their specifications and performance is being reviewed. Also literature dealing with driver visibility requirements and subsequent retroreflectivity levels is being evaluated for a basis to set alternate standards.

2. Data is being collected for three information needs:

   a. in-service sign retroreflectivity
   b. sign replacement costs

c. sign maintenance programs

3. This data will be analyzed to determine:

   a. the number of signs that would need to be replaced to meet alternate standard levels, and
   b. the costs for replacing signs and costs to agencies

4. Economic-based implementation strategies for alternative sign retroreflectivity standards will be developed considering different sign types, roadway types and jurisdiction levels and their maintained programs.

5. A system wide implementation of retroreflectivity stands will be recommended.

Information for sign replacement costs and maintenance programs is being developed from the following sources:

1. Literature

2. A questionnaire survey of selected counties and cities.

3. Discussion with several States and with jurisdictions where on site sign retroreflectivity readings are being taken.

The questionnaire sent to the counties is shown on figure 8; a similar one was sent to the cities.

Some of the preliminary results of the questionnaire are shown in tables 1 and 2. Table 1 shows that for the county jurisdictions, vandalism is the most frequently cited reason why signs need to be replaced. For the cities responding, this factor takes second place to poor retroreflectivity. Table 2 provides some statistics on sign density in terms of signs per mile and per population for the three major sign categories. As expected sign density in terms signs per mile is much higher in cities for regulatory and warning signs. Statistics such as these and others derived from the survey will be extrapolated to a national level and used in the economic analysis.

The major portion of the data collection effort is being devoted to obtaining data on the current retroreflectivity condition of signs. For this effort a nationwide sampling of sign retroreflectivity is being conducted. In establishing the sampling plan the following variables are being included:

1. Geographical Areas - Sites are being selected from eight geographic areas across the United States.

2. Jurisdiction Levels - Signs from roads under all types of jurisdictional control (State, county, city and towns), are being sampled.

QUESTIONNAIRE FOR NCHRP PROJECT 5-11

"IMPLEMENTATION STRATEGIES FOR SIGN RETROREFLECTIVITY STANDARDS"

PART I BACKGROUND

CITY ________ STATE ________ CITY POPULATION ________

TOTAL MILEAGE UNDER CITY CONTROL ________

PART II SIGN INVENTORY INFORMATION

1. NUMBER OF SIGNS UNDER COUNTY CONTROL
   - TOTAL ________
   - REGULATORY ________ (DO NOT INCLUDE PARKING SIGNS)
   - WARNING ________
   - GUIDE ________ (DO NOT INCLUDE STREET NAME SIGNS)

   IS THIS AN ESTIMATE ________ OR BY ACTUAL COUNT ________

2. DOES YOUR COUNTY HAVE A SIGN INVENTORY? YES ___ NO ___

   IF "YES", COMPLETE QUESTIONS 2 THROUGH 4, IF "NO", GO TO PART III

3. WHAT IS THE FORMAT OF YOUR INVENTORY?: (CHECK WHICH IS APPLICABLE)
   - CARD OR PAPER FILE ____
   - MICRO (PERSONAL)-COMPUTER FILE ____
   - MINI OR MAINFRAME COMPUTER FILE ____
   - OTHER ___ EXPLAIN ________

4. IF A MICROCOMPUTER FILE,
   A) IS IT ON A MS-DOS SYSTEM? YES ___ NO ___ IF NO, WHICH FORMAT

   B) CAN WE RECEIVE A COPY OF THE DATA FILE ON DISKETTE? YES ___ NO

   C) IF NO WOULD YOU BE WILLING TO PREPARE SOME INVENTORY SUMMARIES YES ___ NO ___

   IF YES TO EITHER B) OR C) WE WILL CONTACT YOU FOR MORE DETAILS.

5. DOES YOUR INVENTORY INCLUDE: (CHECK IF YES)
   - SIGN TYPE (MUTCD CODE, E.G., STOP SIGN OR R1-1) ___
   - DATE OF INSTALLATION ___
   - DATE OF REPLACEMENT ___
   - SHEETING TYPE (I.E., ENGINEEERING GRADE, HIGH INTENSITY, ETC.)

Figure 8. Questionnaire for NCHRP Project 5-11.

PART III REGARDING SIGN MAINTENANCE AND REPLACEMENT COSTS:

6. APPROXIMATELY HOW MANY SIGNS DO YOU REPLACE PER YEAR DUE TO:
   - VANDALISM, THEFT, ETC. ___
   - KNOCKDOWN ___
   - POOR RETROREFLECTIVITY ___
   - OTHER ___

7. WHAT IS YOUR TOTAL COST FOR SIGN MAINTENANCE/REPLACEMENT?________

8. WHAT IS YOUR AVERAGE UNIT COST TO REPLACE A SIGN?
   A) TOTAL COST PER SIGN (ASSUME AVERAGE SIZE) ____________

   B) IF POSSIBLE PROVIDE COST FOR FOLLOWING:

-MATERIALS	$_____	PER SIGN	$_____	PER SQ. FT.
-LABOR	$_____	PER SIGN	$_____	PER HOUR
-EQUIPMENT	$_____	PER SIGN	$_____	PER HOUR

THANK YOU FOR YOUR RESPONSE, PLEASE MAIL BACK TO:

HUGH W. MCGEE, P.E.
BELLOMO-MCGEE, INC.
8330 BOONE BLVD., SUITE 700
VIENNA, VIRGINIA 22182
703/847-3071

PERSON TO CONTACT:

NAME ____________________
POSITION_________________
ADDRESS:_________________
____

PHONE # _________________
____

Figure 8. Questionnaire for NCHRP Project 5-11. (continued)

Table 1. Reasons for sign replacement.

REASON	PERCENT OF RESPONDENTS COUNTY	CITY
Vandalism	45%	26%
Knockdown	29%	21%
Poor Retroreflectivity	13%	32%
Other	13%	21%

Table 2. Sign density for counties and cities.

	COUNTY		CITY	
Sign Type	Sign/ Mile	Sign/ 1000 Pop.	Sign/ Mile	Sign/ 1000 Pop.
Regulatory	2.4	31.0	19.4	41.6
Warning	2.8	36.4	10.4	24.5
Guide	3.0	19.1	2.9	5.1
TOTAL	8.2	86.5	32.7	71.2

3. Sign Types - Signs from the three major groups, i.e., regulatory, warning and guide, are being sampled. All types of parking signs, street name signs and overhead signs are excluded, however.

4. Sign Material - Two basic sign sheeting materials are being sampled-- enclosed lens and encapsulated lens sheeting.

A sample of over 6,000 signs is being drawn from 25 counties of both urban and rural nature. Over 300 roadway segments classified by jurisdictional control and classification are providing the sign sample. The counties being used as sample sites are listed below.

Delaware, NY	Washington, AL	Adair, IA	Wayne, MI
Berkshire, MA	Levy, FL	Bureau, IL	Madison, MT
Hillsbourough, NH	Pittsburg, OK	Shawnee, KS	Iron, UT
Westchester, NY	Greensville, SC	Vanderburg, IN	Yuma, AZ
Calvert, MD	Dallas, TX	Fillmore, MN	Pima, AZ
Montgomery, TN	Butler, NE	Oneida, WI	Wasco, OR
Mendocino, CA	Sacremento, CA	King, WA	Clark, NV

The measure being collected is the sign retroreflectivity condition. A retroreflectometer, specifically the Model 920, manufactured by Advanced Retrotechnology, Inc. (ARTI) of San Diego is being used for this purpose. ARTI is also providing one of the two data collections crews.

Once the site and roadway segment is selected, the data collection crew, a two-person team, takes four measurements for each eligible sign along the segment. For multiple color signs, readings are taken for all colors so that a contrast level can be determined as well as the retroreflectivity level.

As noted earlier there is no retroreflectivity performance standard in the MUTCD. The only Federal standard for retroreflectivity is found in FHWA's *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects*, FP-85, which states in Section 635.03 that for temporary traffic control devices, retroreflective sheeting on signs, barricades, etc. should be:

- Not less than 75 percent minimum specific intensity per unit area (SIA) for Type II material.
- Not less than 50 percent of the minimum SIA for Type IIA and Type III material.

While setting a performance standard in these terms is one method there are other alternates and considerations. These are discussed below:

1. Rather than setting the standard as a percentage of the minimum purchase specification, it might be more appropriate to set it an absolute value that would apply to all materials. Presumably this value could be tied to some minimum level drivers require for either sign detection or legibility.

2. For fully reflectorized, multiple color signs, contrast is an important factor in sign detection, and especially legibility. Hence, it may be necessary to set minimum contrast ratios for some signs.

3. While minimum retroreflectivity and contrast are important, more critical is the detection, legibility and visibility distances provided to be the motorist. Setting minimum distances for one or more of these parameters may be more appropriate than a brightness or contrast value. In doing so, other sign deficiencies can be considered such as sign or letter size being too small or sign blockage.

4. Finally, another consideration is sign color which for some signs such as the STOP sign, is critical. Field surveys indicate that for silk screened signs as the color fades, retroreflectivity initially increases. Hence, one might find an adequately bright sign but practically devoid of color.

However the performance standard is finally established consideration must be given as to how the standard is implemented. Alternate methods may include:

- Phasing in the standard over several years, reducing the retroreflectivity in increments.
- Having the standard effective some date in the future. This would allow agencies to develop a viable sign maintenance program which would include inventory and inspection.
- Setting standards for only the most critical signs or for the most critical roadway types.

This study will develop more concrete guidelines and recommendations. The final report should be available in mid-year 1991.

DISCUSSION AT EASTERN WORKSHOP

Q: It would be nice if you were to include the new sheetings in your study, the superengineering gradings.

A: We used engineering grade Type II as a general description because you cannot identify superengineering grade by visual observation.

Q: Are you considering looking at the new diamond grade too?

A: No, we haven't approached the diamond grade at all yet.

Q: How many jurisdictions have a sign rotation program?

A: Very small percentage, in terms of systematic, we'll get into that later on in the presentations and discussions. I know some locations that will take certain areas of their jurisdiction and replace signs every so many years—a wholesale replacement—a very good maintenance program. Some jurisdictions replace signs as needed individually. I think we'll be hearing a presentation later on in the session from Rich Cunard who will talk about replacement strategies.

Q: When will the study be ready?

A: The studies should be finishing up in early 1991 and probably the report will be out in mid-1991. But, a lot of the information will be fed into the work that (FHWA) is doing, Jeff Paniati, and his other studies.

DISCUSSION AT WESTERN WORKSHOP

Q: How did you determine the sites that you were using for sign evaluation?

A: We selected sites based on a random selection process. We needed to have a random sample, although we had to stratify it by geographic areas after setting up certain criteria, such as having some urban and some rural sites.

PANEL DISCUSSION ON A PERFORMANCE STANDARD FOR MINIMUM MAINTAINED RETROREFLECTIVITY FOR SIGNS

In both of the regional workshops, four speakers, each representing a different group perspective, participated in a panel discussion to express comments and concerns regarding the establishment of minimum retroreflectivity standards for traffic control devices. The four speakers represented State highway departments, local highway departments, the signing industry, and the motoring public. Summaries of each speaker's comments, as well as points raised from the audience, follow.

STATE AGENCIES

Ken Kobetsky - West Virginia Department of Highways*

Mr. Kobetsky noted that the signing and pavement marking community has moved from *some* retroreflective signs to *all* retroreflective signs in recent years. He then questioned whether retroreflectivity levels were determined by manufacturers and, if so, how?

Although the concept of measuring retroreflectivity with an instrument is straightforward, real world problems arise with actual measurement practices:

- Specific intensity per unit area (SIA) values vary even from the same roll of sheeting. Screened red sheeting used for Stop signs has highly variable SIA values. If agencies used a retroreflectometer to check SIA directly out of the shop, the values would vary.

- Sheeting material is subject to numerous climatological elements, which increase deterioration, including sunlight, desert climates, proximity to chemical plants, etc. For certain signs and sign colors, as sign color fades, the SIA value increases.

- The West Virginia Department of Highways, which controls 35,000 miles of roadway, is concerned about the setting of SIA minimums. The Department cannot maintain a computer sign inventory for all roadways; possibly only the larger roadways could be covered. The West Virginia Department of Highways is currently undertaking a sign service life project similar to that of the Federal Highway Administration (FHWA) and has found a range of sheeting materials with all kinds of SIA values in the field.

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*Presented at eastern workshop only.

- Signs that look good during the day often look bad at night. Also some cracked signs that look bad during the day actually have good SIA values for nighttime visibility.

- From a practical standpoint computer inventories are useful for determining where signs are located and their approximate age. However, it is not very practical to take retroreflective measurements and put the values in the computer inventory. The technology to perform the measurements is available but most agencies will not be able to afford the mobile measurement units.

- A 1986 survey indicates that no State agency had a sign replacement program based on sign retroreflectivity, except for signs in construction zones. Determining which signs are worn out is very subjective.

- FHWA must be careful how it sets SIA minimum limits to prevent creating more tort liability problems. The signing community does, however, owe the travelling public signs that can be seen. In an effort to make sign inventories more manageable, States should reduce the number of signs on the roadways.

Fred Lewis - Utah Department of Transportation*

The signing and pavement marking community needs minimum retroreflective standards, but there must be some guidance on this issue. However, many issues need to be discussed:

- A level of retroreflectivity that is adequate.
- Older drivers' needs.
- Weather conditions, dirt, grime, and frost, which affect visibility.
- Orientation to the sun and its effects on SIA. A northern exposure sign could measure 42 SIA while a southern exposure sign of the same age could measure 30 SIA.
- Sign durability instead of minimum SIA.

- Engineering Grade and Super Engineering Grade sheeting may meet the standards but for how many years? Signs should be evaluated by criticality. Minimum SIA standards should be developed considering the differences in sign criticality.

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*Presented at western workshop only.

LOCAL AGENCIES

W. Scott Wainwright - Montgomery County, Maryland*

- Mr. Wainwright has mixed emotions about setting minimum standards. The concept of minimum standards is good, but the standards need to be workable and practicable. However, there are a lot of bad signs in the system that are not retroreflective at night. Municipalities must provide adequate signs for nighttime visibility.

- There are major concerns about the setting of minimum SIA standards:

  - Liability. Existing litigation conditions are difficult; minimum standards could make conditions more difficult.

  - Flexibility of Standards. Condition of signs varies greatly among the different road types and areas; pollution problems vary.

    - Some overhead signs provide vital information. Nighttime visibility of overhead signs is difficult, especially street name and left turn green ball signs. If agencies cannot provide necessary retroreflectivity these signs may not be used due to fear of liability issues.

  - Economic Impacts. Must maintain sign inventory.

    - Easier for small town and/or State agency with the funds to maintain an inventory. Large cities and counties have a lot of signs but have limited monetary resources.

- Montgomery County, Maryland, currently has 2,000 miles of roadway in its control. The county department has been unable to obtain funds from county, State, or Federal sources for implementing a sign inventory. The more affluent counties (such as Montgomery County) have difficulty obtaining Federal aid money. Most of the Federal aid money seems to be concentrated on the interstate system. The county's current sign budget is $625,000 per year. An estimate of $300,000 for start-up and $350,000-$400,000 annually for maintenance was received from a consultant for the implementation and operation of a sign inventory. The minimum standards would not be affordable. The standards should be phased in on the freeway system only.

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*Presented at eastern workshop only.

John Logan - King County, Washington[+]

- Many local agencies do not have the *Manual on Uniform Traffic Control Devices* (MUTCD). For example, Washington State has not adopted the new MUTCD yet; therefore, King County follows the old manual.

- While King County does have a sign inventory, most large cities and agencies do not; and those cities and agencies without inventories do not know where their signs are located.

- King County has 36,000 traffic signs in its system. Approximately 10,000 traffic signs, including multiple occurrences, are vandalized each year.

- The minimum standard should be set as a service life limit. There would be nc testing or measurements. A sign would just be replaced after say six years of service. It will be difficult for agencies to maintain signs at a minimum SIA standard.

INDUSTRY

Victor Liebe - ATSSA[*]

- The key issues are sign visibility and the needs of the older driver. The signing industry welcomes and supports the implementation of minimum SIA standards.

- The minimum SIA standards will probably reduce maintenance and tort liability costs. With a minimum standard, issues or problem areas dealing with traffic signs and agency liability cannot be fabricated. Also, the standards will eliminate the less qualified suppliers.

Robert Garrett - ATSSA[+]

- The minimum SIA standards are essential for maintaining high quality traffic control devices. For work zone devices, the minimum standards have come from the signing industry.

- The industry strongly supports tight standards, because of foreign competition. However, we need flexibility in the standards to accommodate new technologies, products, and innovations. The standards will also ensure that all suppliers are competing on the same basis.

[+]Presented at western workshop only.
[*]Presented at eastern workshop only.

- Tort liability is a key issue and can be viewed in two ways:

  1. The minimum standards could create problems for the agencies where signs are below the standards and accidents occur.

  2. The minimum standards could eliminate many of the subjective rulings of the court system.

PUBLIC PERSPECTIVE

Gerald Donaldson - Center for Auto Safety[*]

- Minimum SIA standards should not be established without minimum legibility standards for sign symbol and word message. A Transportation Research Board study of older drivers showed the importance of legibility distance. Also, the setting of minimum SIA standards for traffic signs ignores the need for improved pavement markings and temporary traffic control devices.

- The performance levels (i.e., minimum standards) should be simple but should not consider the 85th percentile criteria that is commonly used for traffic engineering design standards. All drivers, especially older drivers, must be accommodated.

- The standards should not consider economics. For example, in work zones where higher standards for signing should be provided the Federal/State regulations actually require lower standards. This is due to economic reasons only. In many instances public safety has taken a back seat to economics.

James Pline - Consultant Representing the Public Perspective[+]

- The key issue is the problems of the older driver. The older driver has problems adapting to changes in light, particularly at night. Traffic engineers should evaluate signing from the lay person's perspective.

- Some sign symbols do not convey the intended message very well. We need to review the sign symbols. Also, sign size is as important as brightness in many cases. Letter size should be 6 in or more. The 4 in legend is too small for many signs. Angularity of signs is critical, particularly on horizontal curves. Signs should be checked to ensure proper orientation.

- Major intersections are a major problem with many visual distractions and too much information. Agencies must inspect signs to determine how the driver is reacting to the message and information. Many bad signs are not identified and

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[*]Presented at eastern workshop only.
[+]Presented at western workshop only.

replaced by agencies. A sign inventory is the best way for agencies to keep track of all signs.

QUESTIONS AND DISCUSSION FROM THE AUDIENCE

Eastern Workshop:

- Do motorists need brighter signs?
- Motorists need brighter signs for a longer period of time, not just brighter signs.
- There is a movement to more and more signs on the roadway.

Western Workshop:

- Should standards be set for a certain service life rather than SIA?
- The economics dictate mass replacement instead of individual replacement.
- Day/Night inspections are critical.
- Agencies have difficulty obtaining funding for nighttime inspections.
- Funds for signing are difficult to obtain.
- Litigation rarely depends on the lack of one specific sign.
- Redundancy signing is suggested.
- Pennsylvania study reported that signing was the number one liability problem.

SESSION 3

MATERIALS SELECTION

CRITERIA FOR THE SELECTION OF SIGN RETROREFLECTIVE MATERIAL

Hugh McGee, Ph.D., P.E.
Principal
Bellomo-McGee, Inc.
8330 Boone Boulevard, Suite 700
Vienna, VA 22182

In *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (FP-85)* (1), four types of retroreflective sheeting are specified for permanent roadway signs. They are:

- Type II and Type IIA, enclosed lens sheeting, which are known as engineering and super engineering grade, respectively.
- Type IIIA and Type IIIB which are known as high performance grades, with "A" for encapsulated glass bead and "B" for prismatic sheeting.

While Type IIIB is recognized in *FP-85*, there are currently no manufacturers of this material. However, in a memorandum dated November 3, 1989, the Federal Lands Highway Program Administration authorized an additional Type III sheeting, identified as Type IIIC, Cube Corner Prismatic Retroreflective Element Material.

This material is similar to Type IIIB, in that it derives its retroreflective characteristics using micro-prism or cube corner material. However, it is not as bright as other Type III sheeting at large entrance angles.

Yet another material is the prismatic type sheeting of 3M Company. This new product has not yet been classified but essentially is the same type of material as Types IIIB or IIIC but with much higher retroreflectivity levels.

Table 3 lists the four major types, their unit costs, their initial specification value for retroreflectivity in terms of specific intensity per unit area (SIA) for white sheeting and their approximate service life. It should be emphasized that the unit costs are estimates and will vary based on the amount purchased by the agency. Also, the service lives listed are variable with various State and local agencies reporting shorter or longer lives for each of the materials.

Given the range in their retroreflectivity levels, their costs, and their service lives, how does an agency select the proper sheeting for their needs? Unfortunately, no firm recommendations can be provided for selecting between these types because there are several factors which can affect that decision and different agencies may give different priority to

Table 3. Comparison of sheetings.

Sheeting Type	Unit Cost	White SIA	Service Life
II - Engineer Grade	$0.65/Sq. Ft.	70	7 Years
IIA - Super Engineering Grade	$1.65/Sq. Ft.	140	10 Years
III A - High Performance Bead	$3.20/Sq. Ft.	250	12 Years
III B - High Performance Prismatic	$3.25/Sq. Ft.	250	10 Years

these factors depending on their policy, location and method of operation. The principal factors include:

- Driver visibility need.
- Durability and economics.
- Practical considerations.

These are discussed in this paper.

DRIVER VISIBILITY NEEDS

Certainly an important criterion for selecting the type of sheeting is the driver's visibility requirements. The ability of a driver to see and read a sign is dependent upon the driver's nighttime vision and several factors that relate directly to the sign, namely:

- Brightness.
- Contrast.
- Conspicuity.
- Legibility.

How these factors might influence the choice of sheeting is discussed below.

Brightness

Brightness refers to the amount of light reflected from the sign that reaches the driver's eye. Brightness varies for each color and type of retroreflective material. In general, the brighter the sign, the more conspicuous it will be. However, high brightness letters or symbols mounted on a low brightness background may reduce legibility because of a halo effect of the brighter characters.

In addition to the retroreflective properties of the material, sign brightness will be determined by several factors including the vehicle headlights, driver's eye height, road curvature, sign placement and others.

Two factors are particularly important in the selection of material; hence they are discussed below:

Placement

Sign placement is an important factor in the consideration of sheeting selection. In general signs mounted overhead or on the left shoulder of undivided roads require higher amounts of retroreflectivity to appear equally as bright as signs on the right shoulder. Hence, overhead signs and left shoulder signs should have significantly more levels of retroreflectivity than signs placed on the right shoulder.

Viewing Distance

A major consideration in the choice of retroreflective material is the distance at which motorists must be able to detect a device so that, if necessary, they will be able to take any action in a safe and timely manner. The distance from the sign where this must occur is the distance which provides adequate time at the operating speed to allow for a chain of events to occur which include detection, recognition, decision-making and maneuver.

Not all signs require all of these actions to occur and therefore not all signs must be visible to equal distances. Many signs do not require a vehicle maneuver, and of those that do, many do not require the movement be completed prior to the sign. Signs which require lane changes with merging activity and those which require a complete stop must be detected and read at considerable distances from the sign. At 55 mi/h the required distances are in the order of 800 to 1,000 ft. At speeds of 30 mi/h or when the sign does not require a driver decision, or vehicle maneuver, the distances may be as short as 200 ft.

The visibility distance of signs at night cannot be increased simply by increasing the level of retroreflectivity. There is an optimum level above which signs become more difficult to read. To accommodate long detection and legibility distances larger signs with larger letters are needed. Traditionally it was thought that with proper reflectance and contrast, signs could be legible at 50 ft for each inch of letter height. That is, a sign with 8 in letters could be read at 400 ft. To allow for the effects of visual acuity less than 20/20 and headlamp misalignment it may be advisable to assume only 40 ft of legibility per inch of letter height.

Contrast

In many ways, brightness contrast is more critical to maintaining the detectability and legibility of signs than the overall brightness of the sign. There are two types of brightness contrast with which sign management must be concerned. External contrast is the ratio of sign luminance to the luminance of the surroundings (i.e., the background against which the entire sign is seen). Internal contrast is the contrast of the letters or symbol against the sign background. External contrast is critical to conspicuity, while internal contrast is critical to legibility.

External contrast may sometimes be changed by relocating the sign. Internal contrast is fixed by the choice of materials, color and the sign fabrication process. Table 2 shows contrast ratios for three color combinations and three types of sheeting according to the *FP-85*.

Table 4. Contrast ratios of fully reflectorized signs.

SHEETING TYPE	white/ red	white/ green	white/ blue
II	5:1	8:1	17:1
IIA	5:1	5:1	14:1
III	6:1	6:1	13:1

Conspicuity

Conspicuity refers to the probability that a sign located in the visual periphery will be seen at a given distance. The level of conspicuity for any sign depends upon the following factors:

1. Eccentricity,
2. Degree to which sign is expected and/or being looked for,
3. Visual complexity of the surrounding area,
4. External contrast, and
5. Size of sign.

Eccentricity refers to the fact that the further the sign is located from the driver's line of sight, the less likely it is to be seen. Signs mounted on the left of a multi-lane road or on the right side of roads with unusually wide shoulders or parking/turning lanes may be less conspicuous.

Eccentricity is generally not a problem for conspicuity at long distances where detection generally occurs. However, eccentricity may be a problem when a sign is used with an unusually short sight distance (e.g. after a turn or merge area). Hence, for these situations it is advisable to use sheeting that maintains its retroreflectivity through wide angles.

Signs are more conspicuous to drivers who are looking for them. On this basis alone guide signs are more likely to be seen than regulatory or warning signs. Also any sign following another sign that alerted the driver to its presence (e.g., STOP AHEAD), will be more conspicuous because of the advance warning.

Visual complexity refers to the presence of both reflective and direct light sources in the driver's field of view. Signs located in areas of low visual complexity are more likely to be seen than signs in highly complex areas. Research by Paul Olson (2) indicates the areas of high complexity (strip development, urban areas, etc.) require 10 times the SIA compared to low complexity areas

Legibility

Legibility is determined primarily by the following factors:

- Size of letters or symbol;
- Stroke width of letters or goodness of symbol;
- Internal contrast (letters against background);
- Brightness of background (partially reflective signs); and
- Brightness of surrounding or ambient luminance.

For any given driver, letter size, contrast and surrounding luminance interact to determine actual legibility distance. With letter size and stroke width held constant, the legibility index of partial retroreflective signs is primarily determined by the luminance of the retroreflective material and the surrounding luminance. The legibility index of fully retroreflectorized signs is determined by the internal contrast of the brighter reflective components to the other portions of the sign.

The luminance of the reflective component of partially retroreflectorized signs should be at least 0.2 candelas per square foot with 1 candela per square foot being a far safer specification. In general, the contrast ratio of fully retroreflectorized signs should be greater than 5 to 1.

Driver Vision and Age

Vision capabilities of the driver play a key factor in detection and comprehension of signs. While visual acuity is the parameter most often cited as an indicator for driver vision, at night other vision parameters are important. This is especially true for the elderly who commonly display reduced pupil size and yellowing of the lenses. Consequently, they require signs that are brighter, have more contrast and are larger. Studies by Olson indicate that the elderly may require up to three times the SIA compared to the younger drivers.

SELECTION GUIDELINES CONSIDERING DRIVER'S VISIBILITY NEEDS

From the above discussion it is apparent that there are many factors that:

- Affect the luminance and contrast of a sign of any given reflectivity.
- Determine the distance where a sign should be conspicuous and where it should be legible.
- Determine the luminance required for conspicuity and legibility.

Given all the factors relevant to the determination of the level of sign reflectivity required to meet the driver's visibility needs, it is not possible to specify the appropriate sheeting type for each possible sign, condition or situation. There are, however, some general guidelines that are offered for the selection of sheeting type based on the visibility requirements discussed. These are:

1. Type II sheeting provides adequate levels of retroreflectivity for all permanent signs in many situations.

2. Type IIA or Type IIIA or Type IIIC sheeting is desirable for regulatory signs, e.g., STOP, YIELD, etc. in high speed areas (45 mph or greater) requiring a driver reaction in advance of the sign.

3. Type IIA, Type IIIA, or Type IIIC sheeting is desirable for all critical signs (regulatory, warning or guide) in any visually complex situation, i.e., dense urban or suburban area with competing light sources, or where signs would be unexpected.

4. Type IIIA sheeting is desirable for all signs placed on the left side of a two-way road (e.g., NO PASSING ZONE pennant) or for overhead signs.

5. For those signs which require wide angular viewing, such as the DO NOT ENTER or WRONG WAY sign at a ramp terminus or signs on a freeway curved ramp, Type IIA or Type IIIA sheeting is suggested.

Of course these general guidelines relate to the brightness levels provided by each of the sheeting types. What needs to be established, and is the subject of FHWA research, is how much each of these sheetings can deteriorate in brightness and still be adequate. In this regard the brightness life of the respective sheetings becomes important, an item which is discussed next.

DURABILITY AND ECONOMICS

Another consideration in the selection of the type of sheeting is the relative durability and service life of the different sheetings and any economic implications. If a more expensive sheeting has a longer service life, it may prove to be economically advantageous to use that sheeting especially if it provides a higher level of reflectivity over the life of the sign. A life-cycle cost analysis, using the agency's experience, would identify any cost benefits.

In making a life-cycle cost analysis several factors should be taken into consideration, namely:

- Cost of the sheeting.
- Cost of the sign in-place including the substrate material, post, hardware, and installation.
- Service life.
- Benefits.

A critical determinant in the economic analysis is the selected performance life. Service lives of the various retroreflective sheeting are highly variable and dependent upon environmental conditions. Type II sheetings have a reported maximum service life of 7-10 years and Type III sheetings are reported to have a 10-15 year service life. Instead of using an estimated service life, the manufacturer's performance life guarantee could be used.

However, the service life of the sign is as important as the service life of the sheeting itself. In areas of frequent vandalism, signs may have a short life. Also, a sign may become obsolete because it was for a temporary situation. In selecting the appropriate performance life the agency should draw on its own experience where possible.

There are at least three methods for making comparative cost analysis. These are discussed below.

The simple procedure for making the comparative cost analysis is to divide the total cost by the performance life. This can be expressed as:

$$C = \frac{TC}{PL}$$

Where:

C	=	Cost per year of useful life
TC	=	Total costs of material and possibly the sign during the life of the sign
PL	=	Performance life, which can be the service life of the sheeting or the sign or the manufacturer's guarantee

This procedure does not properly account for the value of money nor consider the difference in brightness provided.

In the second method the above procedure is modified to consider the level of retroreflectivity provided over the useful life. This is done by including a factor for the average luminance provided over the service life. This could be done by using the following equation:

$$C = \frac{TC}{\frac{(L_n + L_o)}{2} \times PL}$$

Where:

C, TC & PL are as defined above
L_n = Luminance (SIA) of new material
L_o = Luminance (SIA) of worn material at end of useful life

In addition to the disadvantage cited for the first method, this requires amassing data on the sign reflectivity at the end of the service life or guarantee/warranty period.

A third and considered to be a more economically accurate method is to compare the equivalent uniform annual costs. Thorough discussions of this method are presented in economic texts written by Winfrey (3), and Barish and Kaplan (4). In this method, the annual cost of a capital investment to be recovered in "n" years, considering interest rates, is found by multiplying its first cost by the appropriate capital recovery factor (CRF). The uniform amount so determined, if charged at the end of each year for the assumed useful life, will exactly repay the initial investment with interest. Functionally this method is expressed as follows:

$$EUAC = TC \times CRF$$

Where:

TC	=	Total Cost including cost of materials, labor, installation and traffic control
EUAC	=	Equivalent Uniform Annual Cost
CRF	=	Capital Recovery Factor $= \frac{i(1+i)^n}{(1+i)^n - 1}$
i	=	Time value of money or interest rate
n	=	Service life of sheeting

Where the alternatives have different service life, as in the case of alternate sheetings, a "credit" is given to the longer life alternate, effectively reducing its equivalent uniform annual costs.

In a 1988 study for the Kansas Department of Transportation conducted by Bellomo-McGee, Inc. (5), this method was applied to establish the comparative costs of Type II and IIIA sheeting. The results, shown below, indicate that if the expected service life of the two sheetings is realized, then the more expensive and longer-high performance sheeting is more cost effective.

Type Sign	Type II	Type IIIA
Overhead Guide Signs - 15' x 10'	$145.00	$117.00
Ground Mounted Warning Signs - 30" x 30"	$7.70	$5.83

For this analysis, it was assumed that Type III sheeting would have a service life of 10 years, Type III would have 15 years and the interest rate was 8.5 percent.

OTHER CONSIDERATIONS

Some practical considerations may influence the decision concerning which type sheeting to use. These are:

- If the signs are frequently vandalized (i.e., gun shots), which may be the case for very low volume, rural locations, the apparent economic benefit of high performance sheeting would not be realized and the decision concerning which type sheeting to use would be based solely on driver requirements without regard to durability.

- High performance sheeting is more fragile and requires more care in the sign fabrication, handling and storing. Some agencies may not be equipped to provide this level of quality control.

- Having to stockpile, and possibly fabricate signs using different sheetings may not be efficient.

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3. Winfrey, R., "Economic Analysis for Highways", International Textbook Company, Scranton, PA, 1969.

4. Barish, N.N., Kaplan, S., "Economic Analysis for Engineering and Managerial Decision Making", McGraw-Hill, 1978.

5. "Reflective Sheeting Study for Kansas Department of Transportation", Bellomo-McGee, Inc., February, 1988.

DISCUSSION AT EASTERN WORKSHOP

Q: Do you recommend high-intensity warning signs for construction zones? Sometimes the signs tend to get banged around by construction site crews in addition to what happens in the field. Did you do any surface life comparison for high intensity in work zone areas?

A: When we did a cost analysis on work zones, we looked at it on a project by project basis. In other words, we looked at what it would cost to use high-intensity, reflective sheeting for that project for a certain duration versus other material. The service life was just good for that project. I don't think that those types of devices would last much longer than one project and may not even last for the length of the whole project. I think we took the assumption that it was on a project by project cost analysis and assumed a fairly short service life for high intensity. I know that has been a complaint about high-intensity sheeting on construction work zone devices. You do have that tradeoff of handling and low service life versus the brighter material.

DISCUSSION AT WESTERN WORKSHOP

Q: In your study where you looked at some of the ongoing inventories that agencies maintained, how many are going to the life of the reflective sheeting? Maybe given as a percentage. Or do vandalism, design standards changes, etc., require changing signs before they ever get to the end of their service life?

A: Saw one report of Idaho.

Comment (participant from Idaho):

> The average life of warning signs is four and a half years. The surprising thing is that 20 percent were replaced earlier than expected because of changes in the roadway or changes in the manual or some other thing like that, rather than a change in the sign itself. Retroreflectivity contributed to 20 to 25 percent of total signs being replaced—a very small percentage.

Q: Have you considered looking at reducing the size of an engineering sign that is 30 inches to a high intensity sign that's smaller?

A: No. But you need size for a different reason anyway, such as legibility. You also need to consider daylight as well. Going to brighter sheeting doesn't let you decrease the size of the sign. They are independent of each other.

Q: Would this also be true of symbol signs?

A: Yes.

Q: We're considering going from a strictly symbol sign for a crossbuck and doing away with the lettering. We found that there is a lot of reflective area without the lettering. This may true of other symbol signs.

Comment:

It depends on where the driver is getting his or her information. For example, look at a yield sign. The driver doesn't get any information from the letters. You need to look at the critical detail. Where is the driver getting the information, the words or the symbol? Use this to make the determination on how far he can see and what size to use, etc.

Comment:

In referring to Federal specification FP-85, which only applies to direct FHWA projects, FHWA is trying to revise it and come out with FP-92. They are interested in the specifications for reflective sheeting. We are at work on that to come out with something that is toward the engineering grade or the high performance grade or even higher and get away from whether it's beaded or prismatic material.

SERVICE LIFE OF RETROREFLECTIVE TRAFFIC SIGNS—AN OVERVIEW

Kent L. Black
Senior Engineer
Bellomo-McGee, Inc.
8330 Boone Boulevard, Suite 700
Vienna, VA 22182

This paper presents an overview of the "Service Life of Retroreflective Traffic Signs" project (Contract No. DTFH61-88R-00060) sponsored by the Federal Highway Administration (FHWA) and undertaken by Bellomo-McGee, Inc. (BMI). The project commenced in July, 1988 with the final report expected by June, 1990. This paper was prepared to discuss the sign sheeting deterioration conditions evaluated, data collection procedure and the preliminary analysis results from this project.

There were numerous goals of this research project; however, the three main objectives were to determine critical sign sheeting deterioration conditions, collect retroreflection readings for various sign sheeting colors and types, and develop mathematical equations to predict in-service retroreflection based on the deterioration variables. The application of mathematical equations will be within FHWA's Sign Management System (SMS) as part of the deterioration model.

SHEETING DETERIORATION

Through an extensive review of the pertinent literature numerous sign sheeting deterioration conditions were isolated. Certain of the deterioration conditions such as, air pollution, area type, distance from edge of pavement, sheeting manufacturer, etc. found in the literature were determined to be site specific, difficult to isolate or beyond the bounds and constraints of this study. These conditions require more intensive investigation on a more regional level.

The deterioration conditions evaluated through the field collection of specific intensity per unit area (SIA) were as follows:

- Sign orientation to the sun.
- Sheeting age or date of installation.
- Sheeting color and type.
- Ground elevation.
- Solar radiation.
- General climate.
- Precipitation.

The sign orientation, sheeting color/type and ground elevation were determined in the field by the data collection technicians. The sheeting age or date of installation was obtained from computerized sign inventories supplied by the controlling agencies and verified in the field, wherever possible.

The solar radiation, climate and precipitation attributes of the data collection sites were obtained from the Department of Commerce's Climatic Atlas of the United States. The climatological measures of solar radiation and general climate were used to develop the eight data collection zones for the United States, excluding Alaska and Hawaii.

DATA COLLECTION

The general requirements for the data collection included the following criteria:

- 2 sheeting types - Type II enclosed lens and Type IIIA encapsulated lens.
- 4 sheeting colors (red, white, yellow and green).
- 6 age categories for 12 years.
- 8 geographic zones based on solar radiation and climate.
- 11 samples per sampling unit (2 types x 4 colors x 6 age categories = 48 sampling units.
- 25 percent additional data for validation.
- 10 percent surplus data.

or

<u>5,810</u> total samples for statistical analysis.

A total of 19 sites were surveyed with a mix of jurisdictions namely 4 State agencies, 9 city agencies, 5 county agencies and 1 turnpike commission. The actual sites were selected based on the geographic location (i.e., 2 to 3 sites per geographic zone), area type, well maintained computerized sign inventory and monetary/time constraints. The key selection criteria was the presence of a maintained computerized sign inventory by which travel routes, location references, sign type (i.e., sheeting color), sheeting type, date of sign installation etc., could be determined prior to the in-field efforts.

Data collection forms were pre-entered, as available, with the pertinent information from the sign inventories. The general sequence of field data collection included the following:

- Locate selected signs from inventory references and pre-entered forms.
- Two technicians with equipment exit vehicle.
- Sign face washed and dried; however, for 10 percent of the samples SIA readings were taken before and after washing.
- Sheeting type and date of installation verified from sign panel.
- Four SIA readings per color taken and recorded.
- Locate next sign in predetermined sequence.

Using three teams of two technicians each and approximately two months of field time, nearly 6,000 samples were obtained. This total satisfied the projected requirements for statistical validity.

PRELIMINARY ANALYSIS RESULTS

This section provides preliminary results for selected analysis performed to date. The eight equations and resultant validation results will be presented and discussed thoroughly in the final report.

Average SIA

Table 5 provides a summary of the average SIA values by sheeting color, type and age across all geographic zones.

Table 5. Specific intensity (SIA).

Age	Red		Yellow		White		Green	
In Years	EG	HP	EG	HP	EG	HP	EG	HP
0-2	23.25	46.00	91.26	241.16	114.52	307.33	18.60	54.55
3-4	19.40	35.82	75.86	235.52	98.41	288.51	15.30	53.62
5-6	14.89	37.79	73.61	214.09	91.10	281.64	14.42	48.74
7-8	20.45	46.17	64.16	210.35	82.27	279.98	15.26	41.51
9-10	17.14	42.40	72.01	199.95	74.01	266.18	14.15	40.29
11-12	8.77	49.48	46.48	190.04	58.86	261.79	6.06	42.98

These SIA averages, except for the red high performance, depict a general consistency as age increases. Where inconsistencies arise (i.e., high SIA averages for older samples) the limited number of samples particularly for older high performance sheeting explains some of the problem.

Sign Washing

For approximately 600 samples before and after sign washing SIA readings were taken. Based on this analysis engineering grade sheeting benefitted from sign washing more than high performance grade. Table 6 presents the results in terms of percent SIA increase after sign washing:

Table 6. Sign washing results.

Sheeting Color and Type	Percent SIA Increase	No. of Samples
o Red		
- EG	7.1%	65
- HP	9.3%	85
o Yellow		
-EG	13.5%	104
-HP	5.4%	33
o White		
- EG	12.5%	107
- HP	7.6%	107
o Green		
- EG	13.5%	59
- HP	6.7%	26
TOTAL	8.9%	587

The SIA increase after washing by sheeting type were:

- Engineering Grade (EG) Sheeting = 12 percent SIA increase
- High Performance (HP) Sheeting = 8 percent SIA increase

Based on interviews of sign fabricators, manufacturers, etc. high performance sheeting was mentioned to have a "slippier" surface than engineering grade sheeting. This and the fact that engineering grade sheeting signs made up the majority of the older samples (i.e., longer exposure to particle build-up) could explain the differences in increased SIA.

Equation Development

Based on evaluations of scatterplots and other testing, multiple linear regression was determined to provide the best fit of the data. The range of R^2 values (i.e, the amount of variance in the dependent variable explained by the regression equation) was from 0.20 to 0.60 for the eight (i.e., four sheeting colors and two sheeting types) equations. Generally, the age, solar radiation and climate variables were the best predicctors of in-service SIA. The solar radiation and climate variables were used originally to derive the geographic zone system. By including these variables in the regression analysis the data across all zones were grouped together. The poorest predictive variables were ground elevation, precipitation and surprisingly sign orientation to the sun. The following provides an example of the equation form and results for green high performance sheeting:

SHEETING TYPE:	Green High Performance (i.e., primarily guide signs)
DEPENDENT VARIABLE:	Average SIA (i.e., average of the four readings taken from the sign face)
REGRESSION EQUATION:	Average SIA = 230.198-1.86 (AGE) -0.30 (Solar)-0.10 (Degree Days)

Note: Not applicable for predicting new sheeting SIA

COEFFICIENT OF REGRESSION: Adjusted $R^2 = 0.54$

The following section provides a discussion of the problems encountered while modeling in-service SIA.

CRITICAL ISSUES

Through this study several items, which hinder the development of equations to predict in-service SIA, were realized. Some of the items focus on the sheeting material and retroreflective attributes while other items arise from the large scale sampling effort undertaken.

Apparently over the past 10 to 20 years sign sheeting material has changed. Any changes in the material namely in structure and retroreflectance affects the ability to model the deterioration trend. Also, the actual SIA values of new sheeting from even the same production run varies significantly. Without a consistent beginning SIA value again quantifying deterioration trends are difficult. As sheeting color fades, particularly in screened red sheeting, the SIA values tend to increase over time. In this circumstance contrast ratios and not retroreflectance is the key determinant of sheeting condition and performance.

The data collection effort was national in scope which created difficulties with the subsequent data analysis. A rather large sample of nearly 6,000 was achieved but less than 20 sites were surveyed. Therefore, data analysis results were easily biased by unusual circumstances found at one site. Other biases were introduced because site selection depended heavily on the availability of a computerized sign inventory. Reasonably, a jurisdiction maintaining a sign inventory is more aware of sign deterioration. Due to the large scope of the data collection deterioration variables such as sign orientation to the sun and ground elevation were difficult to evaluate. More site/condition specific testing is required to analyze these variables' contribution to sheeting deterioration.

This research will provide a good basis for predicting in-service SIA using readily obtainable input criteria. The predictive equations developed should be an integral component of FHWA's Sign Management System.

DISCUSSION AT EASTERN WORKSHOP

Q: What variations were found across the four readings?

A: That's a good question. I guess I haven't really gone through and done the statistical analysis of that, and these are very general terms I'll use. There are variations across the four readings that we took, and it's more than minimal variation. That also contributes to the difficulties trying to model the deterioration. This makes it very difficult because even within the same sign we can get a variation of SIA values. I don't have any numbers for you but there were very significant SIA changes across the sign face.

Q: Did you make an effort to determine what year the sheeting was manufactured?

A: The underlying assumption here was that very little deterioration of the sign sheeting would have taken place between the date of manufacture and date of installation. It would have been a very difficult effort for us to determine when signs were manufactured and how much difference in SIA there would be between manufacture and installation.

Q: Could you determine what the values of the brand new sheeting were?

A: For brand new sheeting? No, we could not determine that. I have no idea what the new SIA values were for the signs that we measured.

Q: How comfortable are you with using the results of your study in a predictor model in SIA knowing that the R^2 values are low?

A: I'd say I would not rely very heavily on the equations or that they are the law. These are very general guidelines. Again, it was a national effort, and we would need more data on a site specific basis to obtain accurate predictor equations.

Q: Is there a specific number on the variation of SIA in new sheeting?

A: I'll have to hedge, I guess my information or source for that is Jeff Paniati, and he had mentioned to me that FHWA had found that some variability of SIA exists on a roll of sheeting. What color it was I don't know.

Comment:

I can tell you this at least, from the data that we collected for category 1, which would be signs that are new through 2 years old, the scatter plots holding the sign color and type of sheeting constant really are scatter plots. This tends to tell me that the sheeting materials didn't start at the same new value.

Q: On your yellow engineering range, it looks like there was a very definite change in material from about 8 to 10 years.

A: That jump in the curve, and I haven't investigated that completely, shows either that most of the older yellow engineering grade sheeting that we sampled was from primarily one location or a couple of locations where there might have been a different manufacturer's material or it was in particularly good shape. This might be skewing our results. We had no idea of knowing the actual manufacturers of the sheeting.

Q: Was there a difference in your findings between damaged signs and signs that were not damaged?

A: We avoided severely damaged or vandalized signs, or those we did not think we could get consistent readings from across the face. We said "avoid that sign" and strictly tried to stay with ones that were not noticeably delaminated or peeling from the substrate material.

