NCHRP
REPORT 484

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Feasibility Study for an All-White Pavement Marking System

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Feasibility Study for an All-White Pavement Marking System

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AND

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College Station, TX

SUBJECT AREAS
Highway Operations, Capacity, and Traffic Control

Research Sponsored by the American Association of State Highway and Transportation Officials
in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2002
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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NCHRP REPORT 484

Project 4-28 FY 2000

ISSN 0077-5614

ISBN 0-309-06772-3

Library of Congress Control Number 2002115719

Price $17.00

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Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at:

http://www.national-academies.org/trb/bookstore

Printed in the United States of America

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AUTHOR ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 4-28 by the Texas Transportation Institute (TTI). KTA-Tator, Inc. was a subcontractor on the project. H. Gene Hawkins, Jr., Division Head, TTI, was the principal investigator. The other author of the report is Angelia H. Parham, Assistant Research Engineer, TTI. The other primary research staff for this project were Katie N. Womack, Research Scientist, TTI, and Thomas W. Neal, Jr., Senior Coating Consultant, KTA-Tator, Inc.

The research team would like to recognize the support and guidance provided by the NCHRP project panel. The project panel members include Mr. Stephen C. Brich (chair), Virginia DOT; Mr. Daniel E. Centa, City of Pueblo; Mr. Rajinder P. Chawla, New Jersey DOT; Mr. Steve J. Gent, Iowa DOT; Mr. Gerald J. Meis, California DOT; Dr. Ken Opiela, FHWA; Mr. Richard N. Schwab; Mr. Brian A. Stanford, Texas DOT; Dr. James I. Taylor, University of Notre Dame; and Dr. Samuel Tignor.

The survey on driver understanding of pavement markings was a significant effort of this project and involved contributions from many individuals. Special appreciation is expressed to Angelia Parham and Katie Womack of TTI for developing the survey and managing its administration. John Wikander of TTI conducted some of the statistical analysis of the survey results. Ivan Lorenz provided valuable assistance with the graphic elements throughout the research effort.

The driver survey was administered in several locations across the United States by TTI staff. The authors would like to express their appreciation to the following individuals who participated in the survey administration: Sue Chrysler, Todd Hausman, Carol Mendez, Angelia Barham, Sandra Sanders, Nada Trout, and Katie Womack.

Tom Neal of KTA-Tator was a subcontractor to TTI for this project and provide valuable insight on pavement marking practices during the early phases of the project.

Jim Migletz of Graham-Migletz Enterprises provided information on pavement marking practices that was part of an NCHRP synthesis effort that was underway at the time of this research project.

FOREWORD

By Charles W. Niessner
Staff Officer
Transportation Research Board

This report presents the findings of a research project to evaluate the feasibility of implementing an all-white pavement marking system in the United States. The researchers recommend that an all-white pavement marking system not be implemented. The report will be of particular interest to traffic engineers with responsibility for installing and maintaining pavement marking systems.

The use of yellow and white pavement markings has been the subject of debate for transportation agencies since the 1920s. In 1971, the *Manual on Uniform Traffic Control Devices* first required exclusive use of yellow markings to separate traffic traveling in opposite directions. A Federal Highway Administration International Scanning Tour report indicates that the use of an all-white pavement marking system offers considerable advantages and that such a system may be desirable in the United States. This conclusion was drawn by a prominent group of traffic engineers after viewing the all-white systems used in four European countries. A move toward an all-white marking system would also help promote international uniformity.

Several reasons that traditionally have been mentioned as to why the United States would benefit from implementing an all-white pavement marking system are:

- Drivers do not have an inherent understanding of the meaning of yellow markings.
- All other factors being equal, white markings have higher retroreflectivity than yellow markings.
- Most of the industrialized countries of the world use all-white pavement markings.
- Some of the pigments used in yellow markings are difficult to recognize as yellow in nighttime conditions.
- White markings are less expensive than yellow markings and having only one color to apply would reduce the application and supply costs.
- An all-white pavement marking system would eliminate environmental concerns in the use of lead chromate as a yellow pigment.

Under NCHRP Project 4-28, "Feasibility Study for an All-White Pavement Marking System," the Texas Transportation Institute undertook research to quantify and/or identify the advantages, benefits, costs, drawbacks, disadvantages, risks, and implementation issues associated with converting the United States from the present yellow and white system of pavement markings to an all-white system.

The research team reviewed international all-white pavement marking practices and found a variety of stripe lengths, gap lengths, and line widths used to convey various messages with important differences from one country to another. U.S. marking practices were reviewed and a stakeholder's workshop was held to identify needs, limitations, and benefits of converting to an all-white pavement marking system. The eco-

nomic issues, benefits, and drawbacks of changing to an all-white pavement marking system were also assessed.

The key effort undertaken in this project was a driver survey to evaluate how well drivers understand pavement marking patterns and colors. The survey results found that

- Drivers use the yellow color of centerlines as a tool in determining the direction of traffic flow on a road.
- Approximately 75% of the surveyed drivers understand the basic concept that a single broken yellow line separates opposing traffic on a two-lane road.
- The presence of a solid line in the centerline increases comprehension of directional flow to approximately 85%.
- Over 90% of the surveyed drivers understand that a solid line prohibits passing.
- The addition of direction arrows significantly improves understanding of a two-way road situation.

The researchers developed recommendations in three areas. The primary recommendation is that an all-white pavement marking system not be implemented in the United States at the present time. The researchers also identified several actions that should be taken to improve the current yellow-white pavement marking system. These recommendations include implementation of directional pavement marking arrows, increased emphasis on marking color in driver training, increased retroreflectivity of yellow markings, and improved color of yellow markings. Finally, the researchers recognized that there are factors that may, at some time in the future, force the implementation of an all-white pavement marking system. Therefore, the third area presents implementation guidelines to help agencies address the challenges associated with implementing an all-white pavement marking system if it should become necessary.

CONTENTS

FEASIBILITY STUDY FOR AN ALL-WHITE PAVEMENT MARKING SYSTEM

SUMMARY

During the 1990s, numerous transportation professionals began to suggest that there may be benefits to converting the U.S. pavement marking system from a yellow–white system to an all-white one. There are several general reasons that have traditionally been mentioned as the primary reasons why the United States would benefit from implementing an all-white pavement marking system. Those reasons include (in no particular order):

- Drivers do not have an inherent understanding of the meaning of yellow markings.
- All other factors being equal (binder, beads, application, etc.), white markings have higher retroreflectivity than yellow markings. This is compounded by the fact that yellow markings receive less illumination than white markings (headlamps are oriented to the right).
- Most of the industrialized countries of the world use all-white pavement markings.
- Some of the pigments used in yellow markings are difficult to recognize as yellow in nighttime conditions.
- White markings are less expensive than yellow markings and having only one color to apply would reduce the application and supply costs.
- An all-white pavement marking system would eliminate environmental concerns related to the use of lead chromate as a yellow pigment.

The National Cooperative Highway Research Program (NCHRP) sponsored Project 4-28, "Feasibility Study for an All-White Pavement Marking System," to look at the various factors associated with the potential implementation of an all-white pavement marking system and determine if such a system is feasible in the United States. The overall objective of this research project, as described in the proposal, was to "*conduct a feasibility study that quantifies and/or identifies the advantages, benefits, costs, drawbacks, disadvantages, risks, and implementation issues associated with converting the United States from the present yellow and white system of pavement markings to an all-white system.*"

FINDINGS

A number of research activities were undertaken in assessing the feasibility of all-white pavement markings. The primary activity of the research effort was an evaluation of driver understanding of traffic control devices. Researchers also identified pavement marking systems in other countries; conducted surveys of agency and industry perspectives on an all-white pavement marking system; and conducted a stakeholders workshop to identify needs, limitations, and benefits. The results of these evaluations, as they relate to specific issues, are briefly summarized below.

Driver Understanding

The key effort of this research project was a driver survey conducted to evaluate how well drivers understand pavement marking colors and patterns. The researchers surveyed 851 subjects at locations in 5 states. The subject sample include drivers from 47 states, plus Puerto Rico and Washington, D.C. The survey results found that

- Drivers tend to use signs and other traffic as the primary cue to determine whether a road is one-way or two-way.
- Drivers use the yellow color of centerlines as a tool in determining the direction of traffic flow on a road.
- Approximately 75 percent of the surveyed drivers understand the basic concept that a single broken yellow line separates opposing traffic on a two-lane road.
- The presence of a solid line (either double solid or solid and broken) in the centerline increases comprehension of directional flow to approximately 85 percent.
- Over 90 percent of the surveyed drivers understand that a solid line (either double solid or solid and broken) prohibits passing.
- Drivers do not have a better understanding of any of the potential all-white marking alternatives presented in the survey, indicating that there is no inherent benefit to converting to an all-white marking system from the standpoint of conveying the directional message of the road.
- The addition of direction arrows significantly improves understanding of a two-way road situation.
- Drivers are not inclined to recognize the differences between various stripe and gap lengths as a means of conveying information about the direction of traffic flow.
- Wider lines may not be a practical means of indicating opposing traffic. When retracing lines, they often become wider. In addition, many agencies are now beginning to implement wider longitudinal markings on a regular basis.
- The most effective system for all-white markings appears to be one where the centerline is a double line, which would be solid where passing is prohibited and broken where passing is permitted. There are four possible centerline combinations for the double line:
  - Double solid line for passing prohibited in both directions.
  - A solid line with a broken line for passing prohibited in one direction (there are two versions of this pattern, depending upon which direction passing is prohibited).
  - Double broken line for passing permitted in both directions.

Driver Education

Given that the alternative all-white marking schemes presented in the survey did not have inherently higher levels of understanding than the current yellow–white system,

the implementation of an all-white pavement marking system would require a significant driver education commitment. Implementation of an all-white system would require a nationwide driver education media campaign and a revision of all current driver education and driver training materials.

Visibility

Increases in pavement marking visibility may be the most commonly cited reason for converting to an all-white pavement marking system. This reason is based on the belief that white markings are more visible than yellow markings. The researchers identified the following issues related to the visibility of pavement markings:

- Nighttime visibility of pavement markings is based on the distribution of illumination from the headlamp, the retroreflectivity of the marking, and the contrast with the pavement surface. For most pavement surfaces, the retroreflectivity of the marking is the most significant factor in the nighttime visibility of the marking.
  - The retroreflectivity of a yellow marking is typically about 65 percent of an identical white marking fabricated from the same binder and beads and applied at the same thickness.
  - At night, drivers focus their attention on the right side of the field-of-view and tend to rely upon the right lane line or edge line for positional guidance.
  - At typical marking retroreflectivity levels, it is possible to place yellow markings that have the same or higher retroreflectivity value as white markings. This can be achieved by improving the marking material, beads, or application process. Placing yellow markings that have the same or higher retroreflectivity values as white markings will increase the costs of the yellow markings.
  - While all-white pavement markings can improve the nighttime visibility of the overall system, the nighttime visibility of the current yellow–white system can also be improved by increasing the performance of yellow markings.
- Daytime visibility of pavement markings is based on the contrast of the marking with the pavement surface.
  - White markings have lower contrast and are less visible on concrete and faded asphalt pavement surfaces.
  - Visibility of white markings on these surfaces can be improved through the use of black contrast markings. This will increase the costs of using an all-white pavement marking system.

International Harmony

Another commonly cited reason for converting to an all-white pavement marking system in the United States is that it would bring the country into greater conformity with international pavement marking practices. The evaluation of other countries' marking systems identified the following issues related to achieving international harmony in pavement marking patterns:

- The majority of countries contacted as part of this research effort use an all-white pavement marking system. Officials representing the countries contacted did not express any concerns about the effectiveness of their all-white pavement marking systems.

- A review of the actual all-white pavement marking systems used in individual countries revealed that there are important differences between countries. Countries use a variety of stripe lengths, gap lengths, and line widths to convey various messages with pavement markings with important differences from one country to another. As a result, there is no consistent system of all-white pavement markings, even within the European continent.
- While it is possible for the United States to implement an all-white pavement marking system that could be consistent with that used in one or two countries, it is not possible to achieve consistency with a large number of countries because of the variations in all-white pavement marking systems used in different countries.

Costs

Even if all other factors were to favor implementation of an all-white pavement marking system, agency personnel have indicated that they would not favor implementation if there is a cost increase associated with the all-white system. The researchers have not conducted a detailed economic assessment of the cost impacts of implementing an all-white pavement marking system. However, the researchers have been able to identify the following economic issues related to all-white pavement markings:

- Implementation of an all-white pavement marking system in the United States would require all current yellow centerlines to be removed and/or restriped.
  - There are 160,462 mi of road on the National Highway System. At a weighted average of $0.17/ft, it would cost over $144 million to restripe the centerlines and left edge lines of the National Highway System. The National Highway System represents about 20 percent of the total federal-aid highway system.
  - The survey results indicate that a double line centerline is likely to have the best understanding of the traffic direction message. Additional evaluations should be conducted to confirm this conclusion. If a double line were to be implemented, not only would all yellow lines need to be covered with white lines, but a second line would need to be added at all locations that currently have a single yellow line for the centerline. This would further increase the costs of implementing an all-white system.
- The implementation of an all-white marking system is likely to impose a significantly greater pavement marking expense on state and local agencies beyond the costs associated with the activities just mentioned.
  - If the FHWA moves forward with an all-white pavement marking system within the next 10 or so years, the FHWA should consider providing funding to state and local agencies for the initial costs of implementing an all-white pavement marking system.
- There are productivity benefits to implementing all-white markings. These cost reductions result from not having to provide two-color systems on installation equipment. The increased productivity benefits are not likely to offset the additional costs of implementing all-white markings.

Safety

Safety is a factor in any potential improvement to the transportation system. At this time, it is not possible to assess the possible reductions (or increases) in crashes that would be associated with implementing an all-white pavement marking system. Previ-

ous research has attempted to document the benefit associated with incremental improvements in pavement markings (use of wider markings, increases in marking retroreflectivity), but has been unable to do so. The crash-reduction benefits of all-white pavement markings can only be addressed through a field trial of all-white markings.

Material and Environmental Issues

The chemical properties of yellow binders and the associated environmental changes are sometimes cited as reasons to eliminate yellow as a marking color. The following issues are associated with the material and environmental aspects of yellow markings:

- Industry and agencies appear to have largely adjusted to the environmental demands associated with pavement markings.
  - Some agencies are not satisfied with the color of yellow markings.
- Implementing an all-white pavement marking system would eliminate the environmental issues associated with yellow pavement markings.
- NCHRP has funded a new research project to evaluate the color and specifications for yellow pavement markings (Project 5-18). This project, expected to begin in late 2002, will evaluate drivers' ability to distinguish between yellow and white markings, develop color specifications for markings, and assess the extent to which existing markings provide drivers with adequate yellow color. The results of this research, when combined with the establishment of in-service color requirements for markings, should improve the quality of yellow pavement marking color.

Implementation Issues

There are many practical issues associated with the potential implementation of an all-white pavement marking system. Many were identified in the background information chapter, and an implementation plan that addresses many issues is provided at the end of this chapter. The following implementation issues are among the most significant associated with an all-white pavement marking system.

- Implementation of an all-white pavement marking system would require that state laws be changed in many or most states. The meeting schedule of the state legislatures is such that changes in state laws would require a lead time of at least 2 years.
- The wide range in pavement marking durability will pose challenges to converting to an all-white pavement marking system. If a short implementation period is used, then some yellow durable pavement markings will be replaced with white markings before the end of their service life.

RECOMMENDATIONS

The researchers developed recommendations in three areas. The primary recommendation indicates whether an all-white marking system should be implemented. The researchers also developed a series of secondary recommendations that address improvements that are beyond the immediate question of implementing an all-white system. Finally, the researchers recognized that there are factors that may, at some time in the future, force the implementation of an all-white pavement marking system. Therefore, the researchers developed a series of implementation guidelines to help agencies address the challenges associated with implementation.

Primary Recommendation

Based on the findings of the research activities, the researchers recommend that an all-white pavement marking system not be implemented in the United States at the present time.

Secondary Recommendations

In determining that an all-white pavement marking system is not feasible, the researchers identified several actions that should be taken to improve the current yellow–white pavement marking system. These recommendations are as follows:

- **Implement Directional Pavement Marking Arrows**—The survey results indicate that the addition of arrows indicating the direction of traffic flow increase comprehension of that message to over 90 percent. Section 3B.19 of the *Manual of Uniform Traffic Control Devices for Streets and Highways* (*MUTCD*) should be revised to provide agencies greater flexibility and guidance on the use of directional pavement marking arrows to reduce travel in the wrong direction.
- **Increase Emphasis on Marking Color in Driver Training**—The survey results found that approximately 75 percent of the drivers understand the directional message of a single broken-yellow line. While this value is higher than some thought it would be, it also indicates a need to increase understanding of the meaning of marking colors. Driver education and driver training materials and curriculums should increase the emphasis on the meaning of pavement marking color. Increasing the emphasis in current programs would be less expensive and have greater benefits than establishing a new program to educate drivers on the meaning of all-white markings.
- **Increase Retroreflectivity of Yellow Markings**—The reduced nighttime visibility of yellow markings (as compared to white markings) was cited as a major reason to implement all-white markings. Agencies should consider using yellow marking materials that have retroreflectivity values that are similar to those of white markings on the same road. This would entail using higher quality materials for the yellow markings, resulting in an increase in costs.
- **Improve Color of Yellow Markings**—The reduced use of lead chromate as a pigment in yellow markings has resulted in some yellow markings with less intense yellow color, leading to potential confusion with white markings. A new NCHRP project will evaluate color aspects of yellow markings and the results should be used to improve yellow markings.
- **Provide Funding for Potential Implementation**—As mentioned previously, there are potential pavement marking changes on the horizon that may increase pavement marking costs for transportation agencies (in-service minimum retroreflectivity and color specifications). The next section of this chapter presents circumstances that may lead to forced implementation of all-white markings. If minimum retroreflectivity guidelines, color specifications, and forced implementation occur in the same time frame, the federal government should consider providing state and local agencies with financial support for implementing the all-white pavement marking system.

Contingency Recommendations

As indicated in the primary recommendation, the researchers do not recommend implementation of an all-white pavement marking system in the United States. However,

the researchers identified four sets of circumstances that could lead to forced implementation of an all-white pavement marking system. They include environmental constraints, color specifications for pavement markings, minimum levels of retroreflectivity, and wet marking retroreflectivity.

Although the researchers found that the potential for any of these circumstances to lead to all-white markings is small, they developed a preliminary implementation plan for such a contingency. These contingency recommendations provide implementation guidance to initiate the process of implementing an all-white system should it be necessary to do so. The specifics of the implementation plan extend over a period of 9 years and are described in the report.

CHAPTER **1**

INTRODUCTION

Transportation agencies are responsible for building, operating, and maintaining public roads in the United States. Fulfilling this responsibility requires that agencies communicate a wide variety of information to road users. Traffic control devices are one, if not the primary, means of communicating vitally important information to drivers and other road users. The *Manual on Uniform Traffic Control Devices*, or *MUTCD* (*1*), establishes the requirements for these traffic control devices. Traffic control devices can be divided into three major groups: signs, signals, and markings. Each type of device is able to communicate different types of information in different manners. All three are critical to the safety and efficiency of the surface transportation system.

