Research on the End of Life for Retroreflective Materials: A Progress Report

J. F. Paniati and R. N. Schwab

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

An examination of accident statistics confirms that driving at night is more dangerous than driving during the day. In 1987, about 23,000 fatalities, approximately 55 percent of all fatalities, occurred at night, although only 25 percent of travel occurred at night. This translates to a fatality rate (fatalities/vehicle miles traveled) that is more than three times higher at night than during the day.

It is known that a variety of factors contribute to this day/night disparity, including fatigue, intoxication, weather, and so on. However, drivers depend to a large extent on traffic control devices for warning, regulation, and guidance. As visibility conditions become poorer at night, this dependence increases. Many of the cues used by the driver for visual guidance in the day disappear at night. The addition of nighttime inclement weather and glare from opposing vehicles serve to compound the problem. The basic requirement for any traffic control device is that it must be visible and easily understood in time to permit the proper response by the driver. Because of gradual deterioration with age, many traffic control devices fail to meet this basic requirement at night.

This problem is compounded by the aging U.S. population. By 2030, the number of people older than 65 will more than double. Figure 1 shows the projected trend in the U.S. population to 2030. This population has grown up dependent on the motor vehicle and is expected to continue to use automobiles to meet daily mobility needs. Older drivers, as a group, exhibit a significant decrease in perceptual, cognitive, and psychomotor abilities, all of which are related to safe driving performance. Deteriorated signs cause partial difficulty for older drivers because of their decrease in perceptual ability.

Information and Behavioral Systems Division, Office of Safety and Traffic Operations R&D, 6300 Georgetown Pike, HSR-30, Federal Highway Administration, McLean, Va. 22101.

FHWA has recognized the need for traffic control signs and markings to be visible especially at night. Currently, the *Manual on Uniform Traffic Control Devices* (MUTCD) only requires that signs and pavement markings be retroreflectorized or illuminated. A comprehensive research program has been developed by the FHWA Office of Safety and Traffic Operations Research and Development to address the retroreflectivity issue. This research program is premised on motorists' need to detect and respond to traffic control devices in a safe and efficient manner.

The research studies in this program are categorized into several major topic areas (shown in Figure 2): minimum visibility requirements, implementation strategies, service life of signs, sign management system, traffic sign retroreflectometer, and pavement marking retroreflectometer. The program is being undertaken as a cooperative effort involving numerous funding sources, including FHWA research contracts, NCHRP efforts, Small Business Innovation Research (SBIR) funds, and Highway Planning and Research studies.

The research goal for this program is not just to obtain the information necessary to establish minimum retroreflectivity performance requirements, but to develop the tools (management programs and measurement devices) needed to implement them. 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. The status of the research is discussed next.

CURRENT RESEARCH

Minimum Visibility Requirements

In 1987, an FHWA contract 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 that is necessary to satisfy these requirements.

This first step in this effort was to use the existing literature and the results from a controlled field experiment of driver maneuver times to model the driver demand. This demand is based on the distance required by the driver to detect the traffic control device, recognize the message, decide on the proper action, and complete the maneuver (if required). A computerized model of this process, the Minimum Required Visibility Distance (MRVD) Model, was developed. For a

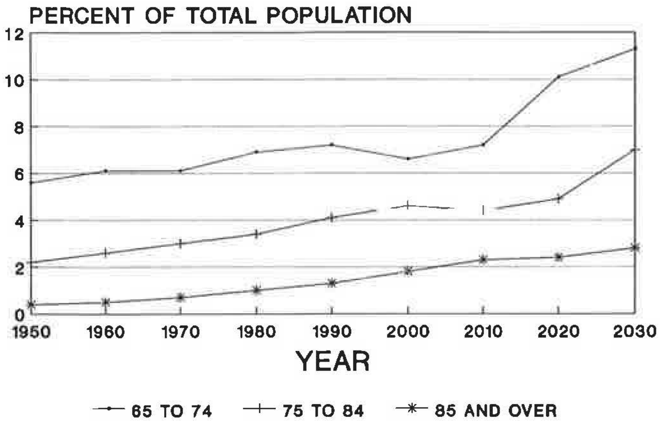

FIGURE 1 Number of elderly drivers as a percent of total population.