DISCUSSION AT WESTERN WORKSHOP

Comment:

I have a question on the orientation issue. Someone on the panel didn't see the deterioration either in retroreflectivity between and north and south facing signs. They did see it in color change. Another FHWA study similar in nature could not identify orientation as something that affected the retroreflectivity. I'd like to hear questions and comments on this.

Comment:

I think that reflects on what the manufacturers have done. Thirty years ago orientation did have an effect on the retroreflectivity. The materials have improved and reduced that effect.

Comment:

We expected to find orientation affecting the retroreflectivity, but in analyzing the data, we couldn't find it anywhere.

Comment:

Try going to the manufacturers. They maintain field tests on orientation on samples for years, and they may be able to provide some data.

Comment:

The U.S. Forest Service has nine different locations where they have data on orientation and different SIA reading for the last 15 to 20 years.

Comment:

We looked at about 500 railroad crossing signs. For those that had been put in during the last 20 years, there wasn't much difference in the orientation, but for those that were 30 to 40 years old, particularly those mounted on steel, there was a big difference if they faced south or north, but not much in the east/west direction.

Comment:

Maybe orientation does not in fact affect retroreflectivity.

Comment:

Contrast ratio may show some orientation effects.

NASHTO REGIONAL TESTING PROGRAM

Donald Casner*
Bridge and Roadway Technology
Pennsylvania Department of Transportation
Transportation & Safety Building
Harrisburg, PA 17122

Many State Transportation Departments across the Nation are attempting to construct and maintain highways with very limited funding, and the prospects of increased revenues are not very promising.

One of the larger problems facing department officials is in the material inspection/ testing areas. Large demands on manpower are required by material acceptance, material quality control programs, and the testing of new materials for use in the transportation sector.

Material testing is, for the most part, a standard process, i.e., ASTM and AASHTO both have specifications and testing procedures that most States follow. One area of materials that does not necessarily follow this pattern is in the area of new materials; materials for which specifications and testing procedures do not presently exist. The question arises that if these specifications exist and the testing procedures are used by most of the States, why do we all test identical materials? Many of the States in this region, as well as the Nation, are unnecessarily duplicating efforts in that they are all evaluating or testing many of the same materials.

A few years ago SASHTO States began a regional testing program for the purpose of evaluating/testing traffic control materials. The idea was to reduce the redundancy of testing required by each state testing the same materials. Not only is the present procedure of individual testing by all States involved costly to the State governments, but also to the material suppliers. Each vendor must provide identical material samples to all states in which they desire to sell the product on which they each do very similar, if not identical, testing.

The NASHTO states comprising the northeastern region of AASHTO have begun a program to consolidate some of the material evaluation and testing efforts for materials that are common to most of the participating States. This began with the formation of a NASHTO ad hoc committee to evaluate traffic striping materials. More recently, the program was expanded to include other materials/products which include:

- Geotextiles and geocomposites.
- Anti-graffiti coatings.
- Reflective sheeting.
- Flexible delineators.

*Presented at eastern workshop only.

- Coatings for structural steel.
- Plastic pipe and culverts.
- Raised pavement markers.
- Tubular markers.
- Concrete admixtures.

This program is undertaken in an attempt to reduce the total manpower requirements and associated expenses resulting from the redundant testing by the States.

The presentation will describe, in detail, the process used by NASHTO to initiate their Regional Testing Program.

DISCUSSION AT EASTERN WORKSHOP

Q: At the test centers, do you have set standards so that when an agency orders that same type of change that they will get what was tested or like material delivered to them?

A: I'm not intimately familiar with pavement marking materials, but my understanding of it is that they test each one by specification. And as they test it, they also test it for performance over a period of time. What they will do is put those numbers together.... (interrupted by comments from the floor)...Thank you, some horror stories that we've heard, at least in our area, put forth that we purchase materials from firms that are located on a State line. We use the identical materials. We use almost the identical standards and specifications to accept it by, and yet we won't accept each other's procedures. And to carry that a step further, within the State of Pennsylvania, there are some horror stories where one engineering district will not rely on another engineering district to test a source. And I think that when you get down to that level and within the State they won't go along with that procedure, it is a monumental task. But I think NASHTO has gone a long way to try to correct the situation.

SASHTO REGIONAL TEST FACILITY

Robert W. Moseley[1+]
Assistant Maintenance Engineer
Mississippi State Highway Department
PO Box 1850
Jackson, MS 39215-1850

Performance testing of traffic control devices has been an integral part of many highway agencies for a number of years. Highway agencies found that performance or research testing on a limited but accelerated manner was an essential mechanism for screening various types of traffic control devices prior to their extensive use by an agency.

Performance claims by a manufacturer as to the durability, conform ability, reflectivity, etc. of their product are readily verified by field and laboratory research testing. Prior to 1989, each of the 12 States that comprise the Southeastern Association of State Highway and Transportation Officials (SASHTO) performed their required field and laboratory research tests on various types of traffic control devices. A majority of the 12 States performed similar tests which resulted in a significant amount of duplicate research testing on the same materials or specific products.

During 1988, a SASHTO Ad Hoc Committee, comprised of representatives from each SASHTO State, developed and implemented the SASHTO Regional Test Facility(ies) (SRTF). The objectives of the Ad Hoc Committee were to:

- Develop a regional test facility concept that minimized the amount of field and laboratory research testing of specific types of material by pooling efforts in an organized manner to significantly reduce the monetary and manhour requirements by both the States and industry.

- Utilize our existing field and laboratory expertise and resources to minimize expenditures while maximizing results.

- Develop field and laboratory research tests that would be acceptable to the 12 SASHTO States.

- Develop organizational and operational procedures for administering the program.

The Ad Hoc Committee accomplished their objectives in a satisfactory manner which is evident by the favorable unanimous vote by the Chief Executive Officers of the SASHTO

[1]Presentation given by Richard Young.
[+]Presented at western workshop only.

States at the 1988 SASHTO Convention. Not only were the organizational, operational, and testing procedures approved, but a permanent SASHTO Standing Committee was established to oversee and administer the operations of the SRTF.

The SRTF is not a building located in a particular SASHTO State nor does it have its own staff, but an organization utilizing existing highway agency personnel, buildings, equipment, test racks, etc. within the SASHTO Region. No initial expenditures were required to implement the program which presently involves 11 of the 12 SASHTO States in some manner in the testing program. At the present time there are no testing responsibilities required of the 12th State, but as the scope of the SRTF is broadened to encompass other types of material, the 12th State will be asked to perform its fair share of research testing.

Table 7 indicates the SASHTO States involved in the program and their responsibilities:

Table 7. SASHTO States and responsibilities for regional test facilities.

STATE	TYPE MATERIAL(S) TESTED BY STATE	RESPONSIBILITIES
Alabama	Striping	Support State (Field Test Decks)
Arkansas	Raised Pavement Markers and Markers Adhesives	Support State (Field Test Deck for Temporary & Snowplowable Adhesives Adhesive Markers)
Florida	Signing	Support State (Field Test Rack)
Georgia	Raised Pavement Markers and Marker Adhesives	Lead State (Field Test Deck for Permanent Markers, Laboratory Work on all Markers and Adhesives, and Writes Report)
Kentucky	Striping	Lead State (Field Test Deck and Writes Report)
Louisiana	Striping Signing	Support State (Laboratory Tests) Support State (Laboratory Tests)

Table 7. SASHTO States and responsibilities for regional test facilities. (continued)

STATE	TYPE MATERIAL(S) TESTED BY STATE	RESPONSIBILITIES
Mississippi		Coordinates Activities of SRTF
N. Carolina	Signing	Support State (Field Test Rack)
S. Carolina		None
Tennessee	Traffic Cones Plastic Barrels Portable Sign Stands Mesh Signs Flex. Del. Posts 1. Ground Mounted 2. Surface Mounted	Lead State (Field and Laboratory Tests and Writes Report)
Virginia	Signing	Lead State (Field Test Rack and Writes Report)
W. Virginia	Reflective Cone Sleeves	Support State (Field and Laboratory Tests)

There have been many hours of discussion by the members of the Ad Hoc Committee and Standing Committee in regard to operational and procedural characteristics of a regional test facility. Based upon these discussions, we have identified some characteristics which define the philosophy of the committee members as pertaining to the SRTF.

The SRTF will:

- Not approve or disapprove products. The test facility(ies) will only provide the field and laboratory test data as required by the field and laboratory test procedures developed and approved by the SASHTO States. Each individual State will be able to review the data and choose those products that are acceptable for use by their Department.

- Not perform industry's field and laboratory research testing. As part of the Product Evaluation Form, the manufacturer/supplier must indicate and substantiate their field and laboratory testing.

- Perform only those laboratory tests that the States have the existing equipment and/or capabilities to accurately perform.

- Limit the number of traffic paint formulas that may be submitted for testing by a manufacturer/supplier over a specified period of time.

- Make the test reports available to cities, counties, States, industry, etc. for a nominal fee of $50.00 per year. This will be accomplished by means of a subscription which entitles the subscriber to a copy of all reports distributed by the test facility(ies).

- Take whatever steps necessary to assure that the test facility(ies) retains its credibility within the SASHTO States and industry.

- Develop a system of fingerprinting the materials that are actually tested in the field and laboratory. The SASHTO States will furnish the test facility with a sample(s) of the materials they are purchasing for fingerprinting purposes. The test facility will furnish the State with a copy of the original fingerprint as well as a fingerprint of the sample(s).

- Charge a testing fee based upon the field and laboratory costs associated with testing a specific type material.

- Operate through a coordinated effort with a specific State being the lead State in the testing of a certain material with other states being support States.

Has the SRTF been successful? During the development phase of this program, it was determined that the 12 SASHTO States spent a combined total of approximately $500,000 during 1987 to perform the required field and laboratory research tests on striping materials, sign sheeting, raised pavement markers and marker adhesives. Hundreds of manhours of duplicate research testing were needlessly being performed at a time when most highway agencies were experiencing manpower shortages. As a comparison, during 1989 there were 75 samples of the four types of materials mentioned above that were submitted for testing by the SRTF. Through our coordinated efforts, approximately $150,000 will be spent testing the 75 samples with an estimated 65 to 75 percent savings in manhour requirements. The vast majority of the $150,000 spent by the various States will be reimbursed based upon the testing fees paid by the manufacturers.

As we enter our second year of testing, we have experienced an approximate 33 percent increase in the number of samples submitted for testing. We attribute this growth to a better understanding of our program by industry and what we are attempting to accomplish. The SASHTO States are greatly appreciative of the support exhibited by industry for the Regional Test Facility in the SASHTO Region.

BREAKOUT SESSION ONE

To encourage feedback from and discussion among the participants, the workshop included two "breakout" periods in addition to presentations and the panel discussion. On the first day of each workshop, participants spent the second half of the afternoon program in simultaneous breakout sessions discussing one of three topics:

1. Alternate face and substrate materials for freeway signs.
2. Alternate face and substrate materials for non-freeway signs.
3. Logo and tourist oriented destination (TOD) signing.

In each breakout session, one participant briefly discussed a group topic as it related to his agency's experiences or policies. The moderator then led a group discussion by posing a series of questions. In the general session that followed, the moderator presented a summary of discussions. Below are the key discussion points, grouped by breakout session topic, as summarized by the moderator.

FREEWAY SIGNING MATERIALS

Sign Face Material

- *Adhesion Problem.* North Carolina reported an adhesion problem with Type IIIA retroreflective sheeting on a large number of guide signs. However, the supplier has corrected the problem under its warranty program.

- *Blotching and Spotting.* North Carolina also experienced a blotching and spotting problem with engineering grade material. The sheeting material was rejected on the basis of its appearance specification.

- *Delamination.* Florida reported problems with delamination of Type IIIA material.

- *Sheeting Combination.* Florida reported on its policy to use Type IIB, "super-engineering grade" sheeting for the copy/legend and Type II, "engineering grade" sheeting for the background. This combination provides an acceptably bright sign for illuminated overhead guide signs.

Sign Substrate Material

- *Spot Welding Problem.* North Carolina reported a problem with spot weld studs used for fastening the panels to the braces and Z-bars. The State is searching for a new type of spot welding.

- *Chemical Disposal Problem.* North Carolina reported on a problem with disposing of the chemicals used for etching and anodizing the aluminum panel substrates.

- *Extruded Panel Problem.* South Carolina reported a problem with porcelain enamel extruded panels where the enamel paint peeled off the extrusion.

- *Fiberglass Sliver Problem.* West Virginia reported on its use of reinforced fiberglass for substrate. The State has experienced minor problems of slivers of the material getting into the silk screens causing blocking of the ink through the screen.

Sign Face Materials and Substrates

- *User-Friendly Sign Inventories.* The western group confirmed the need for a sign inventory at the State and local level. In designing the inventory it needs to be "user friendly" and useable at all levels to insure its acceptance.

- *Aluminum and Plywood Materials.* Aluminum and plywood are materials most often used for sign substrates. Experiences with "pressboard-type material" have not been favorable so far; it doesn't hold up well against gunshots.

- *Color Fading.* Nevada experiences color fading due to the sunlight exposure; the State is experimenting with different inks.

- *Sign Labeling.* Engraving is becoming a popular method for identifying and labeling signs in place; stickers are also still used widely. Felt tip pens are used but the problem with "wash out" over time has been experienced.

- *Sign Refurbishing.* Many expressed the concern that sign refurbishing is not considered a priority item and must compete against other "more demanding maintenance needs." Inventories leading to identification of problems might heighten the awareness of sign improvement needs.

- *Refurbishing and Replacement.* The western group agreed that as much as 50 percent of existing signs need refurbishing or replacement because of appearance, vandalism, or loss of adequate retroreflectivity.

NON-FREEWAY SIGNING MATERIALS

Sign Face Materials

- *Service Life.* In Illinois, Type II sheeting material is used predominately for post mounted signs. Several attendees reported service life of engineering grade as long as 12 years, others reported much less. All seem satisfied with the durability of this material.

- *Encapsulated Lens Sheeting.* Many agencies reported using Type IIIA, encapsulated lens sheeting, especially for the reverse screen signs, e.g. Stop signs.

- *Sign Inventories.* The western group reached a consensus that a sign inventory is needed; the agency needs to know "what is out there."

- *Training.* Training on various aspects of signing is important and the Rural Technical Assistance Program is a good mechanism for achieving training for the local agencies. This training would include information on sign materials, sign installation, sign evaluation, etc.

- *Sheeting Selection.* Selection of the sheeting material should be a local option and should not be mandated by the State or Federal Government.

- *Service Life Guidelines.* Regarding service life and performance standards, the western group felt that only guidelines, not a specific value, should be provided. The western group felt that an expected service life guideline would be most appropriate. With knowledge of its environment and sign material, the local agency could determine the expected useful life of its signs and then replace those at that life.

- *Vandalism.* Because of vandalism, sign inspections have to be done on a regular basis with replacements performed as needed.

Substrate Materials

- *Aluminum.* Aluminum is the material most often used for sign substrate. Using aluminum is advantageous because it can be recycled and then salvaged no matter how thin it gets. However, because of its value, it creates a theft problem especially when the price of aluminum is high.

- *Plywood.* Plywood is used by some agencies; use of this material tends to be a regional choice and is dependent upon the price differential between aluminum and plywood. Plywood is also subject to theft in some areas.

- *Fiberglass.* Fiberglass has seen limited use with some success and failures. One problem relates to the handling of the material in the fabrication process. Slivers of the material get into workers' hands and into screens; this problem has been eliminated to some extent by shearing the material rather than cutting it. It is also difficult to dispose of when no longer useable. The U.S. Forest Service is reported to be using fiberglass material.

- *Vandalism.* Vandalism is a major problem in signing. Some available inks allow easy removal of graffiti markings. Clear overlays can also be applied to the sign face and then peeled off to remove the graffiti or minor scratches.

- *Type II Material.* In discussing the revisions to the FP-85, the eastern group did not reach a consensus on the types of materials that should be included, but did unanimously agree that Type II material should be retained.

LOGO AND TOURIST ORIENTED DESTINATION SIGNING

The groups discussed a number of problem areas in administering the Logo and TOD signing programs:

- *Special Maintenance and Marketing Attributes.* The eastern group discussed logos as compared to outdoor advertising and how they fit together. One is not a substitute for the other. One can be leveraged against the other; this has happened in several States.

- *Complexity.* Logo and TOD signing is becoming complex to the public; it is growing substantially. Thirty-seven States have the program and others are considering it. Each State has to struggle with setting rules and regulations. Logo and TOD signing embraces several areas unfamiliar to the highway community, including a different kind of administration, marketing, and operation that is tied in to development and implementation of these programs.

- *Limited Resources.* These programs present an ongoing challenge to the resources of agencies, which have limited time and staff and which have many high priority tasks to perform that are unrelated to tourist signing, including other types of signing needs. Yet businesses that would benefit from tourist signing see tourist signing as a high priority, and they put pressure on agencies to put tourist-signing needs first. This pressure creates a dilemma for the agencies, which recognize and appreciate the position of the businesses, but which must also tend to many other important highway problems.

- *Costs of Programs.* The cost of these programs are essentially the same among the States, but due to the way the costs are recovered, there are both direct and indirect costs involved. Some of the costs are underwritten by the agency and passed on to the public. In other cases, costs are clearly specified and paid for by the private entity. Hence, the cost differences among the States are great. Businesses must be faced with consistent fees for the logo signs; fees should vary depending upon the area or other factors.

- *Changing Programs.* There is a continuous change to the program, which creates a significant retrofit demand on the agency. For example, the four logo per panel limit for food and lodging has been expanded to six, creating significant retrofitting due to the problems of panel size and support structure requirements.

Also, the coverage area is continually increasing from a few interchanges to several Interstates and to non-Interstate freeways and expressways.

- *Program Implementation.* Three mechanisms for implementation of the program include:

  - A public program underwritten by the agency.
  - A private program carried out for the agency by a private contractor.
  - Semi private/public program carried out by a travel council organized within the State.

- *Logo Display.* Items such as expansion, rural vs. urban, location, proliferation, design, qualifications, renewals, and removals should be considered in setting rules and regulations. The task becomes more manageable if specific rules and regulations are well thought out and clearly defined.

- *Control.* Without proper control by the State, the program spreads out of control and gets mixed in with other motorist services programs such as scenic highway, motorist advisory radio, rest area management, etc. All have to be managed effectively.

In summary, opportunities for solving some of the problems lie in clarifying the rules and regulations up front and adhering to them. Those who operated in such a manner had better success than those who are continuously modifying their program and procedures.

SESSION 4

FIELD ASSESSMENT TECHNIQUES

TRAFFIC SIGN REFLECTIVITY MEASUREMENT USING HUMAN OBSERVERS

Edwin A. Lagergren, P.E.
Assistant Traffic Engineer, District 3
Washington State Department of Transportation
5720 Capitol Boulevard
PO Box 9327, KT-11
Olympia, WA 98504

INTRODUCTION

Driving at night is much more difficult than driving in daylight. A driver's visual acuity, contrast sensitivity, distance judgment, and color discrimination are all impaired by the relative darkness of the night driving environment. Accident statistics compiled by the National Safety Council for the 20 years from 1965 through 1984 indicate that 56 percent of all traffic fatalities occur at night. The fatality rate on a mileage basis for nighttime is more than three times that of daytime. A driver's night vision characteristics and lack of adequate visual guidance information are significant factors in the greater accident and fatality rates at night.[1] Improvement in the nighttime guidance of the driver is likely to improve driver performance. Therefore, an effective method of periodically inspecting traffic signs is important to ensure road safety.

The majority of today's traffic signs are made with retroreflective material for nighttime legibility. As signs age or are covered with road dirt, their retroreflectivity decreases, accompanied by a decrease in effectiveness. The Federal Highway Administration (FHWA) is currently investigating the addition of performance standards for retroreflective traffic signs to the *Manual on Uniform Traffic Control Devices* (MUTCD).[2] At present the MUTCD provides no minimum or replacement standard for retroreflective traffic signs.

The implementation of retroreflectivity standards would create a need for an accurate, reliable and cost-effective method to review traffic signs in the field. The use of observers is the most common, least complicated, fastest, and most cost-effective way to evaluate the retroreflectivity of traffic signs; however, minimal research has been done to verify the accuracy of this method.

STUDY OBJECTIVES

This research project had two primary objectives. The first objective was to review all available literature on maintaining retroreflective traffic signs and survey all State transportation agencies to learn about the methodologies and employed in making retroreflective judgments on highway signs. The second objective was to determine how accurately an observer can be trained to rate the retroreflectivity of traffic signs in a highway environment.

LITERATURE SURVEY

The literature survey uncovered four methods for examining the retroreflectivity of traffic signs:

- Human observers.
- Measuring instruments.
- A combination of instruments and observers.
- Computer-based sign maintenance systems (SMS).

The literature survey showed that instruments to evaluate traffic sign retroreflectivity are accurate but not used on a large scale because of the cost they required. An instrument that would be suitable to evaluate the retroreflectivity of a large inventory of signs has not been developed and may not be developed for several years. A computer-based sign management system may prove to be satisfactory, provided adequate weathering data and several other factors can be obtained. This data collection may also require several years. At present the use of the human observer is widespread but still of unverified accuracy.

QUESTIONNAIRE

The study team mailed a questionnaire to each of the 50 States, the District of Columbia and Puerto Rico to obtain specific details of the policies and procedures used in maintaining retroreflective traffic signs. Eighty-five percent, or 44 States, responded to the questionnaire, indicating a very high interest in the subject of traffic sign retroreflectivity. The main findings are summarized below.

Six States had written, maintained performance standards for retroreflective sheeting material. These standards were based on subjective retroreflectivity performance or manufacturers' performance warranty.

Most other States that had written or unwritten policies based their policies on how often signs should be reviewed.

Eight States used an installation date in their sign inventories as a priority to replace signs.

Thirty-five States put either an installation date or fabrication date on their signs.

Most States reviewed signs for replacement at least once a year.

Sign inspectors were responsible maintenance and traffic personnel (usually both).

Thirty-five States used both day and night visual inspections; 35 States used a combination of moving and stationary vehicles.

Retroreflectometers or material patches were only used as a supplement to visual inspection; Mississippi also used a spotlight during daylight hours.

One-third of the respondents washed signs with varying frequency.

Thirty-one States did not and 13 States did have plans to modify their existing sign inspection procedures.

Only 10 States claimed to be performing or planning research related to sign retroreflectivity in 1986. The most common research was the setting up and monitoring of field weather decks for sign material evaluation. One State also thought that present research was adequate.

EXPERIMENTAL DESIGN

The primary objective of this research was to assess the accuracy of a human observer in determining levels of highway sign retroreflectivity in a highway environment. To accomplish this goal a series of experiments were conducted using impartial observers to rate the retroreflectivity of traffic signs.

Two types of signs were selected for the experiments: the stop sign and the warning sign. These sign types are of high relative importance; they are commonly used, and they are of both sign types, stop signs having a reflective legend and background and warning signs having a non-reflective legend. If observers could be trained to distinguish levels of retroreflectivity for these sign types they could probably be trained for the other colors.

The experiments were performed under three conditions: laboratory, controlled highway and highway. All experiments were done in darkness and under good weather conditions.

Laboratory Experiment

The laboratory experiment (in a gymnasium) was set up to minimize variables by controlling ambient light, geometrics and other environmental conditions. Observers sat in chairs with their eye height at the design driver's eye height of 3.5 ft.[3] Two seven-inch-diameter, sealed beam headlights were placed in front of them to simulate the relationship between the driver's eyes and an automobile's headlights. Signs of known retroreflectivity were placed on a sign post with the bottom of the sign at 7 ft. Observers marked their judgments on rating sheets using a small flashlight to see. The experiment simulated a car parked on the shoulder with the driver observing the sign. Two observation distances, 100 and 200 ft, were evaluated. Observers participated in three sessions in the laboratory.

Controlled Highway Experiment

The controlled highway experiment on the campus was performed similarly to the lab tests. Observers for this test sat in a stationary automobile on approximately level ground and used the same method of recording the sign ratings. The signs were observed at three distances: 100, 200, and 300 ft. The experiment simulated highway conditions, including ambient light, geometrics and viewing through the windshield. The observers also observed signs in three sessions for the controlled highway experiment.

Highway Experiment

The highway experiment was conducted on parts of three State highways under rural and urban conditions. The highway sections were selected for convenience and it is not known if they represent typical highways.

The rural course consisted of two types of highway: a two-lane arterial through a residential area with street lights on power poles spaced unevenly at about 500 ft apart, and a rural road which was totally dark.

The urban course was primarily on a four-lane, undivided urban arterial. The course went through areas of commercial development but also included some sections that were undeveloped and dark. The turn-around point and the few signs on either side of this point were on a four-lane, divided highway (freeway).

During the experiments, a driver and three observers rode in a car. Each observer had a clipboard with a rating sheet, a small flashlight and a writing instrument. In one direction, the driver stopped the vehicle approximately 200 to 300 ft from the warning signs, trying to duplicate the controlled highway relationship between the car and sign. In the return direction the vehicles were driven past the warning signs at the speed limit or about 35 mi/h, whichever speed was slower. The stop signs on county roads and city streets intersecting the State highways were evaluated by duplicating the controlled highway relationship as best as possible considering roadway geometrics and other factors.

SIGN RETROREFLECTIVITY SCALE

The objective of the experiments was to determine if a human observer could be trained to accurately rate traffic sign retroreflectivity. The literature included various studies in which observers rated background complexity, determined legibility distances, observation distances and other sign-related observations. However, all studies were from a driver's perspective of a sign. This study was from a trained maintenance person's or traffic engineer's perspective, and for this reason a retroreflectivity scale for use in sign maintenance had to be developed.

The study team established categories of retroreflectivity and had observers rate signs into these categories. This method was selected over several others because it would allow for some variability in maintained retroreflectivity standards and also it would show how well observers could rate signs into categories based on retroreflectivity levels. Essentially, the experiment would entail calibrating the observers to a retroreflectometer.

The eye is incapable of making an absolute measurement of the amount of light entering it.[4] For this reason the rating categories were fairly large. The research team decided that a scale of five categories was enough; observers rated signs on a scale from 0 to 4.

The scale was described to the observers as 0 being the worst a sign could be and 4 being a brand new sign. Category 1 signs were described as having low retroreflectivity or some other defect that would make the sign ready for replacement. Category 2 signs were described as signs which had an "adequate" amount of retroreflectivity and looked ok. They might also have some defects but not defects detrimental to the function of the sign. A Category 3 sign was described as a sign that had good retroreflectivity.

Warning Signs

A sign retroreflectivity scale for warning signs was established based on the minimum and maximum retroreflectometer readings for yellow engineer grade reflective sheeting and a study by Mace.[5] The boundaries between the five categories of the 0-4 scale were established in the following manner. The boundary between 0 and 1 was set at a specific intensity per unit area (SIA) value of 6 candelas per square per foot-candle (cd/ft^2/fc). All the signs below this level looked extremely dark. The boundary between 1 and 2 was set at an SIA value of 18 based on the Mace findings that signs degraded to this value provided adequate luminance for low complexity sites. The boundary between 2 and 3 was established at SIA 36, based on the Mace finding that this value provided adequate recognition distance for speeds below 35 mi/h. The boundary between 3 and 4 was set at SIA 70, based on the reasoning that all the warning signs the study team had measured with SIAs above this value were new. The Federal acceptance level of SIA 50 for new engineer grade yellow sheeting falls in the middle of Category 3.

Stop Signs

The rating scale for stop signs was established based on the SIA of the legend and the internal contrast of the sign. Stop signs are made of one of three types of reflective sheeting: Type II, IIB and III. The Federal specification FP—85 allows the different types of sheeting to degrade to 75 percent for Type II, 50 percent for Type IIB, and 50 percent for Type III of the acceptance level for new material.[6] Because of this, two separate scales were set up (however, as it turned out observers could not tell what type of sheeting the signs were made of, so in reality rating was done on one scale). Sivak and Olson summarized several studies on sign luminance and concluded that the recommended optimal legend-background contrast for signs with both the legend and background material is 12:1.[7]

The stop sign rating scales were set up on a grid with SIA on the vertical axis and contrast on the horizontal axis. The boundary between categories 1 and 2 was set at the minimum acceptance level of 125 SIA for Type III and 75 SIA for Type IIB sheeting. U-shaped curves were drawn based on the judgment of the study team.

SIGNS

Collection

To conduct the laboratory and controlled highway experiments, a collection of signs representing the range of retroreflectivity were obtained. The collection of signs selected for the laboratory and controlled highway experiments had as few defects as possible so that observers would be rating solely their retroreflectivity. The signs used in the highway experiments were signs that were in place on the highways.

Measurement

The sign retroreflectivity measurements were accomplished with a Model 910F Retro Tech reflectometer. Five measurements (top, bottom, left, and right corners and near the middle) were taken on each warning sign face and then averaged. Stop sign faces were measured in a similar manner for the red, but an additional measurement was taken on each of the four letters.

Presentation

The signs in the laboratory and controlled highway experiments were presented to the observers in a random order.

OBSERVERS

Nineteen observers were hired for the traffic sign retroreflectivity experiments, and 17 observers completed all the experiments. All were licensed drivers with a high school education and residents of the Seattle area. The observers who completed the experiments ranged in age from 20 to 43 years, with a mean age of 26 years, and included nine males and eight females. All had corrected acuity of 20/30 or better with no color deficiencies. The observers were not a statistical sample and do not represent the entire population.

Observer Training

Observers received instruction on how to rate signs in several ways. Two sizes of color chips were used; signs with different ratings were held up together for comparison; observers were shown signs and told their ratings after they had rated the signs; and they were shown signs and told what the signs' rating were without rating the signs. Observers were also shown graphs of the results of their previous sessions, which showed them their mean for each category of warning and stop signs. The training program was continuous and the study team believed that the accuracy of the observers would continuously improve until limited by the sensitivity of the eye.

The highway experiments were done with no calibration. Observers were simply reminded of the rating scale and told to rate the sign from approximately the same position as in the controlled highway experiment.

OBSERVER ANALYSIS

The objective of the experiments was to determine how well an observer can be trained to evaluate the retroreflectivity of traffic signs. The study team did not know if some observers would be better or worse than others and if there would be any way to determine why they were better or worse. To rate the observers a value based on the mean squared difference between the actual sign rating and the observers' sign rating was used. This value was in observer rating units (ORU).

The observers did not dramatically improve throughout the experiments. No consistency in the ranking order of the observers could be determined. The observers reached their optimum accuracy after two or three sessions and further improvement was not possible. The final analysis of the observers also shows that the ORU mean and standard deviation did not change much between the controlled highway and the highway experiments considering any of the 200- or 300-ft distances or the stationary or moving observations. These results seem to indicate that the human eye is not sensitive to differences in sign luminances over the conditions in the experiment.

HIGHWAY EXPERIMENT ANALYSIS

The major objective of this study was to determine how well a trained observer can evaluate warning and stop sign retroreflectivity under highway conditions based on judgments made with available luminance (the headlights illuminating the sign are considered to be a constant). The experiments in the laboratory and on the controlled highway were simply the training ground for the observers. Observers in these experiments rated signs under conditions that were ideal. The distances, geometrics and ambient light conditions, as well as the signs, were all controlled and as consistent as possible. In the highway experiments all of these factors varied from one sign location to the next.

The primary results of the highway experiments were the comparisons of the observers rating of the signs and the retroreflectometer rating of the signs. The observers' and the retroreflectometer ratings were then incorporated into a decision model to replace or not replace the sign. The replacement retroreflectivity level for both types of signs was based on visual complexity for each sign location. Signs would be replaced if a sign on a rural road with dark conditions rated a 1 and if a sign in an area illuminated by street lights and/or commercial lights rated a 2. A sign with a rating of 3 would remain in place under all conditions. The use of these criteria reduced the scale from one of five categories to only three. The 0 and 4 ratings were valuable in the training period to show observers how bad or good a sign could be.

To obtain one value to be used in the decision to either replace or not replace a sign, the median judgment of the observers was used. The median judgment of the observers represented the most likely rating a trained observer would give a sign. The consistency of the observers would be represented by the frequency distribution of the observers ratings for each sign category.

The observer median rating combined with the replacement criteria resulted in one of four possible decisions. Two of the four decisions would have been correct — the observers could have replaced the sign in agreement with the decision model or they could have let the sign remain in place in agreement with the decision model. A decision by the observers not to replace a sign that was scheduled for replacement by the decision model would have created an unsafe condition for the driver and increased liability for the agency. The decision to replace a sign unnecessarily would have created an additional expense for the highway agency.

Table 8 summarizes the decisions of the observers and the decision model for the highway experiments. The table shows that of the 130 signs in the highway experiment, the observers' median ratings and the decision model were in agreement on 103 signs or were correct on 78 percent of the warning signs and 82 percent of the stop signs. Seventeen signs (15 warning and 2 stop) were replaced that should have remained in place. Of these signs, ten had noticeable defects including dirt, dents, bends and one sign face had also been "reconditioned." These signs represented the percentage of signs that are replaced before their service life for reasons other than insufficient retroreflectivity. Ten signs (4 warning and 6 stop) were not replaced when they should have been replaced. Of these signs, two warning signs' retroreflectivity was near the top of their categories and was rated in the next higher category.

The median judgment of the 17 observers, while representing the most likely rating a trained observer would give a sign, does not represent the accuracy of a single observer rating the series of signs. The accuracy of the observers varied within the group. An observer may have rated one sign low and the next high. This inconsistency among observers was averaged in the median decision. In actual practice, agencies would use one or two observers to make sign replacement decisions. For this reason the accuracy of the single observer was also investigated. Table 8 also lists the average sign replacement decisions for the 17 observers in each of the 4 possible rating decision categories. The observers as individuals were in agreement with the decision model on 97 of the 130 signs or were correct on 74 percent of the warning signs and 75 percent of the stop signs. The trained observer as an individual is only slightly less accurate than the group.

SIGN RATING SCALES ANALYSIS

Warning Sign Rating Scale

The warning sign rating scale was satisfactory. While the signs seemed to degrade gradually from one category to another, at the point where the SIA reached about 18, the sign would degrade rapidly. This was the point where all signs were replaced in the study.

Table 8. Highway experiment results.

Observers Decision	Replace		Do Not Replace	
Decision Model	Replace	Do Not Replace	Replace	Do Not Replace
Warning Signs				
Rural				
Number of Signs	15	0	0	41
Median	13	9	2	32
Individual	13	10	2	31
Urban				
Number of Signs	11	0	0	19
Median	9	6	2	13
Individual	8	7	3	12
Total Number of Signs	26	0	0	60
Median	22	15	4	45
Individual	21	17	5	43
Stop Signs				
Rural				
Number of Signs	9	0	0	11
Median	7	2	2	9
Individual	6	2	3	9
Urban				
Number of Signs	18	0	0	6
Median	14	0	4	6
Individual	13	1	5	5
Total Number of Signs	27	0	0	17
Median	21	2	6	15
Individual	19	3	8	14
Combined				
Total Number of Signs	53	0	0	77
Median	43	17	10	60
Individual	40	20	13	57

Stop Sign Scale

Upon completion of the experiments a closer examination of the stop sign rating system was performed. The examination showed that observers can generally rate stop signs based on contrast and retroreflectivity. Signs with low retroreflectivity and good contrast were rated lower than signs with the same contrast but higher retroreflectance, and signs with low contrast were rated lower than signs of equal retroreflectivity but closer to optimal contrast.

The stop sign rating scale used in this study was the first of its type. If the study team were to redesign the scale, some changes would be made. One scale would be applied to all types of sign sheeting material. The vertical axis of the scale would be based on the one thing all stop signs have in common: how well they perform their job, or recognition distance. The horizontal axis would be again the white/red, internal contrast ratio.

ECONOMICS OF USING AN OBSERVER

Economically, what do the observers cost the highway agency when they remove signs that could remain in place or let signs that should be removed remain in place? The study team performed an economic analysis on the signs in the two highway experiments.

The signs that were replaced unnecessarily had been in place for some period of time. To account for the years of sign life that were lost, a deterioration model based on the useful life of the sign was used. Mace uses a useful sign life of seven years for engineering grade sheeting and 12 years for high intensity sheeting.[8] At the end the useful sign life the sheeting material retains 50 percent of its initial retroreflectivity (measured by SIA) and is totally dark after 14 years. Signs are assumed to deteriorate in a linear fashion. Sixteen signs would have been replaced unnecessarily in the study: 14 warning signs made of engineering grade sheeting and two stop signs made of high intensity sheeting.

The useful sign life lost was calculated using the SIA of the signs. Forty-five and 10 years of sign life would have been lost for the warning and stop signs, respectively. Based on current WSDOT sign costs, the sign life lost for these signs would have cost the agency $164. To replace these 16 signs under average conditions would have required 2 sign technicians and a truck for 1 day, for a cost of $360 at current WSDOT rates. The total cost becomes $524.

The decision by the observer to allow a sign that should have been removed to remain in place would have incurred an additional liability for the agency and created a potential hazard for the motorist. The economics of this decision are difficult to compute. Neither the agency nor the motorist suffer any economic loss until a motorist has an accident. After an accident the cost to both the motorist and agency can be quite high.

RETROREFLECTOMETER VERSUS HUMAN EYE

A Retrotech 910F was used to measure the retroreflectivity of the signs used in the experiments. While the Retrotech 910F was easy to use and reliable, certain discrepancies between how a retroreflectometer sees a sign and how a human sees a sign became evident. The Retrotech 910F was designed to be placed directly on the sign face and measure the retroreflectivity of a circular area one inch in diameter. For a 30–inch by 30–inch warning sign, the total area is 900 square inches, by taking five measurements a total area of 3.92 square inches or 0.4 percent of the total area is measured. A great majority of the vandalism and other problems are not measured. Another problem is that the retroreflectometer sees bent signs as flat, and signs that are severely dented or damaged cannot be properly measured. The observer actually sees the luminance of the entire sign and this is sometimes quite different than the retroreflectometer.

SUMMARY

The literature survey and survey questionnaire indicated that at present there is no method of sign review other than the trained observer that is suitable for a large sign inventory. The retroreflectometer, while extremely accurate and consistent, overlooks many factors important to the driver. The development of an instrument that would be suitable to evaluate the retroreflectivity of a large inventory of traffic signs has not been developed and may not be developed for several years. A computer-based sign management system may prove to be satisfactory provided adequate weathering data and several other factors, including accurate records of sign replacement, can be obtained. This data collection may also require several years. The experiments have shown that a trained observer is a valuable part of a sign maintenance program. The trained observer sees a sign in the same way that a driver sees a sign. Agencies will have to continue to rely on observers' judgments for some time to come.

CONCLUSIONS

The observers used in the study were all about equal. The observer can easily tell a "good" sign from a "bad" sign, but because of the category division lines and other variables, including the sensitivity of the eye, the observer cannot be totally accurate.

The trained observer can make accurate and reliable decisions to replace signs. Several factors encountered in the study would improve their accuracy:

- Observers should be used in pairs – one to drive the vehicle and one to keep records.
- Straight, level approach geometrics, clear of obstructions.
- The sign should be plumb and approximately 90 degrees to the observer.
- Dirty signs should be cleaned.
- The observer should be used in conjunction with a sign management system which includes the installation date and the life expectancy of the sign.
- A comprehensive daylight review should be performed prior to the nighttime review.
- The trained observer should be used as the final check after the obvious corrections to the signs on a highway have been made.
- Signs rating 2 could also be checked with a retroreflectometer for final replacement decision.

Sign maintenance will cost agencies more money but it is necessary to decrease nighttime accidents and agency liability.

Recommendations

1. The trained observers should be fully evaluated before undertaking research to develop an "expensive" retroreflectometer to evaluate traffic sign retroreflectivity.

2. Agencies should design a training program to instruct people who are currently making sign replacement decisions. Training would make sign replacement more uniform throughout a jurisdiction and create safer highways for the motorist. Observer training, in combination with regular day and night inspection, would be the key elements in a tort action.
3. The sign maintenance system (SMS) does show promise. The SMS would be especially valuable for large signs in areas where vandalism is not a factor.
4. Replacement of signs at different levels of retroreflectivity for different classifications of highways may be a good way to stretch limited funds.
5. Any future stop sign scale should be based on recognition distance and the white/red internal contrast ratio.
6. The transparent ink used on stop signs should have a specified thickness. The thickness of the ink makes a considerable difference in the appearance of the sign at night. If the ink is too thick, even the red on a brand new sign will look black at night. A specified maximum and minimum thickness or retroreflectometer readings on the red for each type of material would solve this problem. With this specification agencies will also have control over the internal contrast ratio of the sign.

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DISCUSSION AT WESTERN WORKSHOP

Q: Did you do eye exams?

A: Yes, we did. All the observers had 20/30 vision or better. We did not attempt to get observers that were a statistical sample. We were just trying to see if people could do this.

ALTERNATIVE SIGN EVALUATION

Calvin Roberts*
Engineer of Traffic and Safety
Michigan Department of Transportation
425 West Ottawa Street
PO Box 30050
Lansing, MI 48909

BACKGROUND

The State of Michigan has over 1800 miles of freeways which includes Interstate, US, and M routes. Our records indicate about 29,500 regulatory, 12,200 warning and 41,200 guide signs are installed on this freeway system. To maintain these signs at an acceptable level of retroreflectivity, to insure that both the Federal and Michigan *Manual on Uniform Traffic Control Devices*, and the latest safety standards are met; requires a qualified full-time engineering and technical staff dedicated to this activity.

Freeway sign installation by State forces and contract county road commissions is now limited to replacing damaged signs and adding a small number of new signs. All major freeway signing projects, including those required for new freeways and sign upgrading activities, are completed by private contract.

In the late 1960s and early 1970s, Michigan's freeway signing effort was primarily directed toward mainline safety yellow-book projects. Many of these projects consisted of replacing the non-yielding sign supports that we located in the clear zone but retaining existing signs. In addition, State forces were used to install overlays on deteriorated guide signs. Only a few comprehensive sign upgrading projects on freeways were completed during this time. Signing projects were developed and scheduled based on information received from several sources. This included input from department district staff, maintenance forces and the motoring public.

An early phase of signing plan development is the initial field review. This is when primary emphasis to assess signing legend needs and locations are determined. During this time period, an effort is made to retain or relocate at a greater setback as many existing signs as possible. However, it soon became apparent that signs that had been retained because of a good appearance during the daytime field review had poor retroreflectivity one or two years after the signing contract was completed. To correct the deficient signs, it was then necessary to use State forces to overlay or replace previously retained signs soon after the signing contract was completed. Also, contractor bid prices for salvaging and relocating existing signs was as high or higher than the price for removing existing signs and installing new ones.

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*Presented at eastern workshop only.

Another event that affected the signing program was that in the late 1970s and 1980s, the department began to reduce its staffing and maintenance budget. An immediate impact of the staff reduction was a loss of the ability to accomplish large sign replacement or overlay projects using State forces. Since the early 1980s, our department's policy has been to replace all signs (99 percent) when we upgrade a segment of freeway and to install high-intensity sheeting on all projects.

NEED FOR A SIGN EVALUATION

The need for a sign evaluation process in Michigan is the result of past policies in which many of the previous sign upgrading projects primarily addressed mainline safety needs with limited attention given to sign retroreflectivity, manual requirements, and interchange ramp and crossroad signing. Another consideration effecting sign upgrading needs is tort litigation. The department receives numerous claims alleging problems with signs especially freeway signs. Sixty percent of tort cases involve signing. These allegations are:

- The nonyielding sign supports located within the clear zone.
- Improper signing practices - not using diagrammatic signs at locations where the manual indicates they should be used.
- Poor nighttime retroreflectivity.
- Lack of proper warning signs and their installation location in reference to the hazard.

Because of continuing budget restraints, sign upgrading projects must compete with other construction and maintenance related projects for funding.

To upgrade and maintain an acceptable level of sign performance, it was determined that a systematic methodology to identify signing needs and establish project priorities was essential. The method had to consider sign retroreflectivity, manual requirements and yellow-book safety standards. In order to address operational issues that could not be determined in the office, nighttime reviews of freeway segments were initiated to evaluate sign retroreflectivity and condition.

FIELD REVIEW PROCEDURE

In conjunction with our night review process, we strategically developed a form that facilitate the gathering of pertinent information for evaluating the freeway signs. Our goal was to be able to subjectively provide a base of reference to compare segments of the freeway system.

The actual night review of freeway signs was conducted by a three member team. The basic function of each team member remained the same throughout the entire study to maintain uniform data collection. The driver would try to keep a consistent speed to evaluate the signs for the drive-by evaluation and would watch traffic. The evaluator would fill out the rating form and would operate the hand held spotlight for closeup sign inspection. The inventory checker would keep track of the condition of individual signs on an inventory strip map while noting non-retroreflective and missing signs. (Figure 9, a sample inventory strip map, is attached.)

It was generally believed that signs in one direction should be similar to those in the other direction; therefore, routes were reviewed in only one direction with an occasional spot check of signs in the opposite direction. Crossroads were driven in their entirety and ramps were driven in the same direction as the mainline routes, however, the spotlight was utilized to check on the appropriate signs on ramps not driven.

The evaluation for each interchange would begin approximately 1,000 feet in advance of the first sign (usually the 1 mile advance guide sign). All signs within the interchange sequence were observed as they were approached and then given a thorough review with a hand held spotlight, while the vehicle was stopped directly in front of the individual sign. The spotlight would pick up cracked sheeting and deterioration that could not be seen with vehicle headlights. The driver would stop at the exit gore location so that the evaluation sheet could be filled out for the mainline signs. The ramps and crossroads were then driven and rated in a similar manner as the mainline both drive by and individual or stop inspection.

SIGN EVALUATION FACTORS

In order to establish a priority ranking for sign replacement seven evaluation factors were taken into consideration. (Figure 10, a copy of the evaluation form, is attached.) The evaluation factors are the following:

1. *Age*

   - Age of the signs was determined by checking to see when the last contract sign replacement was made.

2. *Average Daily Traffic (ADT)*

   - A greater priority was given for high volume roadways.

3. *Yellow-book*

   - Yellow-book safety factors were noted such as breakaway sign supports, guardrail replacement, and American Association of State Highway Transportation Officials (AASHTO) clear zone requirements.

4. *Up to Current Standards*

   - Were the signs up to current Federal and State sign standards for legend size and colors? Were symbols and exit numbering utilized?

5. *Overlaid*

- Had the signs been overlaid or could we put off the expense of a contract by having a few signs overlaid?

6. *High Intensity or Engineering Grade*

- We note whether the sign sheeting was entirely (1) engineering grade, (2) high intensity legend and engineering background or, (3) high intensity legend and background. Since high intensity sheeting usually does not deteriorate as rapidly as engineering grade sheeting, a roadway with all high intensity sheeting would be given a lower replacement priority.