As a group, pavement markings may arguably be the most valuable and important of all the types of traffic control devices. Indeed, Mr. Al Pepper, former state traffic engineer of Colorado, commented on their importance at a conference in 1949, stating:

> *"I believe most traffic engineers will agree that the use of a marked centerline to keep vehicles in their proper half of the highway is the greatest single contribution to public safety ever devised"* (*2*).

Pavement markings have several unique characteristics that distinguish them from the other groups of traffic control devices. One of the most obvious is that longitudinal markings are continuous along a length of roadway. As such, they provide a continuous stream of information that cannot be provided by signs or signals. Markings are also positioned so that they are near the center of the driver's visual field. Some of the important purposes that pavement markings serve include defining the travel path for vehicles and supplementing other traffic control devices. In some cases, pavement markings fulfill a role that cannot be filled by any other type of device.

Early in the history of pavement markings in the United States, pavement markings could be almost any color, with white, black, and yellow being the most common. As the system of traffic control devices in the United States matured, national uniformity became an important goal and pavement markings started to have the same appearance across the country. The use of color in the U.S. system of markings has remained constant since the early 1970s.

During the last decade of the twentieth century, transportation professionals have begun to question the continued use of yellow as a color in the U.S. pavement marking system. There are many reasons for considering a change to an all-white pavement marking system, some of the most significant being:

- Internationally, most countries have converted to an all-white pavement marking system.
- Yellow markings have lower levels of night visibility than white markings. There are two main reasons why:
  - Yellow is a darker color than white and reflects less light.
  - Yellow markings are on the left side of the leftmost driving lane and receive less illumination from the headlights compared to white markings on the right side.
- The impending establishment of minimum levels of retroreflectivity for pavement markings will require yellow markings to provide a minimum visibility performance, which may be difficult to achieve over long periods. The difference in service life between yellow and white markings may create difficulties for transportation agencies.
- The reduction in the use of lead-chromate pigments have resulted in yellow markings that may not have the necessary depth of color at night to be recognized as yellow. The washed-out appearance of some yellow markings at night can make them difficult to distinguish from white markings.
- The FHWA is in the process of establishing daytime and nighttime end-of-service life color specifications for pavement markings. This will be the first time that color specifications will be specifically applied to markings. It is also the first time that marking color has been defined for nighttime conditions.

CURRENT SYSTEM

The United States uses a yellow–white pavement marking system in which yellow is used to separate opposing traffic on two-way roadways and as the left edge line on one-way roadways (such as divided highways). Yellow also delineates the separation of two-way left turn lanes and reversible lanes

from other lanes. In this manner, the color yellow always defines the leftmost side of the travel path for a vehicle (with the exception of reversible lanes). Figure 1 presents the language from Section 3A.05 of the 2000 *MUTCD* (*1*) that defines the use of color in pavement markings. Specific applications of some of the most important U.S. pavement marking applications are listed in Table 1. Figures 2 and 3 illustrate the current applications of the most significant longitudinal pavement markings for two-lane and multilane roads from the 2000 *MUTCD*. As described later in this report, the use of color in the current U.S. pavement marking system has been unchanged since a 1973 revision of the 1971 *MUTCD*.

RESEARCH PROJECT INFORMATION

The NCHRP established Project 4-28, "Feasibility Study for an All-White Pavement Marking System," to look at the various issues associated with the potential implementation of an all-white pavement marking system in the United States. The tasks that were conducted as part of this project are presented in Table 2.

This report describes the activities and findings associated with the research project. The report addresses the key findings of the research and presents recommendations regarding the feasibility of implementing an all-white pavement marking system. The information in this report is organized in the following manner.

- Chapter 2 provides background information related to all-white pavement markings:
  - evolution of the current U.S. system (detailed information on the evolution is in Appendix A),
  - international practices regarding pavement marking color, and

Section 3A.05 Colors of Longitudinal Pavement Markings

Standard:

The colors of longitudinal pavement markings shall conform to the following basic concepts:

A. Yellow lines delineate:
- **1. The separation of traffic traveling in opposite directions.**
- **2. The left edge of the roadways of divided and one-way highways and ramps.**
- **3. The separation of two-way left turn lanes and reversible lanes from other lanes.**

B. White lines delineate:
- **1. The separation of traffic flows in the same direction.**
- **2. The right edge of the roadway.**

C. Red markings delineate roadways that shall not be entered or used.

D. Blue markings delineate parking spaces for persons with disabilities.

Figure 1. Pavement marking color definitions from the 2000 MUTCD.

TABLE 1 Selected pavement marking applications

Type of Marking	Function	Marking	Color
Longitudinal Lines	Separate opposing traffic	Broken or solid centerline	Yellow
	Indicate no passing zone	Solid line	Yellow
	Separate lanes traveling in the same direction	Broken or solid lane lines	White
	Indicate right edge on one- or two-way road	Solid edge line	White
	Indicate left edge on one-way road	Solid edge line	Yellow
Transverse Lines	Indicate stopping location on intersection approach	Stop line	White
	Indicate pedestrian crossing area	Crosswalk	White

Note: Only some of the most important markings are listed. There are other types of markings.

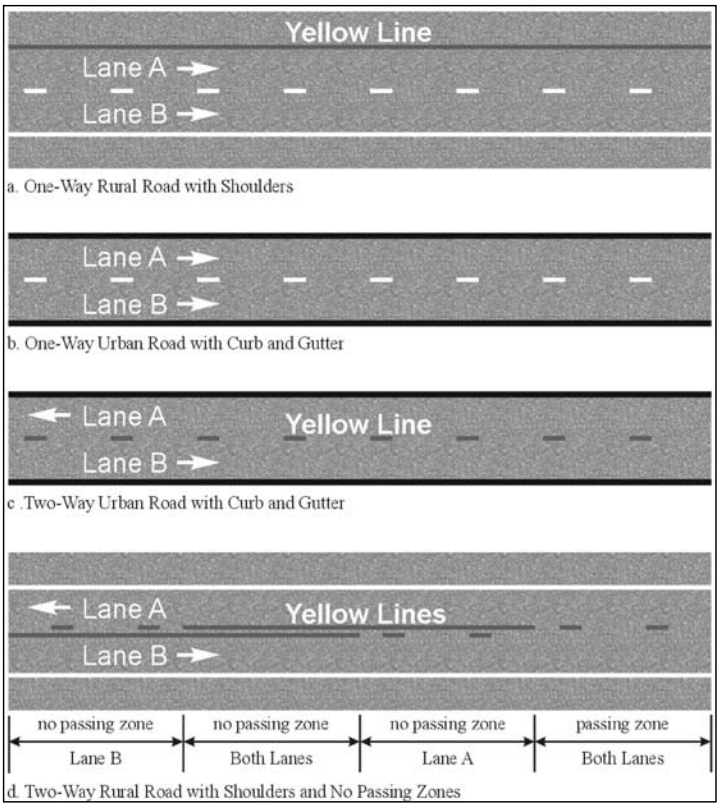


Figure 2. Common U.S. longitudinal pavement markings for two-lane roads.

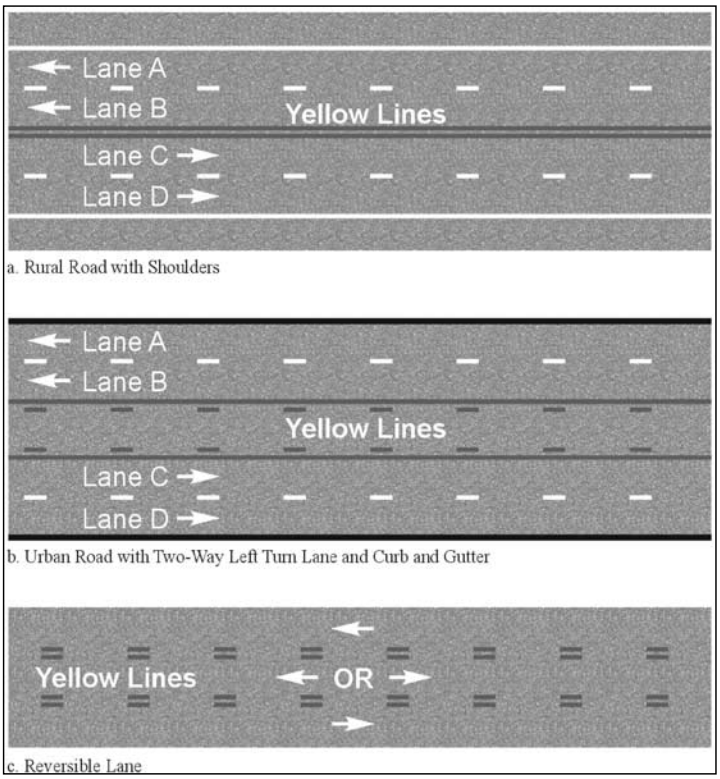


Figure 3. Common U.S. longitudinal pavement markings for multilane roads.

TABLE 2 Research tasks

Task	
A	Review International All-White Marking Practices
B	Evaluate Driver Comprehension of Pavement Markings
C	Review U.S. Marking Practices
D	Prepare Interim Report
E	Assess Economic Issues
F	Evaluate Driver Understanding of Pavement Markings
G	Convene Stakeholders Workshop
H	Assess Benefits and Drawbacks
J	Evaluate Implementation Feasibility of Alternatives
K	Prepare Final Report

  - current U.S. marking practices related to implementation of all-white pavement markings.
- Chapter 3 addresses driver understanding of pavement markings:
  - previous research on driver understanding (detailed information on previous research is in Appendix B),
  - development and administration of the comprehension survey (the survey instrument is in Appendix B), and
  - results of the evaluation of driver understanding.
- Chapter 4 addresses various issues associated with implementing an all-white pavement marking system.
- Chapter 5 presents the recommendations on the feasibility of an all-white pavement marking system.
- Chapter 6 contains the references.

CHAPTER **2**

BACKGROUND INFORMATION

Before assessing the feasibility of implementing an all-white pavement marking system, the researchers established several different data baselines. Baseline information was needed in three key areas before moving forward: (1) how the current U.S. system has developed over time, (2) what marking systems are used in other countries, and (3) the current U.S. marking practices that would be affected by the conversion to all-white markings.

EVOLUTION OF U.S. MARKING CODE

Drivers' familiarity with a marking code, even if they cannot articulate it properly, is a major issue to be considered in changing the code. The interim report for this project contained a detailed summary of the evolution of the U.S. marking code, which is presented in Appendix A. The following provides a brief summary of the evolution of the U.S. marking system and how the evolution could affect the feasibility of implementing an all-white pavement marking system.

The *MUTCD* was first published in 1935 in an effort to bring about greater uniformity in the traffic control devices used throughout the United States. In the first *MUTCD*, lines could be white, yellow, or black, whichever provided the greatest contrast. Use of longitudinal lines was required only at specific hazardous locations (such as approaches to hillcrests, short radius curves, curves with a restricted view, or pavements wider than 40 ft).

The 1948 *MUTCD* was the first to establish specific colors for specific applications. White and yellow were the only colors permitted for markings. White was specified for all applications (including as a broken centerline) except for double centerlines on multilane highways and no-passing zone barrier lines, where yellow was recommended. However, white continued to be permissible for use in these applications. The manual recommended against the use of pavement edge lines.

There continued to be great variation in pavement marking practices even after the 1948 *MUTCD* was published. Individual states continued to use a variety of marking colors and patterns for various applications. The 1961 *MUTCD* was the first *MUTCD* that agencies were required to comply with on federal-aid highways. This edition specified the exclusive use of yellow for the double centerline and for no-passing barrier lines (solid line). It specified white for centerlines on two-lane roads (even when used with a no-passing zone barrier line), lane lines, and all edge lines.

The 1971 *MUTCD* established yellow as the color for separating opposing traffic, eliminating the use of white for a centerline. For 2 years after the publication of the 1971 *MUTCD*, left edge lines could be white or yellow, depending upon the circumstances. However, a revision in 1973 established yellow as the color for all left edge lines.

Although new editions of the *MUTCD* were published in 1978, 1988, and 2000, the use of color in pavement markings has remained constant since 1973. The nation's current system of markings has matured to a stable system that has remained unchanged for almost 30 years. When the maturity of the pavement marking system is considered with respect to the ages of the driving population, it is apparent that there are more drivers that never have driven with white centerlines than there are drivers that can recall driving with white centerlines over 30 years ago. Table 3 presents Census 2000 data on the age of the U.S. population. Assuming that all drivers 15 and over have a driver's license or learning permit, then 56 percent of the U.S. population of driving age has learned to drive since about 1971, when yellow was established as the only color for separating opposing traffic. Although there is a significant percentage (44 percent) of drivers that have driving experience on some roads that used white for a centerline (in accordance with the 1961 *MUTCD* and/or earlier editions), it has been 30 years since these markings were in common use.

Based on the assessment of the evolution of the U.S. marking system, two key findings are evident:

- The current system of using yellow to separate opposing traffic has been in place for 30 years. Fifty-six percent of the driving population learned to drive after yellow was established as the color separating opposing traffic.
- For the remaining 44 percent of the driving population that may have driven on roads with white centerlines, it has been 30 years since they have had such an experience.

Based on these findings, the implementation of an all-white pavement marking system should be perceived as a new experience for the entire U.S. driving population, requiring a driver education program be implemented.

TABLE 3 U.S. population relative to key MUTCD changes

Age	Year Born	Category	Number	Percentage of Population	Percentage of Driving Population
Less than 15	Since 1986	Non-drivers	60,253,375	21.4%	None
15 to 44	1956 to 1985	Learned to drive in 1971 or later (1971 and later MUTCD markings) Yellow used exclusively for centerlines	124,224,142	44.1%	56.2%
45 and over	1955 and earlier	Learned to drive before 1971 (1961 and earlier MUTCD markings) White used for some or all centerlines	96,944,389	34.4%	43.8%
		Totals	281,421,906	100%	100%

Source: Census 2000 data (http://www.census.gov/population/www/cen2000/phc-t9.html)

INTERNATIONAL MARKING PRACTICES

All-white or predominantly white pavement marking systems are used in many countries throughout the world and especially in most European countries. Some of these countries have used all-white pavement marking systems for several decades, while other countries have recently converted to an all-white system. Additionally, the actual pavement markings used for motorways (freeways), dual-lane carriageways (four-lane divided or undivided highways), and single-lane carriageways (two-way, two-lane roadways) vary from country to country. Researchers contacted representatives of many countries using or considering the use of all-white pavement markings to obtain information regarding the types of markings used, how long the markings have been in use, and how well they seem to be understood. These results are summarized in this section.

Researchers contacted officials regarding pavement marking practices in their respective countries using telephone and electronic mail contacts. Selection of the countries was based on previous knowledge of pavement marking systems, a geographically diverse sample, and information obtained when speaking with representatives of other countries.

Two major color systems are currently in use: 17 of the 22 countries contacted currently use single-color systems (white only) for longitudinal lines, while 5 countries currently use a two-color system (white and yellow) for longitudinal lines. Table 4 lists the current use of white and yellow markings for longitudinal lines, arrows, chevrons and hatching, and work areas for the 22 countries contacted.

Current Use of All-White Pavement Markings

In countries where white pavement markings are predominant, white lines are used to separate opposing directions of traffic. However, the pattern, width, spacing, and meaning of the markings vary from country to country. White centerline applications include double white lines, single white lines, a single continuous white line with a broken or dashed white line, and single broken or dashed lines. Other applications of white pavement markings include crosswalk markings, parking spaces, parking prohibition, islands and channelization, and separation markings through intersections. In some countries, yellow pavement markings are used to indicate parking restrictions, crosswalks, and maintenance zones as listed in Table 4.

Pavement Marking Widths

Table 5 lists the width of left edge line, centerline, and right edge markings for motorways (freeways), dual carriageways (four-line divided highways), and single carriageways (two-lane, two-direction roadways). Figure 4 illustrates the varying widths of white pavement marking for motorways. One factor that could affect the interpretation of line width information in the figure is the side of the road that drivers use in each country. This information is presented in Table 6. For all of the countries that drive on the left side of the road, the right and left edge lines are the same width. As a result, the clarification on driving side is not needed to interpret the findings.

Pavement Marking Lengths

Figure 5 illustrates the marking length and gap for both motorways and dual carriageways. Figure 6 illustrates the marking length and gap for single carriageways. Tables 7, 8, and 9 list the lengths of white pavement markings for these three types of roadways for the countries contacted. The design of the pavement markings vary from country to country. As listed in Table 9, the design of passing markings on single carriageways is very different from one country to another.

TABLE 4 Current use of white and yellow pavement markings

Country	Color of Marking				
	Longitudinal Lines		Arrows	Chevrons and Hatching	Work Areas
	Center	Edge			
1. Australia	W	W	W	W	
2. Austria	W	W	W	W	various colors
3. Belgium	W	W	W	W	yellow-orange; orange retroreflective road studs
4. Canada	Y	W	W	Y, W	Y, W
5. Denmark	W	W	W	W	Y
6. France	W	W	W	W	Y
7. Germany	W	W	W	W	Y
8. Hungary	W	W			
9. Iceland	W	W	W	W	W
10. India	W	W	W	W	
11. Ireland	W	Y	W	W	W, Y
12. Italy	W	W			
13. Japan	W, Y	W			
14. Mexico	W	W	W	W	
15. Netherlands	W	W	W	W	Y
16. Norway	Y	W	W	W	
17. Singapore	W	W	W	W, Y	
18. South Africa	W	W			
19. South Korea	Y	W	W	Y	W, Y
20. Sweden	W	W	W	W	O
21. Switzerland	W	W	W	W	O
22. United Kingdom	W	W	W	W	W

Notes: Colors: W=white, Y=yellow, O=orange.

Experiences with Converting to All-White Pavement Markings

Researchers asked officials of countries that had converted to an all-white pavement marking system why they had converted to an all white system. If a country did not use an all-white system, they were asked if they were considering a change to an all-white pavement marking system. Experiences from several countries that have converted to all-white and one country that was considering a change to all-white pavement markings are summarized in the following paragraphs.

Australia

Australia converted to a predominantly all-white pavement marking system approximately 20 years ago. At that time, every state had different standards, and the new all-white system became standard for all states. Yellow markings are used to denote peak-hour restricted parking. Australia has experienced some negative issues regarding nighttime visibility under wet pavement conditions. They have also had problems with glass beads; the beads increase visibility but also make the pavement slicker, and motorcyclists have complained about the slickness. Australia also uses some marking on the edge lines that give a ripple effect. Most markings installed are thermoplastic in order to withstand the hot weather conditions.