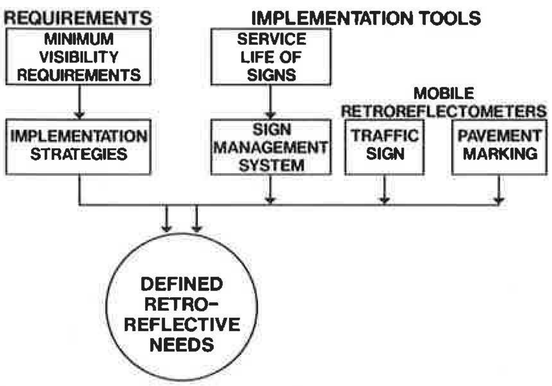

FIGURE 2 Organization of retroreflectivity program.

given traffic control device this model can be used to deter mine the minimum distance required by the driver to respond safely and efficiently.

The second part of the study was to determine the retroreflectivity level required to meet the driver demand. This is a complex process that involves many factors, including the vehicle headlight characteristics, the size and location of the sign, the roadway geometry, and the presence of glare from oncoming vehicles. A previously developed computer model (DETECT), which included these factors, was modified for use. The modified DETECT model was combined with the MRVD model to form a new model, Computer Analysis of the Retroreflectance of Traffic Signs (CARTS). With CARTS the user is able to determine the minimum luminance (and retroreflectivity) required for a specified sign.

To obtain the data necessary to calibrate and test this model, a series of laboratory and field studies were conducted. These studies established the relationship between the retroreflectivity level of a sign and its legibility and conspicuity distances. The final testing and calibration of CARTS has been completed, and the development of a retroreflectivity classification system is under way. It is anticipated that all MUTCD signs will be classified into approximately five categories. Each category will include minimum retroreflectivity values for each sheeting color. Factors considered in the classification will include sign placement, sign size, approach speed of traffic, and message complexity. The scheduled completion date for this project is April 1991.

Economic Assessment of Candidate Performance Requirements

Before the research results from the Minimum Visibility Requirements Study can be implemented, the potential national economic impact of candidate performance requirements must be assessed. The desire for increased driver safety must be balanced with the economic constraints of the highway agencies who must implement the requirements. A 1989 NCHRP research project, Implementation Strategies for Sign Retroreflectivity Standards, has been developed to provide this type of assessment.

As part of this study, retroreflectivity data from about 6,000 unwashed, in-service traffic signs were collected from September 1989 to April 1990. These signs were selected to be representative of various road types (Interstate, primary, urban, etc.) and jurisdictions (state, county, city) in the United States. These data were collected at 25 locations throughout the country.

In addition to obtaining retroreflectivity data, sign replacement cost and inventory practices data will be obtained. These data will be used to estimate the impact of establishing minimum retroreflectivity levels and develop economic-based priorities for sign maintenance budgets. The data collected will help determine how to maximize the benefit obtained from limited funding for sign maintenance. For example, should a highway agency spend its limited sign maintenance funds upgrading 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 effect on highway jurisdictions will be provided. This study was scheduled to be completed in the summer of 1991.

Service Life of Retroreflective Traffic Signs

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

A 1988 FHWA contract, Service Life of Retroreflective Traffic Signs, will model the deterioration of sign retroreflectivity. Retroreflectivity data for 6,000 signs with known dates of installation were collected at 20 sites in 8 geographic regions with varying climatic conditions. Predictive models will be developed for sign deterioration for various color and types of sheeting material. To date, it has been shown that sheeting age, solar radiation levels, and general area climate are the most important variables. The models show a large variation in their ability to predict in-service specific intensity of retroreflection (SIA). This is most likely because of the large initial variation in SIA values for new sheeting, dating errors in the sign inventories, and the limited number of sites surveyed.

The eight equations (four colors by two sheeting types) derived for predicting in-service SIA have R^2 values from 0.2 to 0.6. The goal of this effort was to develop predictive sign-life model(s) that could be incorporated into a sign management system (SMS), described next. Improvement in the predictive capabilities of the sign deterioration models described previously may require calibration with measurements from sample of in-service signs in the jurisdiction in question. This study was scheduled to be completed in March 1991.

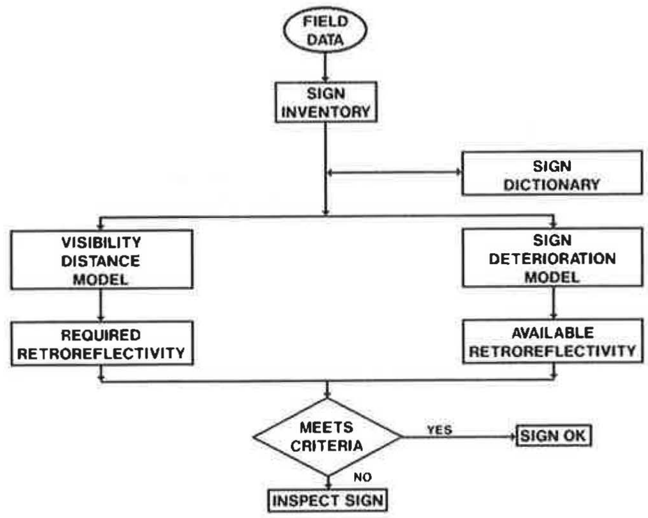

FIGURE 3 Logic flow of SMS.