7. *Drive-by, Stop, Crossroad*

- Signs on the mainline and the crossroads were rated on a scale of 1-4 for both retroreflectivity and cracked sheeting. A (1) indicated that the sign was in such bad condition that it could not be seen. A (2) indicated that the sign was legible from only a close distance, had large cracks in the sheeting or the sheeting was torn. A (3) indicated that the sign exhibited some slight cracking of the sheeting but was good enough to last a few years. A (4) indicated replacement was not required at this time.

A representative level of sign performance was determined and separate ratings made for the mainline and crossroad. This was accomplished by reviewing the mainline and ramp signs as described as part of our under the Field Review Procedure process, and an appropriate ranking was selected for the entire interchange. The same process was followed for the interchange crossroads.

METHOD USED TO ESTABLISH PRIORITIZED LISTINGS

After the field review was completed, the collected data was assembled into a useable form. Segments of roadways were made up from previous segments used to prepare contracts (with some minor modifications). Each control section (this number identified the county) was identified as well as the route number (i.e., I-75, I-96, US-23, M-39) and the interchange number along that segment. The age of the signing or last upgrading was determined and added to this information along with the ADT per that segment. All remaining information gathered was added to a data base file. Ninety percent of this information was equally weighted. Each interchange was then given a numerical value based on this information. The numerical values for each interchange in the segment were added together and then divided by the number of interchanges to determine a numerical value for the entire segment. The segments were then ranked numerically to determine the projects that should require upgrading first.

Segment lists were prepared using three different criteria. First, we ranked the segments using all of the parameters, the second ranking used only the mainline and not the crossroad signing, and because departmental policy in the 1970s dictated that only signing on mainline roadways would be upgraded, a third list using only crossroads along freeway segment was developed. Then we estimated, that cost, to upgrade per segment, by using the higher cost of either a cost per mile of freeway or a cost per interchange. At this time we determined whether cantilevers were required for the crossroad signing since this would increase the cost per interchange. We then related the amount of money the department would spend each year per the number of projects and identified the approximate year the project would be included in our signing program. In each list we identified the funding category according to Interstate, US, and Michigan routes to take advantage of the 90/10 Federal money if possible.

SELECTION OF SIGNING PROJECTS

After the lists were developed and all of the modifications were made, we then determined how much money could be spent on freeway signing for the next 5 years. As we indicated, the projects on the list were split up into special categories as to Interstate, US, and M route projects, and the use of funds also took into account that we wanted to spread the projects throughout the State. It should be emphasized that the actual selection process involved the cost criteria as well as the location in the State. Projects in urban areas were balanced with projects in the rural areas. Our primary goal is to upgrade approximately 200 miles of freeway signing per year.

SHORTCOMINGS OF METHOD

This system provided the Michigan Department of Transportation (MDOT) a subjective methodology to accomplish the goal of prioritizing our inadequate segments, and a way of allocating funds to improve our freeway signing system. Our initial goal, was to develop a systematic approach to our system of sign upgrading, as well as observe how each of our districts differed in application of similar signs. We used some statistical models in our evaluation process in order to provide a better perspective to indicate where the inadequate areas were, but the night visual inspection alone gave the team a very good comparative relationship of segments of freeway signs. One drawback of this process was that it required the team to operate at night for the entire inspection time, as opposed to our normal working hours. To take advantage of earlier hours of darkness this operation had to be done in either the fall or in the spring. The winter months were not used because Michigan implements daylight savings time and because of weather considerations. The summer months were not used because that is the time staff accomplishes a large portion of the field review and data gathering operations. The fall or spring time of year presents the problem of "is the sign face bad or is dew forming" on the sign. Once dew forms then the night review becomes invalid. To compensate for this, we operated only on days when there was not a large shift in temperature effecting the dew point.

IN SUMMARY

Although this process is subjective, we believe that we have developed a process by which we can get a reasonable priority for upgrading segments of freeways. The systematic methodology of the night review in which many variables are categorized, and then adding them into a computer process provides our department with a reliable product. We are convinced that until a device to measure reflectivity is developed, we feel that the system MDOT has developed provides a process to address all of our current freeway signing requirements.

DISCUSSION AT EASTERN WORKSHOP

Q: Did you replace all of the signs in the segment when you went through?

A: We replaced all.

Q: What if most of the signs were good and there happened to be one or two particularly bad ones? Did you take any action?

A: If there were one or two bad ones, then we used our State forces, and they replaced whatever was necessary.

Q: What sort of plan did you use? How did you translate the field inventory into a contract document?

A: Well, we do have a computerized inventory. We are in the initial stages of implementing that in the field. And we develop the complete plans. We do large contracts by developing complete signing contracts, and then we put them out to bid. And, we also work with a number of the local county agencies to develop work authorizations where they implement a lot of these signing projects.

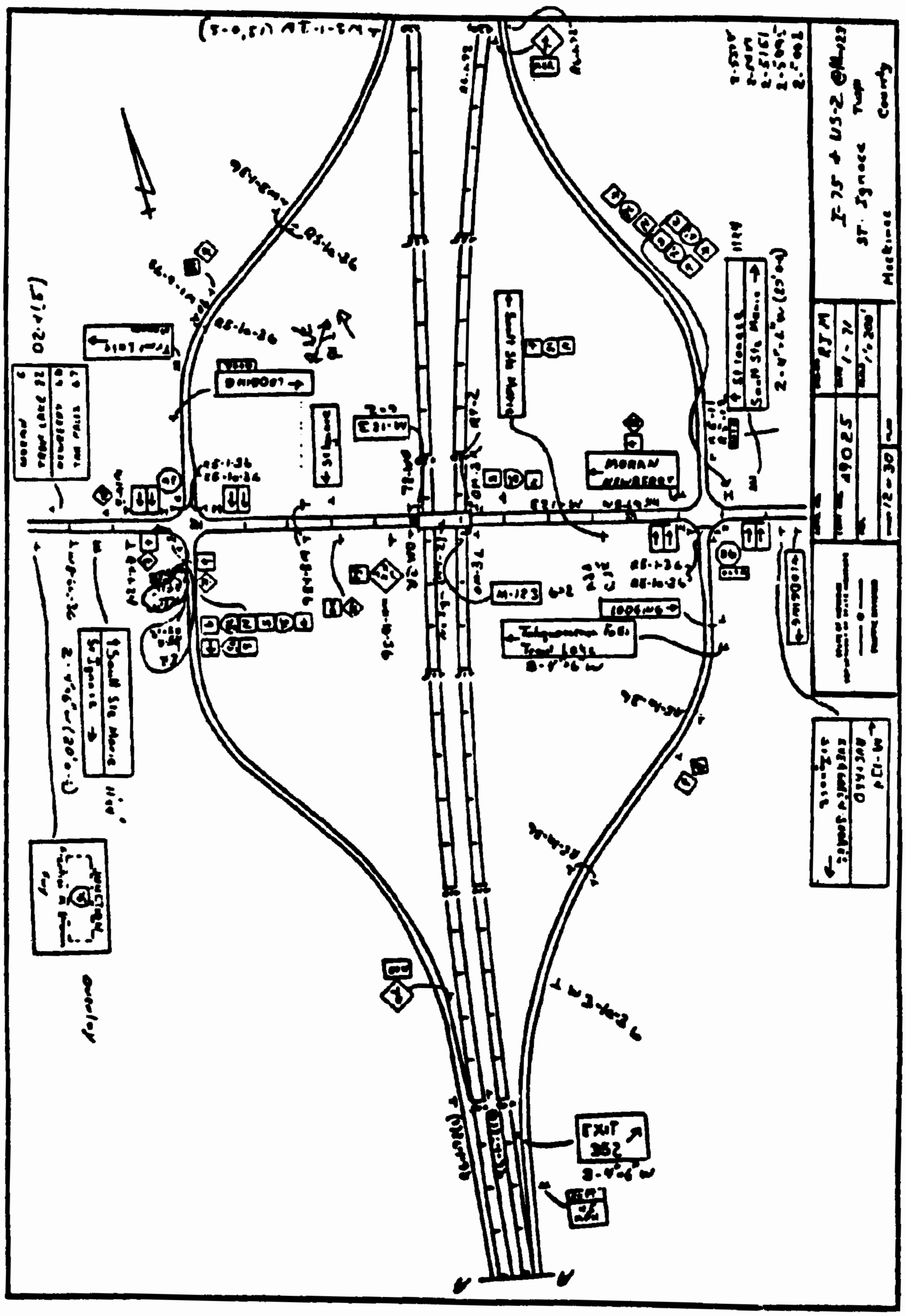

Figure 9. Inventory strip map.

Freeway Sign Evaluation

ROUTE ____________________ INTERCHANGE ____________________

AGE OF SIGNS ____________________

YELLOW BOOKED	NO		SOME	YES
UP TO CURRENT SIGN STANDARDS	NO	SOME	MOST	YES

OVERLAYED	YES	NO
HIGH INTENSITY ON ENG. GRADE	YES	NO
HIGH INTENSITY ON HIGH INTENSITY	YES	NO

DRIVE BY				
REFLECTIVITY	1	2	3	4
CRACKING	1	2	3	4
STOP INSPECTION				
REFLECTIVITY	1	2	3	4
CRACKING	1	2	3	4
CROSS ROAD SIGNING				
REFLECTIVITY	1	2	3	4
CRACKING	1	2	3	4
SIGN STANDARDS	NO	SOME	MOST	YES
CANTILEVERS	NO			YES
YELLOW BOOK	NO	SOME	OK	

(1) VERY BAD
(2) NEEDS REPLACEMENT NOW
(3) GOOD BUT WILL NEED REPLACEMENT
(4) GOOD FOR 1, 2, 3 YEARS

Figure 10. Freeway sign evaluation form.

ALTERNATIVE TO NIGHTTIME SIGN INSPECTION

J. Richard Young, Jr.[+]
Traffic Control & Safety Engineer
Mississippi State Highway Department
PO Box 1850
Jackson, MS 39215-1850

During 1987, 46,386 people lost their lives in motor vehicle accidents. Over 75 percent of the fatalities occurred on the Federal-aid system even though it comprises only 22 percent of the total mileage. The fatal accident rate at night considerably exceeded the daytime rate. Over 55 percent of the fatal accidents occurred at night. One of the reasons for this disparity is the nighttime performance of our passive traffic control devices (our signs). It is therefore assumed that by improving our signing we can affect the nighttime accident rate.

There are several ways to identify the signs which need to be replaced. The obvious and easy way is to make a nighttime drive-by. Another method calls for the use of retroreflectometer. Although the retroreflectometer can be used during normal daylight working hours, it is extremely labor intensive, slow, and therefore expensive. The nighttime drive-by seems simple but it may require additional personnel, overtime pay, or the granting of compensatory leave time. We were never successful at completing an inventory using either of these methods. Subsequently we did not know the extent of our nighttime sign legibility problem until we discovered a third method, the use of a 200,000 Candle Power Spot Light (Q-Beam). We found that for approximately $15 we could buy this tool (hold up Q-Beam) that would give us a reliable indication of sign retroreflectivity anytime we drove by a sign.

We are all faced with having to do more for less or more with less. In our case we could not get that extra labor shift or overtime pay for nighttime sign inspections. We could not give away compensatory leave because our employees already have difficulty finding time to use their regular leave time. The Q-Beam solved these problems. With it we can conduct "nighttime" inspections during regular working hours, right from the maintenance vehicle, and at our convenience.

We began using the Q-Beam and following up with Gama 920 retroreflectivity readings. This experience gave us an indication of acceptable retroreflectivity. We followed this with nighttime sign inspections. With a little practice, we were able to use only the Q-Beam, and with it we could very closely estimate the retroreflectivity and easily identify signs which were not performing properly at night.

Since still photos will not illustrate the flashback effect you should look for with this light, I will show you a video we put together on the use of the Q-Beam. The video will

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[+]Presented at western workshop only.

show you a variety of problems spotted with the Q-Beam that would go undetected by routine drive-by a maintenance crew. For your reference we went back and took some nighttime shots to confirm that many signs which look good by day are very bad at night.

[SHOW VIDEO]

This 16-minute video shows a variety of problems and sign conditions. The emphasis here is to show the light from the Q-Beam flash back at the viewer when the sign is good and to show that it does not when the sign is bad. The importance of this effort is to show that signs which look acceptable to the daylight observer, but not acceptable to the nighttime observer are easily identified.

The video shows that this procedure can best be done under overcast skies or even in the rain. On very bright sunny days we show that the observer must be closer to the sign or use a light brighter than our 200,000 candle power light. Also on very sunny days the rate at which the observer can progress past signs is slower.

Another important factor illustrated here is that the date of sign installation may give the observer a false sense of whether or not the sign is performing satisfactorily at night. We show several examples of signs which are only 4 or 5 years old and look good by day but which are almost or totally gone at night. And on the other side, we show signs which would normally be replaced solely due to their date of installation but we found them to perform well under the Q-Beam and subsequently they performed well at night. You will notice that most of the signs illustrated in the video are black and white. This is because problems appear in these signs sooner due to their vulnerability to ultraviolet rays. However, we do show that warning and guide signs can be inspected in the same way.

The concluding portion of the video shows that inspections can be made while traveling at normal highway speeds. When signs along a route are generally in good condition, an occasional bad sign will be easy to spot. Once signs have been upgraded, a supervisor or superintendent can keep a check on his area by keeping the Q-Beam in his vehicle and flashing it at signs occasionally as he drives through on routine maintenance work.

As you could see, the video camera could not pick up some of those signs at night, especially the ones with background clutter. Just to clarify for you the contrast between daytime and nighttime performance, I will show you slides of those signs.

[SHOW SLIDES]

We know there are a lot of signs on our system that have exceeded their design of life. We know that these signs present a substantial exposure to tort claims. We know that a 59-year old driver needs eight times as much light as a 20 year old to see the same sign during darkness. We know the rate of drivers "driving under the influence" is increasing. And because we know all this and more, we should know that we must identify and upgrade signs which are not acceptable at night.

Although there is no equal substitute for nighttime inspections, that I know of, this is close and it is quick and easy and with experience can produce fully satisfactory results.

I have set up a light for you so you can at your leisure look at the good and bad example signs. I will be glad to answer any questions you have concerning this process.

DISCUSSION AT WESTERN WORKSHOP

Q: Is Q-Beam a brand name or a type name?

A: This is a Brinkman Q-Beam spotlight. "Brinkman" is the brand name, and "Q-Beam" may be a part of the identification. It's a 200,000-candle-power spotlight.

Q: Are they available in any auto store, boat store?

A: Walmart, K-Mart, Service Merchandiser—those types of stores.

Q: What is the system or procedure for replacing signs?

A: They simply make a list and pass it on to the sign crew.

Q: Do you shine the light through the windshield?

A: Through the windshield, through the rain. It works great in the rain. When the crew can't do anything else, they can ride the route and check the signs.

A MOBILE SYSTEM FOR MEASURING THE RETROREFLECTANCE OF TRAFFIC SIGNS

John J. Lumia
Senior Scientist
EKTRON Applied Imaging, Inc.
23 Crosby Drive
Bedford, MA 01730

There is a serious need to devise a practical system for evaluating the nighttime visibility of existing signs and providing data for decisions on sign replacement or refurbishment. At the present time, there are laboratory methods and portable instruments available for measuring the retroreflectance of traffic signs, but easy-to-use mobile systems are not available. Research is currently under way to develop a system which can measure the average retroreflectance of sign legend and background irrespective of color, size, and placement, and which can be operated during daylight from a moving vehicle. Based on the use of a CCD video camera to acquire sign images, a xenon flash as a source of light, and a portable personal computer to analyze the retroreflected sign images, the results of experiments and analyses, indicate that such a system is feasible, well-suited for making measurements from a moving vehicle, and can be built from commercially available components. The experimental and analytical work leading to the above conclusion is presented in this paper.

INTRODUCTION

The "Mobile System for Measuring Retroreflectance of Traffic Signs" (MSMRTS) is aimed at the design of a device for measuring traffic sign retroreflectance during daylight hours, while under way. Further, average values of both legend and background retroreflectance, in units of candelas per foot-candle per square foot (commonly defined as R') are sought. The task is confounded by the fact that accurate measurements depend on the angle between the source and detector, and this is generally not fixed for realistic situations. Signs may be of differing colors, shapes, sizes, and placement. The final system should be simple and not pose a danger to the operator or other motorists.

The basic concept for the measurement of average legend and background retroreflection is the use of a video camera to record the sign, with an electronic flash source to provide a short burst of light sufficiently bright enough to overcome the sign luminance due to ambient daylight illumination. The video camera signal is then converted to a digitally sampled representation of the sign. Using the power of computer image processing, histograms of the retroreflected intensity distribution are exploited to yield average legend and background values. The use of a laser rangefinder in a moving system provides an accurate means of monitoring the distance from the vehicle to the sign.

BACKGROUND

A retroreflector is a device which turns light back toward its source, generally over a wide range of input angles. Signs are typically comprised of either retroreflective sheeting or retroreflective glass beads mounted directly on the face of the sign. The design of this system has been based largely on retroreflective sheeting. Three types of sheeting are commonly used for highway signs, consisting of enclosed glass beads, encapsulated glass beads, and cube-corner prismatic elements. Each of these materials generally have different retroreflective properties, which will be demonstrated with more detail in a later section.

This task requires the measurement of the Coefficient of Retroreflection, or R', with the desired units in candelas per footcandle per square foot. This can be expressed as:

$$R = \frac{I}{E_n A} \tag{1}$$

where E_n is the normal illumination incident on the retroreflector, A is the area of the surface to be measured, and I is the reflected intensity. By suitable manipulation of these parameters, the retroreflectance can essentially be regarded as the absolute brightness of the retroreflective target for a given amount of incident illumination on the target. Arithmetically, this can be expressed as:

$$R = \frac{L}{E_n} \tag{2}$$

where L is the luminance of the reflected light.

How are these quantities measured? The incident illumination is generally measured using an illuminance meter located at the target and facing the direction of light. A more realistic approach for a mobile system is to use the inverse-square law to infer the illumination from the source intensity, or $E = I/d^2$, where I is the intensity and d is the distance from the source to the detector (assuming that for the distances involved the source behaves as if it were a point). The intensity can be readily calibrated from laboratory measurements, while the distance can be measured using an appropriate laser ranging device. The reflected luminance may be measured with a luminance meter, which is similar to an illuminance meter except that the field of view (FOV) of the detector must be limited to a sufficiently small angle. The use of a video camera effectively divides the FOV defined by the system magnification into smaller FOV's, thereby creating individual luminance meters at each sensing element site. Video is attractive because it is a practical way of obtaining a large number of samples suitable for measuring average legend and background retroreflectances.

The video system takes advantage of the contrast which typically exists between legend and background, anticipating a "bimodal" reflected intensity distribution. That is, the contrast difference allows the use of hardware or simple software algorithms to identify and group areas of similar intensity. These groups are expected to correspond to sign legend and background. The average value of each group corresponds to the average luminance, when properly calibrated. Assuming the illumination is known, the retroreflectance is readily obtained.

RESEARCH APPROACH

The approach taken in this phase of the program was to study the critical factors involved in each of the key technology areas identified in the research proposal: the use of a video camera to acquire a large number of sign samples, an electronic flash to provide sufficient amounts of light to overcome ambient sign luminance, range measurement using a laser rangefinder to obtain distance to the sign, and image analysis to evaluate the video image for average legend and background retroreflectance. In order to accomplish this task, a number of analytical studies were conducted in conjunction with laboratory and field experiments. The results of these studies were then used to determine the required performance of each of the system components for use in the breadboard system.

Ambient Illumination Effects

Since daylight measurements are required, it is necessary to either eliminate the effect of ambient illumination, or reduce the effect to a point to which it becomes tolerable with respect to the desired accuracy of the measuring system. Retroreflective effectiveness is usually relevant over small observation angles, and published measurements typically give data out to about 2°. However, retroreflective materials exhibit a small, but appreciable coefficient of retroreflection at large observation angles (the angle subtended by the light source and the detector at the sign. For instance, the R' for enclosed-lens white materials is typically 100 to 120 at a 0.2° observation angle, but generally levels off to a value of approximately 0.3 at angles beyond 20 degrees. Ambient illumination levels can be quite high, approaching 10,000 footcandles for combined sun and clear sky, effectively offsetting the low R' value at large angles.

In order to determine the effect of ambient illumination on sign luminance, samples of white enclosed, encapsulated, and cube-corner materials were measured at various sun elevation angles. Measurements of sample luminance were taken with the plane of the material oriented vertically, but always in a direction closest to facing the sun. The experimental data indicates that at any given angle, the enclosed-lens white material has the maximum luminance, followed by cube-corner and encapsulated materials. For solar angles less than 20 degrees, the rate of change of the ambient luminance increases more rapidly. This should be expected since the sun is creating a smaller observation angle with respect to the detector. This suggests that in order to minimize illumination requirements, it may be necessary to limit the measurement window to times when the sun is above a minimum elevation. At an angle of 20 degrees, the ambient sign luminance was found to be 2500 candelas per square foot for enclosed materials, 2100 candelas per square foot for encapsulated materials, and 2300 candelas per square foot for cube-corner (white) materials.

Measurement Geometry

In a system designed for in-situ measurements, the design of the system to achieve a specific measurement geometry is straightforward. In a moving system, the geometrical relationship between source, sign, and detector is constantly changing. This is important since in general, all retroreflective devices do not behave the same as the geometry is changed. The geometries of concern are observation angle and the entrance angle.

Retroreflective materials are highly directional upon retroreflection, with cube-corner materials the most highly directional, followed by encapsulated and enclosed materials. More importantly from a measurement standpoint, the retroreflective behavior of these materials is significantly different as the observation angle (the angle subtended by the light source and detector at the sign) is varied. Assuming a fixed source-detector separation, the observation angle increases with decreasing distance to the sign. Realistically, the material of the sign being measured will most likely not be known, so that unless the angle is kept constant, or nearly so, for all situations, it will be nearly impossible to relate the measured value to a commonly measured observation angle (such as 0.2°). Hence, in order to maintain sufficient accuracy, there is a "distance window" in which the measurements need to be taken, assuming a fixed source-detector separation.

The effect of entrance angle (the angle between the axis of the light source and the normal to the sign) is far less severe. Generally, the reflected intensity falls by a worst case approximation of 1 percent per degree out to about 20 degrees for cube-corner materials. In moving situations, it would be very difficult to measure this angle. It has been suggested that the video image be exploited to examine the perspective distortion of the sign image to obtain an estimate of the entrance angle, but this function would most likely require operator intervention and seriously limit data collection. However, it can be expected that the entrance angle of most signs at appreciable distances will be small, minimizing this effect. As this angle will be the same for a measurement as for the driver, it will not be considered in the measurement system.

Rangefinder Accuracy

The use of a laser rangefinder is proposed to obtain sign distance information. The particular system under consideration uses a time-of-flight (TOF) method in which short pulses of laser light supplied by a laser diode are sent out to the target. By measuring the time to receive the returned pulse, and knowing the speed of light, the total round-trip distance can be calculated. This value is divided by two to obtain the actual distance to the target. One commercially available device has a sampling rate of 2000 samples per second. In order to obtain accuracy, the unit can average a number of samples to obtain the distance reading. The number of samples per reading is called the repetition rate. The data rate of the interface used to transfer the distance information limits the effective data transfer to approximately 133 readings per second, or 15 samples per reading, with a net estimated accuracy of + 0.27 feet (+ 82 mm) under stationary conditions.

With the system under moving conditions, the distance at which a reading is obtained represents an average value of the measured distance samples taken during the reading interval. This results in a systematic error of approximately half the distance traveled during this time. At a constant speed of 55 mi/h (81 feet per second), and at 133 readings per second, the resulting distance resolution is 0.60 ft (183 mm) per reading, with a systematic error of 0.30 ft (91.5 mm). Coupled with the stationary sampling accuracy of the unit, the net distance accuracy would be 0.30 ft $\pm$0.27 ft. This results in a worst case error of 0.3 percent at a 200 ft (61 meters) range and 0.6 percent at a 100 ft (30.5 meters) range. This should have a minimal effect on the resulting calculation of sign illumination from light source intensity.

Intensity Requirements

For a uniform retroreflective target possessing a given luminance due to ambient illumination, the light source must provide an adequate amount of additional exposure above the ambient signal so that the retroreflection due to the illumination system may be appropriately detected and isolated. This additional exposure factor can be denoted by a constant K. The value of K selected determines the capability of the system to reject the sign luminance due to ambient illumination. For example, a value of 20 implies a 20:1 ratio of artificial to ambient signal, and hence the measured data will have a 5 percent maximum error due to the presence of an ambient signal. The value of K could be as high as the signal-to-noise ratio of the camera, typically 200:1 for CCD cameras, but the additional demands required of the illumination system may not be realistic.

For electronic flash sources, the intensity is not constant over the duration of the flash. For this reason, it is customary to specify flash intensity in terms of an integrated value, denoted by (It_f). It can be shown that this required "intensity exposure," to produce the necessary detection may be expressed as:

$$It_f = \frac{K\, L_{amb}\, t_{cam}\, d^2}{R'} \qquad (\text{for } t_f<t_{cam}) \qquad (3)$$

where L_{amb} = maximum ambient sign luminance for a given material
t_{cam} = camera exposure time
t_f = flash lamp duration
d = distance to sign
R' = coefficient of retroreflection for a given material.

The units for (It_f) are in candela-seconds. It was found that in order to operate effectively with all materials, (It_f) should be based on the retroreflective material (generally enclosed, encapsulated, or cube-corner sheeting) which produces the worst case, or largest value of (It_f). From equation 3, it can be seen that (It_f) is greatest when L_{amb} is large and R' is small. This was found to occur with the enclosed-lens material. L_{amb} was chosen to be 2500 candelas per square foot, based on the white enclosed-lens material (discussed earlier in "Ambient Illumination Effects"). Furthermore, to obtain accuracy over a reasonable range of retroreflection, the value of R' was chosen to be the minimum recommended value corresponding to the enclosed white material, or 70 candelas per footcandle per square foot. Assuming a K value of 20 and a camera exposure time of 1 millisecond, the required value of flash exposure is 28,500 candela-seconds, as long as the flash duration is less than the camera exposure time. From equation 3, flash exposure is directly proportional to K, indicating that system accuracy will be sacrificed if the required quantity of light is not available.

Electronic Flash

The advantage of the electronic flash is that large quantities of light are produced over short periods of time. For maximum efficiency, the flash duration should be less than or equal to the exposure time of the camera.

As equation 3 indicates, exposure requirements are minimized when t_{cam} is reduced. However, the flash exposure t_{flash} must be reduced as well. It would, therefore, seem desirable to reduce t_{cam} as much as possible. But, in general, there is an optimum flash duration in which light output efficiency is maximized for a given flashtube design. Also, the necessity for an appreciable quantity of light for this application will generally require relatively long flash durations (estimated to be from 0.1 to 1 millisecond), but in moving situations, the duration needs to be short enough to "freeze" the effects of image motion due to vibration. Actual exposure time requirements to compensate for vibration are not yet known. This may depend on the characteristics of the vehicle in which the camera is mounted. If the 1 millisecond time described above is not adequate to freeze the motion, the electronic flash may be optimized to operate at shorter durations. Note that the distance covered during the 1 millisecond flash duration is calculated to be 1 inch (25 mm) at 55 mi/h (88.5 km/h), and is expected to have little effect on the image.

One major manufacturer of electronic flash systems offers a commercially available unit used as an obstruction warning light on tall towers and smokestacks. The system has a duration of approximately 1 millisecond in the high intensity mode, and produces 40,000 candela-seconds, nearly 40 percent greater than the 28,500 value described above. The spectral quality of electronic flash units are generally categorized in the daylight region of the spectrum, with typical color temperatures ranging from 5000°K to 7500°K, depending primarily on fill gas, pressure, and energy loading. The output is nominally continuous with few spikes which may adversely affect color measurement accuracy. The unit uses a long linear flashtube in a trough-type reflector having a parabolic cross-section, yielding a long, but narrow beam profile. In the more critical vertical direction, the total beam spread, defined at the 90 percent points, was measured to be approximately 2°.

COMPONENT SELECTION

Based on the operational requirements presented above, a preliminary selection of components has been made. These are categorized as follows: digital frame capture, directed strobe, range measurement, and digital conversion/image analysis. Integration of these components is also discussed.

Digital Frame Capture

In order to satisfy the exposure requirements of this system, the use of a shuttered camera is suggested. An electronically-shuttered camera having a 1/1000 second duration is commercially available. The camera uses a CCD area array measuring 8.8 x 6.6 millimeters (an aspect ratio of 1.33:1) with 491(H) x 384(V) pixels, a signal-to-noise ratio of 46 db (200:1), with a sensitivity of 40 footcandles incident on a diffuse white target using a lens aperture of f/4.0 and a source color temperature of 3200°K (with infrared cutoff filter). The camera has an automatic gain control (AGC) that can be disabled, which is desirable for this application. Additionally, the camera is RS-170 compatible, outputting two interlaced video fields (termed odd and even) in 1/60 second, for a total frame time of 1/30 second. The camera measures 5.5 x 2.5 x 3 inches (140 x 64 x 76 mm).

In order to facilitate synchronization of the camera to the flash unit, the camera has an output which indicates the vertical blanking signal. Also, the camera has an output port available for a video CRT viewfinder for viewing the scene. A color conversion filter to correct the spectral distribution of the flash to 2856°K, and a filter to correct the camera response to a photopic behavior, are attached to the front of the lens.

Directed Strobe

As discussed previously, a commercially available strobe unit is proposed. The reflector, lamp, and trigger transformer will be isolated from the power supply and fitted into a separate enclosure. The input to the supply is 120 VAC and draws 500 watts. Flash-to-flash variability is estimated to be within 5 percent. Production designs could include a flash monitor to mitigate this effect, if warranted.

Range Measurement

The proposed laser rangefinder is reported to be eye-safe and meets FDA approval. The device measures approximately 8 x 5 x 4 inches (203 x 127 x 102 mm) and weighs approximately two pounds. Also included is an RS-232 port to trigger the device and transmit range data.

Digital Conversion/Image Analysis

A personal computer is the essential link between the video camera, strobe, and rangefinder units. This system has a standard RS-232 port which will be used to communicate to the rangefinder, a parallel port for a printer, and two floppy disk drives. A frame-grabber card samples the analog signal from the camera, converts the signal to digital values, and stores the data in memory on the board. This creates a digitized image of the desired video frame. Additionally, an output port is available to facilitate storage of the image on a video tape recorder.

It should be noted that vertical blanking pulses are constantly sent by the camera so that a strobe triggered directly from this signal would flash constantly. A means of generating the strobe trigger for the desired frame only is required. To accomplish this, a custom-built strobe-video synchronizer circuit has been built to monitor the status of the vertical blanking signal on the frame grabber (which is synchronous with the camera) immediately after the operator depresses a switch, and then fires the flash. A trigger signal for the strobe is issued at the parallel port on the computer. A computer keyboard switch was used for the experimental work during this phase. Ultimately, the rangefinder will be used to initiate data acquisition.

SYSTEM CONFIGURATION

The prototype MSMRTS components are integrated as shown in figure 11. This block diagram shows the location of the major system components, consisting of the camera, electronic flash, rangefinder, and personal computer. The flash module consisting of lamp and reflector are mounted below the camera, and may be positioned at the proper height with respect to the camera to obtain the proper observation angle for a given distance. For a 0.2° observation angle at 200 ft (61-meters), the required separation from the camera centerline to the center of the reflector is 8.4 in (213 mm). A bracket secures both the camera and flash head as a unit. The power supply for the flash unit is remotely located. Figure 12 shows a conceptual drawing of the optical head mounted in a vehicle.

SYSTEM ACCURACY

The results of this investigation generally indicate worst-case errors which can be expected for the variables identified. These are summarized as follows:

Measurement Geometry	
observation angle	1-2%
entrance angle	up to 10%
Camera Resolution	5%
Ambient Signal	5%
Electronic Flash	
output variability	$\pm$2.5%
illumination uniformity	U%

It should be noted that because these are worst case errors, the average error will generally be much less than their sum. A better, more realistic assessment of measurement errors will be available using the breadboard system to measure a large number of signs and comparing the data to measurements made using traditional methods.

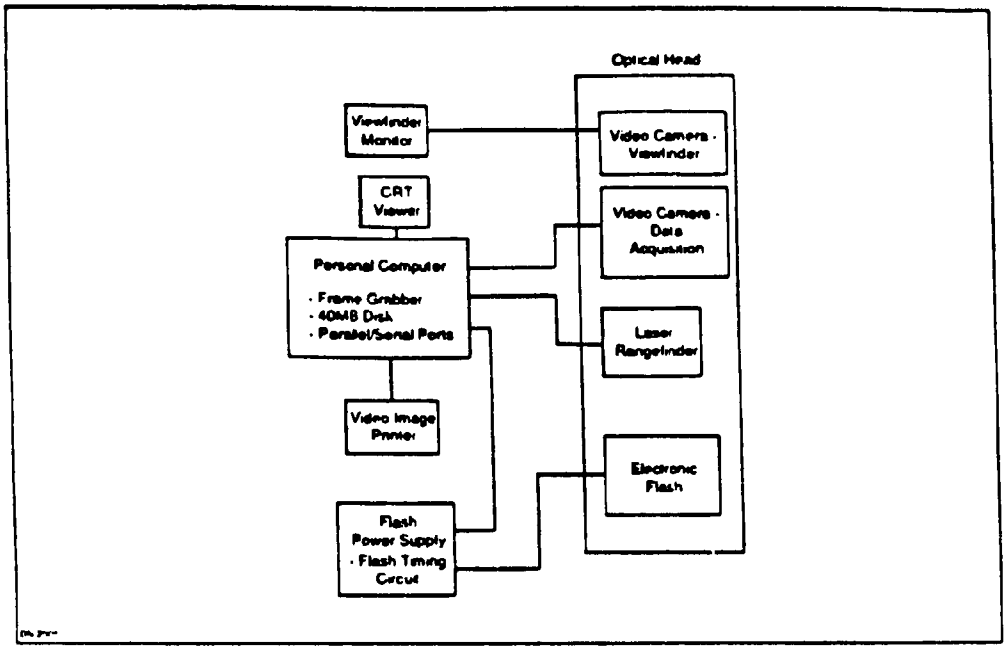

Figure 11. Diagram of proposed MSMRTS prototype.

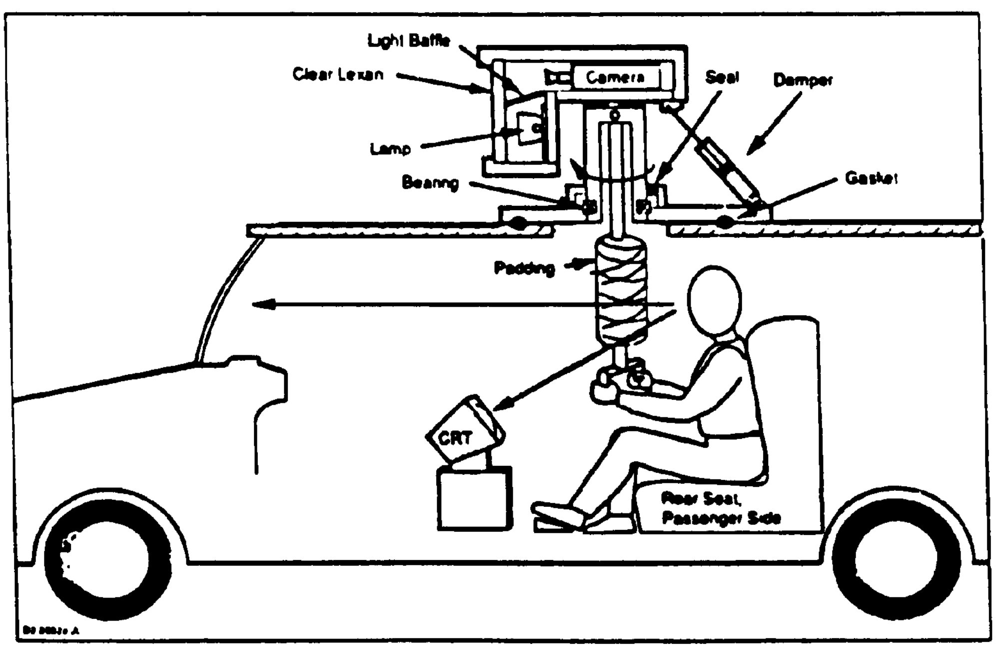

Figure 12. Conceptual design of MSMRTS prototype.

CONCLUSIONS

The research and analysis presented in this report indicate that an accurate mobile system for measuring the average retroreflectance of traffic signs during daylight hours is feasible. The conceptual design of the system is well suited for making measurements from a moving vehicle. The suggested components for this application are commercially available, minimizing the need for an extensive engineering effort.

The highest value of sign luminance due to ambient daylight conditions occurs with enclosed-lens sheeting. Under direct sunlight, the sign luminance is lowest when the sun elevation is highest, and increases as the sun approaches the axis of the camera. If measurements are made when the sun is above an elevation angle of 20°, a realistic balance between required artificial source illumination and operational limitations can be achieved.

Under moving conditions, the angular geometry between source, sign, and detector is constantly changing. The behavior of sign retroreflectance is highly sensitive to the angle between source and detector (observation angle), and this behavior is markedly different among the types of materials currently available. If accurate measurements are to be made with respect to a given angular geometry, a fixed measurement distance is required.

Entrance angle (the angle between illumination axis and the normal to the sign) has a minimal effect on measurement accuracy if this angle is small. This is expected to be the case if a sufficiently long measurement distance is used. Therefore, entrance angle will not be measured.

Accurate distance measurements are required to determine the observation angle and infer the illumination at the sign with as little error as possible. Investigation into the use of a laser rangefinder indicate that a maximum distance measurement error of 0.3 percent at 200 ft (61 meters) and 0.6 percent at 100 ft (30.5 meters) is possible at a speed of 55 mi/h (88.5 km/h).

The intensity requirements of the electronic flash system are based on the amount of exposure needed to adequately exceed ambient sign luminance. For a maximum error of 5 percent due to ambient sign luminance, a flash intensity of 28,500 candela-seconds is required for a camera exposure time of 1 millisecond. This maximum error is calculated for enclosed-lens materials which have deteriorated to minimum recommended values of retroreflectance. A commercially-made electronic flash unit is available which produces 40,000 candela-seconds for a duration of 1 millisecond, and has a life expectancy of 100 million flashes.

A system of components for creating a mobile prototype system is outlined. The components selected for the system are commercially available, thereby minimizing engineering costs. The prototype consists of a compact camera, flash head unit, and rangefinder connected to a personal computer. The flash power supply will be remotely located. Additionally, a CRT viewfinder will be used to monitor and aim the system.

ACKNOWLEDGEMENTS

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DISCUSSION AT EASTERN WORKSHOP

Q: As you approach a sign, how many readings of the sign do you take?

A: There's only one reading as we approach the sign. The operator with the laser rangefinder will have to keep his system pointed at the sign so that the rangefinder can continue its distance measuring process. Once the sign distance is reached, the system only takes one picture of it.

Q: How do you then account for less than perfect sign installation where you may have tilted away or toward the roadway?

A: We didn't recognize that as one of the influencing factors on the quantity of retroreflection. It is not as strong a function of angle as is the observation angle part of it. But we did recognize that if a sign was mounted at an improper angle, that perhaps it was a desirable effect, and the retroreflectivity would be diminished. But perhaps it was a desirable effect because that's how a motorist would be perceiving that sign. We are in fact incorporating the diminished retroreflectivity into that and that should be a key if it in fact does go below some requirement. Someone could then go out there and say that the sign is not mounted properly.

Q: If you were reading two consecutive signs, one mounted at one angle and the other mounted at another angle, and they were mounted the same day, you could get two different readings. Would that indicate that one sign needed to be replaced and the other one didn't?

A: The output of the system would say that the sign needs to be replaced but it shouldn't be construed that way. It could mean that it needs to be replaced or it could mean that it needs to be repositioned. The fact that the system does respond at a lower reading may be because it was mounted improperly. It's a real-world situation. We don't take that out. It is rather complicated to take out, but then we thought that it would be a valuable feature.

Q: What happens to the system if one sign is bad and one sign is good?

A: The field of view right now is for the highway mode—4.5 by 3—which for most instances should be able to acquire for just one sign. Of course, signs mounted off the side of the road are typically smaller. The field of view then would be perfectly adequate for that. But it's a rather small field of view and the chances of getting two signs in it may be somewhat diminished. The system would eventually pick that up, and it might get confused. But these are some of the things that we have to work out.

DISCUSSION AT WESTERN WORKSHOP

Q: What is your guess at the cost?

A: It is difficult to say at this time because we are working with a prototype. The system components have not been fully finalized. There are some things that we may be able to change in order to lower costs. By the time we go into production, the cost of the components may come down, so it would be difficult to say in 1990 exactly what the system is.

Q: Would the cost be more than $100,000?

A: We initially tried to keep the system at about $25,000. Currently, as the components exist today, the cost is about $50,000. The driving factor is the rangefinder, and there are a number of companies that make rangefinders now. When we first looked at this, there was only one company in the rangefinder business, at least low-cost rangefinders that were suitable for mobile use. Now a few more companies are entering into business, so costs are beginning to come down somewhat.

Comment From Lumia in Response to Query About the Difficulty of Completing Image Processing on Highways (Due to Traffic):

The image processing is done at the shop. The only thing that happens in the van itself is to acquire the image. It takes roughly 2 seconds to store an image. Once the system is stored, that leaves only the setup (i.e., entering information about the sign). We are estimating that, probably at a minimum, you will be ready to take a sign every 3-5 seconds. Once the system is storing the information in the computer, you can probably do some setup. However, the range finder and the system have to re-initialize. But that 15 seconds mentioned in regard to image processing only applies to the time it takes for each image, and that is done off-site.

Q: How does your machine handle multiple sign assemblies? Does it capture the whole assembly, or one sign within the assembly at a time?

A: Basically, it gets whatever is in the field of view. We really have not done a lot of work with complex signs, so at this point I cannot really answer that type of question.

Q: That was my precise question. With your field of view of 3 x 4½ ft, if you have a route marker assembly that has, perhaps, six signs on it, can you focus on just one sign, if not in the field, then later in preprocessing?

A: That's a good question. We have not really looked at signs that are down at that small level. It probably will pick up at least a few of them, and, again, it depends on what you're trying to . . .

Q: I don't want an average. I want to know which sign is bad and which sign is good.

A: We have not really looked at many where the signs are that small and had to be separated.

Q: How is your angle? . . . Will the retroreflectivity of signs change with your angle?

A: Yes, it does. The retroreflectivity really does vary very slowly as a function of that angle as opposed to the observation angle, the angle between the source and the detector. We don't attempt to correct for that. The techniques to do that are very time consuming, and I am not sure of their accuracy. However, another thing that has been pointed out was that if the sign is mounted improperly (at the wrong angle), then the retroreflectivity will be reduced. Although it is quite useful to get the retroreflectivity of such a sign, it is also a very true representation of what is happening with respect to where the vehicle is and where the sign is. So, in that case, the system could be pointing out the effectiveness of retroreflectivity with respect to that driver as well, and may point out the need for some sort of sign replacement. It does not give the true picture of that sign and correct for that angle; however, it does correct for the geometry—whatever the geometry setup is at that time—and can be useful in that sense, I think.

PAVEMENT MARKING MATERIALS AND SERVICE LIFE

Charles E. Antle[1]
Professor of Statistics
The Pennsylvania Transportation Institute
Pennsylvania State University
University Park, PA 16802

INTRODUCTION

Some of the results from an NCHRP Project 4-16 conducted by John Jewett Henry, Charles E. Antle and Joseph Carroll are presented in this paper. The following questions are considered:

- How do the retroreflectometer readings of pavement markings made with one type (e.g. Mirolux) of instrument compare with those of another type (e.g. Erichsen)?

- How do ratings of lines in service by a panel of drivers relate to the retroreflectometer readings of the lines? Are all of the instruments equal in this respect? Can a level for a given instrument be chosen so that lines with readings above this level can be regarded as providing satisfactory performance?

- When lines are placed in test decks on the highways will the wheel track portion be useful in predicting the lifetime of such a line used for center line markings? Will the wheel track and left end of such a line in the test deck when measured at the end of 12 months provide useful information for predicting the performance at the end of 24 months? Is it better to predict future performance at a given time than to predict the failure time?

- What are some useful comparisons of lifetimes of the durable materials (e.g. thermoplastics) and the non-durable materials (e.g. alkyds)?

The retroreflectometers considered in this study were a Michigan type instrument, an Erichsen, an Ecolux, and a Mirolux. The test decks were in Pennsylvania, Florida, and Arizona. The materials included alkyds, chlorinated rubber, cold plastic, epoxy, foil tape, methyl methacrylate, solvent borne epoxy, thermoplastic, urethane, and waterbase marking materials.

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[1]Additional authors include John Henry and Joseph Carroll.

COMPARISONS OF RETROREFLECTOMETERS

At the beginning of this study in 1985 the retroreflectometers available on the market were the Erichsen and the Ecolux. Both of these were low angle, rather large, but certainly portable instruments. Their cost was about $10,000 each. It was also possible to build a small high angle instrument known as a Michigan type retroreflectometer for a cost of about $2,000. During the time of the study a very good low angle retroreflectometer known as a Mirolux became available. These four instruments were used in these studies. The Mirolux and the Erichsen have the desirable feature that they are calibrated to read directly in mcd/meter**2lux. The general agreement of the different instruments in reading lines can be measured by the correlations for their readings when reading a large set of lines with all of the instruments. These simple correlation coefficients are not affected by the choice of calibration, and are a measure of how well the measurements by one instrument will be related to the measurements by another instrument by some straight line. A correlation of 1 would indicate a perfect straight line relationship exists between the two sets of measurements. A correlation of .95 or more would indicate very good agreement.

An experiment was conducted at Pennsylvania State University in 1986 to evaluate the correlation between readings by the four types of instruments available for the study. In addition Mr. Erichsen brought one of his instruments and participated in the study so there were two Erichsen instruments. About 50 locations along the roads in PA were selected and at each location the road markings were measured at 5 skip lines. These were then averaged to provide a measure of the performance of these lines. These locations were chosen so as to provide a wide range of performance. The correlations of these averages among the instruments were as given below:

	MIRO	ECOL	ERIC1	ERIC2
MICHIGAN	.87	.95	.92	.94
MIROLUX		.95	.96	.94
ECOLUX			.97	.96
ERICHSEN 1				.97

It is clear that the instruments are in rather good agreement, with the Michigan type instrument showing somewhat less agreement with the others. This was to be expected. The very good agreement among the Mirolux, Ecolux and the two Erichsens indicates clearly that these instruments are about equally useful.