Belgium

Belgium converted to a predominantly all-white pavement marking system in 1975. Exceptions to the all-white system

TABLE 5 Line widths of white pavement markings

Country	Width of Indicated Line for Type of Roadway (centimeters)								
	Motorway (Freeway)			Dual Carriageway (Four-Lane Divided Highway)			Single Carriageway (Two-Lane Roadway)		
	Left Edge	Lane Line	Right Edge	Left Edge	Centerline	Right Edge	Left Edge	Centerline	Right Edge
Australia	12 (5 in.)	8 (3 in.)	12 (5 in.)	12 (5 in.)	15 (6 in.)	12 (5 in.)	12 (5 in.)	10 (4 in.)	12 (5 in.)
Belgium	30 (12 in.)	20 (8 in.)	30 (12 in.)	30 (12 in.)	20 (8 in.)	30 (12 in.)	20-25 (8-10 in.)	15 (6 in.)	30 (12 in.)
Denmark	30 (12 in.)	15 (6 in.)	30 (12 in.)	30 (12 in.)	10 (4 in.)	30 (12 in.)	30 (12 in.)	10 (4 in.)	30 (12 in.)
Finland	20 (8 in.)	10 (4 in.)	20 (8 in.)	20 (8 in.)	10 (4 in.)	20 (8 in.)	10 (4 in.)	10 (4 in.)	20 (8 in.)
France	22.5 (9 in.)	10 (4 in.)	20 (8 in.)	18 (7 in.)	10 (4 in.)	20 (8 in.)	18 (7 in.)	10 (4 in.)	20 (8 in.)
Germany	15 (6 in.)	15 (6 in.)	30 (12 in.)	12-25 (5-10 in.)	12 (5 in.)	12-25 (5-10 in.)	12-25 (5-10 in.)	12 (5 in.)	12-25 (5-10 in.)
Hungary	20 (8 in.)	15 (6 in.)	20 (8 in.)	20 (8 in.)	12 (5 in.)	20 (8 in.)	20 (8 in.)	12 (5 in.)	20 (8 in.)
Iceland	There are no motor ways.			10-20 (4-8 in.)	10-20 (4-8 in.)	10-20 (4-8 in.)	10-20 (4-8 in.)	10-20 (4-8 in.)	10-20 (4-8 in.)
Ireland	15 (6 in.)	10 (4 in.)	15 (6 in.)	15 (6 in.)	10 (4 in.)	15 (6 in.)	15 (6 in.)	10 (4 in.)	15 (6 in.)
Mexico	10 (4 in.)	10 (4 in.)	10 (4 in.)	10 (4 in.)	10 (4 in.)	10 (4 in.)	10 (4 in.)	10 (4 in.)	10 (4 in.)
Netherlands	20 (8 in.)	15 (6 in.)	20 (8 in.)	10-15 (4-6 in.)	10 (4 in.)	10-15 (4-6 in.)	10-15 (4-6 in.)	10 (4 in.)	10-15 (4-6 in.)
Singapore	30 (12 in.)	10 (4 in.)	30 (12 in.)	20 (8 in.)	15 (6 in.)	20 (8 in.)	20 (8 in.)	15 (6 in.)	20 (8 in.)
Sweden	20 (8 in.)	10 (4 in.)	20 (8 in.)	10 (4 in.)	10-15 (4-6 in.)	10 (4 in.)	10-15 (4-6 in.)	10-15 (4-6 in.)	10-15 (4-6 in.)
Switzerland	20 (8 in.)	15 (6 in.)	20 (8 in.)	20-25 (8-10 in.)	15-20 (6-8 in.)	20-25 (8-10 in.)	15-20 (6-8 in.)	10-15 (4-6 in.)	15-20 (6-8 in.)
United Kingdom	20 (8 in.)	10 (4 in.)	20 (8 in.)	15-20 (6-8 in.)	10 (4 in.)	15-20 (6-8 in.)	10-15 (4-6 in.)	10-15 (4-6 in.)	10-15 (4-6 in.)

Notes: Figure 4 illustrates the varying white line widths of centerlines and edge lines on motorways (freeways) based on the information in Table 4. Data provided in metric units. Converted to U.S. units and rounded to nearest whole inch.

are yellow markings used for parking prohibition and yellow-orange markings and orange retroreflecting road studs used for road work. The reasons for changing to an all-white system included:

- Making the system in line with international conventions, agreements, and protocols;
- Achieving internal consistency; and
- Making the system more consistent with the increasingly complex problems they were experiencing.

The problems encountered after converting to an all-white system include:

- Wear and tear of markings, and
- Lack of conspicuity in particular cases, such as adverse weather conditions and lack of contrast on concrete pavements.

France

France converted to a predominantly all-white pavement marking system in 1972. Before that time, some roadway markings were yellow, some were white, and some were not marked. France uses temporary yellow markings for construction. French officials noted that the main benefits of an all-white system are no lead-chromate pigment and increased visibility of the all-white pavement markings.

Hungary

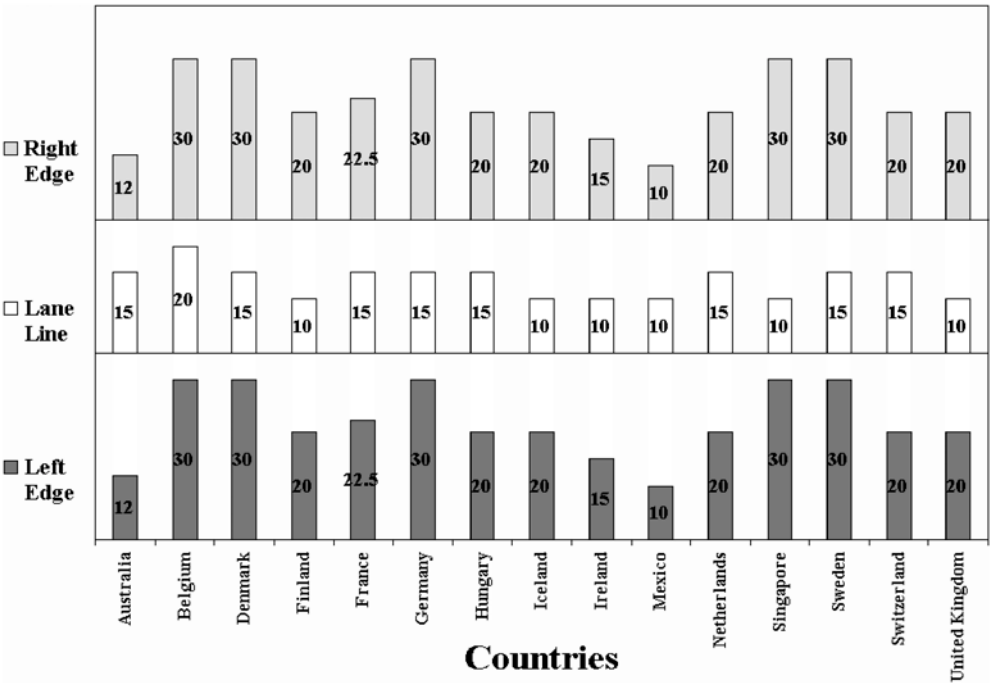
Hungary has had a predominantly all-white pavement marking system since 1970, and their pavement standards follow the European guidelines. Since 1984, Hungary has used yellow markings for parking regulations, bikeways, and for temporary markings. The system appears to be well understood; some studies have been conducted to examine the factors which cause problems such as how well the markings are seen by the driver and the removal of old markings.

Iceland

Iceland has had a predominantly all-white pavement marking system since 1995. Their primary reason for changing was insufficient luminance from the yellow markings and because most of the European countries use white markings.

Norway

In November 1999, Norway was considering converting to an all-white pavement marking system and conducted a



Note: Line widths in centimeters.

Figure 4. Comparison of white pavement marking widths on motorways.

study to evaluate the benefits of changing to an all-white system (*3*). The reasons for the study were

- Norway's road marking system was not in compliance with European agreements and the practice in other European countries,
- white and yellow markings differ in visibility properties, and
- experience has shown that the two-color system complicates and increases the cost of road markings (*3*).

The conclusions drawn at the end of the study are summarized below:

- The Norwegian road marking system is not in compliance with European agreements.
- Drivers need a retroreflection coefficient RL (visibility in darkness) for centerlines of at least 80–100 mcd/m^2/lux, with higher values desired. Comparisons indicate the visible length white lines in darkness to be notably greater than the visible length of yellow ones.
- A change to one-color (white) road markings is estimated to give a saving of close to 10 million 1996 kroner per annum (approximately $1.1 million per year).
- A change to white centerlines would raise the centerlines to a much higher degree of retroreflectivity. The cost was estimated at an additional 30 million kroner (approximately $3.3 million) for the country, but main-

TABLE 6 Driving side of the road

Country	Side of the Road on Which They Drive
Australia	Left
Austria	Right
Belgium	Right
Denmark	Right
Finland	Right
France	Right
Germany	Right
Hungary	Right
Iceland	Right
Ireland	Left
Italy	Right
Mexico	Right
Netherlands	Right
Singapore	Left
South Africa	Left
Sweden	Right
Switzerland	Right
United Kingdom	Left

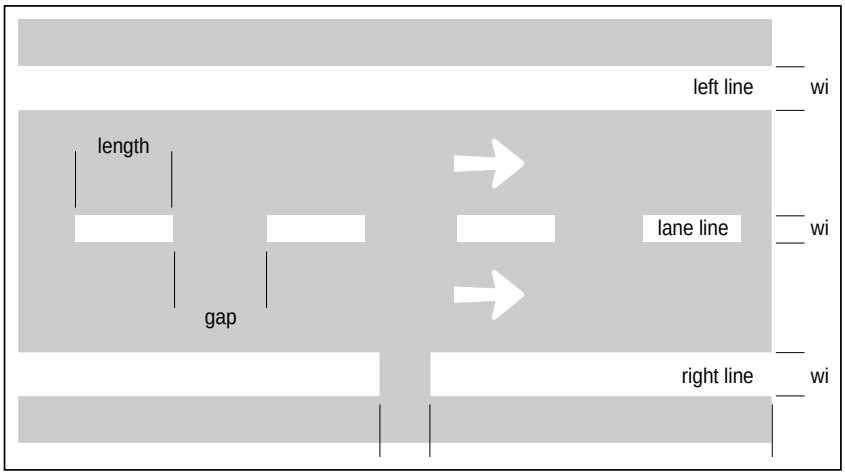


Figure 5. White pavement marking lengths and gaps on motorways and dual carriageways.

tenance needs would be greatly reduced. Also, night visibility would improve.

- Based on the current road marking method, a change to one color would allow quicker installation of new markings after repaving.
- A majority of Norwegian road users prefer the two-color system and rank the use of the yellow centerline higher than the road marking conformity across country borders. However, only 6 percent expect to find it hard to adjust to white centerlines.
- From the analyses made, neither positive or negative traffic safety impacts can be ascertained for the two-color system compared to an all-white system.
- A change to a one-color system will result in some, but not very notable, improvements in working environments for road crews and in environmental pollution.
- A change to an all-white system is not expected to imply significant changes in the use of symbol and line combinations.

Later in 1999, the Ministry of Transport stopped the change from yellow to white pavement markings for the centerline due to the difficulties associated with implementing such a major change in the pavement marking system.

Sweden

Sweden converted to an all-white pavement marking system in 1967. At that time, they also switched from driving on the left side of the road to driving on the right side of the road. They developed a program to address the educational issues

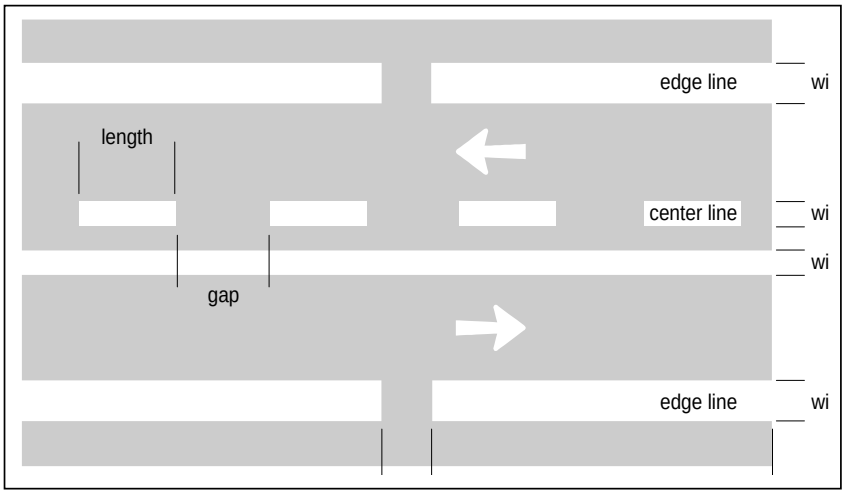


Figure 6. Passing markings for single carriageways.

TABLE 7 Motorway line lengths

Country	Length of Indicated Line (meters)					
	Left Edge		Lane Lines		Right Edge	
	Length	Gap	Length	Gap	Length	Gap
Australia	-	-	-	-	-	-
Belgium	Continuous	-	2.5	10	Continuous	-
Denmark	Continuous	-	5	10	Continuous	-
Finland	Continuous	-	3	9	Continuous	-
France	Continuous	-	3	10	38	14
Germany	Continuous	-	6	12	Continuous	-
Iceland	-	-	-	-	-	-
Ireland	Continuous	-	4	8	Continuous (yellow)	-
Mexico	-	-	-	-	-	-
Netherlands	Continuous	-	3	9	Continuous	-
Singapore	Continuous	-	20	100	Continuous	-
Sweden	Continuous	-	3	9	Continuous	-
Switzerland	Continuous	-	6	12	Continuous	-
United Kingdom	Continuous	-	2	7	Continuous	-

TABLE 8 Dual carriageway line lengths

Country	Length of Indicated Line (meters)					
	Left Edge		Lane Lines		Right Edge	
	Length	Gap	Length	Gap	Length	Gap
Australia	Continuous	-	3	9	Continuous	-
Belgium	Continuous	-	2.5	10	Continuous	-
Denmark	Continuous	-	5	10	Continuous	-
Finland	Continuous	-	3	9	Continuous	-
France	Continuous	-	3	10	20	14
Germany	Continuous	-	4	8	Continuous	-
Iceland	Continuous	-	3	9	-	-
Ireland	2 (yellow)	2 (yellow)	4	8	2 (yellow)	2 (yellow)
Mexico	Continuous	-	5	10	Continuous	-
Netherlands	Continuous	-			Continuous	-
Singapore	Continuous yellow for no parking	-	40	20	Continuous yellow for no parking	-
Sweden	1	2	3	9	1	2
Switzerland	Continuous	-	6	12	Continuous	-
United Kingdom	Continuous	-	2	7	Continuous	-

TABLE 9 Single carriageway line length for passing markings

Country	Length of Indicated Line (meters)			
	Edge Line		Broken Centerline	
	Length	Gap	Length	Gap
Australia	Continuous	-	3	9
Belgium	Continuous	-	2.5	10
Denmark	Continuous	-	5	10
Finland	Continuous	-	3	9
France	3	3.5	3	10
Germany		-	4	8.0
Iceland	Continuous	-	2	6
Ireland	2 (yellow) if warranted	2 (yellow) if warranted	1	5
Mexico	-	-	5	10
Netherlands	Continuous	-	-	-
Singapore	Continuous yellow for no parking	Continuous yellow for no parking	2.75	2.75
Sweden	1	2	1	2
Switzerland	Continuous	-	3	6
United Kingdom	Continuous	-	3	6

associated with the change; however, the program focused on changing sides of the road rather than on changing from yellow to white pavement markings. The Swedish official also noted that white lines are sometimes not visible during snow conditions.

Conclusions

The use of all-white pavement markings for longitudinal lines is widely accepted in 17 of the 22 countries contacted, and only one official contacted expressed a concern regarding driver understanding of one pavement marking color. However, the design of the markings varies from country to country, particularly for passing and no-passing indications. As a result, there is no standard system of all-white pavement markings, even within the European continent.

CURRENT U.S. MARKING PRACTICES

The potential implementation of an all-white pavement marking system would impact all of the transportation agencies in the United States, along with the private sector. Therefore, the research plan included efforts to identify current practices and identify potential impacts on both agencies and the private sector. Information on current practices came from two efforts:

1. Survey of agencies and the private sector and
2. Stakeholders workshop.

In addition to these efforts, the researchers relied on pavement marking information gathered as part of an NCHRP synthesis project that was ongoing at the same time as the research.

Public- and Private-Sector Surveys

In the Fall of 2000, the researchers distributed, through email, a survey of pavement marking practices. The survey was sent to individuals at state and local transportation agencies and to individuals in the pavement marking industry. There were 18 responses from public agencies and 4 responses from manufacturers and suppliers. There were 17 questions in the public agency survey and 10 questions in the private-sector survey. The difference in the number of questions can be accounted for by the fact that the public-sector agency survey included numerous questions related to the size of an agency's road network and the extent to which those roads were marked. These questions were asked in order to provide data for a potential economic analysis of implementing an all-white pavement marking system.

Some of the key findings from the surveys include the following:

- The most common striping materials used by the responding agencies include
  - water-based paint,
  - thermoplastic,
  - epoxy,
  - tape, and
  - ceramic buttons and retroreflective raised pavement markers.
- Agencies appear to be moving toward contractor-applied markings. Those agencies that apply their own markings generally used only paint.
- The costs of pavement markings is highly variable between agencies. Table 10 presents a comparison of some of the cost information provided by agency respondents. Some of the cost information provided by agencies represented detailed costs, while data provided by other agencies were generalized information.
- Information from the private sector indicated significant variability in the price of pavement marking materials, depending upon the material content. For example,
  - AASHTO specification thermoplastic prices (in 2000) averaged $565/ton for white, $515/ton for leaded yellow, and $700/ton for lead-free yellow.
  - Water-based fast dry paint is about $4.50/gal, and low volatile organic compounds (VOC) solvent-based is $6.25/gal.
- As expected, replacement cycles for markings varied greatly depending upon the type of marking, type of road, traffic volume, and whether the agency is located in the snowbelt.
  - Paint is generally replaced every year. At some locations, high traffic volumes require painted markings to be applied more than once per year.
  - Thermoplastic is generally replaced on 2- to 8-year cycles. Durability of thermoplastic is significantly affected by the thickness of the marking and the pavement surface.
  - Epoxy is generally replaced on 2- to 5-year cycles.
- Environmental issues are a concern to both public and private sectors, but more so with the private sector. The private sector has invested significant capital into developing yellow marking materials without lead.

The last six questions of the survey asked for input and opinions regarding an all-white pavement marking system. Some of the most significant of these comments are described on the following pages.

- **What issues do you think should be addressed in a feasibility study of all-white pavement markings?**
  - *Motorist understanding of markings*
    - Older driver habits and differentiation between yellow and white.
    - Driver expectation of yellow on left (especially centerlines) and the implicit warning of opposing traffic flow (seriousness of head-on accidents).
    - The ability of new and existing motorists to learn and retain the meaning of the various pavement marking patterns of an all-white system will be a key factor.
    - Changing to all-white markings would require changes in Department of Motor Vehicle statutes and training materials. Public outreach would be necessary.
    - Will the public accept the change?
    - Drivers have been using yellow as a centerline for more than 30 years.
    - Someone (FHWA, ITE, state transportation departments, professionals) will need to be more responsible for a better educational effort than is being done with the two-color system.