Sign Management System

With 3.8 million miles of highways and the estimated 58 million signs used by highway agencies to assist drivers, the task to monitor the condition of signs is, to say the least, immense.

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 a sign inventory to be created and the age and condition of signs to be tracked. On completion of the study, it is envisioned that traffic engineers or those responsible for sign maintenance will be able to use SMS to determine which signs are likely to need replacement.

Field verification would also be used in making the final determination as to which signs need immediate replacement and which ones could be left in service. This procedure will assist highway agencies in locating deficient signs, using limited maintenance funds more efficiently, and projecting future budget needs.

The data base management portion of SMS has been developed. In its current form, this menu-driven, IBM-compatible system can be used to assemble and maintain a sign inventory. The final predictive software was expected to be operational in late 1991. A 1991 contract is planned to implement and evaluate the system in a small-to-medium sized community. A logic flow diagram of SMS is shown in Figure 3.

Traffic Sign Retroreflectometer

Sign retroreflectivity can now be measured using a portable measuring device, but this device is not suitable for rapid measurement of numerous signs. The current instrument must be placed against the face of the sign to obtain a measurement. If the retroreflectivity of a large number of traffic signs must be measured in the field, then a new instrument is needed. A practical, safe, and cost-effective instrument for measuring sign retroreflectivity from a moving vehicle in daylight hours is currently being developed under an NCHRP research project, A Mobile System for Measuring Retroreflectance of Traffic Signs.

A laboratory, breadboard instrument has been developed. This device has been designed to operate during the daylight from a moving vehicle. It uses a CCD video camera to collect sign images, with an xenon, electronic flash source to provide a short burst of light sufficiently bright to overcome the daylight illumination. The video image is converted to a digital representation of the sign, analyzed with a microcomputer, and a histogram of the retroreflectivity distribution is output. By initially calibrating the instrument to a source with known retroreflectivity, the average legend and background retroreflectivity values can be obtained from the histogram. An example of a digitized image of a typical traffic sign and the corresponding histogram is shown in Figure 4.

In the first phase of the research, a laboratory prototype was developed and tested. During the second phase, the instrument was repackaged and installed in a van for field evaluation and assessment. The instrument and van, shown in Figure 5, were delivered to FHWA in December 1990. FHWA will work with state and local jurisdictions to evaluate the system and determine what modifications or enhancements are required.

Pavement Marking Retroreflectometer

The current state of the art for measuring the retroreflectivity of pavement markings is similar to the measuring of traffic sign retroreflectivity. Portable instrumentation is available for spot measurements, but the instrument must be placed directly on the marking. This does not allow for the rapid assessment of pavement marking retroreflectivity and can require extensive traffic control and driver delay. Through an SBIR study, Measuring Retroreflectivity of Pavement Markings, a laser-based technique for the measurement of pavement marking retroreflectivity from a moving vehicle has been developed.

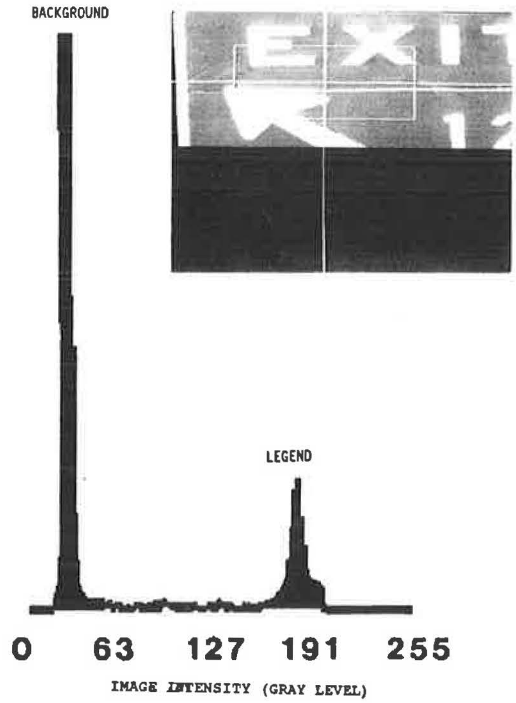

FIGURE 4 Example of sign retroreflectivity data plot.

FIGURE 5 Mobile sign retroreflectometer.