PANEL RATINGS AND RETROREFLECTOMETERS

In order for the readings by the retroreflectometers to be useful it is necessary to relate them to the performance of the lines as rated by ordinary users of the highways. For this purpose a panel test was conducted at Pennsylvania State University in 1986. The set of about 50 selected locations near Penn State were measured by the 5 instruments available to us. Then a panel of 16 people selected so as to have 8 men, 8 women and ages from 18 to 75 were driven over the same set of lines and asked to rate them from 0 to 10 with a 10 being a line that could not be improved and a 0 for one that is useless. A value of 5 would indicate that the line is just satisfactory and anything less than 5 would be a line that would not be satisfactory. The purpose in so designating the value of 5 would be to allow us to choose an instrument measurement that we could regard as the failure level. This is illustrated in figure 13 where the panel average of 5 is used to identify the failure level for the instrument measurements. The actual results for a panel experiment are given in figure 14 where it will be observed that when the Erichsen measurement is above 100 the panel rating will generally be above 5.

A total of five panel experiments were conducted during this study and another study sponsored by the FHWA. It was generally true that the panels gave a rating of at least 5 whenever the readings by the Erichsen or the Mirolux were above 100. Furthermore, the agreement of the panel ratings with the measurements by the instruments was generally quite good, with the exception of the Michigan type instrument. This good agreement by the Erichsen, the Mirolux and the Ecolux with the panel ratings allows one to state with assurance that the real night time performance of the lines in service can be evaluated by these instruments in the daytime. In addition the value of 100 as read by either the Erichsen or the Mirolux is recommended as a failure level. This is not to say that lines should not be improved until they have reached such a failure level. Indeed it is important that they never be allowed to reach this level. Some value well above this should be the level at which the lines would receive attention.

EXPERIMENTAL TEST LINE DECKS

It is often the practice of a State Agency to have a test deck of "bid" lines which will be evaluated in order to approve of future suppliers. These lines may be read in both the wheel track and the center line portion. The wheel track portion serves as an accelerated test and will provide useful information before the center line portion has provided much information. It is not clear as to just how these readings of the wheel track portion should be used to predict the performance of the lines in service. It does seem clear that they may do this for the setting in which they are being observed. It can be seen in figure 15 that the information about the wheel track readings after only 370 days would provide a good means for predicting the center line readings at 793 days for these materials that are in a test deck on the PCC in Arizona. In the case of these durables it will be a very long time before most of them have reached a failure level in the center line portion of the lines, but it does appear that the wheel track portion will provide useful information.

It may be reasonable to ask if durables should be placed in test decks. Unless it is possible to combine the early readings on the wheel track and center line portion in some useful way it would appear that by the time the lines have reached their failure level there would be little interest in those particular lines. A company could not wait 5 years to see if its product is to be added to an approved list of materials. However, as a class of materials it is important to know how they would perform relative to other classes. It was in this sense that the experimental test line projects in Arizona, Florida, and Pennsylvania were established in 1985 and 1986. It should be noted that very few of the durables in Arizona and Florida have reached the failure level in their center line portion, and it would be most useful to have someone follow up on the evaluation of these lines. These lines might now begin to provide

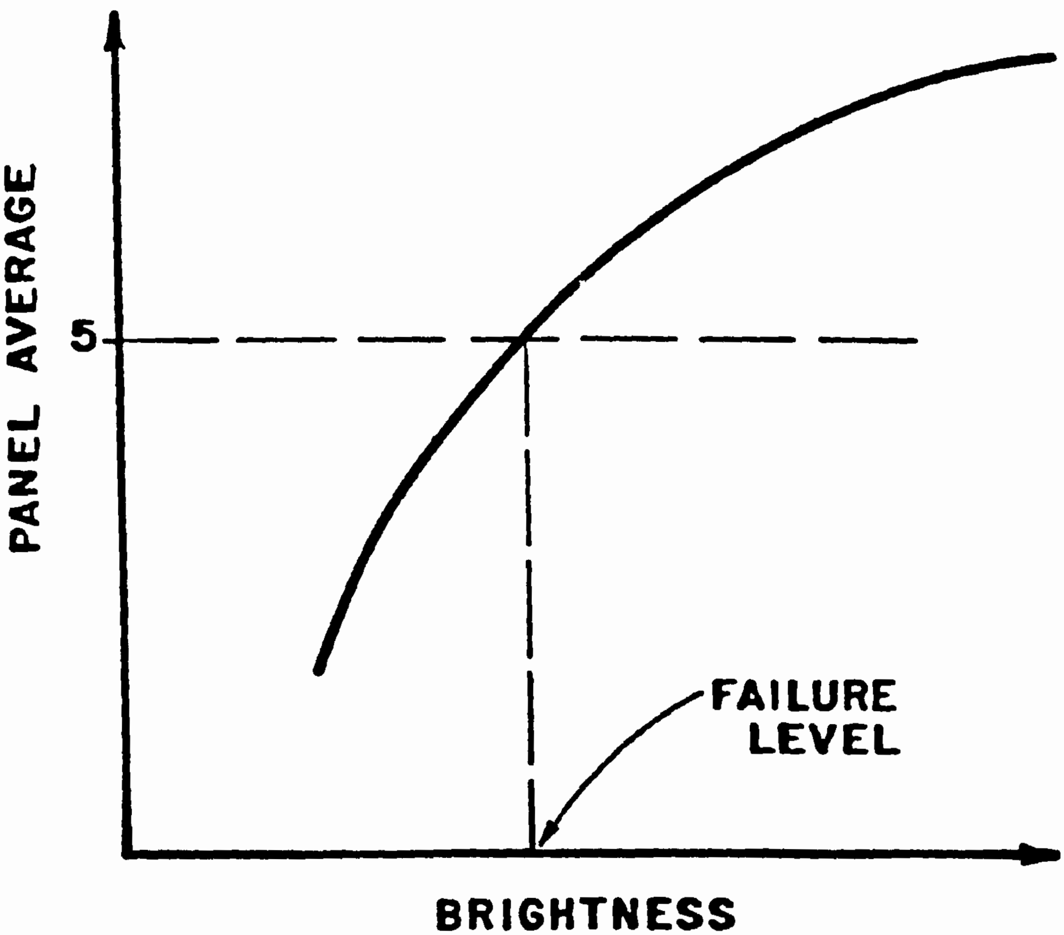

Figure 13. Hypothetical relationship between panel average ratings and measured retroreflectivity for lines in service.

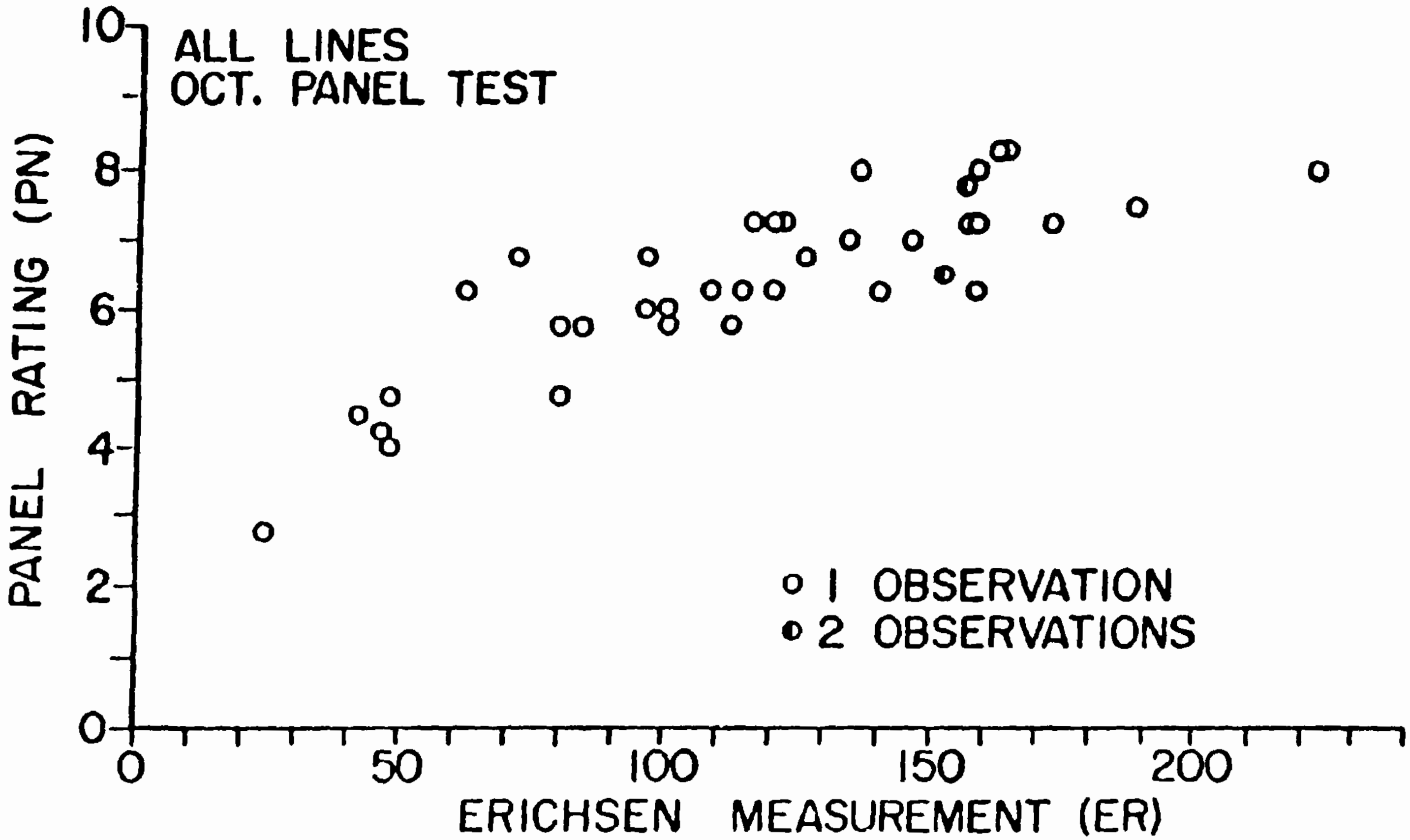

Figure 14. Panel ratings vs. Erichsen measurements for all lines for October Panel Test.

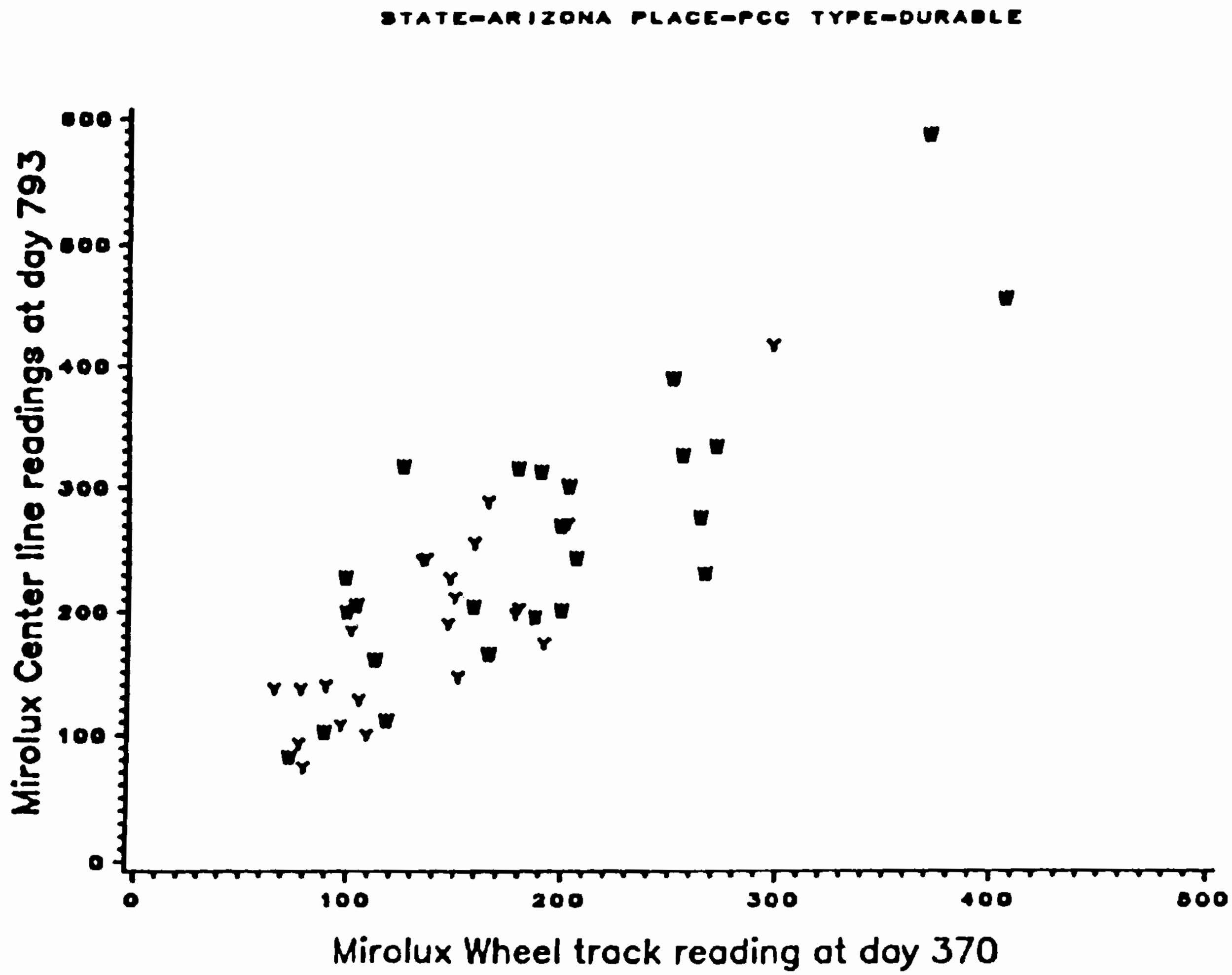

Figure 15. Long-term center line vs. short-term wheel track.

useful comparisons among the different materials. After reading them on a regular basis through June 1988 about all that could be said was that it looks like they could provide good performance for a very long time.

DISCUSSION AT EASTERN WORKSHOP

Q: Was the testing strictly reading retroreflectivity?

A: I think in all cases in Florida and in Arizona, the materials were there but they had lost retroreflectivity. I didn't show Pennsylvania because the durables there don't get a fair shake. The snow plow can remove them from the road, especially in the test decks that we had put down in Pennsylvania.

DISCUSSION AT WESTERN WORKSHOP

Q: How many pavement types?

A: There was an open-grade asphalt, and there was a dense-grade asphalt. It did make a good deal of difference which one they were on. The open grade presented problems with some of the materials.

Q: You have a rating of 100 for white lines, I believe. What did you have for yellow?

A: Actually, that was meant to be for both white and yellow. That's another good point. We did not have enough white lines in any of our studies to sort out the difference between white and yellow. So in the end we just pooled all the lines. Our panel said that if you were below 100 on the Mirolux or the Erichsen, or the Ecolux when adjusted (the Ecolux has to be adjusted), that would not be acceptable to our group of Pennsylvania drivers.

Q: Do you have a published report?

A: We have written a report, and it is in the hands of the committee reviewing it. Maybe that includes some of you folks. We hope to get it through the final review very shortly, and we would be happy for you to request it.

IN-SERVICE EVALUATION OF THERMOPLASTIC AND TAPE PAVEMENT MARKINGS USING A PORTABLE RETROREFLECTOMETER

Robert W. Attaway
Assistant Director
Institute for Transportation Research and Education
PO Box 17489
Raleigh, NC 27619

PORTABLE RETROREFLECTOMETERS

Pavement markings are one of the most important traffic control devices available to the traveling public. These devices serve to regulate, warn, and guide the motorist in the use of highways and streets during the day and night. During darkness and adverse weather conditions the driver's performance depends to a great extent on the reflectivity of the marking and its contrast with the pavement surface.[1]

Reflectivity is the single most important quality of a pavement marking. The fact that "the nighttime fatality rate in the United States is more than three times the daytime rate" indicates the need to provide visual guidance to the road user at night.[2] During the daytime there are many sources of delineation other than pavement markings to aid the driver in the operation of his vehicle. Some of these sources of delineation include the pavement shoulder, roadside foliage, longitudinal joints, the distant view of the road ahead, roadside development, etc. During the day drivers appear to rely on features in the distance for delineation and guidance rather than the road surface delineation.[1]

This is not to say that the daytime appearance of pavement markings is not important because clearly where markings are used as regulatory or warning devices such as centerlines and railroad symbols, they must be intact and visible to be effective. In the vast majority of instances, however, if the reflectivity of a pavement marking is acceptable then its daytime appearance is also.

How Pavement Markings Reflect Light

Pavement markings are reflective because small glass spheres called "beads" are added to the marking material. These glass beads act as tiny reflectors which collect light from a vehicle's headlights and reflect a portion of it back to the driver's eyes. Figure 16 illustrates this procedure showing the vision geometry for a typical driver in a vehicle.[3]

This is a simplification of a complex system. The reflectivity of pavement markings is a function of a number of parameters including the manufacturing and application of the marking material and beads and the physical conditions of the road, driver, and vehicle.[4]

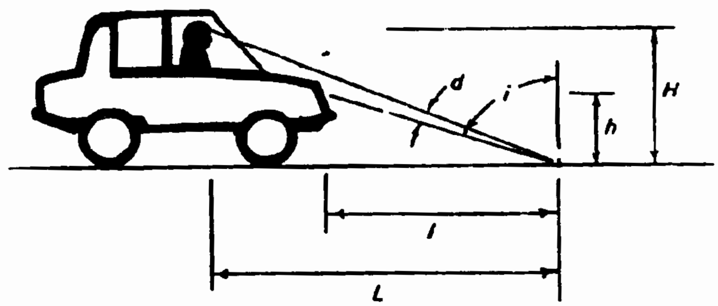

Figure 16. Driver's vision in a vehicle.[3]

L: distance between driver's eyes and observation point
l: distance between headlights and observation point
H: height of driver's eyes
h: height of headlights
e: entrance angle
o: observation angle

Retroreflectometers: Coarse vs. Fine Geometry Machines

In the United States the night visibility of pavement markings has historically been evaluated using human observers under nighttime conditions. While this may be the "ideal" method for determining the true visual performance of pavement markings it has many drawbacks including the subjective nature of evaluators and the need to conduct evaluations after normal working hours.[4]

To overcome these drawbacks retroreflectometers have been developed which provide objective measurements of retroreflectivity of pavement markings and can be used during the daytime. A retroreflectometer is an instrument which attempts to simulate on a reduced scale the night visibility conditions experienced by a driver. The device generally consists of a box which eliminates ambient light, a light source projected on a known area, a light sensor to measure retroreflected light, and provision for calibrating the instrument on a strong retroreflector.

There are basically two types of retroreflectometers in use today, "coarse" geometry and "fine" geometry machines. Coarse geometry instruments, are instruments which do not closely simulate the conditions experienced by the driver while fine geometry more closely simulate those conditions. Some coarse geometry machines would include the Michigan and Virginia Department of Transportation machines. Fine geometry machines would include the Ecolux, Erichsen, Optronik, and Mirolux.[6]

Retroreflectometers Used in this Research

This research used three different retroreflectometers for gathering reflectivity data: Ecolux, Mirolux (Experimental), and Mirolux 12. These three machines are all fine geometry machines, each having an entrance angle of 86.5 degrees and observation angles of 1, 1.5, and 1.5 degrees, respectively.

The Ecolux was used sparingly for in-service evaluations because of its weight and bulkiness. The Ecolux is approximately 33 in long and 10 in wide and weighs 20 lb; in addition it has a 21 lb battery pack and cable which requires an additional person to move it along and keep the cable out of the way during readings. The Ecolux has an analogue scale which is not difficult to read but does require judgment and slows down the data gathering process. The Ecolux reflectivity readings were converted in to millicandelas per square meter per lux ([mcd m^{-2}] x lx^{-1}) using a conversion equation specific to each machine.

In contrast, the Mirolux machines are much lighter and easier to use. This resulted in more flexibility and productivity in data gathering. The units are hand held and approximately 18 in long and 6 in wide with an internal rechargeable 12 v battery pack and a total weight of 14 lb. The read-out is digital and there is a digital battery voltage check. The readings from these two instruments were not the same and required correlation tests be run between each other and the Ecolux retroreflectometer to determine their values. (All the values reported in this report will be in ([mcd m^{-2}] x lx^{-1}) as measured with an Ecolux retroreflectometer.) The two Mirolux machines were used to gather most of the in-service readings on pavement marking tapes and thermoplastics. In fact, without the Mirolux the number of in-service readings taken on these projects would not have been possible.

Establishing "Minimum" Reflectivity Values

Determining the reflectivity of pavement markings has traditionally been a difficult task for traffic engineers in the United States because of the lack of recognized standards and equipment form making high speed field evaluations. In fact, there are no uniformly recognized standards for reflectivity of pavement markings in the United States to this authors knowledge.

Standards are in use in other countries however, most notably France and Germany. These countries have both established reflectivity standards for pavement marking materials. Each country has standards based on reflectivity readings taken with hand held fine geometry retroreflectometer manufactured in that country. The French has established an acceptable reflectivity value of 150 ([mcd m^{-2}] x lx^{-1}) as measured with an Ecolux retroreflectometer and the Germans use a range of values from 150 to 70 SL based on traffic conditions and measured with a german made retroreflectometer.[5, 6]

While the United States does not currently have any "minimum" standards for reflectivity of pavement markings some work has been performed and other work is underway looking at this issue. One of the first such studies was an FHWA project by Allen, O'Hanlon, McRuer and others, "Driver's Visibility Requirements for Roadway Delineation" in 1977. Other research include work done by Ethen and Woltman as presented in the paper

"Minimum Visibility of Pavement Markings". An NCHRP project 4-16 "Cost and service life of Pavement Markings" is also investigating minimum reflectivity values for markings.

This paper is not intended to establish what are the minimum acceptable standards for pavement markings in the United States that task will take much research and discussion to arrive at a consensus among the parties involved. However if objective reflectivity readings are being taken then some value must be used to compare these readings against.

For this research the reports discussed above were consulted for information on acceptable levels of reflectivity for pavement markings and a limited panel evaluation was conducted by ITRE. The panel evaluation was not conclusive. The scope of this evaluation was limited due to lack of funds and only five observers were used evaluating 13 different markings with different amounts of wear. Even though the panel evaluation was not conclusive it did aid in the review of previous work in this area and the decision was made to use a value of 100 ([mcd m^{-2}] x $l.^{-1}$) as measured with an Ecolux reflectometer as a minimum acceptable value for reflectivity. Therefore all the readings presented in this paper will be Ecolux values.

Again it should be noted that the "minimum" value used here is not intended to be a standard. Other agencies may choose to use lower values for markings or some may want a higher level of service and require higher acceptable values that is a choice for the individual agency until a national standard is adopted.

THERMOPLASTIC LONG LINE IN-SERVICE EVALUATIONS

Thermoplastic has been used for pavement marking by the North Carolina Department of Transportation (NCDOT) since the mid 1970s. Numerous evaluations have been conducted by NCDOT on the performance of thermoplastics over this period but most have been informal or specific to a particular roadway project. The consensus among NCDOT field traffic engineers has been that thermoplastic is a durable pavement marking material which performs well for several years when installed on asphalt pavements.

The specific number of years of acceptable service varied from engineer to engineer but generally ranged from 4 to 6 years of service. This performance was based primarily on periodic day and night visual evaluations by field Traffic Engineers. While these evaluations provide useful information on the overall trend in the performance of thermoplastic the fact that there were no standard evaluation procedures being used, the difficulty in measuring reflectivity (nighttime brightness), and the large number of engineers involved in these evaluations (North Carolina has 14 highway division offices with 14 field Traffic Engineers) all with different perceptions and opinions on the performance needs of pavement markings.

In 1985 the NCDOT Traffic Engineering Branch began a Highway Planning and Research Project (NC-HPR-23241-86-4) *Plastic Pavement Marking Materials* to determine how well thermoplastic and preformed tape marking materials were performing in North Carolina. The thermoplastic portion of the project focused on the performance of long line thermoplastic pavement markings. Long line markings include edgelines, lanelines, centerlines, and barrier lines. A variety of projects representing each of North Carolina's geographic regions (mountains, piedmont, and coastal plain) and roadway types were evaluated. The roadway types evaluated included two lane roadways, multi-lane undivided roadways, and divided (interstate type) roadways. The ADTs varied from 5,000 to 20,000.

The purpose of the thermoplastic phase of this research project was to determine how well long line thermoplastic pavement markings are performing on different highways across North Carolina and to determine the expected life of thermoplastic markings. To accomplish this a thorough review was conducted of other research in this area; NCDOT's thermoplastic project information was reviewed; evaluation procedures were developed and tested, and preliminary and final field visits were made to conduct the evaluations.

Inventory of NCDOT Projects

A review was made of all available NCDOT records on thermoplastic pavement marking projects in North Carolina. This review revealed special marking projects dating back to 1976 and long line projects back to 1978. A complete list of these potential projects was assembled for further investigation and preliminary field visits.

Preliminary Field Visits

A copy of the identified thermoplastic projects in each highway division was sent to each respective Division Traffic Engineer for his review, additions, and corrections. Field visits were then arranged with each Division Traffic Engineer to discuss thermoplastic markings, review the data and make field visits to thermoplastic sites.

These visits proved to be a valuable portion of this project. They provided: updates and corrections to the list of projects; allowed the field personnel to find out first hand about this research project; provided a means of learning about the experiences, problems, and opinions of practicing field personnel on the subject of pavement markings; and provided a preliminary review of most of the thermoplastic projects still in service.

Reflectivity Readings and Field Evaluations

Upon conclusion of the preliminary visits, a list of sites for further evaluation was assembled. Of the 1,456 miles of thermoplastic originally identified from Traffic Engineering records, approximately 800 mi were found to be in place in the field. The remainder of the sections were either resurfaced or painted over. North Carolina had two major resurfacing programs in the 80s, and many of the sections of interstate, primary, and urban roadways with thermoplastic installed in the late 70s and early 80s were covered in these programs.

Resurfacing is unavoidable in highway work, and despite careful planning pavements can deteriorate more quickly than anticipated. High volume routes are the routes on which durable pavement markings are placed. They are also routes which are more susceptible to pavement failure and receive a higher level of maintenance.

The resurfacing accounted for the majority of the loss of thermoplastic projects with over 540 mi of the original projects identified having been resurfaced. Information on the condition of these sections at the time of resurfacing was not available at all in most cases and not readily available in the others. Without information on the condition of the marking at the time of resurfacing there is no way an evaluation could be made of those sections. Of the remaining 120 mi of projects approximately 60 mi had been placed on concrete and repainted within the first three years by maintenance forces. Loss of material due to chipping was the major failure of thermoplastic on concrete according to field contacts. The other 60 mi of thermoplastic placed on asphalt had also been repainted by maintenance forces. Lanelines were most frequently the markings repainted on projects installed in 1981 or before.

Through the field visits with the 14 Division Traffic Engineers and in previous studies with traffic services operations, it has been found that the procedures used to evaluate a pavement marking's performance vary substantially among divisions. Some divisions also have higher levels of service for pavement markings than others. Without more definitive information on the marking's performance at the time it was repainted, there is no way to know what its condition was at that time.

Evaluation Procedures

A number of evaluation procedures were examined for use in this project. In the preliminary field visits, some of these ideas were tested. As in the other evaluations, the three most important factors concerning a pavement marking's performance are appearance, durability, and reflectivity. The appearance and durability factors were used in other research projects to evaluate thermoplastic and were generally conducted in the daytime from a moving vehicle or from the shoulder of the road. Evaluation of reflectivity was more difficult because it required nighttime visits to each section and then a subjective rating of the condition.

A series of nighttime reviews of thermoplastic markings indicated that useful information could be determined about the reflectivity of pavement marking in this manner. A number of serious problems were encountered with this method: evaluations had to be made after normal working hours; conditions such as oncoming headlights, peripheral lighting, time of the night, season of concerns. In an attempt to eliminate some of these problems, trial measurements were made on pavement markings using an Ecolux retroreflectometer.

The Ecolux served to eliminate many of the problems encountered in the subjective nighttime evaluations but came with its own problems. The major problem with the Ecolux was that it was not easy to operate under traffic conditions. The Ecolux required two people to operate, one to hold and read the machine and the second to carry the battery pack and umbilical cord. Operating the machine was also a laborious task. The operator had to get on his hands and knees to set up the machine; then had to read an analog scale to get the measurement. These drawbacks made any extensive use of an Ecolux to gather field readings impossible.

Shortly after these trials with the Ecolux, a Mirolux retroreflectometer was provided to ITRE for testing. The Mirolux proved to be the answer to the problems with the Ecolux. It was small, light, easy to operate, and proved to be reliable after repeated use. Testing also revealed a direct relationship between its readings and those of the Ecolux. Finally, an objective means of evaluating the reflective quality of pavement markings was available for use in the field. Armed with this new evaluation tool, ITRE began an extensive field evaluation of thermoplastic.

Before making field visits, the evaluation procedures were finalized and tested. The three areas of evaluation were appearance, durability, and reflectivity.

1. *Appearance* - Markings were rated as acceptable (A) or unacceptable (U) using the following definitions. This was an overall rating for the entire section.

> *Acceptable* - The intent of the pavement marking to guide, warn, or regulate *is clear* to the motorist when viewed from a vehicle operating at normal highway speeds during daylight hours. This is the complete impression conveyed by the marking, including appropriate color (white or yellow).
>
> *Unacceptable* - The intent of the marking to guide, warn, or regulate *is not clear* to a motorist when viewed from a vehicle operating at normal highway speeds during daylight hours.

2. *Durability* - The durability was evaluated according to the percentage of the material remaining on the pavement. This evaluation was made at the same locations that reflectivity readings were made, using the unaided human eye standing over the marking. Only surface area covered was evaluated. Thickness measurements are not practical without a special instrument which was not available at the time of this evaluation.

3. *Reflectivity* - The reflectivity was evaluated using a Mirolux 12 retroreflectometer. Each thermoplastic project was evaluated by taking three sets of reflectivity readings generally in the first third of the project, the middle third of the project, and in the final third of the project. A set of reflectivity readings consisted of at least 18 readings over six skip lines (3 readings per skip) and 18 readings distributed evenly over 300 feet of continuous line. This was done for each line (edgeline, centerline, laneline, or barrierline) in both directions. This procedure was followed for sections approximately 3 miles in length. For sections over 3 miles, an additional set of readings was taken at for each additional segment up to 3 miles. Readings were taken on randomly selected tangent sections within each of the three zones to allow for comparison between sections and for safety.

The following procedure was used for determining the reflectivity performance for a marking on a project. On a given project, all reflectivity readings for a given marking (i.e. edgeline, laneline, or centerline) were totaled and then divided by the total number of readings to get an average reflectivity value. This reflectivity value could then be used to determine whether the edgeline, laneline, or centerline met minimum acceptable reflectivity standards.

Site Selection

After the preliminary visits approximately 800 mi of thermoplastic on 146 pavement marking projects were identified. The decision was made to evaluate thermoplastic sites in all of the 14 highway divisions. This would give a good distribution of geographic and climate types. Approximately 1 week was assigned to each division for data collection. The approach was to check as many sites as possible within each division. In 5 of the 14 highway divisions all thermoplastic sites were evaluated in the remaining 9 divisions approximately half of the thermoplastic sites within each division were evaluated. An attempt was made to evaluate each type of roadway (two-lane, multi-lane undivided, and multi-lane divided) within each division.

Results of Thermoplastic In-Service Evaluations

In the final evaluation, approximately 350 road mi of thermoplastic on 60 different projects were evaluated. These projects covered the period from 1979 to 1986. Sections were grouped according to the type of roadway: 1) two-lane, 2) multi-lane divided, and 3) multi-lane undivided.

With the exception of a couple of sections of roadway in the coastal region of the State, the appearance evaluation criteria was not the controlling factor in determining the performance of a section of thermoplastic. On these particular sections, the pavement was 7 to 8 years old and had highly polished aggregate which gave a pavement color similar to concrete. The appearance of these particular markings varied according to the direction of travel and the intensity of sunlight. The end result was the surface not providing sufficient contrast with the pavement markings to be effective during all these daytime conditions.

This study did not have the instrumentation to measure contrast objectively, so this was done as part of the subjective appearance evaluation. It is interesting to note that these particular sections had good nighttime reflectivity. The failure due to daytime performance was the exception rather than the rule in these evaluations. In the vast majority of cases, it was the reflectivity evaluation which controlled the markings performance in this project.

The importance of reflectivity in the performance of a pavement marking has always been recognized, but an objective evaluation of that performance has been a difficult task. With the use of the Mirolux 12 retroreflectometer, this project has performed an objective evaluation of thermoplastic projects in North Carolina. This evaluation shows why thermoplastic pavement markings were so favorable among NCDOT field personnel. Results show white thermoplastic's providing 6 and 8 years of acceptable performance on all types of highway facilities. Yellow markings are not providing as good a performance according to reflectivity with less than half the projects evaluated providing acceptable service after 3 years. This is based on an acceptable reflectivity value of 100 SL as measured with an Ecolux reflectometer the same value as used with the white material. The color yellow is inherently less reflective than white and may justify a lower level of reflectivity. Experiments in this area however were outside the scope of this project. Table 9 gives a summary of the reflectivity performance of the thermoplastic projects evaluated under this research.

Table 9 shows the number of thermoplastic sections and mileage by year and the percentage (by mileage) that were acceptable ($\geq$ 100) and unacceptable (< 100) as measured with an Ecolux. This table shows that nearly all white thermoplastic markings were found to be acceptable regardless of age. In fact, of the more than 60 projects evaluated, only 2 projects were found to have white thermoplastic unacceptable due to reflectivity. The performance of yellow thermoplastic was not as good, with more than half of the yellow material failing after less than 6 years of service in both the edgeline and centerline conditions.

Durability has not been mentioned in this evaluation until now. Information on durability (percent of material remaining) was gathered at the same time as the appearance and reflectivity data. In all the sections evaluated in the study the factors which controlled the failure were reflectivity level and/or appearance. That is not to say that durability was not a part of the reason the marking failed because clearly it is. If a marking material has come loose from the pavement surface then there is not any glass present to be reflective and no line present to delineate.

In the analysis of field data, it was determined that white thermoplastic markings were rated acceptable according to appearance and reflectivity generally had greater than 70 percent of the material remaining. When less than 70 percent of the marking was present then reflectivity was generally at or below the acceptable level, and appearance was unacceptable or marginal. More than 90 percent of the markings evaluated in this project had 75 to 90 percent of the surface area covered with material. These durability percentages were taken at the locations of reflectivity readings. (For Yellow thermoplastic markings there was not always a relationship between the percentage of material remaining and reflectivity.) Yellow materials as discussed before are inherently less reflective than white materials and in many cases greater the 70 percent of the marking was in place and the reflectivity level was still below the minimum acceptable level.

Another particular problem discovered in this evaluation was the poor performance of thermoplastic on concrete. Only one concrete project of approximately 5 mi had thermoplastic that had not been repainted. This particular section was multi-lane divided, with >20,000 ADT, and was approximately 4 years old. It was in excellent condition. All other sections exhibited extensive chipping and loss of material. According to field personnel, each of these sections were restriped with paint within 3 to 4 years after installation. A variety of explanations were presented for these failures, including poor cleaning of curing compound before placement, excessive loss due to snow plow activity, and a lack of sufficient bond to the concrete.

Table 9. Summary of thermoplastic reflectivity readings.*

TWO-LANE ROADWAYS

YEAR	NUMBER OF SECTIONS	MILES	WHITE EDGE LINE READINGS %>100	WHITE EDGE LINE READINGS %<100	YELLOW CENTER LINE READINGS %>100	YELLOW CENTER LINE READINGS %<100
1979	3	18.0	100	0	44	56
1981	11	38.5	100	0	61	39
1983	1	7.0	100	0	100	0
1984	3	33.0	100	0	88	12

MULTI-LANE DIVIDED ROADWAYS

YEAR	NUMBER OF SECTIONS	MILES	WHITE EDGE LINE %>100	WHITE EDGE LINE %<100	WHITE LANE LINE %>100	WHITE LANE LINE %<100	YELLOW EDGE LINE %>100	YELLOW EDGE LINE %<100
1979	2	14.0	100	0	100	0	43	57
1981	17	84.5	95	4	98	2	39	61
1982	5	33.0	100	0	100	0	36	64
1983	5	32.0	100	0	100	0	37	63
1984	2	9.0	100	0	100	0	100	0
1985	3	21.0	100	0	100	0	100	0
1986	2	17.0	100	0	100	0	100	0

MULTI-LANE UNDIVIDED ROADWAYS

YEAR	NUMBER OF SECTIONS	MILES	WHITE EDGE LINE %>100	WHITE EDGE LINE %<100	WHITE LANE LINE %>100	WHITE LANE LINE %<100	YELLOW BARRIER LINE %>100	YELLOW BARRIER LINE %<100
1981	3	12.0	100	0	100	0	0	100
1985	3	31.0	100	0	90	10	90	10
1986	1	2.0	100	0	100	0	0	100

*The values shown are Ecolux values in ([mcd m^{-2}] x lx^{-1}). They were converted from actual Mirolux 12 readings.

In conclusion, thermoplastic is a durable and reflective pavement marking material when used as a long line marking on multi-lane and two lane roadways with wide lanes. Based on an extensive evaluation of reflectivity using objective readings from a portable retroreflectometer, white thermoplastic is providing acceptable appearance and reflectivity for 6 and 8 years when installed on high type roadways with traffic volumes up to 20,000 ADT in North Carolina. Yellow thermoplastic is providing a marking life of 3 years under similar roadway conditions.

LONG LIFE TAPE IN-SERVICE EVALUATIONS

A second part of the 1985 North Carolina Highway Planning and Research Project was an evaluation of pavement marking tapes. This evaluation included test deck testing and in-service testing of different pavement marking tape products. This research covered a two year period which provided approximately 20 months of observation time from the time of installation. Since long life tapes are used primarily for special markings such as arrows, school and railroad symbols, stop bars, and cross walks one of the in-service tests was to install samples of each long life tape product tested in special marking locations. A site was selected for this test in the City of Oxford, North Carolina (population 8,000). The street chosen was Hillsboro Street, which is the "main street" in the town with on-street parking, signalized intersections, curb and gutter, asphalt pavement and an ADT of 6,500 to 11,000. The route is two lanes with short left turn lanes at signalized intersections.

Oxford Crosswalk and Stop Bar Tests

Five different long life pavement marking tape products were installed at the site. At least three samples (approximately 10 feet in length) of each of the five products were installed as crosswalks and/or stop bars. Visual evaluations were made of these samples at 1, 6, 12, and 20 months of service. During these evaluations the markings were evaluated for appearance (acceptable or unacceptable) and durability (percentage of marking remaining). During this 20 month period 5 of the 17 total samples installed failed due to appearance or durability. At the end of 20 months of service reflectivity was also evaluated. Five reflectivity readings were taken on each section of crosswalk or stop bar with an Ecolux retroreflectometer. These five readings were then averaged to get a reflectivity value for each sample. Table 10 lists the individual crosswalk and stop bar markings and their average reflectivity readings.

Table 10. Oxford crosswalk and stop bar testing reflectivity readings* at 20 months.

	Crosswk Locat.1	Crosswk Locat.2	Crosswk Locat.3	StopBar Left Turn 1	StopBar Left Turn 2
A - SEIBULITE "MM"	69	65	67	(N/A)	(N/A)
B - 3M "STAMARK" 5730	66	59	66	92	(N/A)
C - CATA-TILE	58	(N/A)	(N/A)	80	69
D - PRISMO 60MM	61	56	(N/A)	(N/A)	75
E - PRISMO 90MM	60	56	(N/A)	88	74

*Reflectivity readings were taken with an Ecolux retroreflectometer. The listed readings are an average of 5 readings per test sample.

Using 100 ([mcd m^{-2}] x lx^{-1}) as measured with an Ecolux as an acceptable reflectivity level this table shows these markings performing poorly according to reflectivity. In fact none of the materials tested met the acceptable level of reflectivity. This test raised questions about the reflectivity performance of pavement marking tapes when used as special markings which is where most are used.

To determine whether these poor reflectivity results were indicative of the performance of pavement marking tapes in general an expanded in-service evaluation was conducted on special markings installed by NCDOT maintenance forces in 1985 the same time that test samples were installed. The only long life pavement marking tape approved for use by NCDOT at that time was 3M Company's 5730 "Stamark" PLant Polymer 5730 tape. Therefore this is the material that was evaluated.

In-service Evaluation of 3M's 5730 Long Life Tape used as Special Markings

Approximately 30 projects and locations were identified for evaluation with varying ADTs and traffic conditions. These locations were all in Harnett and Cumberland counties which are in the coastal plain area of North Carolina. A total of 194 individual markings were evaluated. Installation dates were known for all of these markings, and all were installed in the summer of 1985. In this evaluation the same evaluation criteria for appearance, durability, and reflectivity were used as in the other in-service evaluations.

A variety of special marking types were evaluated, including all types of arrows, rail road crossing symbols, and stop bars at rail road crossings. As in the Oxford study, most of the markings evaluated had acceptable appearance and durability (approximately 5 percent of the markings evaluated failed due to appearance and durability). The reflectivity again was the weak point in the performance of these markings. Reflectivity was evaluated using a Mirolux 12 retroreflectometer taking five readings per arrow and ten readings for each railroad symbol. These readings were then averaged to get a reflectivity reading for each marking. Using the 100 SL measured with and Ecolux retroreflectometer as the acceptable value for reflectivity 74 percent of the markings checked were unacceptable due to reflectivity after only two years of service.

Table 11 illustrates the reflectivity performance by showing the number of special markings evaluated by type and the percentage above and below the 100 level as measured with an Ecolux retroreflectometer. As the table shows, the only type of special marking performing reasonably well was the through arrow, but even there only 36 percent of those checked were above the 100 level.

Even if reflectivity values below the established level of 100 as measured with an Ecolux are used a significant percentage of the special marking evaluated would be unacceptable. Table 12 illustrates the percentages of each type of special marking which had reflectivity values below 100, 90, 80, and 70.

Table 11. Reflectivity readings for 3M "Stamark" 5730 Tape used as special markings.

Special Marking Type	Markings Evaluated	Acceptable Readings≥100 Ecolux Number	%	Unacceptable Readings <100 Ecolux Number	%
TURN ARROWS	36	8	22%	28	78%
THROUGH ARROWS	66	24	36%	42	64%
COMBINATION ARROWS	39	1	3%	38	97%
RXR-RAILROAD SYMBOL	33	7	21%	26	79%
--- STOP BAR AT RAILROAD CROSSING	12	1	8%	11	92%
TOTALS	194	51	26%	143	74%

Average reflectivity readings for all arrows and stop bars at railroad tracks are based on 5 readings for each. Railroad symbols are based on 10 readings each.

Table 12. Percentages of unacceptable special markings at lower reflectivity values.

Special Marking Tape	No. of Markings Evaluated	Percentage of Readings <100	<90	Reflectivity (Ecolux) <80	<70
Turn Arrows	36	78%	78%	38%	4%
Through Arrows	66	64	41	20	9
Combination Arrows	39	97	95	62	10
RxR - Railroad Symbols	33	79	70	30	6
---Stop Bar at Railroad Crossing	12	92	75	42	17
School Symbols	8	0	0	0	0
TOTALS:	194	74%	64%	37%	14%

Due to these poor reflectivity readings even under free rolling type conditions it is questionable whether long life pavement marking tape should be used as special markings except under lighted conditions. This is of course based on an acceptable value of 100 mcd/lux/m^2 as measured with an Ecolux retroreflectometer and lower acceptable values may result in different conclusions. The purpose here however is to show that a portable retroreflectometer can be used to evaluate the reflectivity performance of pavement markings. Reflectivity has long been recognized as an important part of a pavement markings performance but due to the subjective nature of nighttime visual evaluations it has been difficult to objectively evaluate the reflective performance of pavement markings. A portable retroreflectometer makes such an objective analysis possible.

SUMMARY AND CONCLUSIONS

The evaluation of pavement markings for reflectivity under in-service conditions is a difficult task for the traffic engineer. Due to the lack of reflectivity standards and high-speed equipment for making such measurements few in-service evaluations of pavement marking reflectivity have been performed.

Until such standards and high-speed equipment are developed highway agencies will have to rely on their own capabilities in the evaluation of pavement markings. These might include nighttime visual evaluations or establish their own acceptable levels of reflectivity and use of portable hand held retroreflectometers currently available.

This paper presented a procedure for using a portable retroreflectometer (Mirolux 12) for evaluating the reflectivity of long lines and special markings. A procedure was presented for taking reflectivity readings under actual field conditions on both of these types of markings. Information was also provided on the selection of an acceptable level of reflectivity.

Two examples were presented in the application of this evaluation procedure one looking at long line thermoplastic markings and another looking at preformed tape used as special markings.

The thermoplastic evaluation shows that white thermoplastic is providing acceptable service under a wide range of traffic conditions in North Carolina for 6 and 8 years. Yellow thermoplastic is providing at least 3 years of service and longer in some cases. The special marking evaluation of preformed tape indicated that these materials were not providing an acceptable level of reflectivity after only two year of service.

These evaluations were based on an acceptable level of reflectivity of 100 ([ncd n^{-2}] x lx^{-1}) as measured with an Ecolux retroreflectometer.

This level of reflectivity was used based on previous studies in the area of pavement marking reflectivity and a limited panel evaluation.

These examples show that useful information can be derived from this type of evaluation to help the traffic engineer in making decisions concerning pavement marking practices.

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DISCUSSION AT EASTERN WORKSHOP

Q: What type of materials were used?

A: It was a combination. The 1981 project was primarily hydrocarbon long lines. But since that time, North Carolina has (as the photographs I've shown coming right behind the paving machine with most of their durable markings or the thermoplastics) gone with alkyds predominantly. I don't know what the split is now. I think some of the re-marking is still with hydrocarbons but they're going more toward alkyds. All of the newer projects, I would say in the last 3 years, were alkyds.

DISCUSSION AT WESTERN WORKSHOP

Q: What is the cost of the Mirolux units?

A: The last ones we ordered were $2,550.

Q: Do you use hydrocarbons?