TABLE 10 Summary of pavement marking costs

Material	Installation	Color	Low	Average	High
Water-based paint	Agency	White	0.02	0.08	0.34
		Yellow	0.02	0.09	0.34
	Contractor	White	0.03	0.07	0.18
		Yellow	0.03	0.07	0.18
Thermoplastic	Agency	White	0.00	0.18	0.30
		Yellow	0.00	0.18	0.30
	Contractor	White	0.11	0.36	0.55
		Yellow	0.1	0.35	0.55
Epoxy	Contractor	White	0.13	0.34	0.50
		Yellow	0.13	0.31	0.45

Note: Costs are $/LF.

- *Implementation*
  - How will drivers know what to do during implementation when both yellow–white and all-white systems are in place?
  - Would existing yellow paint have to be removed or would the application of the white paint over the existing marking work considering the potential for bleed through and failure to fully cover the old marking?
  - Will we have to install additional markings such as arrows because of directional issues?
  - What patterns can be used to convey the message now communicated by yellow?
  - How long should existing yellow markings be permitted to remain?
  - What about roads where raised pavement markers and buttons are used as a replacement for painted lines? Costs of converting these would be much higher.
  - Possible use of yellow raised pavement markers with the white centerline markings to "keep" the yellow meaning, at least through a suitable number of years for driver adjustment and acceptance.
  - Transition period should be short—do not drag it out.
  - Implementation should not begin until 100 percent of state and local agencies have made the necessary changes to laws, codes, and ordinances. A nationwide implementation deadline needs to be established so that the change is universal.
  - If all the current yellow markings were converted to white, this would put a large and sudden demand into the market place for components used exclusively in white thermoplastic. In particular, the increased demand for titanium dioxide (TiO_2) would have to be addressed. This would include analyzing the ability of TiO_2 suppliers to meet a 40 percent or so increase in demand and the effect on the price of TiO_2. The price of an all-white marking system might increase to the point where it would be more expensive than the current yellow–white marking system.
- *Cost impacts and efficiency*
  - What is the cost of and who will fund the yellow-to-white conversion?
  - Need cost and efficiency comparisons between one-color and two-color systems.
  - One color will be less expensive than two colors. But implementation costs would be high. What is the payoff period?
  - A one-color system would make it easier for contractors to stripe in less time.
- *Visibility*
  - White markings are often not as visible on concrete roadways as yellow markings. Not to say lane lines are unimportant, they are probably not as important as the centerline on a two-way undivided roadway. Will the white marking, when used as a centerline marking on a concrete roadway, be sufficiently visible?
  - White is more visible at nighttime and foggy conditions.
  - White will make it easier to meet minimum retroreflectivity requirements.
  - How beneficial is the increased retroreflectivity of a white centerline or left line edge line if the motorist already has a right edge line or skip line of the same retroreflectivity to provide roadway alignment information?
- *Environmental*
  - Clean up/removal and disposal—heavy metals (leads and chromates) are contained in yellow thermoplastic.
- *Safety*
  - Is there a documented safety benefit to using all-white?

- **Advantages associated with an all-white pavement marking system.**
  - Reduces the amount of material types to be stocked or ordered.
  - Eliminates the need to change or clean equipment when converting colors. Will improve productivity of installation.
  - White is more visible.
  - White is lead- and chromate-free (more environmentally friendly).
  - Would eliminate the problem of yellow markings that look white at night.
  - If the majority of the public does not have an understanding of the yellow–white system, then if we change to a single color, it will be easy to implement and would have a high comprehension rate among the public.
  - Fewer Occupational Safety and Health Administration (OSHA) and Environmental Protection Agency (EPA) requirements to deal with during the manufacturing process.
- **Disadvantages associated with an all-white pavement marking system.**
  - The information on direction of travel in a given lane provided by the current yellow–white combination would be lost. Motorist understanding (or misunderstanding) and adaptation to an all-white system may also be a disadvantage.
  - If all-white pavement markings were implemented, there would be considerable cost to replace existing yellow markings, including removal, disposal, and /or storage.
  - There would need to be a major driver education campaign.

- White markings become dirtier faster.
- White does not have good contrast on concrete or light-colored pavements.
- The single disadvantage is the possibility of wrong-way movements. However, this may be overcome with signing.
- Additional signing may be necessary.
- Drivers would have to understand a greater variety of pavement marking patterns.

Stakeholders Workshop

A stakeholders workshop was held in January 2001 in Arlington, Virginia, to identify and discuss issues and concerns related to the potential implementation of an all-white pavement marking system. A total of 29 participants from the public and private sector took part in the all-day workshop. The workshop began with some introductory information about the project and the findings from research activities that had been conducted to date. After the presentations, the group began open discussions on various issues associated with yellow–white and all-white pavement marking systems. These discussions touched on a wide variety of issues and the discussions were not always neatly organized by topic. The major findings of the workshop are described below and organized according to the major issues associated with the potential implementation of an all-white pavement marking system. It should be noted that these findings represent the opinions of the workshop participants. They may not accurately represent real-world conditions.

- **International Practices**
  - European traffic control device systems operate under different philosophies than the U.S. system.
  - European headlights provide much less light above the horizontal than U.S. headlights. This requires Europeans to rely more on pavement markings.
  - Many European countries place a much higher emphasis on pavement markings.
    - European countries use the concept of horizontal signing (signing information on the pavement surface) to a much greater extent than does the United States.
    - European countries maintain their pavement markings to a higher level than most agencies in the United States.
  - European pavement marking colors:
    - There is no single all-white system for the entire European continent.
    - Yellow markings are used in many countries for work zone applications.
  - There is less concern with tort issues in Europe.
    - Experimentation with traffic control devices is more common.
    - Variations from guidelines is a less significant occurrence.
- **Institutional Issues**
  - No one has made a convincing argument for implementing an all-white pavement marking system.
  - Any recommendations to implement an all-white marking system must address the issues of concern to public agencies. Factors that need to be shown or demonstrated include:
    - Implementation of an all-white marking system would improve safety or have no negative impact on safety.
    - Implementation of an all-white marking system would increase driver understanding of the meaning of pavement markings when compared to driver understanding of the current yellow–white system.
    - The cost of implementing an all-white system would be negligible or, if significant, would result in improvements (safety, maintenance, etc.) that justify the additional expense.
    - The transition to an all-white system could be implemented in such a manner to allow the legislative, driver education, and application demands to be handled in a reasonable manner.
  - The perceived benefits to implementing an all-white marking system are as follows:
    - Drivers do not have an adequate understanding of the current yellow–white system, and an all-white system may increase comprehension levels.
    - An all-white marking system has greater visibility benefits.
      - Yellow has a lower retroreflectivity than white, yet it is the more important marking because it separates opposing traffic.
      - Yellow markings get less light from vehicles because they are located on the left side of the vehicle.
      - The costs of meeting minimum retroreflectivity levels for yellow may be too high.
    - White may be a more durable material.
      - Color of yellow markings shifts more during the service life.
      - The life of many marking materials are now longer and this provides greater opportunity for changes in the color of yellow markings during their life.
    - Yellow often has greater concentration of potentially hazardous materials.
      - Many yellow markings contain lead in some form.
      - Many yellow markings require special handling in production and removal processes.
  - The two-lane, two-way roadway provides the greatest challenge in implementing an all-white pavement marking system.

- It is easier to add improvements to the current yellow–white system than to change it to an all-white system.

- **Driver Comprehension**
  - Driver understanding of yellow–white and all-white marking systems is a critical piece of information that must be determined before any implementation of all-white markings can be realistically considered.
  - Changing to all-white markings means that pattern will be the primary communication technique instead of using a combination of color and pattern as is currently done with yellow–white markings.
- **Materials**
  - There are environmental concerns with yellow markings.
    - It is difficult to dispose of lead and chromium paints.
    - Most current yellow thermoplastic material contains lead.
    - Removing yellow markings may require special precautions because of potentially hazardous materials that may be in some yellow markings.
  - Life span of current durable marking materials creates an implementation transition challenge.
    - Agencies will not want to replace durable markings with significant life remaining.
    - Longer life of durable materials creates situations where changes in the material's color and retroreflectivity are more common because of the length of time durable markings are on the road. When markings were applied on a frequent basis, there were less opportunities for the material color and retroreflectivity properties to change dramatically.
  - UV light will impact white epoxy materials, but not other white materials.
- **Visibility and Retroreflectivity**
  - Visibility at night is more critical because there are fewer driving cues.
  - White markings:
    - White markings have higher retroreflectivity than yellow.
    - White markings have poor contrast on light-colored concrete pavements.
    - Black contrast material can be used to improve contrast.
    - White markings are better for older drivers because of their greater visibility.
  - Yellow markings:
    - Yellow markings have lower retroreflectivity than white.
    - Yellow markings are located on the left side where there is less illumination from headlights. When combined with the lower retroreflectivity level of yellow, this produces even lower marking luminance values.
    - Do yellow markings provide greater contrast when snow is on the road?
    - Yellow markings begin to appear white as the distance to the marking is increased.
  - Minimum retroreflectivity:
    - Implementation of minimum retroreflectivity guidelines may require that yellow markings be replaced more often than white markings. This will increase the costs of maintaining markings. White might be replaced on the same cycle as yellow even though there may be life remaining in the white marking.
  - Improving pavement marking retroreflectivity has not been shown to reduce crash rates.
- **Color**
  - Yellow markings have less durable color performance than white.
    - There is wide variation in the color of yellow pavement marking materials.
      - This is especially true for lead-free yellow materials.
  - FHWA and the American Society for Testing and Materials (ASTM) are looking at defining daytime and nighttime color specifications for pavement markings.
    - The ability to conduct field measurements of pavement marking color is limited.
    - The FHWA proposed rule on color specifications was intended to establish end-of-service life color limits.
  - Current color measurement of marking materials is done in laboratories without beads. This provides a different measurement result than a field measurement of marking color with beads at driver viewing geometry (30 m).
  - Glass beads have an impact on the reflected color.
  - Reflected color of markings depends upon the viewing geometry.
- **Alternative Systems**
  - Consider using a double line to indicate separation of opposing traffic.
  - Drivers are unlikely to recognize the difference in meaning between 4-, 6-, or 8-in. lines.
    - As lines are restriped, they sometimes become wider due to the difficulty of exactly tracing the original line. As a result, a 4-in. line may become a 5- or 6-in. line.
    - A wider line reduces the usable width of the pavement surface.
    - Many agencies are already using wider lines in place of the normal 4-in. line.
  - Need to consider whether there is an all-white system that would not require more marking material than the current yellow–white system.
  - Supplemental devices:

    - What supplemental marking symbols, delineators, and signs will be needed to implement all-white markings?
    - May need to make changes in signing code to distinguish one-way from two-way roads.
    - May need to require the No-Passing Zone pennant for no-passing zones.
- **Items for Research Study**
  - Need to evaluate current patterns with all-white markings to show you can't just paint over the old markings.
  - Survey should consider the needs of the rural states (Wyoming and Iowa were mentioned).
  - Survey should have questions that address marking patterns only.
  - Workshop participants would like to review the survey instrument before it is finalized.
  - Add a question at the end of the survey—How can markings be improved?
  - Researchers should contact previous researchers to find out what they learned that is not in their reports.
  - For all-white to be implemented, need to prove that white is safer than yellow or that yellow is less safe than white.
  - We should seek input from an attorney regarding implementation issues if an all-white pavement marking system is found to be feasible.
- **Implementation Issues**
  - The research should demonstrate why an all-white system using the same quantity of marking material as the yellow–white pavement marking system would be more effective than the yellow–white system or an all-white system using a greater amount of marking material.
  - If this research shows some feasibility for all-white markings, then simulator and field studies should be conducted prior to implementation.
  - Funding issues:
    - The FHWA must follow the 1995 Unfunded Mandate Act when enacting changes to the *MUTCD*. This may limit the ability to implement any all-white system that would increase the costs to agencies.
  - Implementing all-white markings would require the *MUTCD* to be changed.
    - Changes in the national *MUTCD* would have to be followed by changes in state *MUTCD*s and supplements.
    - The FHWA would have to conduct rulemaking to change the *MUTCD* and respond to public comments.
    - When the *MUTCD* is revised, the actual implementation of all-white markings would have to be scheduled to occur within a specified transition period.
  - After the *MUTCD* is changed, state legislatures would have to change the applicable laws and regulations in many of the 50 states.
    - This would have to be done before all-white implementation could begin.
    - Some state legislatures meet only every 3 years.
    - Changes in state laws would have to be coordinated with the *MUTCD* changes.
  - Several organizations would have to be heavily involved in the implementation of all-white markings. A partial list of organizations includes:
    - National Committee on Uniform Traffic Laws and Ordinances,
    - Association of American Motor Vehicle Administrators,
    - National Committee on Uniform Traffic Control Devices, and
    - FHWA.
  - Implementation periods:
    - Industry is probably not capable of implementing all-white markings in a 1-year period. Bead companies have difficulty keeping up with current demand. Contractors are spread thin in many areas.
    - 2 to 5 years of advance notice of implementation should be provided to allow agencies to maximize durable products already in the field.
    - The actual implementation period should be short—1 or 2 years.
    - Need to provide early implementation option for new construction that is completed before the implementation period formally begins.
    - May want to transition implementation according to the class of highway.
  - Raised pavement markers (RPMs):
    - Many agencies will have to replace or modify a large number of RPMs to implement an all-white marking system.
    - Can an all-white system be simulated by using only buttons and RPMs?

At the end of the workshop, the moderator asked each of the participants whether they supported, opposed, or were undecided on the issue of implementing all-white pavement markings. Each participant offered comments to support their opinion. A few of the key comments associated with each of the positions include:

- Support implementing all-white markings:
  - Issue is worthy of further evaluation. To implement, all-white markings must have measurable benefits.
  - Manufacturers would prefer dealing with only one color, and white is the better color.
  - All-white markings have better color, higher retroreflectivity, and they are less hazardous.
  - Many of the yellow markings currently in use look white and don't cause any problems for drivers or agencies.

  - The only major issue that needs to be overcome is markings for two-lane, two-way operation.
  - It may take many years to bring an all-white pavement marking system to implementation and the yellow–white system should be improved while preparing for implementation.
  - Driver education needs to be a critical element of implementation.
  - Provides an opportunity to add emphasis on the importance of pavement markings.
- Oppose implementing all-white markings:
  - Converting to all-white has a significant budget impact.
  - Need to improve the current system, not to change systems.
  - The resources needed to implement all-white markings would be better spent improving the current yellow–white system.
  - Safety of current system could be improved through the use of horizontal signing (signing through pavement markings).
- Undecided about implementing all-white markings:
  - Use of RPMs for lane lines and centerlines will make it more difficult and expensive to implement all-white markings. Can't just restripe over old markings.
  - There is not enough information to make an informed decision. Lack of driver understanding data is significant.
  - Nonperformance issues, such as the need to change state laws, may have greater impact on implementation than marking performance aspects.
  - Any benefits will be realized over a long-term period.
  - Should not implement all-white pavement markings without knowing the safety impacts.
  - Concern over environmental issues is overblown.
  - Impacts of RPMs on implementation has been understated.

NCHRP Synthesis

At the same time that this feasibility study of all-white pavement markings was underway, NCHRP was also sponsoring a synthesis study of long-term pavement marking practices (*4*). This synthesis report describes many different practices and provides much valuable information about current practices. Typical costs of pavement markings is one of the most valuable pieces of information in this report, as it relates to an assessment of all-white pavement marking system feasibility. Table 11 presents the cost information contained in *NCHRP Synthesis 306* (*4*). This information confirms the wide range of costs associated with pavement markings in the United States.

Color Specifications for Pavement Markings

In December 1999, the FHWA published a proposed rule that presented in-service color specifications for daytime and nighttime color of pavement markings (*5*). These color specifications were intended to define the end-of-service life for pavement markings in the field. At the conclusion of this research project, the FHWA had not issued a final rule on the color specifications.

However, the ASTM recently published a standard specification for the color of pavement marking materials (*6*). This specification establishes both daytime and nighttime color requirements for markings and applies through the life of the markings. The existence of an ASTM specification does not obligate an agency to meet those requirements. However, the specification may be viewed by some as an "industry-accepted standard." The values in the ASTM specification are almost the same as those in the FHWA proposed rule.

There have been no evaluations of in-service color of yellow pavement markings, so there is no clear understanding of how existing markings will meet the requirements. Nor is

TABLE 11 Cost information from NCHRP synthesis

Material	Application	Number	Typical ($/ft)	Range ($/ft)
Waterborne paint	State Forces	24	0.05	0.02-0.20
	Contractor	21	0.08	0.02-0.18
Solvent paint	State Forces	6	0.05	0.04-0.08
	Contractor	8	0.08	0.02-0.15
Epoxy	Contractor	14	0.27	0.09-0.65
Preformed tape - flat	Contractor	11	1.59	1.01-2.00
Preformed tape - profiled	Contractor	15	2.34	1.50-3.10
Thermoplastic	Contractor	20	0.34	0.10-0.85

Notes: Adopted from Reference (*4*).
Only costs for materials with more than 5 survey responses were included in this table.
All responses were from state agencies. There were fewer than 4 city or county agencies that responded for any particular material.

there a clear understanding of the impact of in-service color requirements on the life of yellow markings. It is possible that in-service color requirements may significantly reduce the service life of markings that meet the color requirements when initially installed. This may require agencies to implement more expensive yellow marking materials.

Minimum Levels of In-Service Retroreflectivity

The 1993 Department of Transportation Appropriations Act requires the DOT to revise the *MUTCD* to include a standard for a minimum level of retroreflectivity that must be maintained for pavement markings. The FHWA has conducted some research that has resulted in research recommendations for minimum values (*7*). FHWA is continuing to conduct additional research to determine the most appropriate minimum values for inclusion in a proposed rule. A value of 100 mcd/m^2/lux is the highest retroreflectivity in-service value for yellow in the research recommendations. This is an achievable minimum retroreflectivity value for most combinations of binders and beads, although it may require some agencies to replace yellow markings more often. The FHWA recently gathered information on the minimum initial values used by some states for evaluating the quality of newly installed markings. Initial retroreflectivity values for white markings range from 175 to 700 mcd/m^2/lux, depending upon the state, the type of marking material, and the time frame in which the retroreflectivity is measured. For yellow markings, the initial retroreflectivity values range from 100 to 350 mcd/m^2/lux.

Pavement Marking Materials

Various materials have been used over the years for pavement markings. All the types have consisted of basically the same components, a resin or binder, a pigment, and a solvent. A resin or binder is used to hold the pigments together in a film as well as provide adherence to the roadway. Pigment is used to impart color to the marking as well as provide hiding and various chemical aspects such as UV resistance. Solvent is typically used to add fluidity to the material to make for ease of handling. The various pavement marking types have typically been known by the type of resin or some characteristic of the resin that is present, for example, solvent-based or water-based. Pavement marking materials have evolved substantially from the paint materials used in the early part of the twentieth century. Today, there are a wide variety of materials that can be used for pavement markings. Table 12 lists the common marking materials and the findings of a recent survey indicating the extent of use among state transportation agencies (*4*).