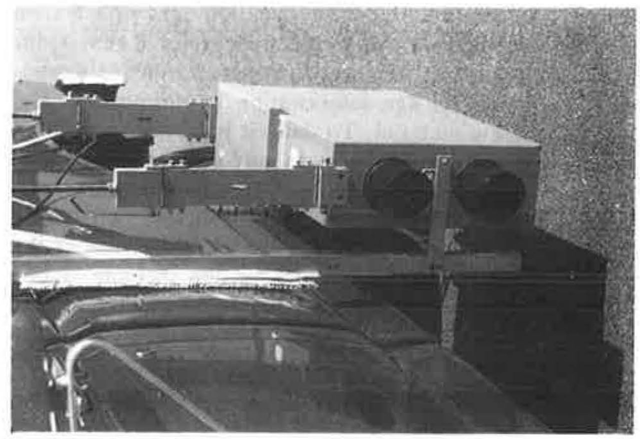

FIGURE 6 Laser pavement marking retroreflectometer.

The prototype laser retroreflectometer, shown in Figure 6, is mounted on the side of a small truck with the bottom of the instrument 5 in. above the road surface.

The laser beam is projected off one surface of a rapidly spinning two-surfaced mirror to a point on the road approximately 30 ft in front of the instrument, making an angle with the road surface of 1°. The beam reflected from the road surface is redirected off the other surface of the rotating mirror to a photo detector. The beam scans each skip stripe approximately 3 times as the vehicle is driven down the highway at normal highway speeds, 20 to 55 mph. The geometry at which the pavement marking is viewed by the instrument is similar to what drivers view.

Work is currently under way to take the vast amount of data the system generates and reduces it to a data presentation format that will satisfy the needs of operating personnel. Statistical sampling procedures and plans for field testing the equipment are being developed. It is expected that a commercial version of this instrument will be available next year.

A number of recent studies have indicated the point at which pavement markings are no longer adequate for driver guidance. For example, the results of NCHRP project 4-16 indicated that rating panels judged the pavement markings to be inadequate for a 45-mph road when their retroreflectometer reading dropped below 100 mcd/m^2/lux. What is now required is the agreement by professionals working in the field on what is a practical retroreflectivity level at which lines should be refurbished. This level must allow adequate time for scheduling the remarking to ensure that the line will not reach the level determined to be unsatisfactory for visual guidance before the next inspection and marking period.

DEMONSTRATION ACTIVITIES

Subsequent to the completion of the above described research, extensive demonstration and implementation activities will be undertaken. The emphasis will be on sign inspection and maintenance training courses and the demonstration of the instrumentation and management and inventory tools that have been developed. Two activities have been completed to date.

Workshops

Two 2½-day regional workshops on field inspection and rehabilitation of traffic control devices were held. At these workshops the progress and current status of research and development efforts to determine performance requirements for in-service retroreflective traffic control devices were reviewed and discussed. Other areas discussed include material selection, improved inventory techniques, field assessment techniques, current state programs, and techniques for refurbishing signs.

Retroreflectivity Manual

A manual has been developed to provide highway personnel with a better understanding of many traffic sign problems.

The manual covers principles of retroreflection; 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.

This manual, *Retroreflectivity of Roadway Signs for Adequate Visibility: A Guide,* FHWA Report FHWA-DF-88-001, was developed for use on Federal Highway Projects, but it may also be used by state and local highway personnel responsible for traffic signs.

Ongoing Activities

Two additional implementation activities are under way. A handbook is being developed to describe and explain innovative materials, equipment, and procedures used by various public agencies in fabricating, installing, and maintaining signs. This handbook will be a helpful reference tool for other jurisdictions to become aware of new techniques that could save time or money in producing and maintaining signs.

The second activity is a revision and updating of the *Roadway Delineation Practices Handbook,* first published by FHWA in 1981. This new edition will incorporate much of the new information on durable materials obtained under NCHRP project 4-16, Service Life and Cost of Pavement Marking Materials. It will also greatly expand the discussion on field evaluation techniques and determining the service life of pavement markings.

CONCLUSION

This research was undertaken to learn more about the problems found in night driving and the problems associated with reflectorized traffic control devices. The human factor needs and requirements for safe nighttime driving were reviewed and evaluated. The program is being used to address the technical aspects of the problem and the financial and managerial problems that would occur if in-service minimum retroreflectivity performance levels were to be adopted. FHWA will work with other organizations interested in this problem, for example, Institute of Transportation Engineers, NCHRP, National Committee on Uniform Traffic Control Devices, AASHTO, and others, to ensure that the results of this program are implemented reasonably and prudently, so that nighttime highway safety can be improved.