A: A lot of those included in the studied 1981 installations (where we had the largest group of data) were hydrocarbons. When we come in behind a pavement operation, all those are alkyd. All of the special markings in the State are alkyd. The only time we use hydrocarbon is when we go in and mark over existing markings or if we have a time limit (we have a five-day time limit on two-lane roadways to put down permanent markings). We are experimenting because the hydrocarbon has been less expensive when doing temporary lines, which will be replaced within a 45-day period.

Q: What kind of thickness?

A: That has changed recently. Historically, it has been 60 mils for edge lines and 90 mils for center lines on two-lane roadways and 120 mils for some other roadways. I think everything has gone to either 90 mils or 120 mils (120 for two-lane lines) in North Carolina. There is a trade-off here depending on snow activity.

Q: Did you take any readings that compared brand-new yellow thermoplastic and brand-new white thermoplastic?

A: We have. We have achieved varying results, but usually the white is about 100 points below. . . . Epoxy is high regardless of what color it is. It retains the beads quite well.

Q: With the yellow, would you consider going to back to 30 mils?

A: That is certainly an option. Coming back with a sprayed application on top is an option. I have also heard the suggestion of coming back with epoxy over thermoplastic; it is a lower profile, so you would not be adding so much profile. However, as far as I know, they have not done anything. They have not set a standard. But that is a concern.

CURRENT RESEARCH AND FUTURE NEEDS IN EVALUATING DELINEATION

Richard N. Schwab
Night Visibility Program Manager
Federal Highway Administration
Traffic Safety Research Division
6300 Georgetown Pike
McLean, VA 22101-2296

Portable, handheld instrumentation has been available to make spot measurements of the retroreflective quality of pavement markings for several years. This equipment must be placed directly on the line being measured and, therefore, the personnel using the equipment are placed in the hazardous position of being exposed to traffic. This requires traffic control to protect highway personnel from oncoming vehicles, which on highly travelled roadways causes driver delay. Therefore, application of these portable devices has been primarily limited to use in acceptance testing of new marking materials, although there has been some research on their use in statistically sampling in-service lines to determine their adequacy. This type of instrumentation can be made to work quite well in small, rural districts, especially on roads with lower traffic volumes.

Most of the portable devices on the market have been limited by the ability to mechanically arrange the optical elements within a reasonably sized box to view the marking at a simulated 45-ft (15-m) distance. For most actual driving situations, a marking at this distance would be just inside the area blocked for view by the hood of the vehicle. A study of delineation found that drivers look at a point approximately three to four seconds ahead of their present location to anticipate the need for heading and speed changes. At typical highway speeds, that means the driver's line of sight is intersecting the road surface at approximately 2.5 degrees rather than the 4.5-degree viewing angle common for most of the portable pavement marking measurement devices.

FEASIBILITY OF A MOBILE RETROREFLECTOMETER

In September of 1986, a Small Business Innovation Research grant was awarded to investigate the feasibility of developing a retroreflectometer to measure pavement markings from a vehicle moving at highway speeds during normal working hours. This would greatly reduce the safety risk to highway personnel and increase the area that can be surveyed for a given budget allotment.

The design investigated utilized a laser light source. A laser produces a fixed power, collimated beam, with constant irradiance across its projected spot. Because the laser output is within a very narrow frequency, the detector can be filtered to read only the radiance of the laser spot, even in the presence of sunlight. This eliminates the need to keep out the ambient light by shrouding the optical measurement system or by maintaining physical contact with the road surface.

In the initial studies, a laser was used to measure a sample pavement marking placed outside the laboratory window where it would be exposed to direct radiation from the sun. Measurements were started at midnight and continued at periodic intervals throughout the following day. By filtering the detector to the same wavelength as the laser, readings made under direct sunlight and night readings were within an uncertainty error of 2.5 percent. This degree of error would certainly be acceptable for a survey instrument. A series of measurements were then made of several different pavement marking materials using the single frequency laser source, with the results compared to standard photometric readings made with a tungsten light source. The results showed that a high correlation could be obtained and that the result obtained from the laser could be used to predict standard laboratory measurements with a high degree of accuracy. Studies were also made during the feasibility research to show that data could be obtained from a moving target and successfully recorded.

A breadboard system was then designed and built. The system allowed manual tracking by superimposing the image of the laser beam over the pavement marking on a small television screen. This worked relatively well at speeds below 30 mi/h (48 ki/h). The results indicated that the quality of existing markings, as well as new markings, could be measured from a moving vehicle during daylight hours. In addition, the system could work regardless of whether the pavement marking was dry or wet.

FIELD PROTOTYPE DEVELOPED

A series of field prototype instruments have been developed over the past 2 years, with each new one incorporating information learned from earlier models. The latest version, Prototype 4, is shown in figure 17. It is built to operate at approximately one-third of the

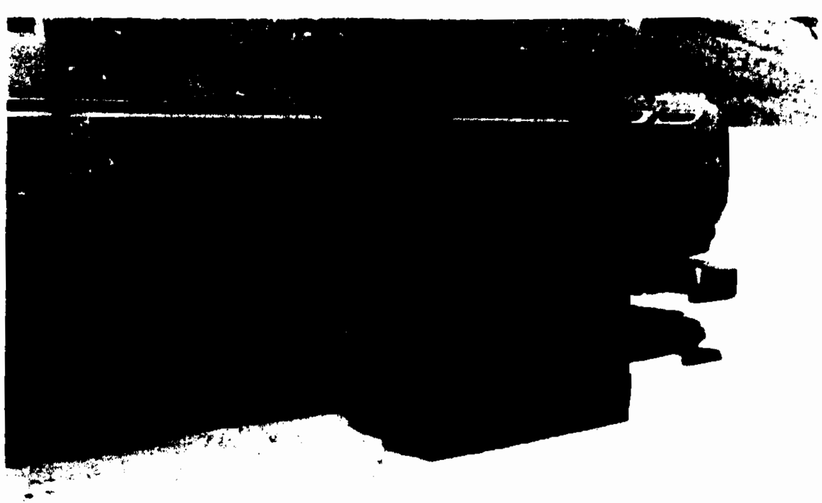

Figure 17. Laser retroreflectometer mounted on pick-up truck.

desired real world geometry. The Laser Retroreflectometer mounts on the side of a pick-up truck approximately 5 in (12 cm) above the pavement. It measures the marking 32.8 ft (10 m) in front of the unit. The hardware, as currently developed, has overcome the geometric limitation of the handheld units. It views the marking at approximately a 1-degree observation angle, which closely simulates the typical driver's viewing geometry.

The equipment is capable of sampling from 200 to 500 data points on each scan of the line as frequently as every 3 ft (0.9 m), while the truck is traveling at 55 mi/h (88 ki/h). This is, obviously, far too much data to store and would overwhelm the traffic engineer trying to interpret results. Research is currently underway to determine what data is required to best satisfy the needs of operating personnel and how to present it. Statistical sampling procedures are also being developed.

DETERMINING WHEN MARKINGS NEED REPLACING

Data from a series of analytic, laboratory, and field studies are available which help define the point when markings are no longer adequate for driver guidance. The results of the National Cooperative Highway Research Program study (NCHRP 4-16) discussed earlier in this session indicate that the rating panels judged the pavement lines to be inadequate when their retroreflectometer reading dropped below 100 mcd/m^2/lux. In an analytical study, retroreflectivity values between 60 and 130 mcd/m^2/lux were found to be the minimum that should be allowed on the roadway at night, depending mainly on the speed of travel. Other research is still underway, but all of the results seem to be "in the same ballpark." At these levels, pavement markings become ineffective and often appear spotty because of loss of beads and peeling.

However, none of these studies have resulted in a practical level for retroreflectivity, which indicates when lines should be replaced. A practical level must allow adequate time for scheduling the remarking; ensuring that the line will not reach the level determined to be unsatisfactory for visual guidance before the next inspection and marking period. Professionals working in the field need to experiment and develop guidance on what would be a safe cutoff level. Furthermore, higher-speed roadways would probably need a somewhat higher level, perhaps 150 to 130 mcd/m^2/lux, than lower-speed, urban streets. This might be an appropriate role for an Institute of Transportation Engineers' Technical Council Committee.

WHERE DO WE GO FROM HERE?

Once the equipment is fully developed and the software produces the desired reports, it will be necessary to field-test the equipment. One or more of the State highway agencies will be loaned the equipment to evaluate its utility with their own personnel. If this evaluation is successful, then the equipment will be marketed by a commercial source. Public companies may also be started to make surveys using the equipment for interested agencies which do not wish to purchase the equipment.

SESSION 5

MAINTENANCE PROCEDURES AND PROGRAMS

PENNDOT'S STATEWIDE PROGRAM FOR SIGN IMPROVEMENTS

Brian A. McCoola, P.E.*
Manager, Traffic Signing Section
Pennsylvania Department of Transportation
1014 Transportation and Safety Building
Harrisburg, PA 17120

The Pennsylvania Department of Transportation (PennDOT) is responsible for the maintenance of 41,344 miles of State highways and has an estimated 1.1 million traffic signs in place. Approximately 35 percent are regulatory signs, 45 percent are warning signs, and 20 percent are guide signs. The Department's Central Sign Distribution Center in Harrisburg manufactures approximately 168,000 signs annually and purchases another 5,000 special order signs each year through contract. Signing in Pennsylvania is maintained by some 75 sign crews working out of 67 county maintenance offices. Eleven Engineering District Offices supervise traffic engineering and signing programs. The State budget for signing activities in Pennsylvania is $13.75 million annually.

In recent years, increasing efforts have been undertaken by PennDOT in design and maintenance areas to address the needs of improved statewide traffic signing. Several factors have influenced the Department to commit added resources and to implement new signing initiatives across the State. Prior to 1987, there were more than 12,000 reported traffic accidents each year which could be attributed to signing related factors. This figure amounts to roughly 8 percent of the approximately 160,000 traffic accidents reported annually in Pennsylvania. Several independent studies concluded that signing problems were one of the major contributing factors associated with tort claims against the Department. Studies also found that as many as 50 percent of the traffic signs on some highways were in need of upgrading due to age, vandalism, vehicle damage, or other factors.

Also focusing an added emphasis on sign initiatives was the realization that Pennsylvania's highways could not efficiently promote economic activity and good movement without adequate signing. Traffic sign upgrading, particularly improvements to destination signs and numbered traffic route markers, was seen to enhance economic development and tourism, two important State priorities.

Prior to 1987, the Department was spending about $10 to $12 million annually for traffic sign maintenance. This figure does not include contract expenditures for the upgrading of signs and delineation, which amounted to an additional $5 million per year. Past signing efforts were primarily "reactive" spot improvements or emergency maintenance, rather than a "proactive" comprehensive upgrading of all signing along specific corridors.

*Presented at eastern workshop only.

SIGN UPGRADING PROGRAM

In the summer of 1987, the Department began the "Sign Upgrading Program" with the goal of updating the signing on all State Routes statewide. An overall completion time period of seven years or less was projected. Under the program, all signing which was the responsibility of the Department was targeted for correction on a systematic corridor-by-corridor basis, beginning with numbered traffic route corridors and sections of road with high accident rates or tort claim histories. All sign types (regulatory, warning, and guide) were to be corrected with the exception of large, major, and supplemental guide signs on freeways and expressways. At the present time, almost all of this work is being done by existing Department forces, supplemented by temporary and seasonal employees where necessary.

The Department's goal was to review the signing on 30 percent of the State Route mileage, and correct the signing on 25 percent of State Route mileage by June 30, 1989. Through the excellent efforts of District, County Maintenance, and Sign Distribution Center personnel, about 42 percent of the State Route mileage was actually surveyed and 33 percent was corrected. For fiscal year 1990 and future years, the goals will be to survey and correct an additional 15 percent of the State Route mileage. As of January 1990, some 17,759 mi or 43 percent of the State highway system was successfully corrected and improved.

In conjunction with the Sign Upgrading Program, a program of Quality Assurance (QA) signing reviews are conducted in each District by Department Engineers from the Traffic Engineering and Operations Division. The reviews are conducted on sign upgraded routes to determine if the work was done satisfactorily. Each sign is field checked and review forms are completed. The Department goal is to review 1,000 mi of upgraded signing during each calendar year.

$15 MILLION TRAFFIC AND DIRECTIONAL SIGN APPROPRIATION

In 1988, the Pennsylvania State Motor License Fund Budget contained a special $15 million statewide appropriation for traffic and directional signing. This appropriation supplemented the Department's normal sign budget thereby enabling an expansion and acceleration of statewide signing improvements. The $15 million was a 2-year continuing appropriation, which means the money must be spent or encumbered by June 30, 1990. Each PennDOT County Maintenance Office was given a portion of the $15 million appropriation. Factors used to determine each county's allocation included: the number of freeway and expressway lane miles in the county; freeway and expressway daily vehicle miles traveled (DVMT) for the county; the number of interchanges in the county; the amount of money spend by tourists/travelers within the county; county sign budget shortfalls; tort claims attributed to county roadways; and traffic accidents within the county.

Each District Engineering Office developed a work plan to define the specific signing projects that were to be funded using their county allocations. All of these projects are now completed, under construction, or in the final design phase. About 92 percent of the construction work will be done by contract. Approximately 83 percent of the allocation will be spent for freeway or expressway signing improvements. The remaining amount will be used for certain high volume arterials and for route markers in urban areas. The freeway and expressway expenditures are significant because the Department has estimated that about $60 million is needed to bring statewide freeway and expressway signing into compliance with current minimum State and Federal standards. Final design of all remaining contract signing work under the $15 million appropriation is now nearing completion and all contracts will be let and awarded by June 1990.

These two signing initiatives represent the most comprehensive signing effort ever undertaken in the Commonwealth of Pennsylvania. Completion of the program will significantly improve highway safety and traffic flow, reduce the Department's tort liability exposure, enhance tourism and economic development, and provide the foundation for a more cost-effective sign maintenance program in the future.

MOTORIST SERVICE (LOGO) SIGNING PROGRAM

In the past several years, the Pennsylvania Department of Transportation has implemented a successful motorist service signing program along Interstate routes. This program is popularly referred to as the Logo Signing Program. Logo signs are blue and white in color and they designate gasoline, food, lodging, and camping services which are readily available at or near interchanges of interstate highways. The PennDOT logo program is unique in that it utilizes a private sector body, the Pennsylvania Logo Signing Trust, to administer the program. This endeavor has been seen as affording various fiscal, administrative and personnel advantages, and it has been recognized as an effective partnership between the public and private sectors.

Logo Signing in Pennsylvania was started in 1984 with a Pilot Program along Interstate Route 84 in the Pocono Mountains Region of Northeast Pennsylvania. Since that time, motorists services have been enhanced and now some 125 of 390 Interstate interchanges in Pennsylvania have some amount of logo signing in place. It is estimated that up to 50 additional interchanges may be added as services become available and as sections of recently completed and soon-to-open Interstate highways are incorporated into the program. Examples include I-78 near Allentown, I-376 near Pittsburgh, and I-476 near Philadelphia.

Logo signs are paid for entirely by qualifying and eligible businesses and are erected at approved interchanges. Certain business eligibility, distance, message, and sign spacing criteria govern their approval and erection in Pennsylvania. The signs are intended to provide travelers with business identification and directional information for essential motorist services. The program has been well received in Pennsylvania by nearly 460 business establishments that participate. Plans are now underway to expand participation in the program by permitting up to six logo sign panels per service at select interchanges. Currently, only four food, lodging, and camping logo sign panels are allowed.

OTHER SIGNING INITIATIVES

Other signing enhancements soon to be implemented in Pennsylvania involve Rest Areas and Welcome Centers, signing for long, steep Truck Grades, and a Statewide Highway Litter Control Program. Some thirty-four Rest Areas along Interstate Routes and seven Welcome Centers located at State borders are scheduled for improvement as part of the Department's sign upgrading program and in cooperation with various State tourism programs. Also now in progress is a year-long study to evaluate signing and safety improvements at nearly 120 long, steep grade "truck hills," many in Central and Western Pennsylvania. A third initiative, slated for implementation in 1990, will be the "Adopt-A-Highway" Litter Control program which has been used successfully in other States. Between 1,000 and 1,500 signs will be manufactured and installed once this program is started in the Spring of 1990.

JOINT EFFORTS TO REALIZE SIGN IMPROVEMENTS

It is clear that a combination of fiscal, engineering, legislative, and management initiatives were effectively joined in Pennsylvania to help bring about the current increased emphasis on statewide sign improvements. From the early planning state to field implementation, the various program elements have reflected the combined and ongoing efforts of many individuals working to achieve a common "service oriented" objective. Through these efforts, and with the effective partnership between public and private sectors, multiple benefits in the areas of safety, service, and sign program improvements are now in place for the many millions of residents and visitors who travel State highways in Pennsylvania.

STATE/LOCAL MAINTENANCE PROGRAMS (MINNESOTA'S SIGN MANAGEMENT PROGRAMS)

Leonard G. Eilts*
Traffic Engineer
Minnesota Department of Transportation
John Ireland Boulevard, Room 309
St. Paul, MN 56601

In the early 1980's the Minnesota Department of Transportation (Mn/DOT) spent nearly $5 million of off-Federal aid system safety funds to improve regulatory and warning signs on the road systems of Minnesota's 87 counties and cities with populations of 3,000 and above.

These county signing projects generated a lot of interest in upgrading township and trunk highway signing. Mn/DOT announced that it would like a county to undertake township signing as a pilot project. As a result of this interest one county engineer, volunteered to be the administrator for a township signing program within his county.

The county engineer did an excellent job of administering the program and the pilot township signing project proved to be very successful. The project was funded with 90 percent Federal Hazard Elimination Safety funds.

Early in 1986 Mn/DOT developed two programs for sign replacement and upgrading to provide uniformity in signing throughout the State of Minnesota. These programs were undertaken, in addition to the normal signing programs, to increase production of signs and help local governments improve their sign compliance and reduce liability. These two programs are:

1. *Mn/DOT District Trunk Highway Sign Upgrade Program* to bring existing signs into compliance with the reflective sheeting policy dated April 15, 1986. (Encapsulated lens [high intensity] retroreflective sheeting.)

2. *Local Government Off-System (Township) Signing Program* to help correct regulatory and warning sign deficiencies.

TRUNK HIGHWAY SIGN UPGRADE PROGRAM

The trunk highway sign management program followed the same format as outlined in the sign management video developed by the American Traffic Safety Services Association (ATSSA).

*Presented at western workshop only.

Sign Inventory

A Mn/DOT sign inventory booklet was developed to guide district personnel in inventory of regulatory, warning, and most green signs which Mn/DOT is required to maintain. Central office personnel provided training to district personnel on inventory procedures using hand-held computers. Two people provided training to all nine districts.

Evaluation

Under this program all of the previously stated signs would be replaced if:

- The background was made of an engineering grade material and installed before January 1983. Signs installed after 1983 could be left inplace but had to be replaced by maintenance before January 1988.

- The background was made of high intensity material and the sign was over five years old.

Sign Replacement Program

It is the intent of this program to replace substandard inplace signs. Only in exceptional cases will new signs and accompanying structures be installed.

Because of personnel constraints within the districts, two methods of sign replacement were considered:

1. Contract fabrication and erection of signs.
2. Contract sign fabrication and district erection of signs.

Mn/DOT decided to upgrade the trunk highway system to high intensity signing over a three year period.

YEAR	DISTRICTS	
1st	6, 7, 8	Southern 1/3 of State
2nd	1, 2, 3, 4	Northern 1/2 of State
3rd	5, 9	Metro Districts

Most districts have chosen to have the entire signing upgraded by contract due to personnel constraints. - Two districts installed their own signs.

As we near completion of this first upgrade phase of signing, we have had additional changes in reflective sheeting policy. On May 16, 1988, a reflective sheeting policy was implemented whereby virtually all signs are made of encapsulated lens (high intensity) retroreflective sheeting. A few orange signs used for daytime operation not directly related to construction and maintenance and the standard stop/slow flaggers paddle are exempt from this policy.

It was felt that traffic safety on the trunk highway system could be cost effectively enhanced. It also addresses signing needs of elderly drivers.

We are also experimenting with brighter sign sheeting in the Metro Districts. This provides brighter signs where traffic volumes are much higher than on rural trunk highways.

Once the first phase of sign upgrading is completed, we will need to bring remaining signs up to current sheeting standards.

Contracts for seven rural districts have been let with other Metro district contracts scheduled for spring and summer lettings this year.

Mn/DOT has funded this district sign upgrade program from State construction funds. This program is expected to cost from $3-4 million.

LOCAL GOVERNMENT OFF SYSTEM SIGNING PROGRAM

In cooperation with the Federal Highway Administration, the Local Government Off System Signing Program was formalized on February 13, 1986.

The purpose of this traffic safety program is to make Federal safety funds (Hazard Elimination Safety, HES) available to local road authorities to bring regulatory and warning signs/devices (on Non-Federal aid local roads) into compliance with the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD).

Three items comprise this 90 percent Federal (10 percent local) cost sharing traffic safety program:

1. Inventory to determine traffic signs/devices needs.
2. Purchase of traffic control signs/devices.
3. Installation of traffic signs/devices.

What Is Reimbursed?

1. Inventory to determine traffic signs/devices needs.
2. Purchase of traffic control signs/devices.
    - Signs
    - Posts
    - Hardware
3. Installation and removal of traffic signs/devices.

This is a federally funded project with 90 percent federal reimbursement and 10 percent local reimbursement. Funds are available on a "first come, first served" basis.

Who Is Eligible?

This program is open to counties, cities and townships that have not previously received Federal aid (safer roads demonstration or safer-off-system funds) for sign inventories and materials/installation expenses on local roads.

Reimbursement of eligible expenses at the 90 percent level is authorized after Mn/DOT has approved:

1. Final field inspection of installed signs/devices.
2. The materials certification.
3. The claims documents.

Mn/DOT and the FHWA initially concurred in designating $2.1 million (HES) funds to address the regulatory and warning sign deficiencies on non-Federal aid roads. Funds are available on a first come, first served basis as 100 percent of the townships within a county agree to participate in the program. A single project has been developed for each county under the administration of the county engineer.

In 1987, Governor Rudy Perpich accepted a national safety award from Robert E. Harris, Deputy Federal Highway Administrator, in recognition of Minnesota's efforts to correct warning and regulatory sign deficiencies on local roads.

The following outline provides an overview of program activities at the Federal, State and local levels.

1. Mn/DOT's Office of Traffic Engineering announced the program statewide by sending the project description to county and city engineers, and township officials. The program manager made presentations at 14 annual township officials meetings around the State promoting the off-system signing program.

2. Applicants submit an executed intent to participate and an application to Traffic Engineering. Traffic Engineering consolidates submittals and sends them to district State aid and traffic engineers for review and feedback. (Several counties have just a few townships not participating. Still, they are not able to participate because it must be 100 percent township participation.)

3. Mn/DOT requests FHWA authorization to proceed with the inventory andconstruction phases of the project.

4. Traffic Engineering authorizes an inventory of traffic control signs/devices. If an engineering consultant is employed, Mn/DOT must approve the consultant contract before work can begin.

5. The inventory, consisting of a summary of material needs and a cost estimate, is sent to Traffic Engineering, the District State Aid Engineer and the District Traffic Engineer for review and approval.

6. Traffic Engineering authorizes project implementation pending the execution of the Mn/DOT agreement and a signed resolution from the local road authority.

7. In accordance with the Mn/DOT Secondary Road Plan, the project participant purchases and installs the materials or advertises, lets and awards a contract for the purchase and installation of materials.

8. After the project is completed and inspected by the District State Aid Engineer, the project participant submits appropriate claims (along with invoices or final contract vouchers) to the District State Aid Engineer for review and approval, who in turn forwards documents to Traffic Engineering for processing.

9. On approval of the final field inspection by both the District State Aid Engineer and FHWA of installed signs/devices, and satisfactory review and approval of claims documents, 90 percent of the eligible total costs will be reimbursed by Mn/DOT.

Inventory costs allowed under this program are $29 per urban mile and $15 per rural mile. Inventories have been conducted by either county personnel or consultants.

Installation of signs can be accomplished by agreed upon unit prices of $16 per sign or $11 per delineator if the project participant installs its own signs or by unit bid prices or at the Federal ceiling rate (whichever is lower) if installed by contract. Signs have been installed by contracts because local governments do not have the personnel to erect signs within prescribed time frames as outlined in the project description.

The response to this program has been overwhelmingly positive. As I mentioned before, there are 87 counties in Minnesota. By the end of 1987 there were 38 counties participating in the program. By the end of 1988 a total of 68 counties were participating in the program. Twenty-nine counties have completed the signing program so far.

Some interesting facts about this program are:

1. Who conducted the inventory?

   1987 - 28 contractors
   10 counties

   1988 - 30 contractors

2. What type of sign material was specified? Participants were encouraged to consider high intensity materials but were allowed an engineering grade option. 34 of 61 counties specified high intensity sign materials.

3. Current statistics as of December 1, 1989, indicate that nearly $2,292,620.44 was spent which covered almost 16,002 mi of township roads. This reflects the completed 29 counties. This is $143.27 per mi.

4. $4.4 million encumbered in 1986.
   $2.8 million encumbered in 1987.
   $7.2 million encumbered total for 43,000 mi.

5. There have been 112,000 signs and 47,000 delineators/object markers installed under this program to date. We estimated three signs/devices per mi at the start of this program and this estimate has been the average.

6. The projected cost of this program when complete is approximately $11 million. The off system sign program is being completed by using Hazard Elimination Safety funds.

This program has been successful because of an outstanding spirit of cooperation by the Federal Highway Administration, Mn/DOT, Mn/DOT State Aid personnel, counties, cities and township officials.

DISCUSSION AT WESTERN WORKSHOP

Q: Was the funding that FHWA provided HES money?

A: Yes.

Q: Are you going to conduct any before and after so you get the relation between accidents?

A: I don't think we are going to do any before and after. We do have our annual Minnesota flashbacks, and we will draw some conclusions from that.

Q: You had said 112,000 signs and 47,000 delineators?

A: And object markers, yes.

Q: Were those sheeting?

A: They were the sheeting.

Q: And when you said delineators, were those along the roadway or bridge ends?

A: Bridge ends, those type, object markers. Basically bridge end markers and any culvert markers, things like that.

Q: Does this mean that every jurisdiction in all counties will have all signs upgraded regardless of the cities, counties, or townships?

A: Yes. We have all the townships and cities involved in the county. Everyone participates before they are eligible to join this program.

Q: Minneapolis and St. Paul also?

A: Yes. We are doing that by counties.

Q: A quick comment on work on the State trunk system: the district program. Could you discuss for a moment the contract? Was it by a route by route basis or was it just buying so many signs? What was the nature of that contract?

A: That was done districtwide in the seven rural districts, where we covered either one half or the total district by contract. In all cases except two, it included the inventory. The district did the inventory, put plans together, and then a contract was let where the contractor furnished the materials and installed them. In the metro district, we are splitting it by counties because they are much bigger contracts.

Q: What kind of cost comparison?

A: I don't have a real good cost comparison, but it's falling within the range we initially set out for the rural districts. There are a lot more signs in the metro district areas. In the metro districts, there will be a much higher cost per mi.

Q: Where you have a county or city road that intersects with a State highway, who's responsible for the stop or yield sign controlling traffic coming onto the State highway?

A: In Minnesota, the State has responsibilty for the stop sign. There is still some difference of opinion on the stop ahead sign. We had always indicated before that the township or county had the responsibility to install the stop ahead sign or the advance stop sign. Based on this past lawsuit, we may be changing that policy. We'll put the sign out there and they'll have to maintain it.

STRATEGIES FOR MANAGING SIGN REPLACEMENT

Richard A. Cunard*
Engineer of Traffic and Operations
Transportation Research Board
2101 Constitution Avenue, N.W.
Washington, DC 20418

INTRODUCTION

For the 157 million U.S. motorists who spend an average of two years of their lives on some part of the 3.8 million mi of public roads in this county, traffic control devices are a major form of governance. The Federal Highway Administration (FHWA) estimates that there are over 58 million traffic signs worth $6 billion on the Nation's roadside. Nationwide, that averages out to approximately 19 signs per highway mi. It is also estimated that over $250 million is spent annually in the fabrication and erection of street and highway signs.

The ability of public agencies to effectively manage their traffic signs and maintain high levels of safety and service in this era of declining maintenance budgets is dependent on a systematic approach to traffic sign maintenance.

My presentation today is based upon the results from the development of the National Cooperative Highway Research Program Synthesis Report #157 *Maintenance Management of Street and Highway Signs* with special emphasis on the management strategies of sign maintenance activities.

MAGNITUDE OF THE SIGN MAINTENANCE PROBLEM

The problem of inadequate funding for sign maintenance is all too evident. For example, a 1988 field survey of 37,211 traffic signs by the Pennsylvania Department of Transportation in the urban district surrounding Pittsburgh found that 60 percent of the locations surveyed needed to have some form of sign maintenance as shown below:

Signs to be left unchanged	14,889	40%
Signs requiring a new sign face of the same type	6,016	16%

*Presented at eastern workshop only.

Locations where signs were missing or requiring a new sign installation	11,461	31%
Signs to be permanently removed	4,445	12%
Signs to be relocated	400	1%

Comparable results are reported from other agencies that have conducted similar studies.

CAUSES OF SIGN MAINTENANCE

What are the causes of sign maintenance activities? It is only by knowing why signs are being replaced, that an agency can implement strategies to better manage their sign replacement activities. The table below provides a summary of the reasons for sign maintenance work activity based upon an analysis of 36,800 sign replacements in the State of Idaho for the period from January, 1981 through June, 1988.

Reasons For Sign Maintenance Activity

Reflectivity/Delamination	30%
Size, Legend or MUTCD Changes	31%
Vandalism	26%
Accident/Weather Related	13%

IMPACT OF MAINTENANCE DEFICIENCIES

Deficiencies in sign maintenance can have serious impacts on the highway system and on public agencies. These maintenance deficiencies primarily result in a reduction in safety for the motorist and increased liability exposure for the agency.

Highway Safety Implications

Deficient sign maintenance can have a number of effects on safety. The most direct effect is the potential for accidents. A missing or poorly maintained sign can be a direct cause of a serious traffic accident. In addition, it is believed that when vandalized signs are not repaired or replaced in a timely manner, "copy-cat" vandalizing of other signs in the immediate area will frequently occur.

Liability Implications

Tort liability judgments attributed to inadequate maintenance of street and highway signs cost public agencies large sums of money each year. In almost every State, the shield of sovereign immunity has eroded as legislators have modified governmental immunity or in some cases immunity has been abolished by judicial decisions.

Studies of tort liability cases have shown that alleged maintenance defects are the cause most often cited in the tort lawsuits. For States, 29 percent of the tort claims against them are related to traffic control devices. For counties and cities the percentage of claims related to traffic control devices were 25 percent and 37 percent respectively.

A study of highway tort liability in Pennsylvania showed that signing deficiencies were cited as the primary factor in 20 percent of the sampled tort actions, second only to pavement deformities. When considering only those highway accidents where a fatality or serious injury occurred, signing deficiencies ranked as the primary factor most often cited (41 percent).

Between July 1, 1979 and June 30, 1988 the State of Pennsylvania paid nearly $100 million in settlement costs for tort liability actions. Had this money been available for maintenance, approximately one million signs could have been replaced.

STRATEGIES FOR MANAGING SIGN REPLACEMENT

Government agencies are using a number of methods to better manage the maintenance of traffic control devices. These methods include: implementation of a Highway Risk Management program; improved detection of sign maintenance needs; development of continuous sign replacement programs; development of off-hours response priorities to improve safety while reducing worker overtime and liability exposure; salvaging and refurbishing sign material; better management of sign vandalism to reduce occurrences; and utilization of contract maintenance to supplement or replace existing work forces.

RISK MANAGEMENT

Given the liability environment that public agencies are operating in today, experts in transportation and law are recommending that agencies adopt a risk management program to minimize tort liability losses. Risk management is a process in which an agency attempts to identify, quantify, and control exposure to tort liability actions. For a traffic agency, a complete risk management program contains many activities, including:

- Recognizing and anticipating the degree of legal risk inherent in all of an agency's system responsibilities and programs, procedures, or actions.

- Ensuring that available resources are used in a manner to achieve maximum reduction of risk and prevention of loss while accomplishing the mission of the agency.

- Preparing a timely, defensive response for actual or threatened legal actions.

- Managing claims to result in proper resolution while achieving economy and fairness to the agency and therefore the public.

While a complete risk management program contains many activities, in general, a Highway Risk Management Program is made up of two separate activities, a Risk Management Program and a Litigation Management Program.

The Risk Management Program is directed at reducing traffic accidents and the risk of incurring liability claims against the agency, principally through the improvement of the safety of the road system.

The Litigation Management Program attempts to provide better defense for the agency once a liability claim has been filed, and thus to minimize the amount of loss from these claims.

In some States, many local agencies which do not have the resources on their own to establish a risk management program have established joint liability pools. These pools have been effective in establishing post-loss strategies for managing the road agency's risks.

Bryer, in a risk management analysis of highway maintenance operations for the Pennsylvania Department of Transportation developed a set of strategies to reduce exposure to tort liability. Those which were related to signing are as follows:

Emergency Maintenance (Working and Non-Working Hours)

1. Develop a communication system such that police departments can contact an individual in authority such that the emergency maintenance needs can be reacted to in a timely manner.

2. Establish a process for crews to quickly assemble to respond to emergencies.

Notification of Hazard

All complaints of hazard should be documented on a standard notification form.

Signing

1. Develop a methodology to identify and correct sign deficiencies.

2. Missing or knocked down STOP signs should be treated as an emergency condition and replaced or reinstalled in a very short period of time.

3. Develop a process to identify sites where foliage can reduce the visibility of a sign.

From a study on highway related tort claims to Iowa Counties eight recommendations were developed for reducing the potential exposure to tort liability. Two of the eight recommendations related directly to sign maintenance management:

1. Establish a continuing sign inventory process.
   A sign inventory is essential to provide evidence of the existence of a particular sign in a particular location at a specific time. It also provides a convenient mechanism for evaluating sign usage for conformance with standards. The inventory process should be continuous with constant updating as signs are added, removed, or replaced.

2. Establish a road and sign notification and inspection program.
   Many claims result from temporary conditions such as sign vandalism. A systematic method of notification of such conditions should be established utilizing assistance from the general public as well as highway department workers and other public employees who travel regularly within the jurisdiction.

DETECTION OF MAINTENANCE NEEDS

An important element of a good street and highway sign maintenance management system is the timely detection of maintenance needs. This detection requires the cooperation of many different agencies and personnel. The sign crew and their supervisor could detect the maintenance need through a procedure of regularly varying their path to and from the maintenance garage. The police department in their travels pass most of the signs on the major road system, particularly at night. The garbage collectors, postal carriers and other maintenance workers are also good sources for information on maintenance needs. Citizens, especially those who drive the same routes on a daily basis are extremely sensitive to any change in traffic control, and they represent a potential patrolling force with complete and continuous coverage. It is good practice to actively seek this input for again it increases the size of the maintenance detection forces. However, in most agencies, little effort has been made to formalize the citizen reporting concept.

Some cities and counties publish a newsletter on a periodic basis. Within it, they provide a listing of frequently called phone numbers including a special telephone listing for sign and signal maintenance needs both during normal business hours and during non-business hours.

Field Inspection

The establishment of a sound field inspection program requires the thorough training of the inspectors and a systematic data collection and analysis procedure.

The Maryland Department of Transportation in 1979-80 embarked on such a night-time field inspection program to determine the retroreflectivity of all regulatory and warning signs on all State highways.

As a first step, Maryland DOT conducted a training program in the inspection and rating of sign retroreflectivity for the 20 construction inspectors who were selected for the project. This training session involved the inspection of various signs with differing levels of deterioration and an interaction process to develop a consistency in ratings amongst the inspectors.

The actual field inspection used the following procedure:

Office Preparation

Each two man team viewed the photologs of the roads to be surveyed and they recorded all existing warning and regulatory signs on a data collection form.

Night Field Inspection

The field inspection consisted of evaluating all the warning and regulatory signs and noting those signs which did not meet the desired retroreflectivity levels. While the inspectors were checking for retroreflectivity, they also noted any defects or other damage.

Daytime Follow-up

Before the replacement signs were ordered, the district traffic engineer reviewed each sign found to have unsatisfactory retroreflectivity to determine the sign's necessity and whether or not it was the appropriate sign and located correctly.

Service Histories to Detect High Maintenance Locations

Many agencies which have computerized sign inventories are using the inventory to maintain a service history of the signs. This service history helps to identify locations where there is an inordinate amount of sign maintenance activity. By identifying the locations of these high frequency maintenance signs, countermeasures can be developed to ameliorate the problem. For instance, if a sign is frequently being stolen, anti-vandal nuts could be used. If a sign is frequently being knocked down, it may be an indication that something is wrong with the road system at this location and should be checked. In addition, the sign placement should be examined to see if it is possible to relocate the sign.

Even those agencies which have a card file inventory system can use the file to identify service histories. However, the identification process would have to be done at the time the data is entered on the card. A system wide search of the card file would probably be too time consuming to be practical.

RESPONSE PRIORITIES FOR EMERGENCY SIGN MAINTENANCE

Emergency repairs which need to be made during off-hours are a major concern to management because of the expense of overtime pay. Different methods are used by agencies to cover emergency repairs occurring outside of the regular working hours. A few agencies keep full operation on a 24-hour basis. These are usually State highway departments or large cities or counties. Others reduce their level of operation during the off-hours, keeping a minimum staffing level to respond to an emergency. Most agencies keep maintenance personnel on a rotating duty roster to be called at home for emergency repairs. Some of these agencies may keep a traffic maintenance dispatcher on 24-hour duty. However, a more common practice in cities is to transfer the dispatching duties during off-hours to a police dispatcher, who either calls the designated repair crew or the duty foreman. Many small agencies have no planned response procedures for off-duty hours. In those jurisdictions, police are usually provided with STOP signs for use where necessary and all other repairs are handled during normal work hours. The decision as to which procedure is to be followed is usually made on the administrative level based upon cost considerations.

With the intent of providing as safe a road system as possible but still keeping control of overtime expenditures, some agencies have developed specific policies related to the after-hours call-in of sign workers for emergency sign maintenance. For instance, some agencies indicate that any red series signs (except parking) or "W1- " yellow series signs require overtime call-in when reported on the off-shift. Other agencies leave it up to the discretion of the foreman or dispatcher to analyze the type of sign and the specific signs importance based upon location and traffic flow to determine if a work crew should be called in. Still others indicate that overtime is not utilized and all sign maintenance takes place on the day shift.

CYCLES OF SIGN REPLACEMENT

Of particular management interest is the impact that deficient signing has on an agencies budget. Because of financial and personnel limitations, it would be impossible for most agencies to gear up to replace all of their deficient signs in a 1-year period. A more realistic approach to the problem is to establish a systematic program for replacement of a certain percentage of signs each year. That way, an agency is able to program the replacements on a continuing basis.

Many agencies have adopted the manufacturers' warranty period, i.e., 7 years for engineering grade signs and 10 years for high performance sheeting in developing a systematic sign replacement program.

For instance, the City of St. Paul, Minnesota has divided the city into seven maintenance districts. Each year the sign department replaces all of the signs in one district. The eighth year the sign department goes back to district one and starts again. Utilizing this procedure, the city is able to ensure that all signs are no older than 7 years. In addition, the replacement program can be accomplished within a reasonable budget and with no increase in staffing levels.

Agencies that have a computerized sign inventory, frequently utilize either a "Life Expectancy" or "Years Sign at Site" data field in the inventory to develop a systematic sign maintenance program. Utilizing the inventory, an agency can ascertain through a computer search exactly what signs need to be replaced each year and develop their program accordingly.

Other agencies periodically enter into a large scale sign upgrading program. For instance, the City of Rochester Hills, Michigan has recently begun a four year program of sign replacement to upgrade the quality of signing on the city streets. The program is as follows:

Year One
- Begin and complete red series signs
- Begin yellow series
- Begin green series on major roads

Year Two
- Complete Yellow series
- Continue green series on secondary roads
- Begin green series on residential streets

Year Three
- Continue and complete green series on residential streets

Year Four
- Replace any other series signing not yet replaced

SIGN REFURBISHING

Because of the declining financial resources of public agencies and the ever increasing cost of aluminum, many agencies are now using some form of salvage and refurbishing for sign faces and posts in order to reduce their material costs.

Currently, most refurbishing is accomplished by using some form of mechanical stripping or by sign overlaying.

Mechanical Stripping

The Missouri Highway and Transportation Department (MHTD) estimates that it has saved $3 for every $1 invested in a sign reclamation effort that is able to salvage approximately 75 percent of Missouri's used signs. The MHTD reclamation process includes a sign blank straightener, a mechanical stripper which uses a sanding procedure, and shearing and punching equipment for re-sizing the blanks.

During the first year of operation, it was estimated by MHTD that 139,000 sq ft of metal signs had been reclaimed by this process and the savings amounted to more than the cost of establishing the system.

The Pennsylvania Department of Transportation (PennDOT) also salvages its damaged aluminum signs. The actual recovery of the sign blanks is done by a contractor, but sign shop labor is expended in sorting and handling the used signs. In fiscal year 1986-87, 33,770 sign blanks, representing 37 percent of PennDOT's annual sign usage, were salvaged.

An analyses of the PennDOT cost savings per square foot of aluminum salvaged is as follows:

Cost Element	Cost/Sq. Ft.
SALVAGE	
Sign Shop Labor	$ .07
Vendor Stripping	.40
Scrap Value of Used Signs	.37
Total	$ .84
NEW SIGN BLANKS	$1.07
FAVORABLE VARIANCE	$ .23

For those agencies which do not have the volume to justify the initial cost of a sign reclamation system, there are private contractors available for doing this activity.

Overlay

Another method of sign refurbishing is the overlay of a new sign face onto an existing damaged or faded sign face either in the field or in the sign shop. This process uses a high-performance sheeting with a thin, semi-rigid aluminum backing that has a very aggressive pressure sensitive adhesive. The sheeting can be overlaid on old signs by wiping the old sign with a solvent, then positioning and applying the new sheeting. The retroreflective sheeting material is then pressed into the metal backing with a hard rubber roller applicator. Using this process, no stripping of the sign face is involved.

Some agencies are using the pressure sensitive overlay material to upgrade large guide signs while still in place in the field. Other agencies are applying the new sign faces in the sign shop instead of in the field. They feel they have better control of the quality of the overlay by applying the new face in the controlled conditions of the sign shop. Whether the overlaying is accomplished on-site or in the sign shop, the ability to upgrade signs with the overlay retroreflective sheeting eliminates the cost of many new sign blanks.

VANDALISM

Sign vandalism cost taxpayers millions of dollars each year, and has been reported as a contributing cause in a number of serious traffic accidents. Surveys of State and local agencies indicate that up to 30 percent of all sign repair and replacement is due to vandalism and that an average of 30 percent of a typical sign maintenance budget is used to repair or replace vandalized signs.

Many agencies indicated that the vandalism problem is related to a specific type of sign (i.e. street name, stop, etc.) and, in many cases, the same sign is repeatedly vandalized. Thus, where this can be identified, there are countermeasures available to reduce the incidence of vandalism.

Excessive maintenance costs and the potential for serious traffic accidents due to vandalized signs has resulted in the development of a wide range of remedial measures and programs.

Most sign vandalism countermeasures fall into one or more of the following categories:

1. Physical Countermeasures: This includes use of property identification seals and agency decals on the back of signs, vandal resistant sign face material and fasteners, raising the height of signs, improving the anchoring of posts in the ground, and using a different type of substrate such as lexan or plywood that continue to perform the sign function, even though marred. Plywood substrate, for instance, reduces the effect of bullet damage.

2. Legal Countermeasures: This includes enacting and enforcing anti-sign vandalism laws and the placement of warning labels on the back of signs warning of penalty for theft, vandalism, etc.

3. Educational Programs: This includes education programs targeted at specific age groups which detail the adverse effects of sign vandalism on accidents and costs to society.

4. Public Information Campaigns: This includes public information spots on radio and TV, and conducting highway sign "amnesty" weeks.

Other techniques to reduce maintenance costs through reduction in vandalism include:

- Peen the bolt threads and nut to eliminate the ability to remove it with normal hand tools.

- Place signs that must be close to the roadway at the maximum practical mounting height.

- Use extruded aluminum sign blanks for street name signs to increase the resistance to bending.

CONTRACT MAINTENANCE

An increasing number of States and municipalities are relying on private contractors to do routine maintenance on our highway system, including sign fabrication and maintenance. A number of reasons have been cited for this trend including, staffing problems due to budget constraints, lack of specialized equipment or skills and taxpayer perception that government has grown too large.

Some agencies may contract out only a portion of their sign maintenance activities such as overhead freeway sign replacement or the installation of signs on new roads or major reconstruction projects. Other agencies have contracted out the sign maintenance activity to such an extent that the contractor is performing the entire sign maintenance activity - from fabrication of the sign in the contractors sign shop to the installation, repair and replacement of the signs on the roadway.

CONTRACT MAINTENANCE IN TORONTO, ONTARIO

The Metropolitan Toronto Roads and Traffic Department, Ontario, Canada has utilized contract maintenance of traffic control devices since the early 1960s. As used in Toronto, the contractor basically replaces every aspect of a normal municipal traffic operations unit, including the production, installation and repair of all traffic control devices including signs.

Advantages

The Municipality of Toronto feels that the privatization of the sign maintenance activity has resulted in a number of finance and budgetary benefits, including:

- Contract maintenance avoids large capital costs for the agency. By contracting out the sign maintenance function, large outlays for facilities, equipment, and training of personnel are not needed.

- Contract maintenance provides for easier budget control. Sign maintenance programs can be accurately estimated since the contractor is paid a fixed price for the maintenance activity.

- The variable costs associated with the work force are eliminated since the contractor is responsible for sick time, vacation time and workers compensation.

- The contractor is able to vary the size of the work force to meet the demand for sign maintenance activity. During the winter months when sign maintenance activity is low, the contractor is able to reduce the staffing levels by up to 50 percent. During special sign replacement programs or during peak maintenance periods, the contractor is able to add personnel to gear up for the larger maintenance effort. This adjustment to staffing levels to meet maintenance needs would be difficult to obtain with governmental personnel.

Disadvantages

The implementation of the contract maintenance in Toronto in the early 1960's was facilitated by the absence of an existing sign maintenance activity. The Metropolitan Toronto Roads and Traffic Department had just assumed maintenance responsibility for the road system. After, an examination of the personnel requirements and the large capital cost outlays for equipment, it was decided that the most effective way to provide this service was through the utilization of contract services. In many agencies with existing work forces and equipment, this total contractual services concept might not be feasible.