Recent federal regulations have significantly reduced the use of two marking materials that were widely used in the past. In September 1999, the EPA issued regulations limiting the VOCs in long-line pavement markings to 150 g/l. This essentially requires that agencies and contractors eliminate the use of solvent-based marking materials or pay the necessary exceedance fees. Agencies are now using water-based or durable marking materials instead of solvent-based materials.

The other major change in pavement marking materials is the most significant one related to the issue of an all-white pavement marking system. Yellow markings were originally created through the use of a lead-chromate pigment. Lead-chromate pigment can be present in latex or alkyd paint, and

TABLE 12 Use of marking materials in state transportation agencies

Type of Longitudinal Marking Material	Number of States[1]	Percentage[2]
Water-based Paint	33	89%
Thermoplastic	30	81%
Preformed Tape - Profiled	20	54%
Preformed Tape - Flat	19	51%
Epoxy	19	51%
Solvent-based Paint	13	35%
Methyl Methacrylate	9	24%
Thermoplastic - Profiled	9	24%
Polyester	5	14%
Polyurea	2	5%
Cold Applied Plastic	1	3%

Notes:
[1]A total of 37 states responded to the survey. States could indicate more than one material used.
[2]Totals add up to more than 100 percent.
Source: Adapted from Reference (*4*).

is used to get the vibrant golden yellow that has been associated with highway centerlines for years. As transportation agencies became more environmentally conscious in the late 1980s (as the result of encouragement from the EPA), the use of lead in marking materials was questioned. This resulted in a move away from paint with lead in it.

In an attempt to shift from lead chromate, organic dyes have been used. It has sometimes proven difficult to provide a color that is recognized as yellow in day and night conditions with organic dyes; the problem has been to get an organic dye that has enough color fastness to last the life of the paint without being too expensive. Providing the necessary hiding is also difficult; as the dyes have virtually no hiding capability.

Other environmental challenges associated with lead in yellow marking materials include worker protection and the treatment of yellow marking materials when they are removed. Worker protection issues fall under the OSHA regulations. Worker safety concerns are related to exposure to lead through spraying paint with lead or removing paint with lead. The rules assume an exposure until there is proven by testing to be no exposure above the action level. The Resource Conservation and Recovery Act (RCRA) regulates the disposal of solid waste that contains lead. Specifically, the solid waste has to be tested for leachability for lead and chromium or other heavy metals identified by RCRA as a characteristic waste. This means that when lead-containing paint is eradicated from the roadway, it has to be collected and analyzed prior to disposal. It cannot be left on the roadway. If it leaches more than 5 ppm, then it has to be treated to a nonhazardous condition prior to disposal.

CHAPTER **3**

DRIVER UNDERSTANDING

As with any part of the traffic control device system, there are many factors that affect the effectiveness of a pavement marking. Certainly, visibility of a pavement marking is one of those factors. However, seeing a marking is only the first step; drivers must also know the meaning of pavement markings or the meaning must be inherently understandable in order to function at an optimal level. In fact, a study of traffic sign symbols suggested that comprehension, or understanding, is the most important criteria in the overall effectiveness of a traffic sign (*8*). Therefore, a critical element in assessing the potential impacts of implementing an all-white pavement marking system is to determine driver comprehension of the current yellow–white pavement marking system in the United States and compare that to potential driver understanding of an all-white system.

As originally proposed, this research project intended to rely upon previous research to assess driver understanding of pavement markings and the potential effectiveness of various all-white pavement markings. However, although that review did identify previous research on driver understanding of pavement markings, much of it was too old or did not address the specific issues of color understanding. Therefore, the research was modified to conduct an extensive evaluation of driver understanding of:

- the current yellow–white pavement marking system, including:
  - understanding of the direction message conveyed by yellow and white and
  - understanding of the passing restrictions conveyed by marking patterns,
- the potential effectiveness of an all-white pavement marking system, including:
  - directional messages and
  - passing restrictions,
- identification of potential enhancements that could be implemented to improve yellow–white or all-white pavement marking systems, and
- drivers' opinions of pavement marking issues, including the potential conversion to an all-white pavement marking system.

This chapter summarizes the findings from the two efforts in this area: (1) evaluation of previous research on understanding of pavement markings and (2) evaluation (through a survey) of current drivers' understanding of pavement markings.

PREVIOUS RESEARCH

Early in this study, the researchers evaluated previous research on driver understanding of pavement markings. The researchers identified 10 major studies in the last 35 years that evaluated various aspects of the extent to which drivers understand pavement markings. The results of the analysis were presented in the interim report and are included in this report as Appendix B.

The effort identified a limited number of previous studies on driver understanding of pavement markings, particularly with respect to the system-type issues. The system perspective of comprehension information was needed for this study in order to assess various elements of the yellow–white system and the identification of potential alternatives for an all-white pavement marking system. Furthermore, many of the studies that were identified were conducted in the 1970s, when the exclusive use of yellow for separating opposing traffic was relatively new. As such, data from those studies could not be generalized to represent understanding of the system today, which has been in use for 30 years. The ultimate result of the review was the finding that there is not an adequate body of recent information to determine the extent to which drivers understand the yellow–white marking code. Also, there was no information on the potential understanding of various alterative schemes for an all-white pavement marking system.

One of the most significant challenges of evaluating previous research efforts was the limited focus of many of these studies. Typically, one or two questions might be asked about pavement markings as part of a larger effort on traffic control devices or other issues. Most of the questions focused on no-passing messages of markings and did not address the meaning of pavement marking color. Another significant challenge in using various studies to make pavement marking system comparisons were the differences in evaluation techniques between studies. Differences in evaluation techniques, subject samples, and the year of evaluation can lead to differences in evaluation results. For example, the studies

that used in-context or simulated real world images of the pavement markings generally had higher levels of comprehension. The higher levels were attributed to contextual clues found in the driving environment.

Table 13 presents a generalized summary of the findings relative to understanding of a broken yellow centerline and a broken white lane line. In this table, the research studies have been arranged in chronological order. However, these results should not be compared directly with one another. Many of these research studies found that drivers who had attended driver education classes had better overall comprehension of pavement markings. Instead of directly comparing results, these findings should be used to gain a general appreciation of the extent to which drivers understand the pavement marking system.

In general, the previous research evaluated as part of the all-white marking evaluation found that significant portions of drivers do not have an inherent understanding of the color meanings associated with the yellow–white pavement marking system. The following information presents some of the researchers' conclusions about the yellow marking color as presented in eight of the 11 studies described in this chapter.

- **Evaluations for the 1971 *MUTCD***: "*Respondents are able to interpret the intended meanings of the form of road markings, but, on the basis of the examples given in this questionnaire at least, they do not apprehend the proposed meanings for colors*" (*10*).
- **Evaluations of the marking code**: "*The research findings indicate that, in fact, color coding of traffic is not "getting across" to the driver. Many respondents, in defining the markings, thought that white lines are intended to show counter traffic movement. Moreover, most drivers did not even recognize that color does communicate traffic movement. . . . Yellow should not be universally used to mark the center of two-way roads. White center markings are preferable. Yellow paint is toxic, it represents a visibility handicap under adverse weather conditions, and it is more expensive than white paint. . . . The research findings bring into question the use of yellow markings to show the separation of counter-moving traffic*" (*11*).
- **AAA 1979 Evaluation**: "*The greatest weakness in motorists' perception of traffic controls was in the area of pavement markings*" (*12*).

TABLE 13 Generalized summary of previous research findings

Study	Year	First Author	Reference	Directional Message Associated with Color Correct Response Rate (percent)	
				Yellow Centerline	White Lane Line
Ohio	1967	Taylor	9	67[1]/89[2]	
Evaluations for 1971 MUTCD	1972	Dietrich	10	29	6
Evaluations of Marking Code	1976	Gordon	11	70	59
First AAA	1979	Hulbert	12	n/a	
Second AAA	1980	Hulbert	13	n/a	
Second TTI	1981	Womack	14	87[3]	47[3]
				53[4]	45[4]
Wisconsin	1993	Palit	15	69	57
Kansas	1995	Stokes	16	88	52
Third TTI	1995	Hawkins	17	77	50
				NE	79
TTI Border	1999	Hawkins	18	72[3]	52[5]
				83[4]	48[6]

Notes: [1]Results from random-order presentation for complete marking system.
[2]Results from system-order presentation for complete marking system.
[3]Results for multiple-choice evaluation.
[4]Results rate for open-ended evaluation.
[5]Drivers from Mexico.
[6]Drivers from Texas border area.
NE=not evaluated.

- **Ohio Evaluation**: "*Significant results were found in many of the studies which indicated that pavement marking systems could be devised to convey meaningful information to the driver. . . . Also, the use of color appears to have greater potential in the long run than the use of line shape*" (*9*).
- **Wisconsin Evaluation**: "*These results suggest the need for an educational program for the general public on the meaning of the pavement markings*" (*15*).
- **TTI 1981 Evaluation**: "*In general, survey respondents indicated a lack of understanding of the meaning of the road marking code system. . . . Respondents showed little understanding of the difference between yellow and white in defining directions of travel. Additionally, although a reasonably good understanding of markings that do not permit passing was found, there was some indication that the premise drivers use was the color yellow, rather than solid versus dashed markings*" (*14*).
- **TTI 1995 Evaluation**: The researchers identified several devices where increased emphasis in driver training classes is needed. Among the recommendations was one to "*Emphasize the difference between yellow and white markings and the restrictions indicated by different marking patterns*" (*17*).
- **TTI 1999 Border Area Evaluation**: Researchers recommended several devices for emphasis in driver education: Among the recommendations was one to emphasize the "*difference between yellow and white markings*" (*18*).

Several major conclusions can be drawn from the findings of the review of previous research. They include the following:

- There is a lack of thorough research on driver understanding of pavement markings.
- In the 1970s, when exclusive use of yellow as a centerline was relatively new, research indicated that significant proportions of the driving population did not distinguish the different meaning between yellow and white lines of the same shape.
- The previous research supports the claim that the yellow–white system could be changed because drivers do not have a high degree of familiarity and understanding with it.
- Drivers are not thoroughly familiar with the meaning of yellow within the pavement marking system, but specific issues of understanding color are not adequately addressed in previous research.

The information on previous comprehension research was presented to the panel early in the research project. After reviewing this and other information, the panel agreed that the project should include an evaluation of current driver understanding of the U.S. pavement marking system. Therefore, the project was modified to devote a significant effort to this issue, including driver understanding of potential all-white pavement marking patterns. Driver understanding of yellow–white and all-white markings were assessed through a driver survey that was administered to 851 drivers at 7 general locations in the United States.

SURVEY DEVELOPMENT

The survey was developed over a series of several months. The researchers established the initial content and format for the survey, then proceeded to administer the survey in a pilot effort. Through pilot testing, the researchers found that the format of the initial survey had numerous shortcomings and the content was too long. This led to an overhaul of the survey format and content. The survey was revised and evaluated in a second pilot effort, which determined that the revised survey was effective.

Initial Survey Development

In developing the initial survey, the researchers attempted to address all of the understanding issues that needed to be answered and to present the information to survey participants in a manner that represented a real-world condition to the greatest extent possible.

Content

In developing the initial survey, the researchers identified numerous items that they felt should be addressed in the evaluation. These included:

- Drivers' ability to describe the pavement marking color code,
- Drivers' reliance on pavement marking color when interpreting marking messages,
- Drivers' reliance on pavement marking patterns when interpreting marking messages,
- Drivers' ability to discern subtle differences in pavement marking patterns,
- Drivers' understanding of the current yellow–white pavement marking system,
- Drivers' potential understanding of various alternatives for an all-white pavement marking system,
- The ability to increase understanding of yellow–white or all-white markings through minor enhancements, and
- Drivers' opinion and input on pavement marking issues.

The initial survey consisted of 55 questions, which could be divided into the following categories:

- Basic understanding of the pavement marking code and driver reliance on the code (5 questions),

- Pavement marking patterns without color (10 questions on 6 different marking patterns),
- Current yellow–white pavement markings (8 questions on 4 different marking patterns),
- Potential alternatives for all-white pavement markings (28 questions on 14 different marking patterns),
- Enhancements to the pavement marking system (2 questions), and
- General comments (2 questions).

Static graphic images were used for all questions except those addressing the yellow–white and all-white markings. Video clips were used for the 36 questions on yellow–white and all-white markings. The video clips were deemed to be necessary for two reasons: (1) the desire to present as realistic a scenario as possible and (2) the desire to evaluate different stripe and gap patterns for the all-white markings. TTI staff filmed the video clips on a local highway. The all-white markings were created by overlaying existing yellow markings with strips of white tape mounted on aluminum panels. These patterns were easily changed from one scenario to another. Table 14 presents the different all-white pavement marking patterns that were included in the initial survey as video clips.

As shown in Table 14, a variety of width and stripe/gap lengths for the all-white markings was included because of the dependence on similar patterns in other countries with all-white markings. The researchers wanted to determine if wider markings or different stripe and gap lengths might convey a sense of opposing traffic to drivers. Figure 7 illustrates the appearance of several different stripe/gap patterns. These images were taken from the video clips used in the initial survey.

Format

The initial survey was envisioned as a self-administered survey that would be presented on a laptop computer. The intent was to present a series of photographs, graphic images, and video clips to survey subjects, who would respond through keystrokes on the computer. This survey format was selected because (1) it presented a more realistic view of roadway scenarios than a static image, (2) it allowed more than one survey to be given concurrently by an administrator, and (3) it allowed automated recording of data entries.

The initial survey was created in Visual Basic so that answers would be automatically saved in a database on the computers as respondents viewed the images and responded to questions on the screen. As mentioned, this format allowed for the use of video clips as a part of the survey. Each of the video clips was 3 to 4 s long. The use of video clips enabled the researchers to display varying patterns of line lengths and spacings in a real-time view, simulating the actual driving situation more realistically than with photographs.

Pilot Testing

Once the initial survey had been prepared and approved by the NCHRP panel, the researchers initiated a pilot test to evaluate the effectiveness of the survey instrument. The initial survey was pilot tested with 15 subjects at two locations

TABLE 14 All-white pavement marking patterns included in initial survey

Line Type	Line Width (inches)	Line Length (feet)	Gap Length (feet)	In Revised Survey?
Single Broken	4	10	10	Yes
Single Broken	4	10	30	No
Single Broken	4	20	20	No
Single Broken	8	10	10	No
Single Broken	8	10	30	No
Single Broken	8	20	20	No
Single Solid	8	N/A	N/A	Yes
Double Broken	4	10	10	Yes
Double Broken	4	10	30	No
Double Broken	4	20	20	No
Double Combination (Passing Permitted)	4	10	10	No
Double Combination (Passing Permitted)	4	10	30	No
Double Combination (Passing Permitted)	4	20	20	Yes
Double Solid	4	N/A	N/A	Yes

a. 4-inch line: 10-ft stripe, 10-ft gap

b. 8-inch line: 10-ft stripe, 10-ft gap

c. 4-inch line: 20-ft stripe, 20-ft gap

d. 8-inch line: 20-ft stripe, 20-ft gap

e. 4-inch line: 10-ft stripe, 30-ft gap

f. 8-inch line: 10-ft stripe, 30-ft gap

Figure 7. Comparison of striping patterns.

in the College Station/Bryan area. During the pilot testing, researchers noted that participants were not taking the time to watch the 3- to 4-s video clips. In most cases, they answered almost immediately upon seeing a still image on the screen. It became apparent that participants could not tell the difference between various stripe and gap lengths in the video clips. Figure 7 provides several examples of striping patterns that drivers could not distinguish from one another. Further, the initial pilot tests indicated that the survey was too long and too repetitive. Because participants did not distinguish between the various scenarios, they thought they were being asked to answer the same question repeatedly. The 55 questions in the initial survey took an average of 20 min to complete.

In addition to the problems with perceived repetition and length, there were glitches in the use of the Visual Basic version of the survey. Although the survey worked well on the laptop computer on which it was developed, it did not work properly when installed on other laptop computers. This prevented the survey from being administered on multiple laptops at the same time, reducing the efficiency of the survey administration process. As a result of the negative experience with the initial survey, the researchers determined that the survey should be significantly revised.

Revised Survey Development

The revised survey was created from the initial survey by eliminating some of the questions, converting the video clips to photographs, and creating a paper-based survey format.

Content

In revising the content, the researchers eliminated 12 of the marking scenarios and combined separate questions for many of the other scenarios that were retained in the survey. The result was a survey that consisted of 20 questions. In general, the questions that were eliminated addressed some of the less common marking situations or the wide variety of stripe and gap lengths in the all-white markings. Table 14 indicates which of the all-white markings were included in the revised (and final) survey instrument. The researchers also refined the introductory questions on the pavement marking code and simplified the presentation of multiple questions that were related to a specific scenario. The content of the final survey instrument is presented in Appendix C.

Format

Once the video clips were eliminated and the number of questions was reduced, the researchers determined that a paper-based survey format would be just as effective as the computer-based format. Therefore, the survey was converted to PowerPoint and printed for presentation from a binder. Each screen was printed in color, and each page was inserted in a plastic sleeve. The sleeves were placed in a hard binder, and each surveyor had a copy of this notebook. This change also allowed the surveyors to more easily approach potential participants because the paper version was mobile: the researcher and participant did not have to move to a specific area where a laptop computer was located. Figure 8 illustrates one question from the survey binder as it was used to collect data from the participants.

