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SYNTHESIS 306

Long-Term Pavement Marking Practices

A Synthesis of Highway Practice

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communication and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the Federal Government. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

The Transportation Research Board evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis report will be of interest to local and state transportation agencies as well as to the pavement marking industry that works with them in long-term pavement marking practices. This report documents the current and best practices for managing pavement marking systems, identifies future needs, and addresses driver needs and methods of communicating information to drivers, selection criteria (e.g., reflectivity, pavement service life, wet weather performance), materials (e.g., color, durability, cost), specifications, construction practices, and inventory management systems. It also explores several challenges facing agencies, including funding, nighttime visibility in rain and fog, quality control after installation, and the shortage of quality labor, and discusses new technologies, methods of performance measurement, and environmental constraints.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This report of the Transportation Research Board contains information derived from survey responses from 61 state, province and territory, county, and city transportation agencies and private companies in the United States and Canada to document long-term pavement marking practices and research, and discusses the many different practices among agencies due to variations in structure, policies, and climate. Three types of surveys were distributed: transportation agency, pavement marking equipment/material manufacturers/distributors, and retroreflectometer manufacturers/distributors. The *Manual on Uniform Traffic Control Devices for Streets and Highways* was used as the guiding document.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the available information was assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the author's research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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James Migletz and Jerry Graham, Graham-Migletz Enterprises, Inc., Independence, Missouri, were responsible for collection of the data and preparation of the report.

James Migletz was responsible for the preparation of this report. Mr. Migletz passed away shortly after completing his work on this report. We wish to acknowledge his dedication in completing this comprehensive study, and his lifetime of outstanding achievement as a transportation researcher and engineer.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of J. Stuart Bourne, Traffic Control/Marketing Engineer, North Carolina Department of Transportation; Benjamin H. Cottrell, Jr., Senior Transportation Research Scientist, Virginia Transportation Research Council; Gene H. Hawkins, Jr., Division Head, Texas A&M System, Texas Transportation Institute; Dal J. Hawks, Region Four Director, Utah Department of Transportation; Neil A. Hodson, 3M Traffic Control Materials Division, 3M Center, St. Paul; Debby Kozol, P.E., Traffic Operations Engineer, Bureau of Highway Operations, Madison; Frank N. Lisle, Engineer of Maintenance, Transportation Research Board; Michael E. Robinson, Highway Engineer, Federal Highway Administration; Peter F. Rusch, State Traffic Engineer, Wisconsin Department of Transportation; and Samuel C. Tignor, McLean, Virginia.

This study was managed by Stephen Maher and Jon Williams, Managers, Synthesis Studies, who worked with the consultant, the Topic Panel, and the Project 20-5 Committee in the development and review of the report. Assistance in project scope development was provided by Donna Vlasak, Senior Program Officer. Don Tippman was responsible for editing and production. Cheryl Keith assisted in meeting logistics and distribution of the questionnaire and draft reports.

Crawford F. Jencks, Manager, National Cooperative Highway Research Program, assisted the NCHRP 20-5 Committee and the Synthesis staff.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance are appreciated.

LONG-TERM PAVEMENT MARKING PRACTICES

SUMMARY

An important means of communicating information to drivers is through pavement markings. Transportation agencies use longitudinal pavement markings, pavement markers, and word and symbol markings to provide long-term markings for their highway systems. Sixty-one state, province and territory, county, and city agencies and private companies in the United States and Canada were surveyed to document long-term pavement marking practices and research. There are many differences in practices among transportation agencies because of variations in their structure, policies, and climate. In addition, because of changes in technology, driver needs, and environmental constraints, there are many more materials being used and evaluated than in the past. Furthermore, new technologies and methods for measuring the performance of pavement markings have been and continue to be developed, making the scope of the topic area quite broad.

In this report, the current and best practices for pavement markings are highlighted and future needs are identified. The relationship of the practice to the *Manual on Uniform Traffic Control Devices* (MUTCD) is documented. In addition, the following issues are addressed:

- The process for making decisions on pavement markings,
- Driver needs and ways of communicating information to drivers,
- Traffic crashes related to pavement markings,
- The criteria for selecting materials,
- Specifications and practices,
- Materials,
- Inventory management systems, and
- Performance evaluations using retroreflectometers.