CONTRACT MAINTENANCE IN MONTGOMERY COUNTY, MARYLAND

Montgomery County, Maryland, in March, 1988 entered into a sign maintenance contract with a contractor to supplement their existing sign crews. Due to political constraints, the county was unable to expand their maintenance staff size to accommodate the rapid population growth that was occurring. As a result, the backlog of signing work orders became unacceptable.

As an initial test, the contractor has provided one, two-man sign crew which is assigned all of the street name sign installation and repair work. As the county gains confidence in the quality of the work of the contractor, other types of sign maintenance activity may be assigned

The contractual agreement in Montgomery County differs from the Toronto agreement in that the contractor is providing the labor and equipment, the county is providing all signs, posts, and related hardware.

Montgomery County staff attribute the good results they have obtained to the very detailed specifications that were developed and aided by the fact that the contractor's foreman is a retired county sign crew foreman who is familiar with county policies and guidelines.

SUMMARY

I have briefly discussed a number of sign maintenance strategies and techniques which agencies are using to improve the quality of their sign maintenance activities. There are many other techniques which you may find useful. These methods include: implementing a sign inventory process; improvements in worker productivity through more efficient equipment such as computer aided drafting systems for sign legend layout and fabrication; use of robotics to reduce personnel requirements; selection of materials which provide better performance and benefits versus costs; improved procurement specifications and determination of manufacturer compliance to specifications; obtaining quantity discounts through joint purchase with other agencies or projection of material needs to allow the purchase of larger quantities; utilization of sign installation techniques that reduce and expedite maintenance; and improved control over the purchasing, storage, and distribution of the many items used for sign maintenance.

In conclusion, by developing a systematic approach to sign maintenance, an agency can effectively manage its traffic sign maintenance and insure that the roadways are safe and efficient for the motoring public.

STRATEGIES FOR MANAGING SIGN REPLACEMENT

Dwayne Hofstetter*
Traffic Engineer, Highway Division
Oregon Department of Transportation
504-A Transportation Building
300 E Summer Street, N.E.
Salem, OR 97310-1354

Oregon is in the process of replacing Interstate freeway signing through a series of rehabilitation projects. This is in response to the need to replace signing that is at or beyond its life expectancy. Interstate freeway signing replacement will be the major topic of discussion, but our experience with off Interstate sign replacement and sign replacement through maintenance programs is also discussed.

INTERSTATE SIGN REHABILITATION

After the completion of the majority of the Interstate freeway system construction during the 1960's, no large signing projects were undertaken on our Interstate system. As time elapsed, the existing signing soon began nearing its intended life span. The constant changes in summer and winter weather conditions and age had a direct effect on sign condition contributing to poor reflectivity, particularly nighttime visibility, as the button copy legend began to decay. Almost all of the freeway guide signs were button copy legend on opaque backgrounds. Vandalism and sign damage also added to sign deterioration. Not only were the signs in need of rehabilitation, but a portion of the sign supports were in need of replacement due to damage and new improved design standards. Because of the condition of the existing signing, it was decided to embark on a series of projects to upgrade our Interstate freeway signing. The original scope of the undertaking was to replace only the mainline freeway signing. As the projects developed into final form, it became apparent that ramp terminal signing and control signing was also in need of replacement and these added to the project scope. Funding for the rehabilitation projects was accomplished through Interstate 4-R (resurfacing, restoring, rehabilitation, reconstruction) funds.

ALTERNATIVE METHODS OF REHABILITATION

As part of the rehabilitation process, a determination between rehabilitating the signing with an overlay or opting for complete sign replacement had to be made. After reviewing available materials we chose a sheet aluminum overlay faced with encapsulated lens reflective sheeting for the rehabilitation projects. Deciding factors in the use of this material were the

*Presented at western workshop only.

guarantee, the expected life cycle costs, and higher levels of service associated with the sheeting. Signs that were damaged and not able to be overlayed were to be replaced.

A number of items need to be considered in determining the use of an overlay versus total replacement. Thickness of overlay, durability, projected lifespan, field installation, and cost should be weighed against the ease of installation, life expectancy and cost of total sign replacement.

When the first of these rehabilitation projects was let, the contractor requested that all the signs be replaced as opposed to overlaying with sheeting for the same bid price. This request for complete sign replacement might have been due to the difficulty of installing the overlays in the field versus sign replacement. The expected sign life was the same for both options, so it was appropriate to approve the request.

PAST AND PROPOSED PROJECTS ON INTERSTATE SYSTEM

Upon determining the scope and method for the sign rehabilitation, a series of contracts were awarded beginning with Interstate 5. Three projects were let with the letting date, length, and contract bid price listed below,

- Section 1 - August, 1984 - 210 mi - $ 987,000.
- Section 2 - August, 1985 - 80 mi - $ 497,000.
- Section 3 - October, 1985 - 25 mi - $1,190,000.
  (Includes 14 mi of urban freeway in Portland.)

As previously mentioned, the contractor requested to replace the signs instead of overlaying the signs in the first project. In the following two projects a choice between sign overlay and sign replacement was given.

In both cases the contractor chose to replace the signs. Contractors will have the option of sign replacement in future projects.

In addition to signing projects completed, four additional projects are to be contracted on the interstate system. These projects are listed below.

Project	Proposed Date	Length	Approximate Cost
Interstate 205	March, 1990	13 mi	$ 700,000.
Interstate 84 (I)	1991	70 mi	$1,200,000.
Interstate 84 (II)	1991	120 mi	$1,200,000.
Interstate 84 (III)	1992	140 mi	$1,200,000.

OBSTACLES ENCOUNTERED

The formation and execution of the sign replacement contracts did not develop without leaving a number of barriers to clear. The first signing contract called for the use of button copy legend on high intensity sheeting. After the contract was completed, complaints of poor sign legibility arose. Upon investigation, it was discovered that as the temperature reached the dew point, the reflectivity of the button copy legend, due to moisture collection, was reduced producing a "washed out" effect of the sign legend. To correct this problem, a separate contract calling for high intensity demountable cutout legend was let. Future contracts were to use the high intensity demountable cutout legend.

Another obstacle experienced was the age of our sign inventory from which contract plans are formed. Due to delays in project scheduling our sign inventory now needs to be reviewed. Signs once scheduled for replacement have been replaced due to damage and/or legend changes and no longer require upgrading. In addition, a number of other signs and supports are now in need of replacement since the original sign inventory. Project costs have also escalated since the original rehabilitation concept due to inflation, cost of materials, and a need for better project scoping. Consequently, the previously quoted project costs may change considerably for the future projects.

PRODUCING POSITIVE RESULTS

A number of past experiences have helped in determining a better approach to replacing our interstate freeway signing. Improved project scoping, reducing the contracts to a size more manageable, and opting for complete sign replacement as opposed to overlay has assisted in producing an upgraded interstate freeway signing system, producing improved target value, daytime and nighttime visibility, and legibility that will last until the updating process must be repeated.

OFF INTERSTATE SIGN REPLACEMENT

Unlike the interstate signing replacement projects, we do not have a program set up to replace our off interstate signing. This signing is normally replaced through an ongoing maintenance process and construction projects. All projects that are scheduled for contract construction are reviewed for signing needs. Due to the limited number of construction projects undertaken in a year, not all signing work needed can be completed. We contract approximately $175 million of construction with approximately $1 million of signing each year. We are dependent upon our maintenance programs to upgrade any deteriorated or damaged signing not replaced by contract signing.

MAINTENANCE PROGRAMS & SIGN REPLACEMENT

Damaged or vandalized interstate highway sign replacement and most of our off-interstate highway sign maintenance is done by our State maintenance crews. We have 16 crews to cover approximately 7,500 centerline mi with over 100,000 signs. In addition to sign maintenance (replacement) the crews also install new signs including logos and tourist oriented directional signs for the Travel Information Council. Each district sign crew keeps an inventory by hand, but we don't have a computerized State inventory and our current maintenance management system doesn't have the capability of providing any categorical or location sign replacement projections or needs other than by district.

We continue to add more new signs each year and in order to maintain our signs at an acceptable level, sign replacement on our construction projects and projects such as the I-4R signing projects are necessary. No additional State personnel are expected to be added for sign maintenance in the future. We are doing a good job of keeping up our regulatory and warning signs, but many of our guide and service signs in several districts are in poor condition.

A computerized sign inventory and sign maintenance management system would help us be more effective, be proactive, and accomplish more. At the present time we don't have any good way to project needs Statewide other than using averages of signs made by our sign shop. We also need some good performance indicators to measure our effectiveness in sign maintenance. A reasonable reflectivity standard would be appropriate when we can practically and efficiently measure sign reflectivity in the field. The inventory sign maintenance management systems and qualitative reflectivity measuring would be very helpful for our sign maintenance programs as well as our sign design work for contract projects.

In closing, coordination between maintenance and construction signing activities on both interstate and non-interstate sign programs must be maintained to ensure that duplication and gaps in signing procedures do not occur. Communication between maintenance and design units will assist in the completion of higher quality signing projects and provide for a sign replacement system that will continue to address the needs of the motoring public.

DISCUSSION AT WESTERN WORKSHOP

Q: I noticed you dropped the word "limit" from your speed signs when I was travelling in your State?

A: The reason that we weren't using the word "limit" is that we've been a basic rule State for years. We just started to use some limits. For example, the legislature this last session went to a limit in some of the residential areas, a 25 maximum speed limit. The only other limits we have are the 55, the Federal maximum, and the 65, but most of our speeds are still basic rule. We didn't use the word limit because of that. When we've gone gradually to some of the limits, we didn't want to have two different signs so we've stuck with just the larger numeral.

THE ROLE OF INDUSTRY FOR BETTER SIGNING

Victor H. Liebe[1]
Director of Education
American Traffic Safety Services Association
5400 Jefferson Davis Highway
Fredericksburg, VA 22401

The topic of this presentation is "The Role of Industry for Better Signing." Highway signing, or a more descriptive broad term would be Highway Sign System Management, has characteristically been a public agency function that goes hand-in-hand with traffic operations. There is no doubt that such a function will remain a public agency responsibility and function even though more elements of the system management are being performed by private industry. So that we all are on the same wavelength, perhaps it is in order to establish just what part "industry" plays in management of the Nation's highway sign system.

Private industry members include quite a number of different entities. Manufacturers that make elements that are directly related to the signs themselves, such as substrates and faces, whether plain or preprinted, are major components. Sign fabricators are those that use the first two items in production of the finished signs. Service companies are those that perform the field function of installation, repair, removal, and refurbishing of the signs. Ancillary businesses include post, fastener, and other similar manufacturers. A final broad category is the Technical Support Services area. These are the consultants and others skilled in a variety of professions that perform valuable and indispensable services to the sign management system. These include Traffic Engineers and Technicians, Computer Science professionals and Technicians, and a variety of other supporting classifications of personnel. The list is nearly endless if it is carried to second, third, and levels beyond, but this should suffice to identify the primary industry categories.

Let's look for a moment at the elements of the sign management system itself to see where these industry components fit in. An ideal Sign Maintenance Management System is comprised of the following elements:

- Physical Inventory; obtaining an accurate, up-to-date record of what signs are in the field, their location, orientation, etc.

- Conditions Inventory (may be included as part of physical inventory); serviceability of sign and post, color (as compared to standard color charts), retroreflectivity.

- Technical and conditions evaluation of system; determination of the signs' value as a regulatory, warning or guide media, placement, meeting of warrants, proper placement; does the sign meet the standards for color, retroreflectivity, etc.

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[1]Presentation given by Robert Garret at western workshop.

- Selection of maintenance strategy and plan; on what basis should a sign system be maintained, sector basis, overall system based on category—i.e. regulatory, warning, guide, parking—what should the cycle be, etc.

- Funding support for plan; general fund as routine maintenance, capital improvement funds, bond issue, grants-in-aid, special assessment, etc.

- Records system selection; manual system, electronic data systems, video log, graphics, etc.

- Implementation; how to perform work, with existing work force, special hires added to force account, outside contract, etc.

- Inspection plan; use in-house staff, special hires, outside contract, etc.

Let's look at how the industry components fit into the elements of the sign maintenance management system.

The Technical Service Support firms may be involved in all of the elements except the implementation, or actual field activities. Generally the consultant firms are brought in to perform the physical inventory and the conditions survey. To a lesser extent, they are retained to organize record systems for maintaining documentation of work completed and for input back into the inventory to keep it current. Often they are involved in the inspection phase on maintenance and upgrading programs.

The sheeting, substrate, post, and fastener manufacturers' roles are clear, as well as the role of the fabricators; they provide the necessary materials used in the sign maintenance system. Their participation is a necessary ingredient in the implementation phase of a program.

A growing part of industry is the role of traffic service companies. These firms got their start a number of years ago in providing traffic control services for contractors that perform construction and maintenance functions. Their role has been expanding, especially in the last half decade, to include other services as well. Pavement marking and sign maintenance programs have particularly grown on an outside contract basis. The experience, to my knowledge, has generally been quite favorable.

I'd like to review one such case study of contract maintenance of a highway sign system that seems to have worked quite well.

In the late 1970's, the Cook County Highway Department, in Northeastern Illinois, reviewed their highway sign system to assess the status of a number of activities. Response time to emergency sign repair and replacement, the cost and efficiency of operation of their sign shop, cost and efficiency of sign field operations, capital investment and annual cost of the overall sign maintenance management program were the items investigated.

At the time of the study, the county had approximately 550 mi (1100 curb mi) of urban and rural roadway apportioned into 5 management districts. The system encompassed many separate suburban municipalities. Each district had one engineer with the responsibility of directing the sign maintenance operation and used one sign crew of three workers.

In order to have a basis for evaluating the current operation, the County Traffic Operations Engineer collaborated with a local Federal Highway Administration (FHWA) representative and a local prominent traffic control contractor. Options to the present system operation were explored from the point of view of an outside contracting source performing the sign maintenance function. Estimates of time to perform given tasks were made and the associated cost estimates were assigned. The overall scope of work considered was acquisition of materials, fabrication of the finished products, maintaining a working inventory, disposal of waste materials, and actual performance of sign repair and replacement tasks. A key element in evaluating the potential operation was the projected ability of the contractor to respond to emergency sign requirements. Since the contractor had a larger work force than the county, as well as a more extensive array of equipment, including service fleet, it was clear that the flexibility existed to provide a more rapid response to the emergency needs.

The assessment of the feasibility exercise was encouraging. Further evaluation continued, concentrating on lines of communications and procedure; an essential element of a contractual relationship if the system was going to work at all. The bottom line conclusion of the study group was that there appeared to be significant benefit to contract maintenance. Since the projected benefits seemed so significant, the county decided to make the move toward trying contractual signing services and bids were taken on May 7, 1980. Evaluation of the bids further indicated a "go" situation. The first contract was awarded on June 1, 1980. Several highlights of the contract merit special attention.

One of the critical elements, as mentioned earlier, was the response to emergency needs. It was necessary for the contractor to respond to a knockdown or other emergency need within a time frame of 4 hours after official notification.

A second factor was the necessity of the contractor to purchase signing materials on hand in the county inventory.

A third principal element was the requirement to respond to routine work order assignments within a period of seven days from date of work order.

And, a fourth element was the provision of the option to extend the contract one additional year, without going through competitive bidding, and with no change to the previous years contract unit prices or conditions. This could be done upon written mutual consent of both the county and the contractor, 90 days prior to the tentative expiration date.

The contract was executed and actual work commenced on sign maintenance on June 1, 1980. The county personnel previously on sign duties were either reassigned within the system or were accounted for through normal attrition.

Due to good first year results, the contract was extended for the optional year. A second contract was let on June 1, 1983 to the successful bidder. After four months of progressive experience with below standard performance with respect to meeting task time limits, especially emergency responses, and failure to perform to material and quality control specifications, the contract was terminated and reverted to bonding control with another contractor performing the work. Subsequent contract were let in June 1984 and June of 1986, each with one year extension, with the original contractor, in June 1988 and in June 1989, which is the present contract year.

A simple item, but nonetheless an important one, was given careful thought: the task assignment procedure and record keeping. A simple but effective five-part work order was s\designed with essential information on it. The work order assigned the task, gave authorization to do the work, provided a suspense record, provided an inspection and documentation of work done record, provided the basis for accounting and payment, and most of all, provided a means of communication amongst all parties involved. One of the highlights of it was that it provided a system for updating the inventory.

After nearly a decade of contract sign maintenance experience, a number of conclusions are quite clear. During the first year of operation, there were ups and downs in the operation, from both parties' points of view, until the system was "debugged." However, both the county and the contractor personnel worked well together since both had a great deal invested in the project. The overall conclusion is that the expectations of benefit from the contract were met and in most cases exceeded. The emergency response in particular has worked far better than anticipated.

An additional benefit has been realized, according to the engineer. The potential for tort liability suits related to the sign system was reduced. In this day, that in itself may be more than enough justification to encourage more of this kind of operation. Overall, the engineer found that the tasks completed were done well within the required time frame, and more quickly than was previously accomplished.

Many things were learning that first year of operation. Some changes in operational strategies were implemented after the first contract period, but the contract remained essentially the same.

The most important ingredient that led to the success of the operation was the cooperation and willingness to work together, along with well established lines of communication between the county and the contractor. Conflicts and differences were quickly worked out which assured continued smooth operation of the arrangement.

One lesson learned after a contractor defaulted was that a successful bidder would be required to have their own sign shop, to the county's satisfaction. This ensures that an adequate inventory of supplies is on hand, or at least able to be fabricated on short notice, and would prevent delays in performance due to lack of materials.

Although many direct and indirect benefits were realized in the county's experience, they cannot be quantified here. Evaluation of the operation is still ongoing. Generally, some of the benefits have been lower unit cost and therefore less cost to the taxpayer; fewer administrative headaches in directing the system; reduced liability claims; and generally a resultant "better peace of mind" through confidence in the contractor.

This example of one instance of contract sign maintenance has been presented, not to offer evidence that such is the only way to go, but rather to show how in one instance, a public agency having a large highway sign system reduced the cost of the operation and in so doing, realized some significant side benefits, through working with and relying on private enterprise.

To summarize what I have covered, I have shown the principle components of those involved in the highway sign industry. I've highlighted the major elements of a typical sign maintenance management system. And finally, I showed an example of how the two fit together to accomplish an important public works function.

As to the future of the role of industry in participating in more and in other kinds of activities in the public works area, this kind of complementary relationship can only grow. As emphasis in governmental spending continues to be a major concern of the general public, so will the effort of the governmental agencies to reduce spending and increase output continue to be a high priority item. Following the Cook County lead in highway sign management, a district of the Illinois Department of Transportation in the same Chicago area contracted the maintenance of its system in 1984. This system encompassed the State roadways in two counties with extensive roadway networks.

As new standards are promulgated for signs, pavement markings, and other devices, such as retroreflectivity standards, industry will respond quickly and favorably. In sign inventories, for example, since technology has jumped in quantum leaps in computer systems, video systems, and in combining the two with integrated video-discs to form an even more powerful system, industry has provided the wherewithal to most any public agency to have a very comprehensive and up-to-date sign inventory. When integrated with the CAD systems, we can get nearly instant graphics on sign inventories and conditions.

When we look at the need to have up-to-date data on sign system conditions, with respect to retroreflectivity, it will not be possible, nor practical, for each public agency to have its own reflectometer, much less the trained personnel needed to use it. Industry will certainly be able to satisfy that need.

And, when it comes to having a systematic replacement and upgrading program, public agencies will just not have the ability to staff up in order to react to the program needs. Private enterprise will respond. Due to the nature of private competition, costs will be kept in line. Industry can more quickly respond to the needs for skilled technicians, and can better weather the peaks and valleys in work load because of its greater flexibility. There is even a more important side benefit to having industry assume a larger role in public works operations: that of transfer of risk.

When I look at the problems that governmental agencies are facing today, such as increasing traffic congestion in even small urban areas with no foreseeable solutions, increased levels of interest in and concern for the older driver, increased levels of concern for driver, worker, and pedestrian safety, and increased pressure for governmental agencies to do even more without increasing costs. It says to me, "Industry can and will play a more significant role in public works projects in the future." It's in the Nation's best interest. Highway sign maintenance is but one of many areas that industry can respond favorably to.

DISCUSSION AT WESTERN WORKSHOP

Comment:

> There is a video of the sign management systems in each FHWA regional office if anyone wants to borrow a copy. ATSSA has completed a video on how thermoplastic pavement marking materials should be applied and inspected. This seems to be the main area of problems. The video is directed toward the public agency inspector. FHWA is purchasing copies and will send out copies to each of the regions and divisions.

Comment:

> It sounds like the Government sign shops are not as efficient as private contractors. My feeling is that the Government sign shops could make signs just as cheaply as outside contractors, but they're being managed by too many high-salaried people. There are too many people trying to manage the Government sign shops, which raises the overhead. They could be run efficiently if they would just put someone with a good head for business in the sign shop and let him or her run the place.

A: I didn't mean to indicate that public sign shops, or State sign shops, were poorly run or not as well run as private sign shops. I tried to emphasize that there is a place for everything. The best thing is for Government and private industry to work together. As a basic principle, personally, I think our system in this country is based on the free enterprise system, and when that is allowed to work well, it works the best. I think that if a private industry is available it will serve a function for Government that should be used rather than Government getting into that business. Government agencies have gotten into some businesses that they shouldn't be in—those where there is private industry available to do things. But there are instances, for example, the Cook County situation, in which that's not going to work. The best thing is where the public and private sectors work together at solving problems.

Comment:

> What has been successful for us in Los Angeles, is that we do most of our work as half forced account and half on contract. Contractors are able to handle peaks. Contractors are able to do things that our government system can't do. For instance, if you really want to get work out, a contractor can pay his people a little more to work longer days and get the work done faster. That is not possible in our government system. We have

contract work and also our own sign shop and the same for stripers. That's also worked out well. That also lets me know what's more efficient.

BREAKOUT SESSION TWO

On the third day of the eastern workshop and on the second day of the western workshop participants attended a second simultaneous breakout session to discuss one of three additional topics:

1. Using contracting vs. in-house forces and prison industries.
2. Alternate procedures for sign replacement.
3. Traffic control procedures during sign maintenance.

In each breakout session, one participant briefly discussed a group topic as it related to his agency's experiences or policies. The moderator then led a group discussion by posing a series of questions. In the general session that followed, the moderator presented a summary of discussions. Below are the key discussion points, grouped by breakout session topic, as summarized by the moderator.

CONTRACTING VS. IN-HOUSE FORCES AND PRISON INDUSTRIES

- *Initial Contract*. When initially developing a contract for sign replacement or maintenance by outside contractors, the contract should last for at least 2 years. Developing a working relationship with a contractor to arrive at a steady flow of deliveries and activities takes time. Unless the agency has a good program of prequalification, penalty clauses for nonperformance or late delivery are suggested.

- *Finding Qualified Contractors*. Several agencies expressed concern in getting qualified contractors to help with sign fabrication and installation. This might be due to the fluctuation in State activities. Often when there is a new sign improvement program, there is a lag period before contractors start responding. Local and regional firms are not likely to move beyond an area where they can be cost efficient unless they know there will be a sustained program and opportunity for them.

- *Raw Material Problems*. Sign shop operators, both public agency and prison industry, expressed the concern for significant problems with the raw material, both the sheeting and the substrate.

- *Prison Industries*. Many States use Prison Industries for sign fabrication because they are required to do so by State law. For the most part, States have worked with their Prison Industry to ensure a good product and are satisfied.

- *Cost Comparison*. Oregon has one central sign shop in which it fabricates all but large overhead guide signs. Recently the State put out for contract bid 2,700 standard signs for building up its stock. The lowest bid was only $200 under the sign shop estimate of $120,558 ($45/sign). Oregon felt it was a good idea to put sign fabrication out for bid-to check the cost competitiveness and effectiveness of in-State sign shops.

- *Cost Comparison*. The Utah Department of Transportation stated it can produce more signs at lower cost and in quicker time than if done by outside contract. When the closing of the sign shop was being considered, the sign shop staff proved that they could fabricate signs 7-13 percent cheaper than Utah Correction Industries; the shop also responded more quickly in replacing critical signs.

- *In-House Vs. Contractors*. Los Angeles discussed its program, which consists of about 50/50 sign fabrication by in-house forces and outside contractors. The county considers this policy to be effective—it keeps the in-house shop active and keeps the contractors' bids down. The contractors realize that they could lose all business to in-house operations if their bids become too high.

- *Conditions for Effective Contracting*. The western group agreed that under certain conditions (including those that follow) contracting of sign fabrication can be cost effective.

  - More than one sign fabricator in the area.
  - Agencies do not have to rely solely on contractors.
  - Agencies cannot afford or allow overtime for its own staff or cannot hire more employees for peak demands.

- *Contract Methods*. Regarding some contract methods, the following points emerged:

  - Agencies need a person to monitor the contract for performance and quality.
  - Penalties for late delivery or inferior products should be included.
  - Incentives (cash bonus, etc.) may be helpful for emergency situations but generally are difficult to include in contracts.

SIGN REPLACEMENT AND REFURBISHING METHODS

- *System 5 Overlays*. The eastern group reached a consensus that 3M's System 5 overlays have not always been good for large guide signs, but are satisfactory for small, post-mounted standard signs such as Stop signs.

- *Sign Overlays*. Many States use aluminum overlays for sign refurbishing. Thickness of the aluminum has been examined with thicknesses ranging from 0.050" to 0.063". Riveting is used with spacing of usually 12" with 6" on the edges. Use of hand-held portable power drills are being used effectively, eliminating the need for generators. Mississippi uses extruded aluminum for new sign substrate. When refurbishing, the State uses overlay with vertical strips of 0.063" aluminum and rivets the strips to the existing sign panel. The sign shop makes the overlay sign. The rehabilitation work is done by maintenance crews operating out of the central office. District sign crews work on non-freeway signing. Some States feel that the overlay thickness needs to be increased to 0.080". One State that uses wood for substrate has used 0.03" thick aluminum overlays but has increased to 0.04" thick aluminum panels.

- *Button Copy Vs. Demountable Sheeting*. Button copy is being used less extensively with most agencies using demountable reflective sheeting for the copy/legend. The use of porcelain material for background is on the wane.

- *Adhesion*. Virginia tried using contact cement for adhering the overlay to the existing panel, but this method was not effective because the overlay cannot be moved once contact is made with the glue.

- *Materials Salvaging*. Salvaging of aluminum substrates is commonplace; some States salvage within their own shops and some use outside contractors. Quality control is a problem and checks have to be made to ensure signs are clean and re-anodized.

- *Silk Screen Cleaning*. Virginia has identified a silk screen cleaning process with non-toxic chemicals. (The company is Intercontinental Chemical Corporation of Cincinnati, OH; detailed information can be obtained from the company or from Robert Feldman of the Richmond District of Virginia Department of Transportation, 804-524-6193.)

- *Brightness Vs. Durability*. The eastern group discussed the issue of very bright vs. bright enough sheeting. Some participants felt that the industry should focus on developing a durable sheeting that well exceeds the minimum requirements for a long time.

- *Signing as a Priority*. One participant, as a final summary comment, suggested that a good byproduct of a minimum brightness standard would be the attention and priority that signing would get within the public agencies.

- *Freeway Guide Sign Materials*. Regarding materials for freeway guide sign replacement, Mississippi is using all Type IIIA sheeting material placed on extruded aluminum panels; Wyoming is using Type IIIA for copy and Type II for the background.

- *Sign Widening*. When Mississippi has to widen an existing guide sign, the crews remove all the extruded panels, put on longer panels (but only alternately), and then attach up to 0.125" vertical strips of sheet aluminum.

- *Sign Refurbishing*. In Mississippi when an overlayed guide sign needs refurbishing, crews simply remove the overlay and replace it with a new overlay at the same time. The replaced overlay is taken back to the sign shop and stripped of the legend. Then, the reverse side is used for another overlay panel.

- *Sign Replacement*. Mississippi replaces its guide signs about every 10 years. Earlier replacements are necessary with premature deterioration and are replaced under manufacture warranty.

- *Premature Failure*. States are experiencing more frequent premature failure of the Type II sheeting material; they attribute this problem to inferior products resulting from low bidding.

- *Need For Quality Sheeting*. The group reached a unanimous consensus that reliable, quality "engineering grade" sheeting is needed.

- *Fiberglass Overlays*. Mississippi has experimented with 0.08" fiberglass for overlays; no problems so far (1-2 yrs). Other States have experienced problems with this material.

- *Plywood Substrate*. Wyoming and Utah use plywood for substrate because of its lower cost, greater flexibility in shaping and handling, and ability to absorb bullets and minimize deterioration. Experiences with pressboard products have not been successful to date.

- *Overhead Sign Illumination*. States have varying policies regarding illumination of overhead signs; some States illuminate all signs, others will not illuminate signs in rural areas. The Federal Highway Administration's (FHWA) position is that the decision not to illuminate an overhead sign should be made based on an engineering evaluation considering sight distance, volume, sign criticality, and other factors.

- *Letter Size*. None of the States represented have gone to a larger letter size in response to perceived needs of older drivers.

TRAFFIC CONTROL DURING SIGN MAINTENANCE & REPLACEMENT

- *Training and Tools*. There are differences in the attention given and attitude toward traffic control during sign maintenance and replacement between State and local agencies. In general, States give their personnel training and the tools for setting up proper traffic control during sign operations. The tools consist of the *Manual on Uniform Traffic Control Devices* (MUTCD). Responsibility is assigned to the crew chief to set up whatever traffic control is necessary. The process is much less formal for local agencies because they are operating on lower speed or lower volume roads or in an urban environment. Also, the crews are usually no more than two people. The issue of productivity vs. safety arises because of the trade-off between spending time setting up traffic control versus getting the job done as quickly as possible.

- *Crew Training*. Training in work zone control is necessary on a continuous basis. All western States have training programs. Some have special meetings to discuss problems; in Utah they have weekly "tool box" meetings to discuss particular problems or procedures. One eastern State indicated that it has a policy of gathering work crews together on the morning of a project to discuss the specific operation and how to establish traffic control. States have refresher training which is tied into recertification.

- *State Vs. Local Training*. Many States include local agencies in their training programs. Training for local agency crews, however, remains a critical problem.

- *Exposure During Set Up*. There is an issue of exposure to crews while setting up traffic control devices. Some feel that the actual setting up is more dangerous in some cases than the work zone itself. The FHWA position on this aspect is that even though it takes more time to set up the traffic control plan, it is worth it as it reduces the probability of an accident and resulting injury to the workers or motorist. Local agencies are less rigid in application of traffic control. Some use a 15-minute exposure criteria; if a crew will be working for 15 minutes or less, they will not use any special traffic control.

- *Few Liability Concerns*. Eastern group members expressed no special problems about liability; hence, liability may not be as much of a problem as commonly thought.

- *Availability of Assistance*. State agencies have the ability to call upon assistance for complex situations; local agencies do not have the luxury.

- *Strobe Light Proliferation*. The increased use of devices to attract the attention of the motorist, such as strobe lights attached to the work vehicles and flashing arrow boards, creates conflicts. One problem with the strobe lights is their proliferation for uses other than "official" road activities. The group agreed that regulations restricting the use of amber lights for highway department purposes should be created.

- *Variable Message Signs*. Agencies could use variable message signs more effectively. These devices could be used to provide temporary guide signing while permanent signs are being replaced.

- *Truck-Mounted Attenuation Devices*. There is an increase in the use of truck-mounted attenuators and arrow boards for traffic control. The former has been reported to have prevented serious injuries on several occasions. Often, however, their use is limited because signing crews do not have high priority. These devices also limit access to the truck bed, which may hold the signs and equipment.

- *On-Site Replacement*. For overhead guide signs, the group reached a consensus that immediate replacement or refurbishing of deficient signs in place is necessary unless the sign is redundant. In that case, the deficient sign panel could be taken back to the sign shop and refurbished there. Immediate replacement is the policy of agencies for most signs.

- *Outside Contractors*. Virginia does use an outside contractor for sign maintenance and refurbishing and includes a pay item for traffic control. The State feels it is necessary to have traffic control as a pay item in order to get it.

- *Traffic Control Plans*. For routine operations, reliance is placed on the supervisor for traffic control and his or her knowledge of the MUTCD. For complex projects, i.e., replacement of overhead signs on freeways, traffic control plans will be developed in advance.

- *Standards*. The current MUTCD lacks standards that consider lower speeds and volume in the determination of traffic control requirements.

- *Moving Blockades*. On high-speed, high-volume roads, sign maintenance is performed at night or during low volume conditions. Some States have used a moving blockade to temporarily stop traffic when overhead signs are being removed or replaced. This has not worked very well, however.

- *Contracting for Traffic Control*. Contracting out traffic control is increasing. The advantages are availability of trained personnel and lower costs that come with paying just for the time traffic control is needed. The practice is also expected to help reduce liability of the State or at least create a shared liability.

SESSION 6

IMPROVED INVENTORY TECHNIQUES

MICROCOMPUTER-BASED SIGN INVENTORY SYSTEM

Steven C. Hearn[1*]
Assistant District Traffic Engineer
Virginia Department of Transportation
PO Box 259
Colonial Heights, VA 23834

The Virginia Department of Transportation is composed of nine construction districts. We currently have 360 miles (951 lane miles) of interstate highways for which Traffic Engineering has sole responsibility for signing maintenance replacement activities.

Our interstate system runs the entire range from rural to highly urban. The number of interchanges included in this system is 96.

Prior to 1987, no one was aware of what signs were on the system, where they were located or the sign's age. It was understood that the Department had a large investment in its interstate signs, but no one *knew* how much.

It was decided by Traffic Engineering management that an inventory would be conducted to determine the size of our signing assets. The District was told that no funds were available to have this task done under contract; thus, an in-house inventory was planned and carried out.

In conjunction with our inventory, the District Administrator asked for a report of signing conditions. It was determined that to be cost effective all inventory data would be collected at night so that a night inspection could be performed at the same time.

Work on this project began in October, 1987. Winter months were selected because of the extended hours of darkness and the reduced traffic on our interstates. Virginia is a prime tourist destination as well as the mid-point location of a major north-south interstate route (I-95); therefore, our winter months saw a significant decrease in average daily traffic (ADT).

We used two teams for data collection. Each two-person team was assigned a vehicle with a distance measuring device, and data collection was started with the mainline of our interstate routes.

The basis for data collection was the milepost marker. Each sign's location was pinpointed by its distance from the previous milepost. Specific data for each sign was noted on the data collection log (i.e., size, message, standard number, color, and type of sign structure).

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[1]Presentation given by Robert Feldman.
[*]Presented at eastern workshop only.

Much of the data needed for each sign was obtained by reviewing project sign plans or subsequent sign overlay project plans. Based on installation or date of maintenance replacement, we would later be able to create a six-year plan to budget sign replacement fund.

In previous years, maintenance/replacement funds were provided on a lump sum basis with very little tracking of how or where funds were used. The current Department administration initiated a system whereby maintenance/replacement funds were assigned to specific elements. All traffic control devices are assigned to Element 08. Monies in this element are further assigned to specific counties, specific routes, specific areas on the assigned route and specific maintenance/replacement activities (i.e., sign replacement and/or pavement marker replacement).

Funding for each location was provided only after an acceptable justification was submitted as to what work would be performed and the anticipated cost. If this justification was approved, funding was requested through the Maintenence Division's Budgetary Process. The completed process could result in full requested funding, reduced funding or no funding.

All funding approved for Element 08 must be spent on traffic control devices. In the past, maintenance/replacement money was very fluid and could be used for any maintenance activity, such as bridge repair or the plant mix schedule. The new system has been strengthened to the extent that Central Office approval must be obtained before moving available funds from one location to another within Element 08.

This new procedure has mandated that each district prepare a fully justified plan of how needs will be met and how adequate and timely funding would be assigned to specific locations.

After approximately four months, all mainline interstate routes had been inventorized. It was then up to management to determine in what format the data would be stored and presented. It was determined that the LOTUS spreadsheet would meet our needs. A spreadsheet was laid out and the entry of data was begun. This process was conducted during the day, while at night the inventory data collection was begun on each interchange.

Each ramp was assigned an alphabetic character, as was each direction of travel on the crossroute. Each exit ramp was measured from the gore area to the top/bottom of the ramp with each sign's location and message noted. On- ramps were measured from their intersection with the crossroute to the bottom gore area with all signs logged. Cross routes were logged from each junction sign.

Data collection of our interchanges was a very time-consuming effort. Two hourly employees were hired to collect interchange data. This data collection was done during the day and at night, sometimes 14 hours per day. The average diamond interchange was found to have between 30 to 40 individual signs, while full cloverleaf interchanges can have as many as 60 individual signs. A quick summary reveals that there are over 3,800 interchange signs.

At the conclusion of all data collection and data entry, a complete "ride through" was conducted to verify sign placement and to add/delete signing changes.

A final data printout was prepared for each of our residency offices and their routes of responsibility. A meeting was conducted within each residency to emphasize how important the inventory was and to make it clearly understood that all sign replacement or changes must be reported to the Traffic Engineering Section so that our records can be maintained accurate and up to date.

The completion of this task has met and exceeded our initial expectations. Our objectives which were achieved are the following:

- A complete uniform and centralized data base of interstate signs.
- An inventory which, though computerized, was "user friendly" while utilizing existing microcomputers and software and requiring very little additional employee training.
- Create an inventory which could be maintained current with minimum personnel/equipment demands.
- The flexibility to gather numerous fields of data through use of the Lotus spreadsheet, which permitted selected field displays based on data retrieval demands and requirements.
- Creation of a simple inventory format which would enable others to conduct field inspections with a limited amount of training.
- Create an accurate, verifiable system upon which future budgetary request could be based.
- Create a complete inventory system which would clearly pinpoint missing signs which would address the issue of possible tort liability.
- Create a complete/concise signing information source which would answer signing questions without requiring a field trip.
- Create a system to verify future claims which may be made against our sign material(s) provider where warranty failures may occur.
- Create a computerized inventory system which was versatile enough to be used in the field on a lap-top computer.
- Create an inventory system which could be down-loaded in the future to a statewide computerized traffic control device inventory.

VIRGINIA DEPARTMENT OF TRANSPORTATION STATEWIDE TRAFFIC CONTROL DEVICE MANAGEMENT SYSTEM

Fred F. Small*
Assistant State Traffic Engineer
Virginia Department of Transportation
1401 East Broad Street
Richmond, VA 23219

Good Afternoon:

Steve Hearn has provided you a presentation on computerized sign inventories utilizing micro computer at the local level. At this time, I would like to address expansion of that concept to a statewide program.

The Virginia Department of Transportation (VDOT), as I am sure each of your organizations have, recognized the need to develop a system to accurately and timely manage the important traffic control device program. Millions of dollars are spent each year in installation and maintenance of traffic control devices. Management and Legislators are requiring more attention to accountability and demonstrated budgeting requirements, both Fiscal and Human Resources, for the program. This, coupled with the need to maximize the utilization of our limited technical staff in response to traffic complaints and investigations and increased attention to tort liability dictate that we develop and maintain an effective automated management system.

One of our first initiatives in this area was to develop a system that would bring all major roadway components into a database with a common locator system. This system incorporates traffic volumes, roadway inventories, pavement management, accident data, structures, railroad grade crossings and traffic control and safety devices. Through this system design, any one of these subsystems can interface with the other and allow various inquiry capability.

The information I am now going to display (figures 18 and 19) indicates that data which can be captured in the traffic control device subsystem. You will note that there is a tremendous amount of data displayed; however, it must be kept in mind that all this data does not come from a single point, but encompasses the expressed requirements of individual responsible users throughout the Department. I should further point out that all the data will not be available immediately when the system comes on line. It will be a building process with priority placed on the criticality of the elements based on top management and the individual managers immediate need.

*Presented at eastern workshop only.

I realize this has been a very brief overview of the system; however, time does not permit more specific details to be addressed. Should you desire more information, please feel free to contact me after the meeting or at VDOT.

FILE NAME: Traffic Control/Safety Device (TCD/TSD) Inventory File

DESCRIPTION: This file consists of one record for each TCD/TSD recorded as being on the Link/Node System. These records contain data describing Signs and Sign Mounts, Signals, Guardrails/Barriers, Pavement Markings, Striping, and Delineators.

ACCESS METHOD: Normal Indices

DESCRIPTORS:
TCD/TSD ID
DUPLICATE TCD/TSD ID
DISTRICT/RESIDENCY/MAINT. COUNTY/AHD/DEVICE GROUP
DISTRICT/ROUTE ID/DEVICE GROUP
DISTRICT/DEVICE GROUP

RELATIONSHIPS: This file is used in conjunction with the Link File, by using the Route ID and Link Sequence No. or Node, to obtain additional data concerning the characteristics of the road.

This file is used with the TCD/TSD Activity File to access activities for a TCD/TSD for specific section(s) of road.

SIZE: 650,000 Records

Figure 18. Traffic control/safety device inventory file.

TCD/TSD INVENTORY FILE

DATA ELEMENTS

D	TCD/TSD ID		
	TCD/TSD PRIMARY ID		
	DISTRICT	A	1
	RESIDENCY	A	2
	AREA HEADQUARTERS	A	2
	TCD/TSD NO.	N	5.0
	TCD/TSD SUFFIX	N	3.0
D	DEVICE GROUP	A	1
	STATUS	A	1
	MAINTENANCE COUNTY	A	2
	ROUTE ID	A	14
	LAST UPDATE DATA		
	LAST UPDATE USER ID	A	8
	LAST UPDATE DATE	P	8.0
	LAST UPDATE TIME	P	7.0
	DUPLICATE REFERENCE INDICATOR	A	1
	TRAVEL DIRECTION	A	1
	PLACEMENT INDICATOR	A	1
	PLACEMENT FEET	N	3.0
	FACING DIRECTION	A	1
	BEGIN LINK SEQUENCE NO.	P	7.0
	BEGIN OFFSET DISTANCE	N	3.3
	END LINK SEQUENCE NO.	P	7.0
	END OFFSET DISTANCE	N	3.3
	BEGIN USER REFERENCE		
	BEGIN NODE	A	6
	BEGIN DIRECTION FROM NODE	A	1
	BEGIN DISTANCE FROM NODE	N	3.3
	END USER REFERENCE		
	END NODE	A	6
	END DIRECTION FROM NODE	A	1
	END DISTANCE FROM NODE	N	3.3
	SPECIFIC DATA	A	325 (*SEE REDEFINITIONS)
	PIMS CODE	A	10
	MUTCD CODE	A	6
	LAST INSPECTION PERIOD	A	1
	LAST INSPECTION LIGHT CONDITION	A	1
	LAST INSPECTION DATE	P	8.0
	LAST INSPECTION REPORT	A	1
D	DUPLICATE TCD/TSD ID	N	13.0
	ENGINEERING DRAWING NO.	P	4.0
	FABRICATION DRAWING NO.	P	4.0
	USER REFERENCE DOCUMENT NO.	A	10
	USER REFERENCE DOCUMENT DATE	P	8
	GENERAL COMMENT	A	70

Figure 18. Traffic control/safety device inventory file. (continued)

SUPER DESCRIPTORS

S DISTRICT / RESIDENCY / MAINT. COUNTY / AHQ / DEVICE GROUP
S DISTRICT / ROUTE ID / DEVICE GROUP
S DISTRICT / DEVICE GROUP

*EACH OF THE FOLLOWING GROUPS REDEFINES THE SPECIFIC DATA FIELD:

DELINEATOR ROADSIDE DATA	
DELINEATOR COLOR	A 1
DELINEATOR TYPE DESCRIPTION	A 30
DELINEATOR COUNT METHOD	A 1
DELINEATOR NUMBER OF ITEMS	N 4.0
GUARDRAIL/BARRIER DATA	
GUARDRAIL/BARRIER TYPE	A 1
GUARDRAIL/BARRIER SUBTYPE	A 2
GUARDRAIL REFLECTOR PIMS CODE	A 10
LIGHTING DATA	
LIGHTING TYPE	A 1
LIGHTING NUMBER OF ITEMS	N 4.0
PAVEMENT MARKING DATA	
PAVEMENT MARKING TYPE	A 1
PAVEMENT MARKING COLOR	A 1
PAVEMENT MARKING MATERIAL TYPE	A 2
PAVEMENT MARKING NUMBER OF ITEMS	N 2.0
SIGN DATA	
SIGN TYPE	A 1
SIGN HEIGHT	
HEIGHT FEET	N 2.0
HEIGHT INCHES	N 2.0
SIGN WIDTH	
WIDTH FEET	N 2.0
WIDTH INCHES	N 2.0
SIGN THICKNESS (INCHES)	N 1.3
SIGN REFLECTIVITY	A 2
SIGN MANUFACTURER CODE	A 10
SIGN MESSAGE	A 30 (OCCURS 10 TIMES)
SIGN MOUNT DATA	
SIGN MOUNT TYPE	A 2
SIGN MOUNT DESCRIPTION	A 30
SIGNAL DATA	
SIGNAL NUMBER OF BULBS	N 2.0
SIGNAL ACTUATOR TYPE	A 1
SIGNAL CONTROLLER TYPE	A 1
SIGNAL CABINET BT NO.	N 5
SIGNAL COORDINATOR	N 7.0
SIGNAL GROUP NAME	A 20
SIGNAL EQUIPMENT MANUFACTURER	A 10
STRIPING DATA	
STRIPING TYPE	A 2
STRIPING LINE MILES WHITE	N 3
STRIPING LINE MILES YELLOW	N 3

Figure 18. Traffic control/safety device inventory file. (continued)

FILE NAME: TCD/TSD Activity File

DESCRIPTION: This file contains a record of each activity pertaining to Work Orders or replacements/removals performed on any TCD/TSD contained on the TCD/TSD Inventory File. This file is used for Work Order planning, installation, repair, replacement, and removal activities and the storage of historical data for replaced/removed TCD/TSD's.

ACCESS METHOD: Normal Indices

DESCRIPTORS: TCD/TSD ID - to provide a unique key for each Activity File record with the ID matching the Inventory File record.

DISTRICT/WAS ACTIVITY/SUB-ACTIVITY - to allow the accessing of all work done of a specific type.

WORK ORDER NO. - to allow access by an outstanding or old Work Order No.

RELATIONSHIPS: This file is used, in conjunction with the TCD/TSD Inventory File, to provide Work Order installation, repair, and modification history.

SIZE: 350,000 Records

Figure 19. Traffic control/safety device activity file.