The revised survey was organized into four general sections:

- Introduction and initial open-ended questions to determine if drivers mentioned pavement markings as some-

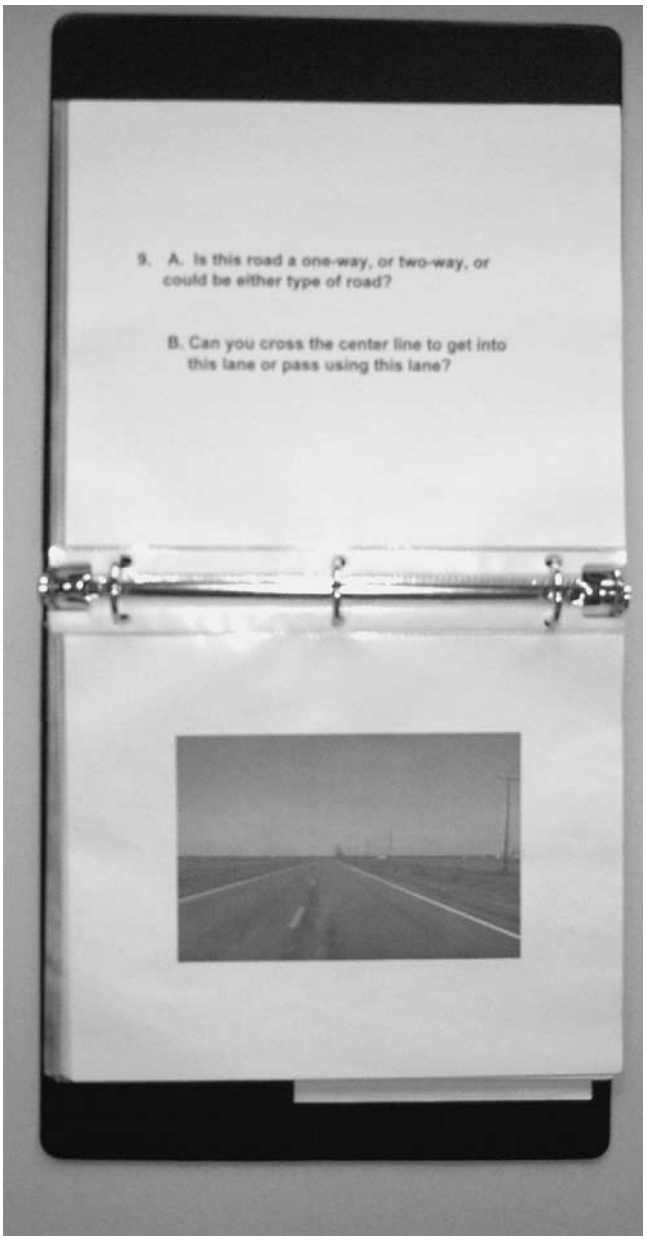


Figure 8. Survey binder.

thing they would look for when deciding which way to go in an unfamiliar situation,
- Scenarios where all pavement markings are shown in black on a gray road to determine driver understanding of patterns,
- Actual photos of road scenarios with pavement markings shown in yellow and white to determine driver understanding of color, and
- Actual photos (originally videos) of all-white pavement markings to determine interpretation of the markings.

These sections were followed by two questions about new arrow patterns and an open-ended question asking for opinions on converting to an all-white pavement system.

Pilot Testing

After developing a revised survey instrument, researchers pilot tested the revised survey instrument. Two pilot tests were conducted in the College Station/Bryan area, with a total of 30 subjects participating in the survey. The experience gained from the first pilot test found that the recorded responses indicated answers to the questions, but not the respondents' confidence in the answer. In many cases, the respondent would make statements such as "I'm not really sure, but I think it is supposed to be yellow, so that's what I'll say." In the survey results, this would be recorded as a correct response even though the respondent did not have any degree of confidence in the answer. Therefore, in the second pilot test, a follow-up question was added to the second and third questions in the survey to assess subjects' certainty of their answers.

The experiences gained from the pilot testing of the revised survey indicated that the survey instrument was effective and that the effort could move forward into the survey administration stage.

SURVEY ADMINISTRATION

The first surveys were conducted in August 2001 in Houston, Texas. In all, surveys were administered in six metropolitan areas in five states around the United States to a total of 851 subjects. Table 15 lists the survey locations and number of surveys completed at each location.

Site Selection

The survey was administered in public places where drivers could be recruited and where a waiting period was typical. The researchers selected driver licensing offices, airports, train stations, and bus stations for survey locations in order to include a wide variety of drivers. The researchers' original plan was to collect survey data in airports. Some data were collected at airports prior to September 11, 2001, but no surveys were administered in airports after this date because of security restrictions. Instead, the researchers used train and bus stations as the primary locations for collecting survey data.

TABLE 15 Survey sites

City and State	Location	Number of Surveys Completed
Atlanta, GA	Hartsfield Airport	5
Atlanta, GA	Greyhound Station	70
Chicago, IL	Amtrak Station	398
Dallas, TX	Amtrak Station	47
Dallas, TX	Greyhound Station	7
Emeryville, CA Oakland, CA San Francisco, CA	Amtrak Stations	65
Houston, TX	Amtrak Station	33
Houston, TX	Driver License Station	69
Houston, TX	George Bush Intercontinental Airport	50
Houston, TX	Greyhound Station	75
Minneapolis, MN	Human Factors & Ergonomic Society Conference	10
Minneapolis, MN	Small Social Settings	14
St. Paul, MN	Amtrak Station	8
Total Number of Surveys		851

The survey was conducted in five geographically diverse areas of the United States: Texas, Illinois, Georgia, California, and Minnesota. The intent was to avoid limiting the results to one region of the country. As the location selection expanded to include more than driver licensing offices, the net result was that the sample included drivers from almost every state and territory of the United States, with larger frequencies from the survey state sites.

Administration

Potential participants were approached and asked if they would be willing to complete a survey about driving that would take approximately 10 min. If the potential participant said no, surveyors thanked them and moved on. If the potential participant said yes, the surveyor positioned the notebook so that the participant could clearly see the images and text after first determining that the participant was a driver. The surveyor began by assuring the respondent that the survey was not a test and would in no way affect the participant's driver license.

The surveyor then read each question aloud, waited for the participant's answer, and recorded each answer on an answer sheet. The surveyor gave the participant a squeezable stress vehicle after they completed the survey in appreciation for their participation.

SURVEY RESULTS

Data from the survey consist of the responses from 851 subjects to various demographic and roadway marking questions. The results presented in this section simply address the frequency and percent responses to each question. A more detailed analysis of the results is presented at the end of this chapter. The analysis is presented according to the major sections of the survey: demographics, basic marking color code, marking patterns, yellow–white markings, all-white markings, and follow-up questions. The response percentages presented herein have a standard error of ±3.5 percent for the reported percentages, based on a sample size of 850 and a 95 percent confidence level.

Demographics

The first five questions in the survey asked the subject for demographic information. In addition to the five questions, the survey administrator recorded the gender and apparent ethnicity of the subject. While gender determination is straightforward, the values recorded for ethnicity may, by not being self-reported, involve an unknown degree of ambiguity. Table 16 presents the results of the demographic analysis. The 851 subjects that participated in the survey represented 47 states, the District of Columbia, and Puerto Rico. Table 17 presents the geographic distribution of the survey respondents.

Basic Marking Color Code

The first three questions of the survey were intended to identify driver understanding of the basic color code of the current yellow–white pavement marking system. All three questions were open-ended and subjects were allowed to give multiple responses. All subject responses were recorded in the order that they were given. All three questions presented the photograph shown in Figure 9. The second and third questions presented the graphics in Figures 10 and 11, respectively, in addition to the graphic shown in Figure 9.

Responses to Question 1 are shown in Table 18. The actual responses to this question were open-ended, and multiple responses were allowed. There were a total of 2,041 responses among the 851 subjects (an average of about 2.4 responses per subject). In tabulating the responses, the individual responses were grouped into eight distinct categories and one catch-all category (Other). Subjects were asked to continue providing answers until they could not think of any other cues to traffic direction. Therefore, Table 18 also indicates the frequency and percentage that each of these responses were given as the first, second, and third response from each subject. Presenting the results in this manner gives an indication of the primary tool that a driver would use to determine whether a street is one-way or two-way.

Table 19 presents a rank order of the responses as a function of several different considerations. This information shows that drivers tend to use signs and other traffic to determine whether a road is one-way or two-way. While drivers rely upon markings in general, they tend to be a secondary consideration if there are other cues available to provide directional information. Only about 10 percent of all the responses specifically mentioned looking at the color of the markings. About one-fourth of the subjects mentioned markings as one of their responses.

In Questions 2 and 3, a graphic was presented along with the photograph (see Figures 10 and 11). The graphic had arrows indicating one- or two-way traffic and black pavement markings. Subjects were asked to indicate the color of the broken line in the center of the street and the degree to which they were certain of their answer. They were also asked to indicate the certainty of their answer, with a 5 indicating they were positive and a 1 indicating they were guessing. Table 20 presents the responses for a two-way street (Question 2) and Table 21 presents the responses for a one-way street (Question 3). A small number of subjects gave a fractional answer (e.g. 3.5, 4.5) as their response on the certainty question. In these cases, the response was rounded down to the nearest integer.

TABLE 16 Demographic results

Survey Data				U.S. Population[1]
Question/Demographic	**Categories**	**Number**	**Percentage**a	
How long have you been driving? (851 responses)	Less than 1 year	21	2.47	N/A
	1 – 5 years	133	15.63	N/A
	6 – 10 years	115	13.51	N/A
	More than 10 years	582	68.39	N/A
Did you take Driver's Education in order to get your driver's license? (849 responses)	Yes	553	65.14	N/A
	No	296	34.86	N/A
What is your age group? (850 responses)	16-19	72	8.47	7.5%[2]
	20-29	218	25.65	17.7%[2]
	30-39	144	16.94	19.9%[2]
	40-49	164	19.29	19.6%[2]
	50-59	149	17.53	14.3%[2]
	60 or above	103	12.12	21.1%[2]
What is the highest grade you completed in school? (849 responses)	Less than high school	55	6.48	24.8%[3]
	High school or GED	180	21.20	30.0%[3]
	Some college or technical school	250	29.45	24.9%[3]
	College graduate	364	42.87	20.3%[3]
Where do you live?	City	See Table 17 for distribution		N/A
	State			
	Zip Code			
Observation of subject gender (838 responses)	Male	455	54.30	49.1%[3]
	Female	383	45.70	50.9%[3]
Observation of subject ethnicity (840 responses)	Anglo	604	71.90	62.6%[4]
	Black	151	17.98	12.3%
	Hispanic	55	6.55	12.5%[4]
	Other	30	3.57	10.2%

Notes: [1]Data based on the 2000 U.S. Census.
[2]Data based on percentage of total driving age population (16 and over).
[3]Data based on total U.S. population.
[4]Census data includes Hispanic with White for reporting purposes. They have been separated in this table.

TABLE 17 Summary of sample distribution by state

State	Number	State	Number	State	Number	State	Number
AK	2	ID	2	MT	11	Puerto Rico	2
AL	11	IL	150	NC	8	SC	5
AR	7	IN	19	ND	3	SD	2
AZ	8	KS	3	NH	2	TN	10
CA	95	KY	5	NJ	8	TX	185
CO	18	LA	11	NM	1	UT	1
CT	3	MA	7	NV	2	VA	12
DC	1	MD	7	NY	16	VT	1
DE	3	ME	2	OH	18	WA	3
FL	31	MI	27	OK	3	WI	29
GA	31	MN	26	OR	7	WV	1
HI	1	MO	16	PA	22		
IA	7	MS	5				

Figure 9. Photo for Questions 1 through 3.

The results of these two questions show that a substantial number of the subjects have an understanding of the use of marking color to differentiate between one- and two-way roads. About 70 percent of the subjects indicated yellow for a two-way street and about 80 percent indicated white for a one-way street. When these responses are combined with those of Question 1, it is apparent that this knowledge is not the primary tool drivers use to distinguish direction of travel on a road.

One other question in the survey addressed the color of pavement markings. Question 8 presented a graphic of a divided highway and asked drivers to indicate the color of the markings for one direction of travel. Figure 12 presents the graphic used for this question and the results are presented in Table 22. The labels identifying the specific lines were not part of the graphic image shown to survey participants. In the actual survey, the administrator would point to the line that the question was asking about.

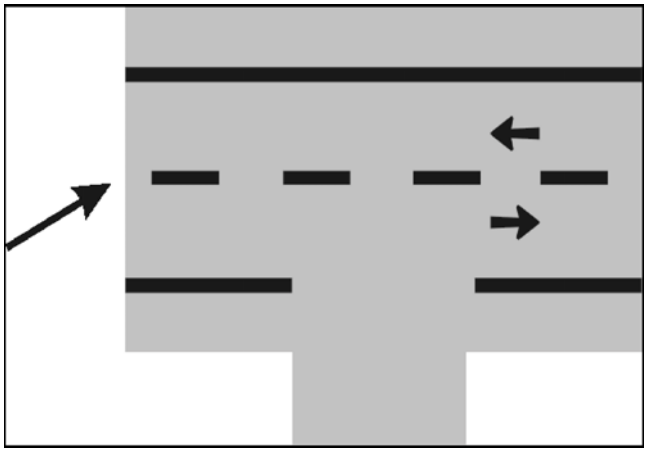


Figure 10. Graphic for Question 2.

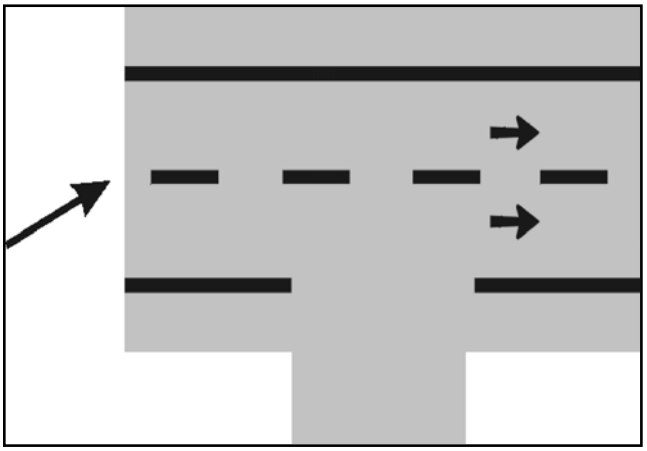


Figure 11. Graphic for Question 3.

While approximately three-fourths of the subjects correctly identified the color of the lane line, these results indicate a significant lack of understanding of the color of edge lines. Only 39 percent correctly identified the color of the left edge line and 66 percent correctly identified the color of the right edge line.

Marking Patterns

Questions 4 through 7 presented graphic images of road scenes where the pavement markings were black. The intent of these questions was to determine if drivers associate specific messages with the marking pattern alone (sans color). Two issues were addressed for each question: direction of traffic (one-way or two-way) and passing/lane changing restrictions. The graphic images presented with each question are shown in Figures 13, 14, 15, and 16.

The first part of each question addressed whether the traffic flow on the road was one-way, two-way, or either. Respondents were also allowed to indicate that they did not know or were not sure. The results for the first part of Questions 4–7 are presented in Table 23.

The second part of Questions 4–7 addressed whether the marking presented a restriction on passing or changing lanes. Respondents answered the questions based on driving the vehicle shown in the graphic image. The results for the second part of Questions 4–7 are presented in Table 24.

The results to the direction of traffic question indicate that drivers tend to associate a solid line with two-way traffic. The broken line question was correctly answered (could be either two-way or one-way) by almost 60 percent of the subjects. Another 30 percent provided the safer response of two-way traffic. The passing prohibited in one direction and the double solid line markings were strongly associated with two-way traffic (82 and 80 percent, respectively). There was no

TABLE 18 Responses to Question 1

Question: How would you know if this is a one-way or a two-way road? What would you look for that would tell you? Is there anything else you would look for? Is that everything?								
Response (open-ended)[1]	**Overall**		**First Response**		**Second Response**		**Third Response**	
	Freq.	**Percent**	**Freq.**	**Percent**	**Freq.**	**Percent**	**Freq.**	**Percent**
Look for a sign	545	26.7	310	36.4	180	23.4	51	13.5
Look for One-Way sign	187	9.2	99	11.6	68	8.8	20	5.3
Look for Do Not Enter sign	34	1.7	8	0.9	13	1.7	10	2.6
Look to see which way signs are facing	17	0.8	5	0.6	6	0.8	3	0.8
Look at direction traffic is moving	504	24.7	104	12.2	228	29.6	160	42.3
Look at the markings	294	14.4	134	15.7	121	15.7	37	9.8
Look at the color of the markings	209	10.2	129	15.2	56	15.2	22	5.8
Look for an arrow	89	4.4	17	2.0	39	5.1	29	7.7
Other	162	7.9	45	5.3	58	7.5	46	12.2
Total	2041	100%	851	100%	769	100%	378	100%

Note: [1]The response categories represent generalized aggregation of the specific responses provided by subjects.

TABLE 19 Rank order of Question 1 responses

Rank Order	**Rank Order By Types of Responses**			
	All Responses (2041)	**First Response (851)**	**Second Response (769)**	**Third Response (378)**
First	Sign	Sign	Direction of traffic	Direction of traffic
Second	Direction of traffic	Markings	Sign	Sign
Third	Markings	Marking Color	Markings	Other
Fourth	Marking Color	Direction of traffic	One-Way sign	Markings
Fifth	One-Way sign	One-Way sign	Other	Arrow

TABLE 20 Responses to Question 2 (two-way street)

Question: If this is a two-way street, what color would this dashed line be?			**Question: How sure you are of your answer?**		
Responses	**Frequency**	**Percent**	**Responses**	**Frequency**	**Percent**
White	214	25.2	1 (Guessing)	21	2.5
Yellow*	591	69.5	2	50	6.0
Either	18	2.1	3	139	16.7
Other	12	1.4	4	152	18.2
Don’t know	8	0.9	5 (Positive)	473	56.7
Not sure	7	0.8	Total	835	100%
Total	850	100%			

Note: *Indicates the correct response.

TABLE 21 Responses to Question 3 (one-way street)

Question: If this is a one-way street, what color would this dashed line be?			Question: How sure you are of your answer?		
Responses	**Frequency**	**Percent**	**Responses**	**Frequency**	**Percent**
White*	665	79.2	1 (Guessing)	31	3.9
Yellow	95	11.3	2	47	5.9
Either	11	1.3	3	151	18.9
Other	24	2.9	4	117	14.6
Don't' know	29	3.5	5 (Positive)	455	56.8
Not sure	16	1.9	Total	801	100%
Total	840	100%			

Note: *Indicates the correct response.

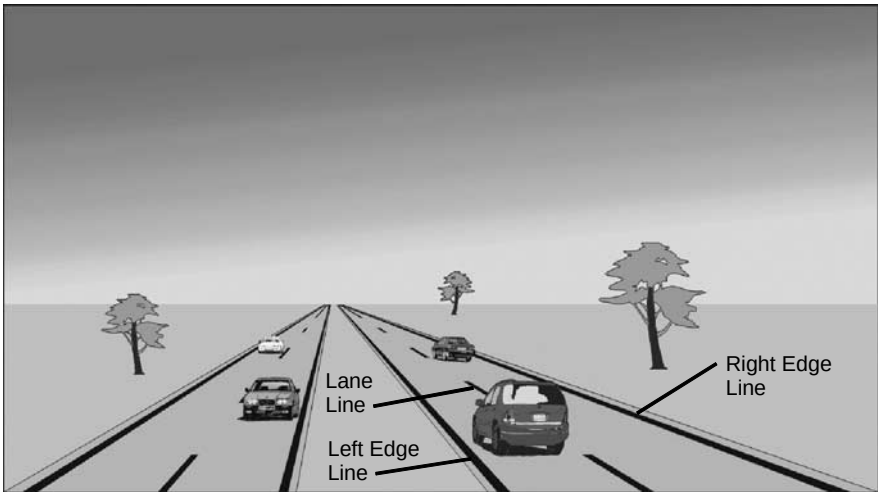


Figure 12. Divided road line color (Question 8).