The top four problems and challenges facing transportation agencies and the pavement marking industry are finding the funding for pavement marking programs, nighttime visibility in rain and fog, quality control when markings are installed, and a shortage of quality labor. The estimated total money spent on pavement markings in the year 2000 by the 50 state transportation agencies, 13 Canadian provinces and territories, U.S. counties, and U.S. cities was $1,548,616,821 on 6 148 088 centerline-km (3,818,688 centerline-mi) of highways. The MUTCD specifies and recommends where centerline, lane line, and edge line markings are to be provided based on the type of roadway, the width of traveled way, and the average daily traffic. Some agencies exceed the recommendations of the MUTCD.

Results of research on pavement marking material color, retroreflectivity, and durability are used to improve marking programs. Policies and specifications guide material selection, placement, and evaluation.

Eight state agencies have summarized guidelines for the selection of materials based on 11 factors, the most common being type of line, pavement surface, traffic volume, and type of street and highway. Centerlines and lane lines are more likely to receive durable markings

than edge lines. Interstate highways, freeways, and expressways are more likely to receive durable markings than two-lane, two-way highways. Highways with higher traffic volumes and pavements in new or good condition are more likely to receive durable materials. Most agencies specify the standard line width as 100 mm (4 in.). Wider markings are used to provide greater emphasis.

Drivers encounter difficulties in nighttime guidance because pavement markings often disappear, especially during rain and fog. Increasing retroreflectivity can increase pavement marking visibility and preview distances. A preview time of 2 s was found to be the minimum acceptable limit on roads with properly maintained pavement markings and retroreflective raised pavement markers (RRPMs). At 90 km/h (55 mph), delineation must be visible at least 49 m (162 ft) ahead. A preview time of 3 s is recommended to provide long-range guidance information. At 90 km/h (55 mph), delineation must be seen at least 74 m (243 ft) ahead.

Older drivers require more light to see delineation and are slower to react. It appears that older drivers cannot be accommodated at all speed levels with pavement markings. However, the addition of RRPMs makes it possible to accommodate most drivers.

The standard for measuring pavement-marking retroreflectivity is the 30-m (98.4-ft) geometry. The American Society for Testing and Materials specifies that a new marking is required to have a minimum initial retroreflectivity of 250 millicandelas per square meter per lux (mcd/m^2/lux) for white markings and 175 mcd/m^2/lux for yellow markings. Some state agencies require higher initial retroreflectivity, depending on the material, whereas others do not have any initial retroreflectivity requirements.

The FHWA has developed candidate MUTCD criteria for retroreflectivity of pavement markings, but no such criteria have yet been approved and implemented as policy. The criteria are based on speed, road class, color of line, and presence or absence of roadway lighting or RRPMs. The FHWA sponsored research to determine the impact of the minimum retroreflectivity values on a typical state agency. To meet the minimum values, a typical state agency may have to replace as much as 25% of markings in the fall and 45% in the spring. It may be necessary to increase the amount of money spent annually on pavement markings from $2.4 to $3.5 million. However, the increase would be offset by a reduction of fewer than two fatalities.

Pavement marking retroreflectivity under wet pavement conditions averaged only 46% of the comparable values under dry pavement conditions. For example, to achieve a wet-pavement retroreflectivity of 150 mcd/m^2/lux, the marking would need a dry-pavement retroreflectivity of 326 mcd/m^2/lux.

A scanning tour of European pavement marking practices recommended that all-white pavement markings and tiger tail ramp markings both be studied for U.S. implementation. Chevron markings spaced at 40 m (131 ft) to indicate the proper vehicle spacing reduce tailgating and accidents and have an 80:1 benefit-cost ratio.

The long-term trend in the United States and Canada shows reductions in traffic fatalities. U.S. traffic fatalities decreased 12% from 1988 through 1998, while traffic fatalities in Canada decreased 29%. However, over the 10-year period from 1991 through 2000 traffic fatalities in the United States remained fairly constant, averaging 41,256 fatalities per year (ranging from 39,250 to 42,056). The variation in fatalities appears to be random.

Pavement markings can reduce traffic crashes occurring under darkness. Fatal crashes in the United States are more likely to occur under darkness than injury or property-damage-only crashes. In 1999, 23% (1,449,000) of all traffic crashes in the United States occurred under darkness during normal weather. An FHWA study of pavement marking retroreflectivity showed an 11% reduction in nonintersection traffic crashes occurring at night on dry pavements. In 1999, 4% (270,920) of all crashes occurred under darkness during conditions of rain and/or fog. The FHWA study of pavement marking retroreflectivity did not show a reduction in nonintersection nighttime crashes on wet pavements.