TCD/TSD ACTIVITY FILE

DATA ELEMENTS

D	TCD/TSD ID		
	TCD/TSD PRIMARY ID		
	DISTRICT	A	1
	RESIDENCY	A	2
	AREA HEADQUARTERS	A	2
	TCD/TSD NO.	N	5.0
	TCD/TSD SUFFIX	N	3.0
D	DEVICE GROUP	A	1
	ACTIVITY DATA		
	ACTIVITY TYPE	A	1
	ACTIVITY DATE	P	8.0
	ACTIVITY CREW	N	3
	LAST UPDATE DATA		
	LAST UPDATE USER ID	A	8
	LAST UPDATE DATE	P	8.0
	LAST UPDATE TIME	P	7.0
	WORK ORDER DATA		
	WORK ORDER ORGANIZATION CODE		
	WORK ORDER DISTRICT	A	1
	WORK ORDER RESIDENCY	A	2
	WORK ORDER AHQ	A	2
D	WORK ORDER NO.	N	10.0
	WORK ORDER DATE	P	8.0
	WAS ACTIVITY/SUB-ACTIVITY		
	WAS ACTIVITY TYPE	N	5
	WAS SUB-ACTIVITY TYPE	N	3
	FMS ACTIVITY/SUB-ACTIVITY		
	FMS ACTIVITY	N	3.0
	FMS SUB-ACTIVITY	N	3.0
	PIMS CODE	A	10
	NARRATIVE	A	70 (OCCURS 5 TIMES)
	HISTORICAL DATA		
	ROUTE ID	A	14
	BEGIN NODE	A	6
	BEGIN OFFSET DISTANCE	N	3.3
	END NODE	A	6
	END OFFSET DISTANCE	N	3.3
	TRAVEL DIRECTION	A	1
	FACING DIRECTION	A	1
	PLACEMENT INDICATOR	A	1
	PLACEMENT FEET	N	3.0
	ENGINEERING DRAWING NO.	P	4.0
	FABRICATION DRAWING NO.	P	4.0

S DISTRICT / WAS ACTIVITY/SUB-ACTIVITY

Figure 19. Traffic control/safety device activity file. (continued)

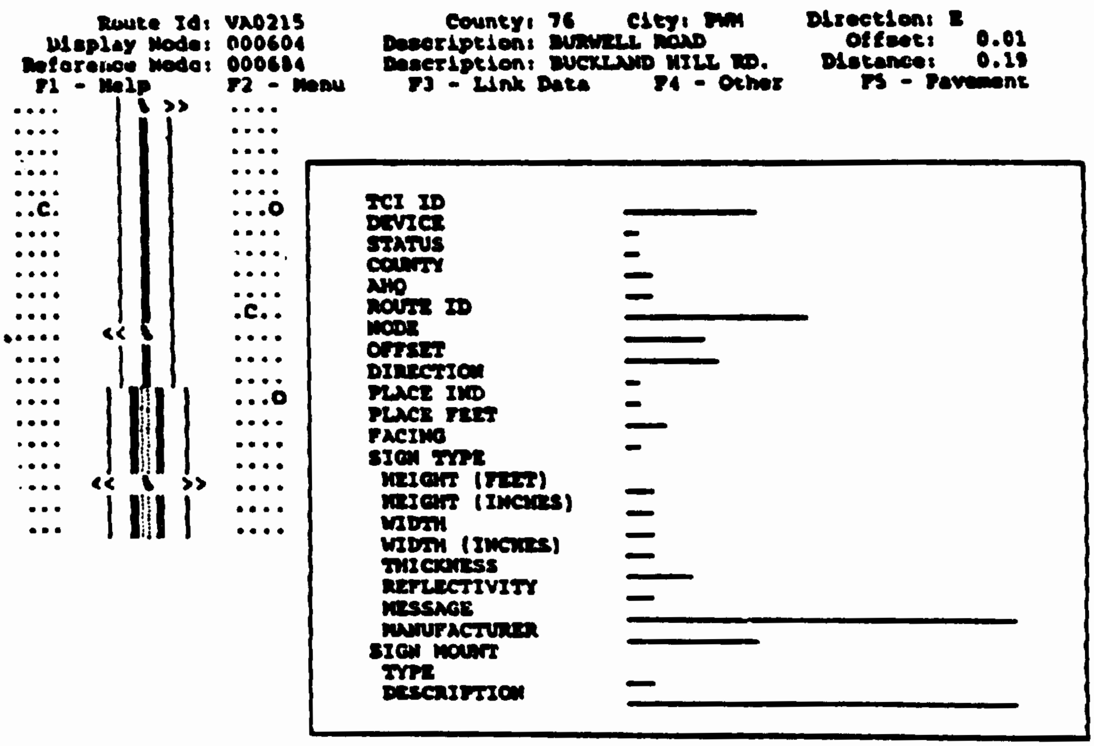

Figure 19. Traffic control/safety device activity file. (continued)

IDAHO TRANSPORTATION DEPARTMENT SIGN INVENTORY PROGRAM

W. Dan McComb, P.E.*
Assistant Traffic Engineer
Idaho Transportation Department
PO Box 7129
Boise, ID 82707-1129

Idaho recently implemented a new sign inventory system. It is resident on the mainframe computer located at Idaho Transportation Department (ITD) Headquarters and updated from terminals located in the District Offices. It is an on-line accounting of each physical sign on Idaho's highways. Each sign record has additional work history records linked to it for all past work done on the sign.

A correct and current sign inventory is very important for several reasons:

1. We want to know if a sign is missing so that it can be replaced. Knock down and theft of signs sometimes go unnoticed.

2. History of sign installation and maintenance performed is very important to sign and post material evaluation.

3. A correct and detailed historical record is a must for any tort case filed against the State.

4. Various types of reports are required for management and the public.

Idaho's sign inventory system is a great improvement over the previous system. Each individual sign has a six digit sequence number and no other sign will have this number. All information about the sign such as size, material, color, location, orientation, etc. is in the inventory. Also, the sign is located by a roadway coded segment that never changes and a milepost that very seldom changes.

Previous to the new program and the installation of District terminals, the sign crews would fill out a sign status form. The forms would then be forwarded to the Headquarters Traffic Section where they would be checked and the sign maintenance data entered.

Now, the sign foremen or lead workers enter the sign inventory updates directly to the screen. Paperwork is greatly reduced as is the chance of error.

Reports can be requested via terminal for any data or history contained in the accumulated data base. The reports can be requested for any type of sign or signs for any time period and for any section of highway.

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*Presented at western workshop only.

ITD is currently working on a program to use a lap top computer in the field. The maintenance data will be entered in the field and dumped to the mainframe from the District Office.

DISCUSSION AT WESTERN WORKSHOP

Q: How do you handle equations in mileposts?

A: It's done by a program.

Q: What about roads that are not on the system?

A: We don't keep anything on here except our own highways. They're mileposted.

Q: Can you call up signs older than a specified date you can enter?

A: Yes, we can put parameters on them and find out how old a certain sign is.

Q: How much detail do you have on guide signs?

A: On that master screen there was one entry that was called "legend" and you can put it in there. If it doesn't fit you can put it in the remarks section on the bottom.

Q: You said biennial reports and you can get printouts twice a year?

A: You can get it any time you want.

Q: How long does it take to print?

A: As fast as the fastest printer can go. It doesn't take very long.

Q: Can you tell, for example, what signs are 5 years old, high intensity and so forth?

A: Yes, I think so.

Q: I didn't see any indication for direction—northbound or southbound.

A: That's in there. Part of that master screen was oriented for the driver. It lists a code.

Q: What type of computers are in the field office?

A: Most of them are data terminals. Emulators can be bought to simulate PC operations.

Q: Can you sort by the class or type of sign?

A: Yes. We can tell how many we have, their size, where they're located, etc.

Q: How may signs do you have on the system?

A: A bunch. It would be easy to find out. All we have to do is look at our serial number, the key number, and it will tell you how many we've got.

MILWAUKEE'S COMPUTERIZED SIGN INVENTORY

Richard J. Butula, P.E.*
Traffic Engineer and Superintendent
Bureau of Traffic Engineering and Electrical Services
Department of Public Works
City of Milwaukee
841 North Broadway
Milwaukee, WI 53202

As the title of this presentation indicates, I will be telling you about Milwaukee's computerized sign inventory. But before we get to where we are today, I want to reflect back to how our sign inventory developed. Knowing the background and the evolution should provide you with a greater appreciation for what we are able to do today.

In the beginning, before I was even born, individual records were kept for each sign location on index cards. As crude as this method may seem today, it did provide a record of where and when a particular sign was installed. Unfortunately, this only showed the one location.

The next development in the early 1960s was to show the sign inventory on quarter section maps. This was able to provide a better visualization of an area but, space limitations restricted the amount of data that could be entered.

Starting in 1964, inventory cards were developed for each lineal block. They provided information for all the signs on the block as well as information about signs that may have been replaced. Although this system provided accurate information, it did have its limitation, as will be shown a little bit later.

In 1973 the City of Milwaukee was awarded a Federal grant to develop a computerized sign inventory. This project consisted of three parts. As initially planned, each part was to have been completed in a single year. Phases One and Two were a complete field inventory of all signs under the jurisdiction of the City of Milwaukee. Phase Three was the creation of a computer system, and entry of the data obtained in Phases One and Two.

Although the inventory phases were completed very close to the schedule, the system design, programming and data entry took more time than expected. The total cost over the 5-5-year period of the grant was $135,796.67.

The project accomplished all of the goals set forth in the original grant application. It provides accurate information to the courts, attorneys, and police department. It allows the scheduled replacement of aged signs without additional field inspection. It allows for the

*Presented at eastern workshop only.

location and scheduled replacement of nonstandard signs with standard signs. It allows field crews to identify the type of sign that needs to be replaced if one is missing. It provides the engineering staff with a list of locations that have a high frequency of damage reports. It provides statistical information necessary to schedule maintenance, inspection and/or replacement, and budgets for such activities.

RECORD DESCRIPTION

The minimum information required to enter a sign record includes the following:

- **Address**

  This is a five-digit numerical and a single-digit alphabetical field. The range for the numerical field is from 00100 to 12499. It specifies the location of the sign utilizing the existing house number system for the City of Milwaukee. The single-digit alphabetical field allows for locating signs within an intersection by coding an "I" in the field. It is also used to indicate an estimated address by an "E" code. Addresses are estimated whenever there is no address physically in the field. This is done either by interpolating between existing addresses in the field, or using the addresses assigned by the Bureau of Engineers plat books.

- **Roadway**

  This is a five-digit mixed alphabetical and numerical field. This five-digit field codes the street on which the sign is located. Each street has a unique code, and there are 1,728 street codes.

- **Location Within The Roadway (Figure 20)**

  This is a three or four-digit code that specifies the physical location of the signs within the roadway.

- **Sign District**

  This is a single-digit numerical code ranging from 1 through 6, inclusive which specifies in which district the sign is located.

- **Direction of Travel**

  This is a two-digit alphabetical code that specifies the direction of travel from which the sign is visible.

- **Sign Code**

  This field of mixed alphabetical and numerical input consists of two parts. The first is three digits and the second is four-digits long. The code is basically those contained in the MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES FOR STREETS AND HIGHWAYS with some minor additions to handle obsolete or unusual signs. This data is used mainly by the computer for sorting data and identifying the sign record by type of sign. Both the field crews and engineering personnel generally use the data in the comment field for identifying the signs.

- **Size**

  This field of numerical data consists of two three-digit parts, and specifies the nominal sign size. The three-digit field allows for the possible conversion to metric measurements.

- **Mounting**

  This two-digit alphabetical field specifies on what the sign is mounted.

- **Comments**

  This is a 65-digit mixed numerical and alphabetical field which fully describes the sign. This provides both the field crews and the engineering personnel with an easily readable description of the sign. The description is usually abbreviated. for example HAZ MRK is "Hazard Marker," KR is "Keep Right" and SCH XING is "School Crossing."

- **Installation Date**

  This is a six-digit numerical entry that identifies the date on which the sign was installed at the location, on the mounting, and for the direction of travel previously indicated.

- **Replacement Date**

  This is a six-digit numerical entry that is used to identify the age of the sign. It indicates when a sign is installed in the field. The replacement date is used to anticipate when the sign should be replaced because it has reached or exceeded its expected life.

Other information which may be added to the sign inventory to become part of the record includes:

- **Removal Date**

  This is a six-digit numerical entry that specifies the date on which the sign was permanently removed.

- **Maintenance Date**

  This is a six-digit numerical entry that specifies when, during the current year, the sign received maintenance attention. Each sign record may contain up to 14 maintenance dates.

- **Type of Maintenance**

  This is a single-digit alphabetical code that specifies the nine different types of maintenance performed; i.e., sign missing, new installed "M," deliberate vandalism, sign reinstalled "V," deliberate vandalism, new sign installed "U," and non-deliberate damage, new sign installed "D."

DATA OUTPUT

The following is a brief description of the major types of reports and the way each is utilized. Also mentioned is the procedures used with the previous card system.

Engineering Record (Figure 21)

This program prints all records on the master file and all information available for each record. This report is run quarterly. It is used by the engineering staff and the sign shop supervisor as a record of existing field conditions and to indicate any removals or maintenance that occurred during the current year. It should be noted that temporary relocations, removal or replacement of signs are not entered on the computer. At the end of each year after all work completed during the year has been entered, this report is run and one copy is stored as a record of the changes during that year. This report replaces six file cabinet drawers of sign record cards which were previously described.

In order to make a sign record change with the card system, the proper card had to be located and pulled from the file. The record card was changed and then the card had to be refiled. With the computerized system, the data is simply entered at the terminal.

District Sign Record (Figure 22)

This report prints all sign records without removal dates by sign district. It gives all the information necessary to determine what the signing in the field is designed to be. This report is also run quarterly. One copy of the portion of this report covering their district is given to each crew to carry in their truck so that they have instant access to the information.

Prior to computerization, when a crew determined that a sign was missing, they radioed the sign shop. The sign shop then phoned the engineering office which then determines what the sign should be from the record card. This information was then relayed to the crew by the sign shop. By having the information in the truck, this time consuming process has been eliminated.

Sign Inventory Report (Figure 23)

This program provides a total, by sign code and size, of the number of signs installed, removed, the net change, and the total number of signs in the field for any period specified. This report is also run quarterly. It is used at the end of the year to calculate the total plant value.

Under the old system, a hand tally was kept on a large "Bed Sheet" as each sign record change was made. The starting figures resulted from the 1960's inventory. At the end of 1977, it indicated a total plant of 111,103 signs. Comparable data from the computer inventory was 84,060 signs. Today we have 99,100 signs.

Engineering Sign Age Report (Figure 24)

This program provides a total by sign code and size of all signs with replacement dates prior to a specified date. This program is run as needed, and is used to determine the number of signs that should be replaced because they have exceeded life expectancy, and to determine the material needs to fabricate replacement signs. These determinations are made from evaluations of materials on our sign test rack.

Without computerization, this data would have been virtually impossible to determine.

DISTRICT SIGN AGE REPORT

This program prints out all sign records with replacement dates prior to a specified year and which are to be replaced in each district. It is given to each crew so that they can replace these signs as part of their maintenance program. This report is run as needed, and serves as the work order.

This information was not available prior to computerization.

Total Sign Maintenance Report

This program lists the total number of maintenance occurrences for a specified period of time by type of maintenance. This report is run quarterly. It provides data on the number of signs replaced and maintenance code as well as the total number of signs replaced and the total number of maintenance occurrences.

This information was not available prior to computerization.

Non-Conforming Sign Report

This report prints all records without removal dates that have a specified sign code or combination of sign code and size. This report is run as needed, and is used in the replacement of obsolete signs. The printout can be used as a work order to replace these signs with acceptable signs.

This information was not available prior to computerization.

There are six sign districts in the City of Milwaukee. Over the years some districts have had more signs installed than others. This has lead to complaints of disparity by some sign crews. By having the inventory on the mainframe computer, the city's Central Electronic Data Services (CEDS) office was able to plot and summarize the number of signs in each district. In collaboration with the sign shop supervisor, CEDS was able to try various alternative district boundaries to more equitably distribute the number of signs to be maintained in each district. There were other factors involved than pure number of signs. These included travel times, density of signs, and frequency of damages or vandalism.

Without the computerized inventory, however, this would have been a significantly more difficult task.

When the district changes were ultimately approved, the record update in the computer inventory was relatively simple, since all signs on the specific blocks were changed at one time.

Back in the mid-1970's all we had available to us were mainframe computers, and as you can see from our applications the information provided is extremely valuable. It should also help in providing an overall infrastructure data base for our entire Department of Public Works.

I do feel, however, that with today's high density personal computers, our sign inventory could be provided by one of these desktop units. As with most things in this world, there are advantages and disadvantages. If you should decide to computerize your sign inventory, the overall needs and objectives of your agency will have to determine your choice.

DISCUSSION AT EASTERN WORKSHOP

Q: How many signs are replaced using this particular method?

A: We program to replace about 5,000 to 6,000 signs a year. Last year we were only able to replace about 3,500. We are not budgeted by task. We are budgeted by the overall bureau operation, and if we end up getting a lot of storm problems and things of that nature, our work hours take away from maintenance hours. Unfortunately we are not able to replace at the rate the signs are deteriorating.

Q: How many signs were replaced because of vandalism?

A: Vandalism replacement, we had 570. It was a good year.

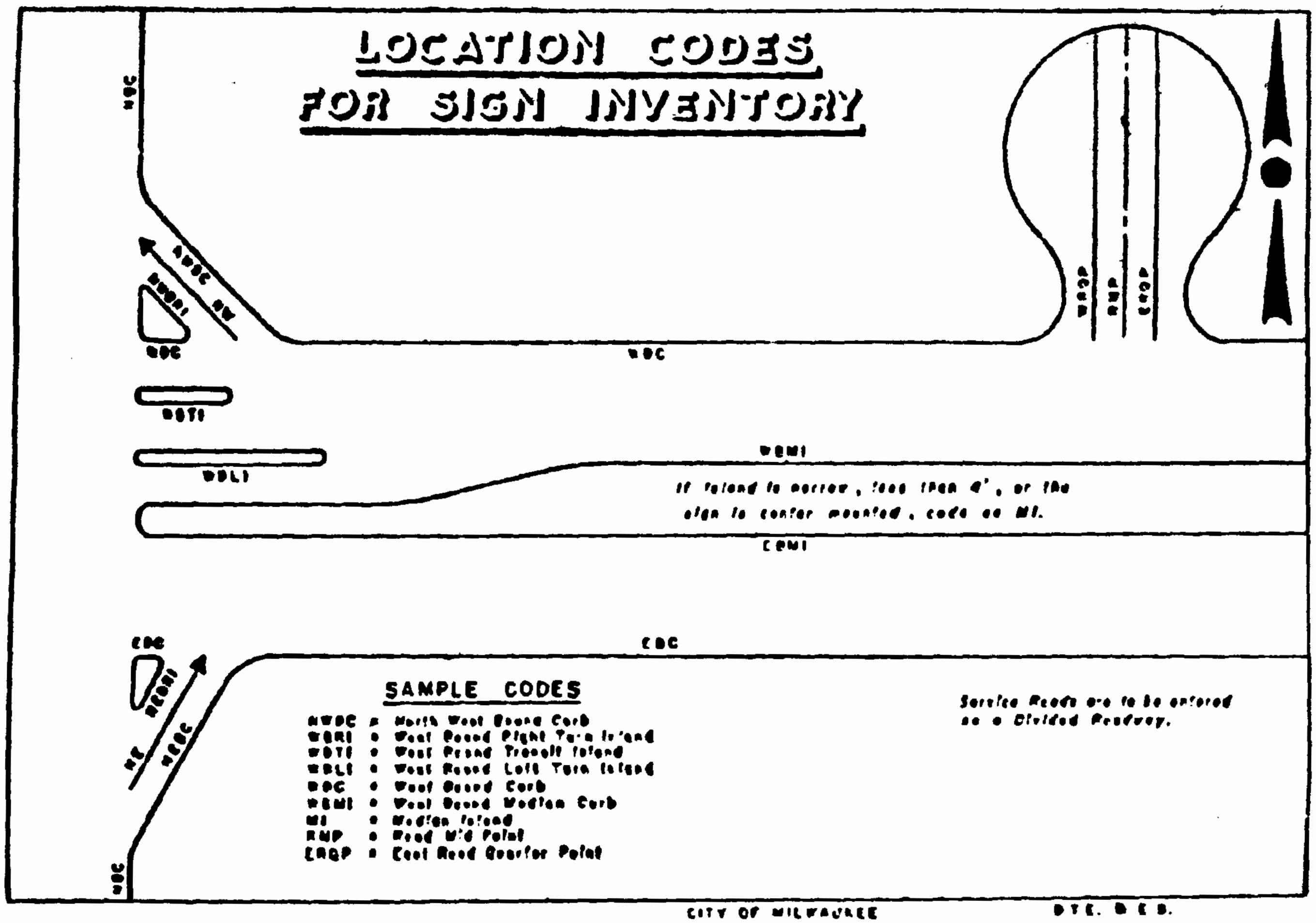


Figure 20. Location codes for sign inventory.

```
                         ENGINEERING SIGN RECORD AS OF 08/01/88                  075 025   PAGE   1502
                         W TEUTONIA                 AV      T3412
                                                                                 INST DAT REM DATE REPL DAT
ADDRS DIS  LOC DIR SIGN CODE  SIZE  MT        COMMENTS                           08-14-75          04-12-87
02179E 6   MI   SE MI -3LM   12X 36 PS HAZ MRK                                   09-08-67          04-12-87
       6   MI   SE R4 -7     24X 30 PS RR                                        00-00-01          00-00-01
02199E 5   INT  NA 11 -1       1X  1 NA W GARFIELD AV INTERSECTS
---------                                                                        07-30-81          07-30-81
02202  0   NWRC NE D3 -1M    10X 30 CP N TEUTONIA AVE SNS                        07-30-81          07-30-81
       0   NWRC NW D3 -1M    19X 36 CP W GARFIELD AVE SNS                        02-19-73          04-09-85
02213  0   SERC SE R7 -15M   18X 24 CP 2HP7-7ES DA                               02-19-73          04-09-85
02220  0   NWRC NW R7 -15M   18X 24 CP 2HP7-7ES DA                               02-20-87          02-12-86
02225E 0   SERC SE R2 -1     24X 30 CP SL30                                      00-00-70          04-09-85
       0   SERC SE R7 -15M   18X 24 CP 2HP7-7ES DA                               02-19-73          04-09-85
02237  0   SERC SE R7 -15M   18X 24 CP 2HP7-7ES DA                               02-19-73          04-12-85
02240E 0   NWDC NW R7 -1DM   18X 24 CP NPAT LA 2HP7-7ES RA                       00-00-01          00-00-01
02299E 0   INT  NA 11 -1       1X  1 NA W NORTH AV INTERSECTS
---------                                                                        01-21-88          01-21-88
02300  2   NWRC NW D3 -1M    10X 30 CP W NORTH AVE SNS                           00-00-68          00-00-68
02306E 2   NWRC NW R7 -15M   18X 24 CP 2HP7-7ES LA                               00-00-69          02-24-81
02311E 2   SERC SE R7 -1DM   18X 24 PS NPAT LA 2HP7-7ES RA                       02-20-87          02-12-86
02320  2   NWRC NW R2 -1     24X 30 CP SL30                                      10-28-86          10-03-72
       2   NWRC NW R7 -1DM   18X 24 CP NPLZ7-9 LA 2HP7-7ES RA                    09-28-79          09-28-79
02324  2   NWRC NW R7 -15M   18X 24 PS 2HP7-7ESS LA NPLZ7-9 RA                   10-28-86          10-28-86
02328E 2   NWRC NW R7 -1DM   18X 24 CP 2HP7-7ES LA NPLZ7-9 RA                    00-00-69          00-00-69
02331  2   SERC SE R7 -15M   18X 24 CP 2HP7-7ES DA                               00-00-68          00-00-68
02354  2   NWRC NW R7 -15M   18X 24 CP 2HP7-7ES DA                               00-00-69          00-00-69
02363  2   SEBC SE R7 -15M   18X 24 CP 2HP7-7ES DA                               02-21-73          02-21-73
02364  2   NWBC NW R7 -1DM   18X 24 CP NPRS LA 2HP7-7ES RA                       03-15-82          03-15-82
02360  2   NWRC NW S1 -1     30X 30 CP ADVANCE SCHOOL                            01-28-88          01-28-88
02370E 2   NWEC NW S2 -1     30X 30 PS SCH XING                                  00-00-72          09-11-83
02379  2   SEBC SE R7 -1DM   18X 24 PS 2HP7-7ES LA NPAT RA                       07-31-79          02-19-89
02381E 2   MI   NW MI -3LM   12X 30 PS HAZ MRK
       010389 D  021989 D                                                        07-31-79          02-19-89
       2   MI   SE MI -3LM   12X 36 PS HAZ MRK
       010309 D  021989 D                                                        07-31-79          02-19-89
       2   MI   NW R4 -7     24X 30 PS RR
       010309 D  021989 D                                                        00-00-01          00-00-01
02398E 2   INT  NA 11 -1       1X  1 NA W MEINECKE AV INTERSECTS TO THE EAST
---------                                                                        03-15-82          03-15-82
02401E 2   SEBC SE S2 -1     36X 36 PS SCHOOL CROSSING                           10-11-84          10-11-84
02402  2   NRC  NM D3 -1M    10X 30 CP W MEINECKE AV NSNS                        10-11-84          10-11-84
       2   NRC  WB D3 -1M    10X 42 CP N TEUTONIA AV NSNS                        04-08-88          04-08-86
02403E 2   SEBC SE R7 -15M   12X 18 PS NPAT DA                                   10-11-84          10-11-84
02411  2   SRC  EB D3 -1M    10X 42 CP N TEUTONIA AV NSNS                        10-11-84          10-11-84
       2   SRC  SB D3 -1M    10X 36 CP W MEINECKE AV NSNS                        00-00-01          09-00-01
02417E 2   INT  NA 11 -1       1X  1 NA W MEINECKE AV INTERSECTS TO THE WEST     02-17-75          05-09-89
02419E 2   MI   NB MI -3LM   12X 36 PS HAZ MRK
       012489 D  040689 D  050989 D                                              02-17-75          05-09-89
       2   MI   SB MI -3LM   12X 36 PS HAZ MRK
       012489 D  040989 D  050989 D                                              02-17-75          05-09-89
       2   MI   SB R4 -7     24X 30 PS RR
       012489 D  049689 D  050989 D                                              02-14-84          02-16-87
02022  2   NRC  NB R7 -15M   12X 18 PS NP RA                                     09-14-77          05-24-88
02420E 2   NRC  NB R7 -1DM   18X 24 PS NPLZAT LA 2HP7-7ES RA
                         W TEUTONIA                 AV      T3412
```

Figure 21. Engineering sign record report.

DISTRICT 2 SIGN RECORD AS OF 06/01/89 JOB 675 030 PAGE 578

N TEUTONIA AV 13412

ADDRS	LOC	DIR	SIGN CODE	SIZE	MT	COMMENTS	REPL DATE
02300E	NWNC	NW	D3 -1N	16X 30	CP	W NORTH AVE SNS	01/21/80
02300E	NWNC	NW	R7 -15M	18X 24	CP	2HP7-7ES LA	00/09/48
02311E	SENC	SE	R7 -10M	18X 24	PS	NPAT LA 2HP7-7ES RA	02/20/81
02320	NWNC	NW	R2 -1	24X 30	CP	SL30	02/12/86
	NWNC	NW	R7 -10M	18X 24	CP	NPLZ7-9 LA 2HP7-7ES RA	10/03/77
02324	NWNC	NW	R7 -15M	18X 24	PS	2HP7-7ESS LA NPLZ7-9 RA	09/26/79
02370E	NWNC	NW	R7 -10M	18X 24	CP	2HP7-7ES LA NPLZ7-9 RA	10/24/44
02331	SENC	SE	R7 -15M	18X 24	CP	2HP7-7ES DA	00/00/49
02354	NWNC	NW	R7 -15M	18X 24	CP	2HP7-7ES DA	00/00/49
02343	SENC	SE	R7 -15M	18X 24	CP	2HP7-7ES DA	00/00/47
02364	NWNC	NW	R7 -10M	18X 24	CP	NPRS LA 2HP7-7ES RA	02/21/73
02360	NWNC	NW	S1 -1	30X 30	CP	ADVANCE SCHOOL	03/15/82
02370E	NWNC	NW	S2 -1	30X 30	PS	SCH XING	01/20/88
02379	SENC	SE	R7 -10M	18X 24	PS	2HP7-7ES LA NPAT RA	09/11/83
02381E	MI	NW	M1 -3LM	12X 30	PS	HAZ MRK	02/19/89
	MI	NW	R4 -7	24X 30	PS	KR	02/19/89
	MI	SE	M1 -3LM	12X 30	PS	HAZ MRK	02/19/89
02380E	INT	NA	I1 -1	1X 1	NA	W MEINECKE AV INTERSECTS TO THE EAST	00/00/01
02401E	SEWC	SE	S2 -1	30X 30	PS	SCHOOL CROSSING	03/15/82
02402	NWC	NB	D3 -1N	10X 30	CP	W MEINECKE AV NSNS	10/11/84
	NWC	WB	D3 -1N	10X 42	CP	N TEUTONIA AV NSNS	10/11/84
02403E	SEWC	SE	R7 -15M	12X 18	PS	NPAT DA	04/08/85
02411	SWC	EB	D3 -1N	10X 42	CP	N TEUTONIA AV NSNS	10/11/84
	SWC	SB	D3 -1N	10X 36	CP	W MEINECKE AV NSNS	10/11/84
02417E	INT	NA	I1 -1	1X 1	NA	W MEINECKE AV INTERSECTS TO THE WEST	00/00/01
02419E	MI	NB	M1 -3LM	12X 30	PS	HAZ MRK	05/09/89
	MI	SB	M1 -3LM	12X 36	PS	HAZ MRK	05/09/89
	MI	SB	R4 -7	24X 30	PS	KR	05/09/89
02422	NWC	NB	R7 -15M	12X 18	PS	NP RA	02/14/87
02426E	NWC	NB	R7 -10M	18X 24	PS	NPLZAT LA 2HP7-7ES RA	05/20/88
02429	SWC	SB	R7 -10M	18X 24	CP	NPAT LA 2HP7-7ES RA	00/00/69
02431	SEWC	SE	S1 -1	30X 30	CP	ADVANCE SCHOOL	03/15/82
02430E	NWC	NB	R7 -10M	18X 24	CP	2HP7-7ES LA NPLZAT RA	04/20/79
02453	SWC	SB	R7 -15M	18X 24	CP	2HP7-7ES DA	04/25/90
02460	NWC	NB	R7 -7M	18X 24	PS	NPBS LA	05/14/82
02477	SWC	SB	R7 -10M	18X 24	PS	2HP7-7ES LA NPLZAT RA	04/21/88
02480	NWC	EB	D3 -1N	10X 42	SS	N TEUTONIA AV NSNS	10/11/83
02481	SWC	SB	D3 -1N	10X 36	CP	W WRIGHT ST NSNS	10/11/84
02499E	INT	NA	I1 -1	1X 1	NA	W WRIGHT ST INTERSECTS	00/00/01
02502	NWC	NB	D3 -1N	10X 30	CP	W WRIGHT ST NSNS	10/10/88
02513	SEWC	SE	R7 -10M	18X 24	PS	NPAT LA 2HP7-7ES RA	03/29/86
02518	NWWC	NW	R7 -15M	18X 24	CP	2HP7-7ES DA	04/23/85
02533	SENC	SE	R7 -15M	18X 24	CP	2HP7-7ES DA	04/03/88
02540E	NWNC	NW	R7 -15M	18X 24	CP	2HP7-7ES DA	11/24/87
	NWNC	NW	S1 -1	30X 30	CP	SCH	02/09/81
02553	SENC	SE	R2 -1	24X 30	CP	SL30	02/20/85
	SEWC	SE	R7 -15M	18X 24	CP	2HP7-7ES DA	02/10/85

N TEUTONIA AV 13412

Figure 22. District sign record report.

SIGN INVENTORY AS OF 12/31/83 JOB 675 035 PAGE 1

SIGN CODE	SIZE	NUMBER INSTALLED	NUMBER REMOVED		NET CHANGE	TOTAL IN FIELD
C1 -2M	30X 42	0	2	-	2	193
D1 -1FM	18X 24	0	17	-	17	0
	24X 30	19	0	+	19	19
D1 -1M	18X 30	0	0	+	0	7
	18X 30	2	0	+	2	13
	30X 42	0	0	+	0	2
	12X 24	1	1	+	0	3
	12X 30	0	0	+	0	2
	14X 60	0	0	+	0	1
	15X 21	0	0	+	0	1
	18X 24	1	1	+	0	5
	18X 30	6	1	+	5	29
	18X 48	1	0	+	1	1
	24X 24	11	0	+	11	11
	24X 30	1	1	+	0	13
	24X 36	0	1	-	1	11
	24X 48	0	0	+	0	5
	24X 60	0	0	+	0	1
	30X 30	0	0	+	0	5
	30X 30	0	0	+	0	4
	33X144	0	0	+	0	1
	36X 36	0	2	-	2	1
	36X 42	0	0	+	0	1
	36X 48	0	1	-	1	2
	36X 60	0	0	+	0	2
	36X 72	0	0	+	0	2
	36X 84	0	0	+	0	2
	40X 72	0	1	-	1	0
	42X 36	0	0	+	0	1
	48X 48	0	0	+	0	1
	48X 84	0	0	+	0	3
	48X 96	0	0	+	0	25
	60X 48	0	0	+	0	2
D11-1	18X 24	0	1	-	1	95
D11-2M	15X 21	0	0	+	0	21
D3 -1DM	18X 36	2	0	+	2	2
	18X 24	0	0	+	0	6
	18X 36	2	0	+	2	195
	18X 42	0	0	+	0	4
	36X 36	0	0	+	0	1
D3 -1M	8X 24	0	0	+	0	2
	18X 30	71	68	+	3	13962
	18X 36	39	46	-	7	6938
	18X 42	0	1	-	1	228
	10X30	0	0	+	0	1
	10X30	0	0	+	0	1
	30X 30	2	0	+	2	2
D3 -1MT	18X 30	0	0	+	0	4
D4 -1A	24X 30	0	0	+	0	7
D4 -1L	24X 30	4	0	-	2	53
D4 -1M	24X 30	0	0	+	0	4
D4 -1PM	8X 12	0	10	-	10	9
D4 -1R	24X 30	7	4	+	3	65
D4 -2	18X 24	0	2	-	2	6
D4 -2D	6X 24	0	0	+	0	2
D4 -2L	6X 24	0	0	+	0	2

Figure 23. Sign inventory report.

ENGINEERING SIGN AGE REPORT AS OF 01/23/89 [illegible] PAGE 1
SIGN REPLACED PRIOR TO 1971

SIGN CODE	SIZE	NUMBER
C1 -2M	30X 42	0
D1 -1FM	18X 24	1
D1 -1M	10X 30	0
	10X 36	0
	10X 42	0
	12X 24	0
	12X 30	0
	14X 60	0
	15X 21	0
	18X 24	1
	18X 30	0
	24X 30	0
	24X 36	0
	24X 48	0
	28X 60	0
	30X 30	0
	30X 36	0
	33X144	0
	36X 36	2
	36X 42	0
	36X 48	0
	36X 60	0
	36X 72	0
	36X 84	0
	40X 72	1
	42X 36	0
	48X 48	0
	48X 84	0
	48X 96	0
	60X 48	0
D1 -2M	24X 30	0
D11-1	18X 24	3
D11-2M	15X 21	0
D3 -1DM	18X 24	0
	18X 30	0
	18X 42	0
	36X 36	0
D3 -2M	8X 24	0
	16X 30	3
	10X 36	0
	10X 42	0
	10X30	0
	10X36	0
D3 -1MT	10X 30	0
D4 -1A	24X 30	1
D4 -1L	24X 30	11
D4 -1M	24X 30	1
D4 -1PM	6X 12	14
D4 -1R	24X 30	15
D4 -2	18X 24	0
D4 -2D	6X 24	0
D4 -2L	6X 24	0
D4 -2R	6X 24	0
D52-14R	36X 30	0
D8 -2	24X 30	0

Figure 24. Engineering sign age report.

COMPUTERIZED HIGHWAY SIGN INVENTORIES

Thomas M. Pickford, P.E.*
Director of Public Works
Shawnee County
Courthouse B-11
Topeka, KS 66603

The need for complete, accurate and easily accessible Highway Sign Inventory is a known fact.

Sign inventories are used for a number of essential purposes. The most important use of the inventory is to provide a written record of the type of sign, its location, and the authority used to place the sign.

Sign inventories are also used for evidence in court cases, for budgeting functions and for replacement and repair scheduling.

There are three basic ways to produce a sign inventory:

1. Hand Recorded Manual Records. (A typical sample is shown as figure 25.)

2. Computerized, using a simple software program with keyboard entry from field notes. (Figure 26 illustrates a print-out form from this type of system.)

3. Computerized and VHS recorded in the field using a mobile vehicle equipped to produce a finished product.

Here are a few slides that help illustrate the inventory options and equipment needed to maintain sign records.

1. Manual Inventory. Field book, inventory form. This method is the slowest for both entry and recall purposes and is subject to recording errors.

2. Computerized Inventory. Mini-computer, computer print-out, field book. This system is slow for entry, fast for recall and subject to recording errors.

3. Mobile Computerized VHS System. Van, camera, computer, printer and GPS (figure 27).

The Shawnee County Public Works Department, after analyzing the various options, decided to not only computerize the inventories, but also computerize the generation of the

*Presented at western workshop only.

field information gathering system. We also decided to VHS tape the records and tie the tapes and computer generated information together. We also enhanced the system by equipping the van with a GPS position locator.

A list of the equipment, with 1988 bid prices, is included to illustrate how the individual components fit together to make up the complete unit. For an investment of less than $50,000.00, a very flexible road inventory machine is handling the Shawnee County Sign Program (figure 28).

The system, as developed, has the capabilities to completely monitor and inventory the county's signs and pavement markings.

A 10-minute VHS tape, produced by the recording system, is shown to illustrate the recording capabilities of the VHS—Computer—GIS System.

The operators of the van and equipment can produce a high quality, VHS visual record of the signage on the roads. They can enter onto the tape automatically; the time and date, the latitude and longitude, speed of vehicles; and, from a digitizing board, they can enter into the computer the description of the sign, its condition and information to produce maintenance work orders directly from computer memory at the end of the day.

The software program produces a completed sign inventory that includes the date of inspection, type of sign, condition of sign, location of sign by route and where located on route, direction of travel, date sign originally installed, date of replacement or repair, size of sign, reflectivity, and comments such as "Too far from pavement" and report on standardized or coded defects.

The system, from its basic capabilities, keeps historical records of what the drivers on roads actually see at any given time period. It can record the time a driver first views the sign, up to any required reaction necessary to safely traverse the road.

It can be used for accident investigations, to verify what the driver, or drivers, viewed approaching the accident site. Driving the route at the posted speed and at the estimated vehicle's speed. These tapes are admissible evidence and, because they are timed, dated, and located directly onto tape, they are difficult to attack or degrade in court.

The system also produces a record of pavement striping and can be used to position the striping. It also is set up to provide speed limits for horizontal curves.

Shawnee County's operation plan for maintaining current highway sign inventories includes: driving, filming the recording all county roads three times a year. Doing the same on the Township Roads one time a year.

Our system was produced by HMR Communications, Inc. of West Newton, PA.

Not only have we greatly enhanced our highway sign inventory capabilities, we also have a system that can be utilized for other county road purposes. The system will pay for itself in approximately three years.

I highly recommend this type of road recording vehicle for sign inventory and maintenance.

DISCUSSION AT WESTERN WORKSHOP

Q: What kind of a price, roughly, is a vehicle like that?

A: This vehicle was bid on and delivered to us with 5 days of training for $48,500. I have all of the prices for you in the proceedings. We had them bid individually for each item because we wanted to pick and choose. It turned out that we got it at such a price that we picked the Cadillac of everything. We got the best that was available.

Q: Why did you feel you had to go to that level of sophistication?

A: We plan on tying this whole system into our geographical mapping system, which is presently in place as far as the parcels are concerned. We are actually going to do design and estimating off of the systems. We have a current program of relocating all the section corners in Shawnee County, and in this process, we are converting all of the altitude and longitude to the State and Federal plane and coordinate system. We will have a software program that will do this off of this computer system in the vehicle as well as off the main GIS system. Approximately 5 years from now, the two systems will be compatible, we will no longer manually produce sign maps. We will simply produce the map the we have off of the main GIS system.

Q: I noticed that you don't have any mileposts marked.

A: We actually start out at 0 on the County line on each road. The inventory of our tapes is by road or route.

Comment from the speaker:

We made one other wise move with this system. We bought the software so that it is compatible with dBASE IV and Lotus 1-2-3. We did that because they produce such beautiful pictures—graphs and circles for making presentations to the commissioners and at road hearings and things of that nature. That was the right move because we have already used it in two hearings for quarries.

Q: How often does the system update the location?

A: Every 10 seconds.

Q: And you can do that on the go?

A: On the go. The quality of that varies depending upon whether you're reading A, B, C, D, E, or F on your equipment. It's sketchy and the inertial guidance system or dead reckoning takes over. It is plenty accurate for this service. You're only talking about being off about 15 or 20 feet at most.

Q: Do you have a paper describing the equipment?

A: We have a complete description of the equipment. I didn't put the bid documents in there, but all you have to do is contact me and I will supply you with the information. I did list each model of equipment, what its individual cost was and the total delivered cost of the vehicle. We made two mistakes: I told you about the post; the other one is the glare. The equipment is so sensitive that it picks up almost any glare that gets in front of the camera. We had to get some black, rough surface cloth and cover those areas where we were picking up the sun. It works great in the rain, and the pictures at night were unbelievable. You put the lights on and you can see the definition of how far out those lights reach in great detail.

Q: What kind of an image do you get?

A: We've had a little bit of a problem with that. They tell me it's been resolved. You would usually get the upper part of the picture, which was causing some concern with being able to read the printout across the top because of some moving lines. That is a problem that can be resolved, and they tell me they have gotten that resolved. Your freeze-frame imagery is more than good enough for anyone who is trying to pick up any information off the picture.

SHAWNEE COUNTY

SIGN MAINTENANCE

TRAFFIC ENGINEERING DEPARTMENT

A	B	C	D	E	F	G	H	I	J
DATE	INTERSECTION	DISTANCE FROM INTERSECTION AND DIRECTION	SIGN LEGEND AND/OR CODE	SIZE	TYPE OF SURFACE	LOCATION	POST TYPE	REMARKS	INITIALS
11-27-59	Closed Stubbs from 105th to 1[illegible]		1 day	Culvert installation				2 large barricades	JL CL
11-27-59	61st & Stanley	NW corner	Stop - street name	30-6X	R	L	5.5 5-10	Reset new street signs	JL CL
11-27-59	21st & Hickman	SW corner	Stop	30	R	L	5.5 5-10	Reset new sign & posts	JL CL
11-27-59	63rd & Anthony	NW corner	Stop	30	R	L	5.5 5-10	Reset new sign & posts	JL CL
11-27-59	56th & Maple Hill	1st curve south (600 north of)	Left curve	30	R	L	5.5 5-10	Reset sign & posts	JL CL
11-28-59	Closed Woodring	101st to 105th	one day	culvert	Replacement			2 large barricades	JL CL
11-28-59	83rd & [illegible] west leg	600' north	Stop ahead	30	R	L	5.5 5-10	Reset new sign	JL CL
11-27-59	57th & Davis	600' east	+ crossroad 35 MPH	30-18	R	L	5.5 5-10	Signs up & good advisory; Reset new installation	JL CL
11-27-59	57th & Davis	600' west	+ crossroad 35 MPH	30-18	R	L	5.5 5-10	Signs up & good advisory; Put new installation	JL CL
11-27-59	53rd & [illegible]	1st culvert west	1 hazard	12x36	R	1NE	5.5 5-9	Reset new sign & posts	JL CL
11-29-59	77th & Douglas	600' south of 1st turn	Left turn 35 MPH	30-18	R	R	5.5 5-10	Reset new signs	JL CL
11-29-59	61st & [illegible]	Changed flashing red light bottom east bound [illegible]						[illegible]	JL CL
11-30-59	10th & [illegible]	500' south	Deer xing	30	R	R	5.5 5-10	Reset sign & posts	JL CL
12-1-59	[illegible]	600' north	[illegible]	30	R	L	5.5 5-10	Reset new sign & posts	JL CL
12-1-59	[illegible]	600' south	[illegible]	30	R	L	5.5 5-10	Reset new sign & posts	JL CL
12-2-59	10th & [illegible]	1st curves east	[illegible]	30	R	L	5.5 5-10	Reset new sign & posts	CL
12-4-59	[illegible]	200' north	[illegible]	[illegible]	R	R	5.5 [illegible]	Reset sign & posts	JL CL
[illegible]	[illegible]	[illegible]	1 [illegible]	[illegible]	R	1-E	[illegible]	[illegible]	J[illegible]

Figure 25. Hand-recorded manual reports.