TABLE 22 Question 8 results

Question: This is a sketch of an interstate highway, showing both the northbound and southbound sections. What color do you think the left edge line would be? What color do you think the lane line would be? What color do you think the right edge line would be?						
Responses	**Left Edge Line**		**Lane Line**		**Right Edge Line**	
	Freq.	**Percent**	**Freq.**	**Percent**	**Freq.**	**Percent**
Yellow	331*	39.0%*	171	20.3%	228	26.9%
White	461	54.3%	642*	76.1%*	555*	65.5%*
Other	26	3.1%	20	2.4%	34	4.0%
Uncertain	31	3.7%	11	1.3%	30	3.5%
Total	849	100%	844	100%	847	100%

Note: *Indicates the correct response.

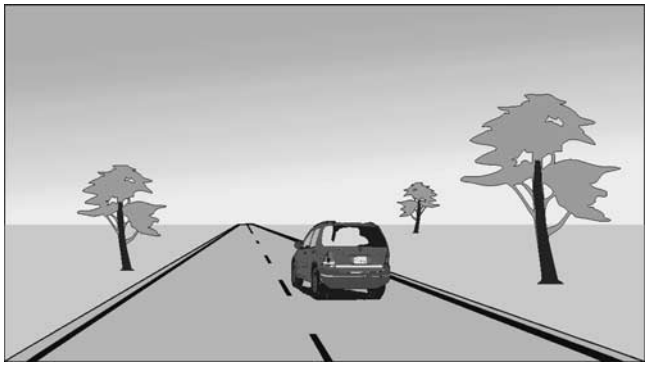


Figure 13. Broken line pattern (Question 4).

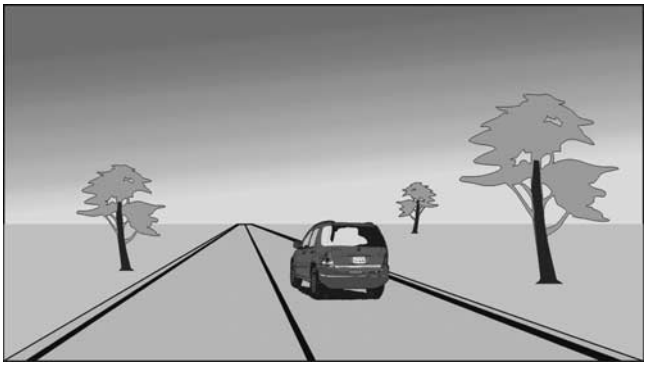


Figure 15. Single solid line pattern (Question 6).

clear consensus on the single solid line, which is not surprising, given that this marking pattern is not used as a centerline or lane line.

The second part of each question addressed the passing restrictions implied by the various marking patterns. Again, subjects associated a definite meaning to the patterns. The two solid lines that drivers normally see (double solid centerline and passing prohibited in one direction) were associated with no-passing by over 90 percent of the subjects. No-passing was also associated with the single solid line, but at a lower percentage (79 percent). Almost 95 percent indicated that passing was permitted with the broken line.

Yellow–White Markings

In the next section of the survey, subjects were presented with actual photographs of road scenes with various yellow–white marking schemes. The intent of these questions was to assess driver understanding of the current yellow–white pavement marking system. As with the marking pattern questions, two issues were addressed for each question: direction of traffic (one-way or two-way) and passing/lane changing restrictions. The graphic images presented with each question are shown in Figures 17, 18, 19, and 20.

The first part of each question addressed whether the traffic flow on the road was one-way, two-way, or could be either. Respondents were also allowed to indicate that they didn't know or were not sure. The results for the first part of Questions 9–12 are presented in Table 25.

The second part of each question addressed whether the marking presented a restriction on passing or changing lanes. The results for the second part of Questions 9–12 are presented in Table 26.

The results for these questions again show that a large percentage of drivers tend to associate the presence of a solid line with two-way traffic and with no passing. The double solid line and the solid and broken line combination (passing prohibited or permitted in one direction) all had correct response rates between 86 and 88 percent for the directional message. When only a broken line was shown, the correct response rate for the directional message dropped to 74 percent, with another 20 percent indicating the road could be either one-way or two-way.

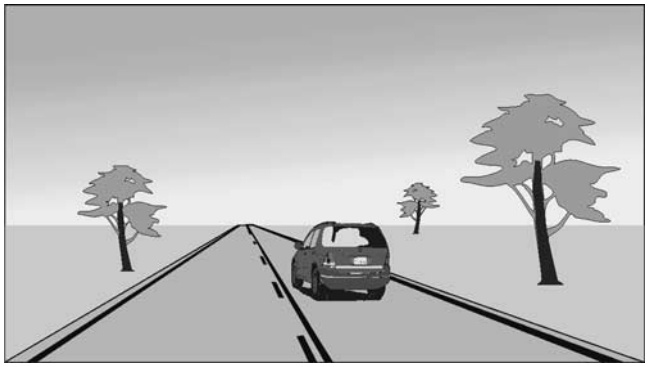


Figure 14. Passing prohibited in one-direction pattern (Question 5).

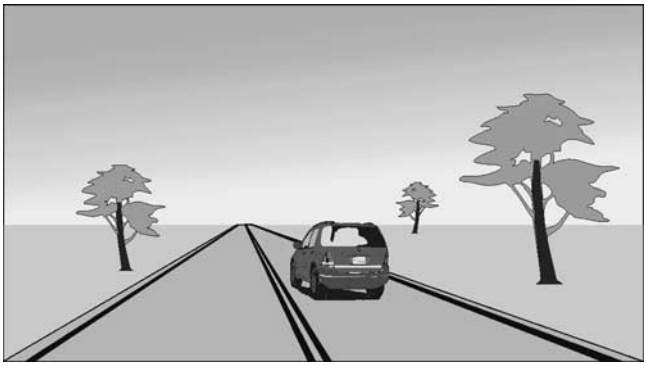


Figure 16. Double solid line pattern (Question 7).

TABLE 23 Results for directional aspect of Questions 4–7

Question: Is traffic on this road two-way, one-way, or could it be either?							
Number	**Marking Pattern**	**Response**					**Number of Missing Responses**
		1-way	**2-way**	**Either**	**Don't Know**	**Not Sure**	
4A (Figure 13)	Single Broken Line	91	258	490*	5	4	3
		10.7%	30.4%	57.8%*	0.6%	0.5%	
5A (Figure 14)	No Passing in One Direction	54	698*	89	3	6	1
		6.4%	82.1%*	10.5%	0.4%	0.7%	
6A (Figure 15)	Single Solid Line	194	378	172	39	47	1
		22.8%	46.8%	20.2%	4.6%	5.5%	
7A (Figure 16)	Double Solid Line	53	672*	91	16	13	6
		6.3%	79.5%*	10.8%	1.9%	1.5%	

Note: *Indicates the correct response.

TABLE 24 Results for passing aspects of Questions 4–7

Question: Can you cross the centerline to get into the left lane or pass using the left lane?						
Number	**Marking Pattern**	**Response**				**Number of Missing Responses**
		Yes	**No**	**Don't Know**	**Not Sure**	
4B (Figure 13)	Single Broken Line	794*	43	3	9	3
		93.5%*	5.1%	0.4%	1.1%	
5B (Figure 14)	No Passing in One Direction	48	793*	2	6	2
		5.7%	93.4%*	0.2%	0.7%	
6B (Figure 15)	Single Solid Line	153	660	17	10	11
		18.2%	78.6%	2.0%	1.2%	
7B (Figure 16)	Double Solid Line	50	786*	6	3	6
		5.9%	93.0%*	0.7%	0.4%	

Note: *Indicates the correct response.

Figure 17. Broken yellow centerline (Question 9).

Figure 18. Double yellow centerline (Question 10).

Figure 19. Yellow passing prohibited in one direction (Question 11).

Figure 20. Yellow passing permitted in one direction (Question 12).

TABLE 25 Results for directional aspect of Questions 9–12

Question: Is traffic on this road two-way, one-way, or could it be either?							
Number	**Marking**	**Response**					**Number of Missing Responses**
		1-way	**2-way**	**Either**	**Don't Know**	**Not Sure**	
9A (Figure 17)	Single Yellow Broken Line	57	626*	159	4	3	2
		6.7%	73.7%*	18.7%	0.50%	0.4%	
10A (Figure 18)	Double Yellow Solid Lines	41	746*	55	4	4	1
		4.8%	87.8%*	6.8%	0.5%	0.5%	
11A (Figure 19)	Passing Prohibited	45	736*	62	5	3	0
		5.3%	86.5%*	7.3%	0.6%	0.4%	
12A (Figure 20)	Passing Permitted	36	735*	71	3	6	0
		4.2%	86.4%*	8.3%	0.4%	0.7%	

Note: *Indicates the correct response.

TABLE 26 Results for passing aspects of Questions 9–12

Question: Can you cross the centerline to get into the left lane or pass using the left lane?						
Number	**Marking**	**Response**				**Number of Missing Responses**
		Yes	**No**	**Don't Know**	**Not Sure**	
9B (Figure 17)	Single Yellow Broken Line	793*	55	2	0	1
		93.3%*	6.5%	0.2%	0%	
10B (Figure 18)	Double Yellow Solid Lines	24	824*	2	0	1
		2.8%	96.9%*	0.2%	0%	
11B (Figure 19)	Passing Prohibited	67	777*	3	2	2
		7.9%	91.5%*	0.4%	0.2%	
12B (Figure 20)	Passing Permitted	699*	139	4	5	4
		82.5%*	16.4%	0.5%	0.6%	

Over 90 percent of the subjects responded that a solid line in their lane indicated a no-passing zone. A broken line alone was interpreted as permitting passing by over 90 percent. However, a broken line with a solid line in the other direction (passing permitted in one direction) had a correct response rate of 83 percent. While still high, these results indicate that a small percentage of drivers (9 percent) associate the solid line with a no-passing message even though the passing restriction applies to traffic in the opposing direction.

All-White Markings

In the fourth section of the survey, subjects were presented with actual photographs of road scenes with various all-white marking schemes. The intent of these questions was to assess how well drivers might understand the directional and passing messages conveyed by various patterns of all-white markings. As with the previous yellow–white questions, two issues were addressed for each question: direction of traffic (one-way or two-way) and passing/lane changing restrictions. The graphic images presented with each question are shown in Figures 21, 22, 23, 24, and 25.

Table 27 presents information on the width and stripe and gap lengths for the all-white markings used in Questions 13–17. The all-white marking scheme was created by placing aluminum covered with white marking tape on an existing roadway so that the white markings covered the existing yellow markings.

The results for the first part (direction of traffic) of Questions 13–17 are presented in Table 28. The results for the second part (passing restrictions) of Questions 13–17 are presented in Table 29. As with the previous questions, respondents were also allowed to indicate that they didn't know or were not sure.

The results for these questions indicate that only the double-line marking patterns with at least one solid line had comprehension levels where over three-fourths of the subjects indicated it was a two-way road. The double broken line had 64 percent indicating a two-way road. Only half of the subjects interpreted the single broken line and the single solid line as a two-way road.

Figure 22. Double white centerline (Question 14).

These results show that the double-line markings did a better job of conveying the two-way message than the single lines. Understanding of the double-broken line was at least 15 percent less than that of the double-line markings that contained at least one solid line. Since the subjects did not seem to attach an inherent meaning to these markings, it appears that implementation of an all-white pavement marking system would require some form of campaign to teach drivers the meaning of the lines.

Follow-Up Questions

Four follow-up questions at the end of the survey addressed various issues associated with all-white pavement markings.

Figure 21. Single broken white line (Question 13).

Figure 23. White passing permitted (Question 15).

Figure 24. Double wide white line (Question 16).

Figure 25. Double broken white line (Question 17).

Questions 18 and 19 presented supplemental marking symbols that are widely used in countries with all-white pavement marking systems to help drivers. Question 20 provided subjects with a chance to comment on all-white markings in general and any other issues they wanted to note.

Question 18 presented a two-lane road with an arrow located within the centerline as shown in Figure 26. This type of marking is used in European countries to indicate the beginning of a no-passing zone. The actual responses given by subjects were divided into general categories for analysis. Table 30 presents the summary of responses for this question.

The responses to the no-passing arrow in the centerline indicate that it has a very low inherent understanding among the survey participants. The low comprehension level might

TABLE 27 Marking dimension for all-white markings

Question	Line Pattern	Line Width (inches)	Stripe Length (feet)	Gap Length (feet)
13 (Figure 21)	Broken Line	4	10	10
14 (Figure 22)	Double Solid Lines	4	Not Applicable	
15 (Figure 23)	Passing Permitted in One Direction	4	20	20
16 (Figure 24)	Single Solid Line	8	Not Applicable	
17 (Figure 25)	Double Broken Lines	4	10	10

TABLE 28 Results for directional aspect of Questions 13–17

Question: Is traffic on this road two-way, one-way, or could it be either?							
Number	Marking	Response					Number of Missing Responses
		1-way	2-way	Either	Don't Know	Not Sure	
13A (Figure 21)	Single Broken White Line	153	424	262	5	5	3
		18.0%	49.9%	30.9%	0.6%	0.6%	
14A (Figure 22)	Double Solid White Lines	59	667	111	4	6	4
		7.0%	78.8%	13.1%	0.5%	0.7%	
15A (Figure 23)	Passing Permitted	47	692	101	5	4	2
		5.5%	81.5%	11.9%	0.6%	0.5%	
16A (Figure 24)	Single Solid Wide White Line	180	435	171	35	27	3
		21.2%	51.3%	20.2%	4.1%	3.2%	
17A (Figure 25)	Double Broken White Lines	134	542	120	29	23	3
		15.8%	63.9%	14.2%	3.4%	2.7%	

TABLE 29 Results for passing aspects of Questions 13–17

Question: Can you cross the centerline to get into the left lane or pass using the left lane?						
Number	Marking	Response				Number of Missing Responses
		Yes	No	Don't Know	Not Sure	
13B (Figure 21)	Single Broken White Line	789	52	5	2	3
		93.0%	6.1%	0.6%	0.2%	
14B (Figure 22)	Double Solid White Lines	52	788	7	2	2
		6.12%	92.8%	0.8%	0.2%	
15B (Figure 23)	Passing Permitted	703	140	5	1	2
		82.8%	16.5%	0.6%	0.1%	
16B (Figure 24)	Single Solid Wide White Line	137	674	21	5	14
		16.4%	80.5%	2.5%	0.6%	
17B (Figure 25)	Double Broken White Lines	701	107	15	17	11
		83.5%	12.7%	1.8%	2.0%	

be attributable to the lack of contextual cues when asking the question or may be due to driver unfamiliarity with this marking. The results indicate that the marking should not be implemented without further evaluation. Use of this marking in other countries indicates that it may have value as a marking symbol and deserves future evaluation.

Question 19 presented directional arrows on a two-lane road as shown in Figure 27. This type of marking is also commonly used in Europe to indicate direction of travel on roadways, particularly at intersections. Responses were categorized into correct and incorrect responses, where a correct response was one where the subject indicated that they needed to move from the left lane to the right lane or to stay in the right lane.

The results of Question 19 indicate a very high level of understanding associated with the directional arrows. Such arrows might have significant value in locations where drivers may be confused as to the direction of traffic flow. (See Table 31.)

Question 20 asked drivers what they thought of converting to an all-white pavement marking system. Responses were categorized into those that support the idea, those that do not, those that are undecided, and those that gave no response. Table 32 presents the summary of responses for this question. The results indicate a strong driver opposition to the concept of an all-white pavement marking system, with only one-fifth of the drivers supporting the concept. While this information may be useful in gauging public response to a change in marking color, the responses should be carefully interpreted. It may not be appropriate to ask random drivers about changing to an all-white pavement marking system. Negative responses may be a normal reaction to any change. Further, they are not likely to know or appreciate the reasons why such a change would be important.

Figure 26. End passing zone arrow (Question 18).

TABLE 30 Summary of Question 18 responses

Question: If you are driving in the left lane, what does this arrow tell you? (Figure 26)		
Response	Frequency	Percent
Merge	297	34.9%
Curve or Turn	142	16.7%
Can't Pass	135	15.9%
Other	129	15.2%
Not Sure	121	14.2%
Exit	24	2.8%
No Answer	3	0.4%
Total	851	100%

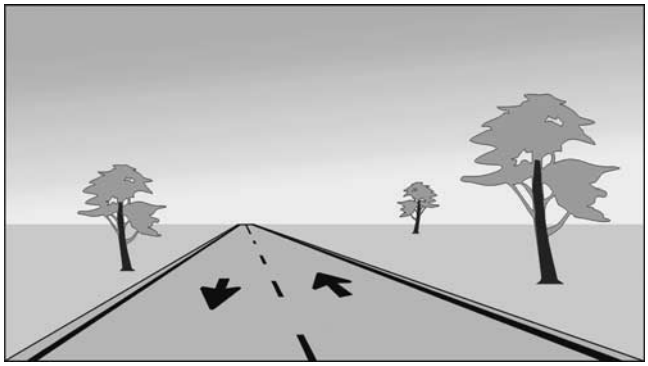


Figure 27. Directional arrows (Question 19).

DETAILED ANALYSIS OF RESULTS

While the previous section presented the basic results for the questions in the survey, this section presents a more detailed analysis of the results.

Associations Between Driver Knowledge and All-White Marking Interpretation

Drivers' comprehension of an all-white pavement marking system may be influenced by their level of understanding of the current yellow–white pavement marking system, in the sense that drivers having greater knowledge of the yellow–white marking scheme may be able to use this knowledge to their advantage when interpreting the meanings of all-white markings. Two types of questions in the survey, the first dealing with black markings (Questions 2 through 8), and the second dealing with the existing yellow–white scheme (Questions 9 though 12), provide a possible opportunity to distinguish between respondent perceptions of marking patterns and their perception of marking colors. The presentation of certain identical marking patterns across three general types of survey questions (black markings, yellow–white markings, and all-white markings) offers further information about the respondent interpretations of the meaning of certain marking patterns.

TABLE 31 Summary of Question 19 responses

Question: If you are driving in the right lane, what does this arrow tell you? (Figure 27)		
Response	**Frequency**	**Percent**
Correct	795	93.4%
Questionable	19	2.2%
Wrong	29	3.4%
No Answer	8	0.9%

TABLE 32 Summary of Question 20 responses

Question: What do you think of the idea of the U.S. using only white lines on the pavement?		
Response	**Frequency**	**Percent**
Support	172	20.2%
Don't support	487	57.2%
Undecided	186	21.9%
No Response	6	0.7%
Total	851	100%

Scoring Survey Responses

The tabulation of scored responses, or the total number of responses corresponding to an identifiably "correct" choice, is an aggregate measure that is helpful for more compact presentation of the data. This measure is especially applicable when one is interested in some general measure of knowledge, as the number of correct answers is presumably correlated with the level of a respondent's knowledge. Nineteen questions in the survey were judged to have identifiably correct or desired responses, based on the information contained in the *MUTCD* or in the proposed all-white schemes developed by the researchers. These survey questions and their corresponding "correct" responses are shown in Table 33. The direction and passing color aspects were considered to be separate questions for purpose of this analysis.