The three types of pavement marking specifications are prescriptive/material, performance-based, and warranty provisions. Of the agencies surveyed, 75% were satisfied with their specifications. Most agencies are confident that they are receiving good materials, but less sure that the application of the markings is adequate. Agencies are starting to use more performance-based and warranty provisions contracts to place more responsibility for quality markings on contractors.

A number of methods are used for preparing the pavement surface for material application including sweeping; air, sand, or water blasting; use of solvents; grinding; and scraping. Air cleaning is often done with a nozzle on the striper located immediately ahead of nozzles that spray the marking material. Surface preparation becomes more complicated when using durable materials and on portland cement concrete pavement. Grinding is the most common method of removing markings. Markings containing hazardous materials, such as lead or chromium, are required be taken away when removed from the pavement.

Sixteen types of materials are being used for longitudinal markings, with state agencies using the largest variety. There has been a shift away from using conventional solvent paint with a high volatile organic compound content. Waterborne paint is the most common material and is used by 78% of the agencies, followed by thermoplastic at 69%. Waterborne paint is striped on almost 60% of the total mileage at a cost of 17% of the total money spent on pavement markings. Thermoplastic is striped on almost 23% of the total mileage at a cost of 35% of the money spent on pavement markings. Durable markings are being used to increase the service life of pavement marking systems. The trend is to have contractors apply durable markings, many of which require specialized equipment and highly trained workers.

The service life of longitudinal pavement markings varies by color of line and type of pavement surface. At a threshold value of 100 mcd/m^2/lux, white lines have a service life of 34 months, which is 42% greater than the 24-month service life of yellow lines. The longer service life of white materials shows a benefit of an all-white system of pavement markings. Lines on asphaltic concrete pavement have a service life of 33 months, which is 27% greater than the 26-month service life of lines on portland cement concrete pavement. However, service life is highly variable and is affected by material, traffic volume, and other factors.

The service lives, costs, and life-cycle costs of longitudinal pavement markings vary considerably by the type of marking material. The cost of traffic delay because of striping operations and measurement of retroreflectivity can add significantly to the life-cycle cost of longitudinal markings. New products are coming on the market that can improve nighttime visibility in adverse weather and have the potential to improve traffic safety.

Acceptable retroreflectivity in an RRPM is dependant on cumulative traffic volume. Retroreflectivity may last for as little as 6 months on a high-volume freeway with truck traffic. The more durable and expensive RRPMs become cost-effective when average annual daily traffic reaches 10,000 veh/day per lane.

An inventory management system tracks the service life of pavement markings by storing information on installations, inventory, retroreflectivity, specific action steps, costs, and suppliers in a database. The goal of implementing an inventory management system is to enable transportation agencies to select cost-effective markings with increased service lives that will reduce the cost of marking a highway system. Longer-lasting retroreflective markings that reduce traffic crashes will be the benefit of such a system. One-half of the surveyed agencies have implemented or are planning to implement an inventory management system. At this time, agencies have not had enough experience with inventory management systems to realize any benefits.

The FHWA has been promoting techniques to inspect and evaluate pavement markings. Some agencies have specifications and guidelines addressing performance evaluations. New markings are usually inspected within 1 month after placement, but there is no universally accepted schedule for inspecting existing markings. Training courses are available to enable personnel to become more proficient with inspection procedures. Agencies are using 30-m (98.4-ft) retroreflectometers to evaluate retroreflectivity. Field tests of four hand-held and two mobile retroreflectometers showed that measurements collected with these instruments were within an 8% range, which is a good correlation.

Retroreflectivity data were incorporated into a geographical information system to evaluate pavement-marking life cycles and develop predictive models for materials. The ability to efficiently review and query retroreflectivity data by type of pavement marking, condition, location, and jurisdiction benefits both the administrative and operational areas of a transportation agency.

Mobile and hand-held retroreflectometers each have advantages and disadvantages. Agencies selecting a hand-held or mobile retroreflectometer should consider initial capital cost, maintenance costs, manpower resources, required data accuracy, equipment reliability, and compliance with current testing standards.