SHAWNEE COUNTY

SIGN MAINTENANCE

TRAFFIC ENGINEERING DEPARTMENT

A	B	C	D	E	F	G	H	I	J
DATE	INTERSECTION	DISTANCE FROM INTERSECTION AND DIRECTION	SIGN LEGEND AND/OR CODE	SIZE	TYPE OF SURFACE	LOCATION	POST TYPE	REMARKS	INITIALS
12-1-59	29TH & CROSS	Changed [illegible]	Light Bulb	OVERHEAD	[illegible]	NORTH	Bound	Through all day	[illegible]
12-1-59	37TH & STUBBS	NE CORNER	STOP	30	R	R	[illegible]	REPLACED MISSING REF	[illegible]
12-1-59	93RD & STEWART	1ST CORNER EAST	1 HAZARD	18X36	R	1SW	[illegible]	RESET SIGN & POSTS	[illegible]
12-1-59	105TH & RITTNER	SE CORNER	STREET NAME ASSY		R	R	[illegible]	RESET SIGN & POSTS	[illegible]
12-1-59	CLOSED SE 109TH AT STUBBS WEDS	FRIDAY AT CLINTON			[illegible]	3 LARGE BARRICADES			[illegible]
12-7-59	67TH & STUBB	SW CORNER	STREET NAME ASSY		R	L	[illegible]	RESET NEW SIGNS	[illegible]
12-7-59	107TH & BURLINGAME	500' NORTH	STOP AHEAD	30	R	L	[illegible]	RESET SIGN & POSTS	[illegible]
12-11-59	37TH CT & KINGS ROAD	NW CORNER	STREET NAME ASSY		R	L	[illegible]	RESET NEW SIGNS & POSTS	CC
12-11-59	[illegible] & DOUGLAS	NE CORNER	STREET NAME ASSY		R	R	[illegible]	RESET NEW SIGNS IN STOP SIGN	CC
12-11-59	50TH & [illegible]	SW CORNER	STREET NAME ASSY		R	L	[illegible]	RESET NEW SIGNS & POSTS	CC
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]
12-14-59	53RD & N TOPEKA	300' SOUTH	STOP AHEAD	24X30	R	R	[illegible]	RESET SIGN & POSTS	[illegible]
12-14-59	45TH & SHAWNEE HTS	Changed Red Light	NORTH Bound		[illegible]	[illegible]			[illegible]

Figure 25. Hand-recorded manual reports. (continued)

SIGN INVENTORY

INTERSECTION: ______________ SURVEY PARTY: ____________

AT ____________________ ____________________

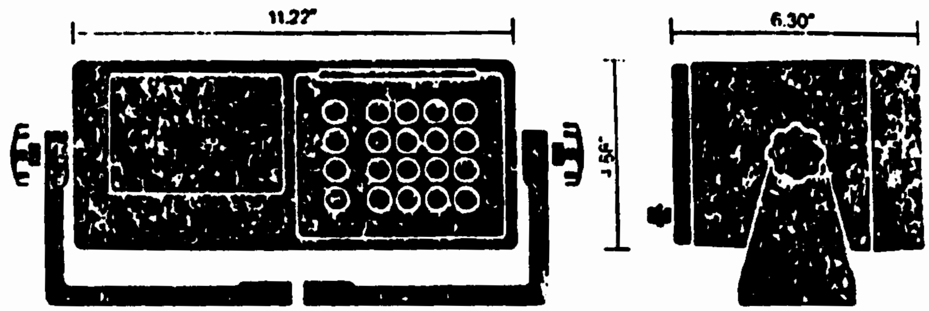
A	B	C	D	E	F	G	H	I	J	K	L	M
DATE	SIGN NUMBER, DIRECTION	DISTANCE FROM INTERSECTION	SIGN LEGEND	SIGN CODE	SIZE	TYPE OF SURFACE	CONDITION	VISIBILITY	LOCATION	POST TYPE	REMARKS AND DESCRIPTION	INITIALS

Figure 25. Hand-recorded manual reports. (continued)

CODE	MESSAGE	ROUTE	MILE	DIR	INST/REPL	SZ	PHY	REF	DEF	INSPECTED	COMMENTS
370004	4 WAY STOP	37	1	N	22-Jul-78	S	G	G	0	12-Jul-84	
820002	NO LEFT TURN	82	12	W	12-Jul-68	S	X	G	0	10-Jul-85	SIGN MISSING
760002	NO PASSING	76	18	W	20-Oct-71	S	P	F	2	16-May-83	TOO FAR FROM PVMNT
820001	ONE WAY	82	31	E	17-Jan-71	S	X	G	2	10-Jul-85	SIGN DOWN
760006	SPEED 40	76	21	E	21-Sep-74	N	F	F	3	01-Dec-83	
420005	SPEED 55	42	6	E	30-Jun-81	S	F	F	0	16-Oct-84	
870001	STOP	87	30	S	17-May-76	N	P	P	3	10-Jul-85	POST BENT
170001	STOP	17	18	S	01-Oct-76	S	F	P	0	12-Aug-82	LOOSE MOUNTING BOLT
620002	STOP	62	2	E	08-Oct-78	S	P	P	0	10-Dec-84	
920001	STOP	92	4.6	E	18-Feb-77	S	G	G	0	18-Jun-82	
160002	STOP	16	5.2	E	03-Feb-69	S	P	P	0	28-May-84	VERY OLD SIGN
160001	STOP	16	23	N	09-Mar-76	S	P	G	0	21-Oct-83	
670001	STOP AHEAD	67	4	S	04-Oct-79	N	G	P	4	12-Jun-85	TREE OBSTRUCTION
710008	WEIGH STATION	71	40	N	22-Mar-81	N	F	G	0	05-May-82	IMPROPER SIZE SIGN
240008	YEILD	24	7	W	05-Jun-80	S	P	P	4	10-Jul-85	OBSTRUCTED BY TREES
560004	YIELD	56	7.3	N	14-Aug-82	S	P	G	1	01-Jun-82	

Figure 26. Hypothetical sign inventory data base.

SHIPMATE RS 5100



RS 5100	
Satellite fix accuracy	0.05NM RMS (average value) plus speed error
UTC* time accuracy	± 1 second
Receiver frequency	400 MHz
Receiver sensitivity	− 149 dBm
Input power	10-32 V, max. 13 W. Automatic power reduction function. 4 W (Sleep Mode)
Memory storage	Internal battery stores without external power. Time, date, lat, lon, waypoint, geo height, mag. variation, mag deviation, alarm dist., lon pulse and sum log, heading, speed, satellite orbit data for predictions and all settings
Keyboard	Multilayer sealed, tone response
Dimensions/Weight	H 4.88", W 11.22", D 6.30" / 8.82 lbs.
Temperature range	14°F to 131°F
Humidity	0-95% rel.
Vibration	0-50Hz, 1 g
Self test	Automatic function every 60 minutes
Interface	NMEA 0183 input/output, RS 232 c 300, 600, 1200 baud
Functions	Auto starting, auto geo height, auto time, date, great circle rhumbline computations between any waypoints, ETA en route, deviation table, 3 past and 9 future sat data immediately available, unlimited no. with calculation time, sat counter, average calculations on multifixes, signal suppression on bad sat, and 50 other special functions
Log input	100-32,000 pulses/mile
Compass input	Sine, cosine
Gyro compass input	Syncro, stepper. Fully field programmable
Connections	Printer RS 6150, plotter RS 2000, RS 5200 GPS , remote RS 5110
*Universal Time Coordinate	
RS 5142 Antenna	
Amplifier gain	15 dB/50ohm
Input power	Through co-axial cable
Cable length max.	RG 8/u 98' RG 8/u 196' with extra amplifier RG 8/x 65'
Temperature range	− 13°F to 167°F
Humidity	0-100% rel.
Weight	1.32 lbs.
Diameter/Length	Bottom 1.77", top 0.78" 30.70"
Required supporting tube	1.50" outside diameter

Changes may be made without notice

Figure 27. Specifications for mobile computerized VHS system.

ROAD RECORDING VEHICLE

VEHICLE - CHEVY 1/2 TON WINDOW PASSENGER VAN - C-10 SPORTVAN	16,796.00

Van shall be full sized and equipped with the following: two (2) captain's swivel seats, one rear bench seat, cruise control, automatic transmission, instrument gauges, ride packages, carpeting and insulation package, outside spare tire carrier, power brakes and steering, high capacity heater/air conditioning, heavy duty alternator and battery, gasoline powered, V-8 engine, heavy duty suspension package, minimum 25 gallon fuel tank (dual tanks preferred), and all interior alterations and installation of equipment.

POWER EQUIPMENT: (Total a and b) 3,267.00

(a) 115V - 2,000 watt AC generator(gas powered from vehicle tanks), remote start, isolated compartment, low rpm and sound deadened(if needed), totally serviceable from outside of vehicle.

(b) Roof-top mounted auxillary air conditioner/heater, 4,000 BTU, thermostatically controlled.

VIDEO EQUIPMENT:

Installed to operate by filming through windshield from inside of van. Camera mounts to be so designed to allow easy access to van engine compartment.

(a)	VHS Color Camera - Broadcastor Studio Quality Furnished Panasonic WDV 5000 with WDCRD, WPH10, WV831P	1,375.00
(b)	Stabilized Zoom Lens w/Remote control Panasonic WDLZ14/8AF	935.00
(c)	Two (2) VHS Video Recorder/Players: One for van and one for office. Counters to be synchronized. JVC BR3100U	1,350.00
(d)	Video Color Monitor - For Van NEC PM1271A	465.00
(e)	19" Video Color Monitor - For Office NECP, 1971A	740.00

Figure 28. Equipment list with 1988 bid prices for complete inventory machine.

(f)	Video Camera Pan and Tilt w/Remote Control (This included with camera description)	1,100.00
(g)	Omni Directional Microphone Panasonic WVMC12	120.00
(h)	All Necessary Cables, Connectors and Mounts	470.00
COMPUTER HARDWARE/FIRM WARE:		
(a)	IBM Compatible Computer (DOS 3.21) (Business System XT2000 PX)	702.00
(b)	Double Disk Drive 5.25" Floppy Disk (DSSD 40 Track Soft Sectored Disks)	89.00
(c)	640K R.A.M.	160.00
(d)	IBM 8088 Processor and Math Co-processor	90.00
(e)	Graphics Generator for Video Overlay	2,990.00
(f)	Parallel/Serial Printer + Communications Ports	110.00
(g)	9" Video Screen (Integral to Unit)	82.00
(i)	Digitizing Tablete	645.00
(j)	Distance Measuring Device +/- 2' Accuracy per Mile (Transmission Mount and Self Calibrating)	440.00
(k)	Sensors for Roadway Profile Data	122.00
(l)	Peripherals for Auto Date/Time and Data Aquisition	120.00
(m)	All Necessary Cables and Connectors	120.00
SOFTWARE SYSTEM:	(Total a, b and c)	5,120.00
(a)	Shall be menu driven and user friendly	
(b)	The system output basically should produse video tapes of the roadway environment and an inventory data base.	
(c)	Capable of Inquiry, Edit and Report Generation.	

Figure 28. Equipment list with 1988 bid prices for complete inventory machine. (continued)

The system must allow the overlaying of computer or keyboard information on to the video tape and be able to position data at any location on tape, Provide single stroke data entry.

MANUALS/TRAINING:	1,100.00

Two (2) complete sets of Operating Manuals are to be furnished with equipment, including Schematics and Drawings, any special tools or cleaning instruments, and training of personnel in use of equipment.

DELIVERY: Shall be made to the Shawnee County Garage, 21st and Topeka Blvd., Topeka, KS 66612.

Please State Best and Firm Delivery Date:

90 Days A.R.O.

Please State Number of Training Days Suggested:

5 Days (Quotation based on this period)

Base Price for Automated Roadway Information System (WITHOUT Van, Generator or Auxillary Air Condition/Heater)	18,445.00
Base Price for Automated Roadway Information System (INCLUDING Van, Generator and Auxillary Air Conditioner/Heater)	38,508.00
Delivery Charge (if applicable) (Applies only if van is ordered)	480.00
Total Price with Delivery:	$ 38,988.00
Options:	
(a) Geo-location option in latitude and longitude	9,790.00
Shipmate RS 5100	
TOTAL PRICE WITH DELIVER AND OPTION:	$ 48,778.00

Figure 28. Equipment list with 1988 bid prices for complete inventory machine. (continued)

VIDEODISC TECHNOLOGY AS AN IMPROVED INVENTORY TECHNIQUE

William Baker[1]
Chief, Traffic Performance Branch
Office of Traffic Operations
Federal Highway Administration
400 Seventh Street, S.W.
Washington, DC 20590

The need for better information management is increasing rapidly in many areas and highway engineering is no exception. All highway agencies, State and local, conduct inventories and must store and manage highway-related information. Roadway features, traffic control devices and pavement condition are some examples of the types of data that are expected to be routinely collected, managed, and analyzed by highway agencies. Recent advances in laser and videodisc technology offer a promising concept for improving the collection of these data and maximizing its usage.

During the past several decades, State highway agencies have traditionally obtained photologs of their highway network. Basically, these combine pictorial, geographical, geometric, and other digital data designed to assist personnel in identifying, analyzing or otherwise using the information in a home-based situation without traveling many miles to the field. These systems have been generally based on photographic film techniques and are used for inventory purposes, accident analyses, maintenance, design, and a variety of fact gathering information and decision making processes. Automated systems to identify and collect pavement distress data have been recently developed or are being studied. Again, most of this current technology involves photographic recording and digital quantification of the severity of the distress in pavement. These current systems require expensive equipment and large amounts of storage and produce a film record that must be reviewed sequentially. The photographic records are expensive to process and still difficult to equate to corresponding digital data although in recent years microcomputer technology has greatly enhanced combining photographic records with microcomputer data base information.

Video is easy to record, relatively inexpensive to process or duplicate, and easy to handle. These characteristics, in conjunction with recent advances in obtaining higher resolution images from video, have made video technology more attractive to the highway industry. There have also been advancements in the use of laser technology. Laser technology is now used in highway-related areas such as surveying and rut measurement. The most advanced general public use of the laser has been in the reading of video imagery from encoded videodiscs for home movies. A prime benefit of laser videodisc technology is that records can be accessed randomly to display high resolution stills or continuous pictures on a monitor. Additionally, storage requirements for these records are greatly reduced.

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[1]Additional author includes Vincent Nowakowski.

Combining video imagery and laser disk storage with microcomputer technology allows one to combine the pictorial and digital data for a variety of specific applications for use by highway professionals. The Federal Highway Administration (FHWA) has recognized the potential of combining these technologies and is putting together a demonstration project titled "GIS/Video Imagery Applications." Two pilot presentations are planned for the summer of 1990 and about 40 more presentations anticipated over the two year life of the project. The Video Imagery sessions of this project will focus on two areas. First, it will provide hands-on demonstrations of two types of video laser disc systems. Presently, both systems use video laser discs produced from 35-mm photolog film. However, each uses a different process to produce the discs and each can play laser discs produced directly from video cameras. Second, it will provide a hands-on demonstration of a van equipped with an electronically shuttered video camera that can record images directly onto videodiscs. This will demonstrate that it is possible to record, store, and retrieve pictorial/digital data using off-the-shelf-equipment.

As indicated by the title of the demonstration project, Geographic Information System (GIS) technologies will also be demonstrated. Basically, a GIS is a computerized data base management system for the capture, storage, retrieval, analysis, and display of spatial (locationally defined) data. At least three different GIS software packages will be demonstrated and each of the videodisc systems will be tied into a GIS. While this demonstration project highlights GIS and videodisc technology, this paper discusses the two video disc systems that will be demonstrated by FHWA.

CONNECTICUT LASER VIDEODISC SYSTEM

The first system is the Connecticut Department of Transportation's (ConnDOT's) Photolog Laser Videodisc System. ConnDOT has developed an optical video laser disc system to store and retrieve a photographic inventory of the State's highway system. Information accumulated from an annual photolog survey is processed and stored on 12-in laser videodiscs. The photolog survey inventory is collected by two vans manufactured by the Techwest Corporation of Vancouver, British Columbia. ConnDOT's 3,800 mile State highway system is photologged in both directions at 0.01 mile intervals. The sequential photographs contain images of the pavement surface and the roadside environment. On-board equipment stores information on the highway location, date, and time the data are collected. Other on-board instrumentation simultaneously collects typical second generation photologging data such as horizontal and vertical curvature, cross slope, grade, side friction, and roughness.

The collected survey data is stored on tape cartridges in the photolog vehicle, then transferred to personal computers. These data are separated into unique files depending on route, direction and year collected, checked for errors, and reformatted. The edited data are then uploaded to the ConnDOT mainframe computer.

Production of the laser videodiscs proceeds simultaneously with the photolog operation. The storage capacity of the double-sided laser discs is 108,000 images (54,000 images per side). The 12-in diameter discs, which resemble phonograph records with a reflective aluminum surface, are write-once-read many times (WORM) storage media that can be economically copied. In simple terms, photolog images are digitized and recorded onto the reflective surface by a high-energy laser beam. A low-energy laser beam retrieves the stored data, reading one side of the disc at a time.

The ConnDOT determined that approximately 53,000 frames on each side of the disc would be coded with the photolog images. One-half of these frames contain the original images obtained in the inventory. During processing a 6:1 enlargement of a portion of the pavement surface is produced. This zoomed image is stored on the remaining 26,500 frames on the same side of the disc. The resulting disc contains 26,500 normal images of the pavement and right-of-way, and 26,500 corresponding zoomed pavement surface images. The final product is an inventory of 265 mi of the State's highways per disc side.

As stated earlier, the discs are produced from 35-mm photolog film. The film is developed, edited, and spliced onto reels containing about 26,500 frames (1656 ft) of film. This film is sent to a videodisc premastering facility and transferred to one-in Type C videotape. After adjusting the color balance, brightness, and contrast, the normal and enlarged portions of the film image are recorded onto videotape. These tapes are then shipped to the 3M Corporation in St. Paul, Minnesota, where each is mastered onto one side of a double-sided laser videodisc. The total production cost of each double-sided disc is about $5,000 per disc per side. Economies result, however, during disc replication. The replication cost is only about $30 per side per disc.

ConnDOT's Photolog Laser Videodisc Viewing Stations consist of the following hardware:

- IBM PC/AT with 640K RAM memory, two 360K floppy disk drives, a 20 megabyte hard disk drive, monitor, and printer.
- New Media Graphics Graphover 9500.
- Hitachi VIP-9550 Laser Videodisc Player.
- Studio quality video monitor.
- Graphics tablet with puck (mouse).
- Color video printer or black and white video printer (optional).

The viewing system is controlled with an IBM PC/AT personal computer through a specially developed software package called "SuperHIWAY." The program controls the operation of the micro as well as the graphics generator and the videodisc player. During operation the user can retrieve any photolog image, normal or enlarged, and view it on the video monitor within 3 seconds. Additionally, the PC monitor can display information from any data file that is spatially referenced to the image on the video monitor. Other features of the viewing system include: viewing the opposite direction; varying the speed for viewing the images; and overlaying a grid for longitudinal and lateral measurements.

Some typical uses of the system include:

- Route/mileage location determination.
- Pavement condition rating, roughness evaluation, and paving quantity estimate.
- Inventory data base with geometric data and roadway features.
- Reference of existing highway, roadside features, and land use.
- Preliminary engineering location and site review.
- Pavement marking inventory and design.
- Review accident locations.

ROADVIEW III

The second system to be demonstrated by FHWA is the ROADVIEW III manufactured by Mandli Communications of Middleton, Wisconsin. The ROADVIEW III consists of a Panasonic TQ-3032 player which is interfaced with an Apple MacIntosh II-X computer. The system is a self-contained highway photolog viewing station based on analog optical disc technology as the visual storage medium.

The ROADVIEW III is intended for high density storage and retrieval of film and video based photographic records at speeds less than half a second. It uses a map based interface to aid in the search of data and images for highway photologs, aerial photograph files, road plans, and other image data bases.

There are two basic differences between the laser discs used in ROADVIEW III and ConnDOT. First, ROADVIEW III's 12-in discs are encased in plastic cassettes and use 36,000 frames per side per disc when recording in a high resolution mode. The other difference is production costs. Each blank double side disc used in the ROADVIEW III system costs about $330. Data is recorded onto each blank disc in a recording studio in real time. Thus each disc costs $330 plus studio recording time.

If one assumes a cost of $1,000 per session for a recording studio and that two double-sided discs can be produced in a session, this works out to about $830 per double-sided disc. Every disc produced using this procedure will cost the same amount. Naturally, the cost can go up or down depending on actual studio costs and the actual number of discs produced each session.

After images have been recorded, the next step is to index the images before the disc is placed into the work station library. The ROADVIEW III software package allows the user to select the facility, district, route, and county. The operator then is instructed to insert the appropriate disc into the videodisc slot. Once the operator has done this, a menu bar appears on the top of the screen. The menu bar allows the user to display a data screen and control screen; index and search a disc; display roadway alphanumeric data from other data bases; and create a temporary playback file of user selected images. Another key feature of the work station is the ability to organize image data to facilitate analysis. The operator can view the opposing direction by pushing one button. Other features include:

- Defining the speed for viewing the images.
- Overlaying data (or removing data) on the screen over the images.

The FHWA is very enthusiastic about the future of laser videodisc technology. It anticipates a large and receptive audience for these technologies and considers them a natural progression of conventional photolog systems.

DISCUSSION AT WESTERN WORKSHOP

Q: Did they go out every so many years or every other year?

A: They go out, I believe, at least once a year and reshoot. A number of States do that with photologging anyway. I believe Wisconsin is one of those. But, it's cheaper now to produce this medium. You're not processing or handling film, or any other process associated with that.

Q: How much does it cost to convert the disc?

A: Well, there are two different formats for discs. A lot of it is a function of how many discs you have. In Connecticut, the first disc costs $5,000. Each disc after that is $60. In Wisconsin, the first disc is $600 and so is each disc thereafter. I can't explain that to you any more than I just did because we're still putting the costs together. There are two different formats and what's going to come out of all of this work in Iowa, Wisconsin, and Minnesota is nailing these kinds of costs down.

Q: You store it directly on the disc in the van?

A: Right in the van. You walk away with this disc, and it's all ready to go.

SIGN MANAGEMENT SYSTEM

Jeffrey F. Paniati
Highway Research Engineer
Federal Highway Administration
6300 Georgetown Pike, T-210
McLean, VA 22101-2296

INTRODUCTION

Today's highway system is a dynamic one which continues to grow and change. As the complexity of the system increases, the motorist's reliance on traffic signs for information also increases. Nighttime conditions add to the problem by reducing the driver's visibility and eliminating many of the other cues that the motorist uses for guidance. This problem is reflected in highway fatality statistics which show that the mileage fatality rate (fatalities per vehicle-mile) is three times higher at night than during the day. While it is known that there are a number of factors which contribute to this (for example, alcohol and fatigue), it is also known that drivers rely on signs for the necessary warning, regulation, and guidance to move smoothly and safely toward their destinations.

If traffic signs are to work as intended, then they must be installed properly, inspected regularly, and replaced when the retroreflectivity of the sign is no longer adequate. The Federal Highway Administration (FHWA) has undertaken a major research program to address the problem of sign retroreflectivity. The goal of this program is to establish minimum in-service retroreflectivity levels for traffic signs and markings and to develop the management programs and measurement tools necessary to effectively implement these requirements. An overview of the entire retroreflectivity research program is presented in a paper titled, "The Federal Highway Administration Retroreflectivity Research Program," which is included elsewhere in these Proceedings.

This paper describes one part of this research program, the Sign Management System (SMS). In its most basic form, this system allows a sign inventory to be created and the age and condition of signs to be tracked. However, the SMS goes beyond a simple inventory; it will use computer models to predict when a sign is likely to need replacement. This will assist highway administrators in locating deficient signs, using limited maintenance funds more efficiently, and projecting budget needs.

This paper presents an overview of the SMS along with a discussion of the current and planned capabilities of the system.

SYSTEM REQUIREMENTS

The SMS is designed to run on IBM-compatible microcomputers with 512K RAM and either two 360K floppy disk drives or a hard disk. The software was developed using dBASE

III PLUS and then compiled. This allows the system to run on a microcomputer equipped with MS-DOS (Version 2.0 or later). dBASE III PLUS is NOT required to run this program.

SYSTEM OPERATION

The SMS operates from a series of menus and input screens. The menus allow the user to move through the system, while the input screens allow data to be entered and the inventory created. A Help Key is provided to assist the user in the data input process.

SYSTEM DESIGN

The SMS is comprised of four modules, each of which can be accessed through the main menu.

Sign Inventory

This is the main module in the system. It allows the user to create a new sign inventory data base, add new signs (records) to an existing data base, modify fields within existing records, and delete unwanted records. For each record entered, two screens are created. The input screen (figure 29) contains information on the location of the sign, its characteristic data, and predictive information. The history screen (figure 30) is automatically created when a new record is entered and is updated each time the sign is inspected. This screen provides an inspection history for the sign. This information can be used to track sign deterioration and estimate sign life. A preassigned function key allows the user to switch between the two screens.

Other features of the Sign Inventory Module include:

Default - Allows default values to be set for any field(s). This is designed as a timesaver by allowing redundant information to be entered once and reused on subsequent records.

Locate - Allows records to be viewed, modified, or deleted. The record ID number can be used to locate an individual record. In addition, any combination of route name, station number, and intersection name can be used to select a set of records.

Archive - Allows inactive records (for signs which have been removed from service) to be stored in a separate archive file. The information in archive files can be accessed, but it cannot be changed.

Sign Dictionary

The sign dictionary contains standard sign characteristics such as color, shape, and size for each sign in the *Manual on Uniform Traffic Control Devices* (MUTCD). When the SMS is fully operational, the dictionary will be used as a standard reference by the models to

S M S - Modify/Delete (ART)

LOCATION — ID # 1 — ROUTE NAME/# CONSTITUTION AVE.

INTERSECT PENNSYLVANIA AVE. — STATION 100.00 — DIRECTION N

POSITION R — OFFSET 5 — HEIGHT 7 — ORIENTATION S

DATA — MUTCD R2-1 — LEGEND "SPEED LIMIT" [25]
(<F4> Insert DICTIONARY value)

SIZE: W: 24 H: 30 — SHEETING 2 — BACKING A — POST S — CONDITION F

INSTALL DATE 10/19/82 — INSPECT DATE 10/28/87 — SIA: L: — B: 38

COMPLEXITY H — SPEED 25 — CURVE N — LANES 6 — FLOW 2

RESULTS — AVAILABLE SIA 0.0 — REQUIRED SIA 0.0

RECOGNITION DISTANCE 0 — REPLACEMENT DATE

<F3> DISPLAY Special Keys

Figure 29. Sign management system imput screen.

Sign History (ART)

ID # 1 — INSTALL DATE 10/19/82 — SHEETING 2

INSPECT DATE	CONDITION	SIA L	SIA B	REPLACE DATE
10/19/82	N	0	70	
10/30/84	G	0	50	
10/10/86	G	0	43	
10/28/87	F	0	38	

Complete these fields to archive sign:

REMOVAL DATE / / — REASON

<Esc> PREVIOUS screen — <F1> HELP

Figure 30. Sign management system history screen.

reduce the data entry requirements and minimize the possibility of error. The dictionary can currently be used as a reference source for information commonly found in the MUTCD. Signs can be located using the MUTCD code or the sign legend.

Parameters

This module allows the user to enter estimated sign replacement costs ($/square foot of material). This cost is then used in the Reports module to generate estimated sign replacement costs for any group of user-selected signs. In the future, this module will also contain the parameters for the available retroreflectivity, required retroreflectivity, recognition distance, and replacement date models.

Reports

This module allows the user to generate hard-copy reports from an SMS inventory data base. These reports can be used to output information from active or archive files. The reports are based on four user-selected criteria (location, sign type, installation data, and retroreflectivity level) which can be used in any combination. The replacement cost for each sign meeting the criteria is provided, along with a total cost for the entire set selected.

CURRENT STATUS AND FUTURE RESEARCH

In its present form, the SMS can be used to create a sign inventory and implement a systematic review process based on the age of the sign and a subjective assessment of its condition. Ongoing research studies on the "Minimum Visibility Requirements for Traffic Control Devices" and the "Service Life of Retroreflective Traffic Signs" will provide the information necessary to develop and implement the predictive models. It is anticipated that the complete SMS system will be available in the spring of 1991. The practical application of the SMS will be studied in a planned FY 1991 study. This effort will involve the implementation and evaluation of the SMS in a small-to-medium sized jurisdiction. It will document the costs of implementing the SMS and any modifications or enhancements which are required.

DISCUSSION AT EASTERN WORKSHOP

Q: When will this project come to Dallas?

A: At this point, people come up and say, "Put us on the list," and that's just how we're doing it.

Q: You don't just produce one set of disks, you produce a lot of disks when you get them.

A: The costs that we get are two different ways with cost per disk information on it. It naturally is a function of how many you buy but in Wisconsin, it is costing $600 per disc with information on it, that is both sides with approximately 1,000 mi of information on the disk. Each copy is $600. And that's with the Panasonic format. In Connecticut it's $10,000 for the master disk and $60 per disk after that. We're in an early stage in all of this. We're putting all the costs together. The only information we're getting from Wisconsin, Minnesota, and Connecticut is that it is cheaper than photologging. It looks like it's well worth doing. From the reactions we're getting, it appears every State with our ongoing photolog is going to get this as fast as they can.

DISCUSSION AT WESTERN WORKSHOP

Q: How do you call up a sign?

A: To call up a sign, you have a variety of different ways you can do it. You can use a sign's unique ID number if you know it. I guess I should mention that in inventory, we have sort of the same categories we described earlier. You can add a sign. You can delete a sign. You can locate a sign or modify one. To locate it, you can use, as I mentioned, the ID number. If you know the location, you can enter the route and the milepost. If it's entered by intersection and distance, you can enter that. You can also enter a range. If you're not sure, you can enter the intersection from this intersection to that intersection or from this milepost to that milepost and flip through the signs until you find the one you're looking for. So, there are a variety of ways depending upon how much knowledge you have about the individual sign.

Q: Did you set it up so that you can do mass updates?

A: We haven't—mainly because the thought is that you would go down and want to record some information about the individual ones. I don't see any reason why we couldn't do that because that's basically what we do when we're entering new data. We have that mass capability where we have certain information that's automatically put onto the screen each time and we have the flexibility of changing that if we want to. But you don't have to, so I'm sure we could do the same thing with an update mode as well. That might be something we need to look into. That's the kind of the thing on which we're looking for feedback—input about things that you need to do; things that would make your life easier. And that's what we want the system to do.

SESSION 7

LOOK TO THE FUTURE

FUTURE FHWA RESEARCH, DEVELOPMENT, AND IMPLEMENTATION

Jeffrey F. Paniati
Highway Research Engineer

Guenther W. Lerch
Highway Engineer

Federal Highway Administration
6300 Georgetown Pike
McLean, Virginia 22101-2296

The Federal Highway Administration (FHWA) has developed a comprehensive research program to study the issue of minimum in-service retroreflective requirements and to develop the management programs and measurement devices necessary to implement these requirements. Status reports for all of the major research studies appear earlier in the proceedings. The completion dates for these studies vary, but the majority will be completed between July 1990 and July 1991.

At this time, FHWA plans to develop and refine the results of the retroreflectivity research program. While FHWA has not completed allocating funding for individual studies, future research will most likely fall into the following four areas: refining research results, testing and evaluating management and measurement tools, demonstrating results and training users, and preparing technical handbooks and guides.

REFINE RESEARCH RESULTS

Upon completion of the research on minimum retroreflectivity requirements, FHWA expects that good information will be available for most typical driving situations. However, additional refinements will be required to fully examine the range of factors that impact these requirements. These factors include the effect of rain, snow, dew, and other weather conditions, the tradeoff between increasing sign size and sign retroreflectivity, the impact of changing headlamp designs, the effect of complex visual backgrounds, as well as others. Pilot studies in these areas have begun, and FHWA anticipates that additional research efforts in these areas will take place in the future.

TEST AND EVALUATE MANAGEMENT AND MEASUREMENT TOOLS

As part of the retroreflectivity research program, FHWA is developing the Sign Management System (SMS) and the measurement devices for sign and pavement marking retroreflectivity. Additional work will be required to field test these programs and instruments so that they can be fully developed into effective engineering tools. Work in this area will include implementing the SMS in a small municipality to evaluate its utility, as well as the testing and evaluation of the measurement devices by State and local highway agencies in fully operational situations.

DEMONSTRATE RESULTS AND TRAIN USERS

FHWA will use its in-house resources and cooperate with organizations such as the National Committee on Uniform Control Devices, the American Association of State Highway and Transportation Officials, the Institute of Transportation Engineers, and others to ensure that the results of this research program are disseminated and implemented in an efficient manner. Planned activities include demonstration programs to introduce the results of the research to State and local highway agencies and to develop training courses targeted at engineers and technicians in the proper techniques for the inspection, maintenance, and refurbishment of traffic control devices.

PREPARE TECHNICAL HANDBOOKS AND GUIDES

Included in the Fiscal Year 1990 contract program of the FHWA is the revision and update of the *Roadway Delineation Handbook*. The handbook, initially published in the early 1980s, has been a valuable resource for practicing field engineers concerned with the installation and maintenance of highway delineation systems. A revised version of the handbook should be available for distribution in late 1991. Pending the establishment of final regulations pertaining to minimum performance standards for traffic control devices, FHWA will revise and reissue the *Retroreflectivity of Roadway Signs for Adequate Visibility Guide*. The original guide, released in November of 1987, has become a highly successful resource document for State and local highway agencies responsible for sign installation and maintenance.

PARTICIPANT FEEDBACK

Following the final presentation session, participants were given the opportunity to ask any lingering questions or make any final comments concerning the workshop. The participant feedback period took place at both workshops following the last presentation in the Look to the Future session. A summary of the comments is set out below.

EASTERN WORKSHOP

Actions for Improving Signing and Pavements

To maintain goals and objectives consistently, one participant suggested that the Federal Highway Administration (FHWA) write down national positions and distribute them to each division office. Another participant noted that funds for signing will not be available from State budgets unless they are initially designated as such at the Federal level. Another participant commented that, because of the heavy snowfalls in the Northern States, agencies in the North cannot replace markings within 14 days year round. He also suggested that the FHWA do testing of pavement markings in northern States such as Michigan or New York.

Liability Concerns

One participant expressed concern about establishing a minimum range of numbers for retroreflectivity, because they may offer "lawyers something to run with." In response to this concern, Philip Russell commented that FHWA cannot "make every agency liable for every sign." Another participant, also commenting on the question of legal liability, suggested that FHWA talk with attorneys to find out whether retroreflectivity standards would, in fact, invite legal difficulties and how. Another participant suggested that standards may actually decrease liability problems because they will establish a definite level for the highway community to adhere to. Without standards, any good lawyers can find a different expert to refute the standard set by an agency's expert.

Brighter Does Not Always Equal Better

Because industry sees brighter as better, one participant suggested that established standards will avoid further extension of this trend and the economic burden that accompanies it. Philip Russell then commented that the numbers determined so far are lower than he expected. He hopes that such a standard will turn industry away from creating brighter and brighter materials and toward developing more durable materials with more angularity.

WESTERN WORKSHOP

Observation Angles

A participant from the Denver office noted a topic rarely addressed during the discussions: observation angles of sign sheeting and the decreased luminance as viewed from trucks as compared to cars. Richard Schwab addressed the concern by saying that FHWA is looking at this problem, which applies to some other drivers as well as truck drivers. Another element that must be factored in with observation angles is required characteristics of braking systems. Work is also being done to look at vision standards for truck drivers.

Vision Requirements and Older Drivers

A participant remarked that FHWA had given no guidance on vision requirements regarding problems with older drivers. Guenther Lerch responded that FHWA has created a new program emphasis area that addresses older drivers. One participant suggested that problems of older drivers are not vision problems, but are political problems and noted the need to consider the entire human not just their vision.

Headlights

One participant, who expressed concern that new car headlight designs cut off the top and bottom of the light beam, thus eliminating a driver's ability to see signs or pavement markings at night, asked whether there was any Federal movement to create headlight requirements. Guenther Lerch responded that the National Highway Traffic Safety Administration, which has the authority for rulemaking of vehicle designs, is concerned about the new headlamps. Another participant commented that the new headlights are designed to look good and to sell cars, not to help consumer safety—a problem that stems from not enough rulemaking in the past.

Application of the Standards

Concerning the retroreflectivity values, one participant asked under what conditions would the standards be applied and pointed out that if the standards will apply under wet conditions more research specific to these conditions must take place. He finished by asking whether there was any current or planned research in this area. In response, Richard Schwab described one study under way that simulates wet weather conditions. The study is the first step in the long process of developing standards for adverse conditions. Initially, however, the standards will be created for dry, ideal conditions.

APPENDIX A. SPEAKERS

Charles E. Antle
Pennsylvania State University

Robert W. Attaway
Institute for Transportation Research and Education

William Baker
Federal Highway Administration

Kent L. Black
Bellomo-McGee, Inc.

Richard J. Butula*
City of Milwaukee [Wisconsin]

Donald Casner*
Pennsylvania Department of Transportation

Richard A. Cunard*
Transportation Research Board

Leonard G. Eilts+
Minnesota Department of Transportation

Robert A. Feldman*[1]
Virginia Department of Transportation

Robert M. Garrett+
American Traffic Safety Services Association

Steven C. Hearn*
Virginia Department of Transportation

Dwayne Hofstetter+
Oregon Department of Transportation

Edwin A. Lagergren
Washington State Department of Transportation

Victor H. Liebe*
American Traffic Safety Services Association

John J. Lumia
EKTRON Applied Imaging, Inc.

W. Dan McComb+
Idaho Transportation Department

Brian A. McCoola*
Pennsylvania Department of Transportation

Hugh McGee
Bellomo-McGee, Inc.

Paul L. Olson
The University of Michigan Transportation Research Institute

Jeffrey F. Paniati
Federal Highway Administration

Thomas M. Pickford+
Shawnee County [Kansas] Public Works Department

Calvin Roberts*
Michigan Department of Transportation

Philip O. Russell
Federal Highway Administration

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* Presented at eastern workshop only.
\+ Presented at western workshop only.
[1] Presented paper for Steven C. Hearn.

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Richard N. Schwab
Federal Highway Administration

Fred F. Small[*]
Virginia Department of
Transportation

J. Richard Young, Jr.[+1]
Mississippi State Highway Department

[*] Presented at eastern workshop only.
[+] Presented at western workshop only.
[1] Also presented paper for Robert W. Moseley.

APPENDIX B. PARTICIPANTS

EAST COAST

Jerry W. Alcorn
City of Murfreesboro [Tennessee]

M. G. Alderman
Virginia Department of Transportation

Charles E. Antle
Pennsylvania State University

Robert W. Attaway
North Carolina Institute for Transportation

David A. Badger
Forest Service USDA

William Baker
Federal Highway Administration

Bruce D. Baldwin
Federal Highway Administration

Kent L. Black
Bellomo-McGee, Inc.

Brian Bowman
Auburn University

Travis Brooks
Federal Highway Administration

Warner Brooks
Town of Vienna [Virginia]

Archie Burnham
Archie Burnham Consulting

James Bushey
City of Oswego [New York]

Richard J. Butula
City of Milwaukee [Wisconsin]

Donald Casner
Pennsylvania Department of Transportation

Hon-Leung Chan
City of Dallas [Texas]

David Cochran
Maryland State Highway Administration

Simon K. Cornett
Kentucky Department of Highways

Michael A. Corwin
Delaware Department of Transportation

John P. Couch
Town of Chapel Hill [North Carolina]

Robert E. Craven
National Association of County Engineers

Needham C. Crowe
North Carolina Department of Transportation

Richard A. Cunard
Transportation Research Board

Larry Dean
Medina County [Ohio]

Frank L. Dolan
Monroe County [New York] Department of Public Works

Gerald Donaldson
Center for Auto Safety

Jon C. DuFresne
Virginia Department of Transportation

Anthony Eldering
New York State Department of Transportation

Robert A. Feldman
Virginia Department of Transportation

David E. Garrett
Cobb County [Georgia] Department of Transportation

James G. Geest
Federal Highway Administration

James E. Gordon
Maryland State Highway Administration

G. Glenn Grigg
North Carolina Department of Transportation

John W. Hazelette
City of Norfolk [Virginia] - Traffic Engineering

Lap T. Hoang
Florida Department of Transportation

Paul Hoover
Pennsylvania Turnpike Commission

Gary R. Houde
New York State Deparment of Transportation

Ron Jeffrey
Town of Vienna [Virginia]

Lee Jewett
Eastern New York Correctional Facility

Richard S. Kaske
Addison [Illinois] Township Highway Department

Gerald A. Kearney
City of Huntsville [Alabama] Department of Transportation

James T. Kerr
City of Murfreesboro [Tennessee]

Marvin Kittle
City of Madison [Wisconsin] Traffic Engineering

Ken Kobetsky
West Virginia Department of Transportation

Edwin A. Lagergren
Washington State Department of Transportation

Louis Landry
City of Lafayette [Louisiana] - Traffic Services

Randy B. Lee
North Carolina Department of Corrections

Thomas E. Lee
Virginia Department of Transportation

Guenther W. Lerch
Federal Highway Administration

S. Page Lever
South Carolina Department of Highways & Public Transportation

Victor H. Liebe
American Traffic Safety
Services Association

John J. Lumia
EKTRON Applied Imaging, Inc.

Lucien M. Madison
Virginia Department of
Transportation

Michael E. Mahone
City of Huntsville [Alabama]
Department of Transportation

Daniel Malloy
Township of Radnor [Pennsylvania]

Charles H. Mayeres
Columbus, Ohio, Traffic Engineering

Brian A. McCoola
Pennsylvania Department
of Transportation

Hugh McGee
Bellomo-McGee, Inc.

Thomas D. Migrock
Montgomery County [Maryland] Traffic
Engineering

Francis J. Mirack
Federal Highway Administration -
DC Division

Stephen Moore
Delaware River & Bay Authority

John Nazal
Alachua County [Florida] Public Works

Bob Nordlund
Michigan Department of Transportation

Paul L. Olson
The University of Michigan Transportation
Research Institute

David Orr
Yates County [New York] Highway
Department

Jeffrey F. Paniati
Federal Highway Administration

John Payne
DC Department of Public Works

Raymond M. Peck
Medina County, Ohio,
Engineer's Office

Vic E. Peyton
Virginia Department of
Transportation

Gary Platz
Virginia Department of
Transportation

Frank K. Price
Department of Public Works
[Washington, DC]

William J. Raves
Pennsylvania Turnpike Commission

Calvin Roberts
Michigan Department of
Transportation

Philip O. Russell
Federal Highway Administration

James C. Sanford
City of Jamestown [New York]

James D. Schroll
Anne Arundel County [Maryland]
Traffic Engineering Division

Richard N. Schwab
Federal Highway Administration

Frank Shepard
Virginia Transportation Research Council

Fred F. Small
Virginia Department of Transportation

Paul L. Stout
Maryland State Highway Administration

Norris Todd Talley
Virginia Department of Transportation

Walter J. Tennant
National Association of County Engineers

John W. Thompson
Montgomery County [Maryland] Division of Traffic Engineering

M. J. Trickey
Florida Department of Transportation

Don S. Turner
South Carolina Department of Highways

Marvin K. Tweedy
Virginia Department of Transportation

Robert L. Vecellio
Auburn University

W. Scott Wainwright
Montgomery County [Maryland] Division of Traffic Engineering

Jim Weaver
Federal Highway Administration

Lynn Wolfe
State of Alabama Highway Department

WEST COAST

Ken Adair
Utah Department of Transportation

Charles Antle
Pennsylvania State University

Robert Attaway
North Carolina Institute
for Transportation

Bill Baker
Federal Highway Administration

Aida Berkovitz
Federal Highway Administration

Kent Black
Bellomo-McGee, Inc.

Nicholas Boerger
City of Rapid City [South Dakota]

Keith Brown
Utah Department of Transportation

Archie Burnham
Archie Burnham Consulting

C. F. Campbell
National Association of
County Engineers

Eric Cheng
Utah Department of Transportation

Norman W. Childress
Benton County [Washington] Engineering

Ross Christensen
Utah Department of Transportation

Marvin Crabb
City of Grand Prairie [Texas]

Carl Craner
Utah Department of Transportation

George A. Dale
Wyoming Highway Department

John Kenneth Dalling
Bonneville County [Idaho] Road and
Bridge Department

Jim Eberling
Utah Department of Transportation

Paul Edwards
Utah Department of Transportation

Leonard G. Eilts
Minnesota Department of Transportation

Barry W. Fairfax
Seattle [Washington] Engineering
Department

Donald L. Fenton
Federal Highway Administration -
Montana Division

Gary L. Fox
City of Des Moines [Iowa]

Robert M. Garrett
American Traffic Safety
Services Association

Zeke Gonzalez
Utah Department of Transportation

Mike Gostovich
Wyoming State Highway Department

Richard O. Gumtau
Federal Highway Administration

John Gunderson
Utah Department of Transportation

Steven C. Herring
City of Boulder [Colorado]

Dwayne Hofstetter
Oregon Department of Transportation

Dan Julio
Utah Department of Transportation

P. D. Kiser
Nevada Department of Transportation

Edwin A. Lagergren
Washington State Department of Transportation

Richard R. Larkins
City of Grand Prairie [Texas]

Kurt G. Larson
Salt Lake City [Utah] Department of Transportation

Elmer J. Leland
Federal Highway Administration

John L. Leonard
Utah Department of Transportation

Guenther W. Lerch
Federal Highway Administration

Fred Lewis
Utah Department of Transportation

John J. Logan
King County [Washington]

John J. Lumia
EKTRON Applied Imaging, Inc.

Bill L. Manwill
Bonneville County [Idaho] Road and Bridge Department

Richard A. Mather
State of Oregon - Public Utility Commission

Joe McBride
Utah Department of Transportation

W. Dan McComb
Idaho Transportation Department

Hugh McGee
Bellomo-McGee, Inc.

Robert Molnar
Pima County [Arizona] Department of Transportation

Michael Moore
Pima County [Arizona] Department of Transportation

Doug Myers
City of Longmont [Colorado]

David M. Neeley
U.S. Department of Agriculture Forest Service

Lee Nielson
Utah Department of Transportation

Gregory J. Novak
Federal Highway Administration - Nevada Division

Paul L. Olson
The University of Michigan Transportation Research Institute

Jeffrey F. Paniati
Federal Highway Administration

Frank R. Papacun
Maricopa County [Arizona] Highway Department

Jack F. Parker
Bonneville County [Idaho] Road
and Bridge Department

Thomas M. Pickford
Shawnee County [Kansas] Public Works
Department

James L. Pline
Engineering Consultant

Blain Pollock
Utah Department of Transportation

Craig J. Reiley
Oregon Public Utility Commission

Joshua K. Richardson
City of Longmont [Colorado]

Troy Michael Robertson
City of Rochester [Minnesota]

David C. Royer
Los Angeles [California] Department
of Transportation

Philip O. Russell
Federal Highway Administration

A. J. Schepp
Wyoming State Highway Department

Greg Schertz
Federal Highway Administration -
Region 8

Richard N. Schwab
Federal Highway Administration

Tracy P. Shaw
Pima County [Arizona] Department
of Transportation

John W. Sheldrake
Oregon State Highway Division

Duncan J. Silver
Federal Highway Administration

Jerold Simpson
Colorado Department of Transportation

Layne Slack
Utah Department of Transportation

Daniel Soriano
City of Albuquerque [New Mexico] -
Traffic Engineering

Clifford Steele
Salt Lake County [Utah]

Glenn Stephens
Clark County [Washington] Public
Services

Doug Swain
Salt Lake County [Utah]

Milton C. Taylor
U.S. Department of Agriculture -
Forest Service

Ritchie Taylor
Utah Department of Transportation

Jerry Wardell
Utah Department of Transportation

Michael Widdison
Utah Department of Transportation

Marcus Worrell
Federal Highway Administration

J. Richard Young, Jr.
Mississippi State Highway Department

Helmut T. Zwahlen
Ohio University