For the purposes of scoring, any response not corresponding to the correct response was judged incorrect, including missing values. The rationale behind the inclusion of missing values as incorrect responses is the assumed tendency of subjects to not answer questions they do not know the answer to or the tendency of the interviewer to forgo a survey question the respondent finds difficult in order to maintain the flow of the interview and maintain respondent interest.

Three summary measures for each respondent were tabulated:

- SCRBLK, the total number of correct answers for black-marking questions (Questions 2A, 3A, 4A, 4B, 5A, 5B, 7A, 7B, 8A, 8B, and 8C); and
- SCRYW, the total number of correct answers for the yellow–white marking questions (Questions 9A, 9B, 10A, 10B, 11A, 11B, 12A, and 12B).
- SCRBYW, the total number of correct answers for each respondent for the black-marking and yellow–white marking questions (does not include the all-white questions);

Likelihood-ratio chi-square tests were conducted to determine associations between scores and the responses to all-white marking questions. Since the all-white marking responses are nominal categorical variables, and because some

TABLE 33 Questions with an identifiably correct answer

Question	Issue	Issue	Correct Response	Count	Percent
2A	Line color	Two-way centerline	Yellow	591	69.5%
3A	Line color	One-way lane line	White	665	78.1%
4A	Direction	Black single broken line	Either	490	57.5%
4B	Passing		Yes	794	93.3%
5A	Direction	Black broken and solid line - passing prohibited	2-way	698	82.0%
5B	Passing		No	793	93.2%
7A	Direction	Black double solid lines	2-way	672	79.0%
7B	Passing		No	786	92.9%
8A	Line color	Left edge line	Yellow	331	38.9%
8B	Line color	Lane line	White	642	75.4%
8C	Line color	Right edge line	White	555	65.2%
9A	Direction	Yellow single broken line	2-way	626	73.6%
9B	Passing		Yes	793	93.2%
10A	Direction	Yellow double solid lines	2-way	746	87.7%
10B	Passing		No	824	96.8%
11A	Direction	Yellow broken and solid line - passing prohibited	2-way	736	86.5%
11B	Passing		No	777	91.3%
12A	Direction	Yellow broken and solid line - passing permitted	2-way	735	86.4%
12B	Passing		Yes	699	82.1%

Note: Question 6 not included in the list of questions with identifiably correct answers.

values of the scores occur relatively infrequently, the values of the various score variables necessarily had to be grouped into categories to accommodate subsequent chi-squared tests. For black-marking scores (SCRBLK) and yellow–white marking scores (SCRYW), this resulted in the few lowest-valued and highest-valued scores being aggregated. The total number of black and yellow–white correct answers (SCRBYW) had a larger number of values as well as low frequencies of lower-valued scores; these scores were therefore grouped into approximate quintiles. Table 34 shows the distributions of the categorized scores. For example, 176 subjects (21 percent of the sample) answered 8 of the 11 black marking questions correctly. These scores themselves are then used to assess the relationship between understanding of current marking patterns and colors and understanding of potential all-white pavement marking systems.

Chi-Square Tests for Association

Likelihood-ratio chi-square tests were conducted to ascertain associations between the various scores and the responses to white-marking questions. For these tests, non-committal responses to the all-white marking questions were excluded, as these responses were sparsely occurring and hence could compromise the tests. With few exceptions, the tests indicated highly significant evidence (p-values less than 0.01) for association between scores on the black and yellow–white questions and the all-white marking questions. Table 35 presents the test results.

Association Between Demographic Variables and Survey Responses

With the exception of driver experience, all demographic variables had highly significant relationships with the number of black- and yellow–white markings correctly answered. The likelihood-ratio chi-square test indicates that driver experience was not judged to influence total scores. Nor was age seen to influence scores except for respondents over 50 years of age. Respondents 50 years and older were less likely to achieve the highest scores compared to younger respondents, and were more likely to have the lowest scores. In particular, respondents older than 59 years had the greatest percentage of lower than average scores and the lowest percentage of higher than average scores.

Respondents who have taken a driver education course were less likely to have the lowest scores than those who have not taken the course, while also being more likely to have the highest scores. Increasing education level was clearly associated

TABLE 34 Distributions of categorized scores

Score	Number of Questions Answered Correctly by a Subject	Frequency	Percent
Black Marking (SCRBLK)	<7	122	14.3%
	7	137	16.1%
	8	176	20.7%
	9	221	26.0%
	10 or 11	195	22.9%
Yellow-White Marking (SCRYW)	<6	49	15.0%
	6	94	11.1%
	7	180	21.2%
	8	449	52.8%
Total for Black and Yellow-White Markings (SCRBYW)	<14	196	23.0%
	14 or 15	190	22.3%
	16	146	17.2%
	17	163	19.2%
	>17	156	18.3%

with increasing scores; better educated respondents were more likely to have higher scores and less likely to have lower scores.

Comparisons for Certainty

The second and third questions of the survey presented subjects with a photograph and graphic image of a two-lane road. The road was identified as a two-way or one-way road and the subjects were asked to indicate the correct color of the line between the lanes. They were then asked to indicate how confident they were with their answer (a response of 5 indicating that they were positive of their answer). Table 36 presents the relationships between the yellow or white color choices and the certainty of the answer. The certainty categories have been aggregated into three new categories, with responses of 3 or 4 combined together and responses of 1 or 2 combined together. This aggregation is motivated by the relative paucity of responses in the lower-rating categories. For the two-way and one-way road scenarios, the percentages of subjects who were positive of their responses were 43 and 48 percent respectively for the correct response. In comparison, the percentage of subjects who were positive of their response when, in fact, it was wrong is 11 percent for the two-way road and 4 percent for the one-way road. This indicates that about 10 percent of

TABLE 35 Tests for association between scores and white-marking responses

Question	Issue	Marking	SCRBLK		SCRYW		SCRBYW	
			Statistic	P-value	Statistic	P-value	Statistic	P-value
13A	Direction	White single broken line	17.5894	0.0245	66.7183	<0.0001	35.0582	<0.0001
13B	Passing		12.3390	0.0150	22.6249	<0.0001	16.0271	<0.0001
14A	Direction	White double solid lines	50.4398	<0.0001	102.8719	<0.0001	97.7704	<0.0001
14B	Passing		33.1549	<0.0001	25.4472	<0.0001	36.1400	<0.0001
15A	Direction	White broken and solid line - passing permitted	64.3913	<0.0001	197.6098	<0.0001	157.4057	<0.0001
15B	Passing		42.9155	<0.0001	152.4541	<0.0001	107.0930	<0.0001
16A	Direction	White double wide solid line	28.4341	0.0004	36.4174	<0.0001	35.7738	<0.0001
16B	Passing		54.0615	<0.0001	20.6562	0.0001	50.5396	<0.0001
17A	Direction	White double broken lines	17.2313	0.0278	55.4064	<0.0001	35.3270	<0.0001
17B	Passing		23.2098	0.0001	43.1464	<0.0001	45.4720	<0.0001

TABLE 36 Comparison of certainty

Color Chosen	Question 2 (Yellow Centerline)			Question 3 (White Lane Line)		
	Certainty[1]	Freq.	Percent	Certainty[1]	Freq.	Percent
White	5	95	11.2%	5	405	48.2%
	3 or 4	95	11.2%	3 or 4	203	24.2%
	1 or 2	24	2.8%	1 or 2	54	6.4%
Yellow	5	367	43.2%	5	30	3.6%
	3 or 4	185	21.8%	3 or 4	48	5.7%
	1 or 2	37	4.4%	1 or 2	17	2.0%
Other[2]	—	47	5.5%	—	83	9.9%
Total	—	850	100.0%	—	840	100.0%

Note: [1]For the level of certainty, 5 = certain and 1 = guessing.
[2]The other category includes color choices of either, other, not sure, or don't know. It also includes responses of white or yellow without an associated certainty.

the subjects are certain that a white line would divide opposing traffic on a two-way road while 4 percent are certain that a yellow line would divide two lanes of traffic traveling in the same direction. Another interesting interpretation of these results is that the percentage choosing the correct response increases as the certainty of the response increases.

Comparisons Across Questions

The researchers developed the survey so that comparisons could be made between questions that addressed similar marking patterns or colors. Table 37 summarizes the questions that addressed similar issues. Table 38 presents a comparison of the results for these questions. The following paragraphs compare some of the differences between the various questions.

Directional Message

Six questions addressed broken lines. Five of them related to a single broken line and one was a double broken line. When the broken centerline was yellow, about 70 percent of subjects correctly identified it as two-way. When asked the color of a lane line on a one-way street, 79 percent correctly picked white. But when shown a two-lane road with a white lane line marking, only 18 percent identified it as a one-way road, while 50 percent identified it as a two-way road. A comparison of the direction message results for the single broken line questions (Questions 4, 9, and 13) indicates variations in the response patterns. Respondents are approximately 2.4 times more likely to interpret the markings as indicating a two-way road if they are yellow–white as opposed to black (74 percent vs. 30 percent), and nearly 1.5 times as likely if they are yellow–white as opposed to all-white (74 percent vs. 50 percent). Likelihood-ratio chi-square tests bear out these findings, with a highly significant difference ($p < 0.0001$) in the pattern of responses across these questions. The results of these questions suggest that respondents rely upon color to determine the direction of traffic on a two-lane road. The difference in the pattern of responses between the black marking and all-white marking questions provokes a question as to whether the type of image presented in the questions had an effect on the response patterns.

Five questions addressed solid lines. About 50 percent identified a single solid line, irrespective of whether it was white

TABLE 37 Questions on color and pattern

Questions Addressing Pattern and Color Combinations			Color		
			Yellow	White	Black
Pattern	Single	Broken	#2, #9	#3, #13	#4
		Solid		#16	#6
	Double	Broken		#17	
		Passing Prohibited	#11		#5
		Passing Permitted	#12	#15	
		Solid	#10	#14	#7

Note: The following questions were not comparable to any others: 1, 8.

TABLE 38 Results comparison

Pattern	Line	Question	Directional Message	Passing Message
Broken	Single Yellow	2	70% - yellow for color of centerline	N/A
		9	74% - two-way	93% - permitted
	Single White	3	79% - white for color of lane line	N/A
		13	18% - one-way 50% - two-way* 31% - either one- or two-way	93% - permitted
	Single Black	4	11% - one-way 30% - two-way 58% - either one- or two-way*	94% - permitted
	Double White	17	16% - one-way 64% - two-way* 14% - either one- or two-way	84% - permitted
Solid	Single Black	6	23% - one-way 47% - two-way* 20% - either one- or two-way	79% - prohibited
	Single Wide White	16	21% - one-way 51% - two-way* 20% - either one- or two-way	81% - prohibited
	Double Yellow	10	88% - two-way	97% - prohibited
	Double White	14	79% - two-way	93% - prohibited
	Double Black	7	80% - two-way	93% - prohibited
Solid and Broken	Yellow Passing Prohibited	11	87% - two-way	92% - prohibited
	Black Passing Prohibited	5	82% - two-way	93% - prohibited
	Yellow Passing Permitted	12	87% - two-way	83% - permitted
	White Passing Permitted	15	82% - two-way	83% - permitted

*Indicates correct or desired correct response when more than response is given. If only one response is listed, it is the correct response.
Black lines were intended to address message conveyed by pattern only.
All responses were provided if there was not a single response of 70 percent or more.
Table 27 indicates the stripe and gap lengths associated with the all-white marking questions.

or black, as a two-way road, but about 22 percent identified it as a one-way road. The double solid line was associated with two-way traffic, with responses between 79 and 88 percent, regardless of color. A comparison of the results for the solid single black line and solid single wide white line (Questions 6 and 16, respectively) indicates no large differences in the pattern of responses and a likelihood ratio chi-square test indicated no significance differences in the responses. The pattern of responses to the solid double line questions (Questions 7, 10, and 14) indicates that respondents' interpretations differ, depending on whether one-color markings (black or white, Questions 7 and 14, respectively) or yellow–white markings (Question 10) are used. The use of yellow in the double solid line increases the correct response rate (88 percent for yellow, compared to 79 and 80 percent for white and black, respectively). A likelihood-ratio chi-squared test indicates this is a highly significant difference in the response patterns for the directional aspect of the question.

Four questions addressed the solid and broken line where passing is permitted in one direction and prohibited in the other. These double line markings were associated with two-way traffic, with response levels between 82 and 87 percent. The relationship between the solid line and the direction of travel did not appear to influence the results. The likelihood-ratio chi-square tests of statistical significance indicate weak significance or no significance in the direction aspects responses to the various solid-broken combination lines. This would seem to indicate that for this particular marking pattern, the choice of color for the marking has relatively little effect on respondents' interpretation of that marking.

Table 39 presents sorted results for the directional message of the markings evaluated in the survey. Overall, the results indicate that double lines and solid lines had the higher comprehension levels. All of the markings consisting of two lines, with at least one of them being a solid line, had comprehension levels of 79 percent or higher. When these

TABLE 39 Sorted results for directional message

Sorted by Direction, then Percent				Sorted by Percent			
Marking	**No.**	**%**	**Direction**	**Marking**	**No.**	**%z**	**Direction**
Double Solid Yellow	10	88	two-way	Double Solid Yellow	10	88	two-way
Yellow Passing Prohibited	11	87	two-way	Yellow Passing Prohibited	11	87	two-way
Yellow Passing Permitted	12	87	two-way	Yellow Passing Permitted	12	87	two-way
Black Passing Prohibited	5	82	two-way	Black Passing Prohibited	5	82	two-way
White Passing Permitted	15	82	two-way	White Passing Permitted	15	82	two-way
Double Solid Black	7	80	two-way	Double Solid Black	7	80	two-way
Double Solid White	14	79	two-way	Single Broken White	3	79	one-way
Single Broken Yellow	9	74	two-way	Double Solid White	14	79	two-way
Single Broken Yellow	2	70	two-way	Single Broken Yellow	9	74	two-way
Double Broken White	17*	64	two-way	Single Broken Yellow	2	70	two-way
Single Solid Wide White	16*	51	two-way	Double Broken White	17*	64	two-way
Single Broken White	13*	50	two-way	Single Broken Black	4*	58	either
Single Solid Black	6*	47	two-way	Single Solid Wide White	16*	51	two-way
Single Broken Black	4x	30	two-way	Single Broken White	13*	50	two-way
Single Broken White	3	79	one-way	Single Solid Black	6*	47	two-way
Single Solid Black	6x	23	one-way	Single Broken White	13x	31	either
Single Solid Wide White	16x	21	one-way	Single Broken Black	4x	30	two-way
Single Broken White	13x	18	one-way	Single Solid Black	6x	23	one-way
Double Broken White	17x	16	one-way	Single Solid Wide White	16x	21	one-way
Single Broken Black	4x	11	one-way	Single Solid Black	6x	20	either
Single Broken Black	4*	58	either	Single Solid Wide White	16x	20	either
Single Broken White	13x	31	either	Single Broken White	13x	18	one-way
Single Solid Black	6x	20	either	Double Broken White	17x	16	one-way
Single Solid Wide White	16x	20	either	Double Broken White	17x	14	either
Double Broken White	17x	14	either	Single Broken Black	4x	11	one-way

Notes:
* indicates correct or desired correct response when more than one response per question is presented.
x indicates incorrect or desired incorrect response when more than one response per question is presented.

double lines were yellow, comprehension levels were over 87 percent. The double yellow markings had the highest comprehension levels of any of those evaluated, with respect to the directional message.

The results for the single lines indicate that yellow was the only marking that indicated two-way traffic at a comprehension level of 70 percent or more. The one-way directional message was not addressed in detail in the survey. The one question that did assess the issue (Question 3) found that 79 percent were able to correctly identify the color of the marking as white.

The survey included several questions on all-white pavement markings in order to assess whether respondents attached an inherent meaning to specific all-white marking patterns. Five marking patterns were presented:

- Single 4-in. broken line with a 10-ft stripe and a 10-ft gap,
- Single 8-in. solid line,
- Double 4-in. solid lines,
- Double 4-in. broken lines, and
- Double lines with one 4-in. solid line and one 4-in. broken line with 20-ft stripe and 20-ft gap.

The highest comprehension level of these all-white marking patterns was the 82 percent associated with the double solid and broken line (passing permitted). The double solid line was correctly interpreted by 79 percent, and the double broken line was correctly interpreted by 64 percent. The double solid white interpretation was 8 percent lower than the double solid yellow. The double solid broken line appears to be a better all-white pattern for indicating two-way traffic

TABLE 40 Sorted results for passing message

Sorted by Action then Percent				Sorted by Percent			
Marking	**Q**	**%**	**Action**	**Marking**	**Q**	**%**	**Action**
Double Solid Yellow	10	97	prohibited	Double Solid Yellow	10	97	prohibited
Double Solid White	14	93	prohibited	Single Broken Black	4	94	permitted
Double Solid Black	7	93	prohibited	Double Solid White	14	93	prohibited
Black Passing Prohibited	5	93	prohibited	Double Solid Black	7	93	prohibited
Yellow Passing Prohibited	11	92	prohibited	Black Passing Prohibited	5	93	prohibited
Single Solid Wide White	16	81	prohibited	Single Broken Yellow	9	93	permitted
Single Solid Black	6	79	prohibited	Single Broken White	13	93	permitted
Single Broken Black	4	94	permitted	Yellow Passing Prohibited	11	92	prohibited
Single Broken Yellow	9	93	permitted	Double Broken White	17	84	permitted
Single Broken White	13	93	permitted	Yellow Passing Permitted	12	83	permitted
Double Broken White	17	84	permitted	White Passing Permitted	15	83	permitted
Yellow Passing Permitted	12	83	permitted	Single Solid Wide White	16	81	prohibited
White Passing Permitted	15	83	permitted	Single Solid Black	6	79	prohibited

Note: All responses are correct responses.

than a single broken line (64 percent vs. 50 percent, respectively). This indicates that if an all-white pavement marking system is implemented, a double line system might be the most effective means of indicating opposing traffic.

These results indicate that yellow has an important role in conveying the directional message of pavement markings. The results also indicate that there is no inherent benefit to converting to an all-white marking system from the standpoint of conveying the directional message of the road.

Passing Message

The other message evaluated in the survey was the ability to pass a vehicle (on a two-way road) or to change lanes (on a one-way road). The results for the passing message indicated a higher level of understanding compared to the directional message. As shown in Table 40, all of the responses varied between 79 and 97 percent.

For single broken lines, the correct response rate varied between 93 and 94 percent (passing permitted for all lines). Color seemed to have little impact on the interpretation of the message. The double solid line pattern had correct response rates (passing prohibited) of 93 and 97 percent. Again, color had little impact in interpretation. Both solid and broken double line combinations (passing permitted) had a correct response rate of 83 percent. The solid and broken double line combination (passing prohibited) had correct response rates of 92 and 93 percent. Within a given message (prohibited or permitted), color had little impact.

The white double broken line was correctly interpreted by 84 percent, indicating some inherent meaning to this all-white marking. However, the single solid wide white line was interpreted correctly by 81 percent, which is about the same as the solid black line.

In general, the passing restriction message of these markings seems to be well understood by the survey subjects.

CHAPTER **3**

DRIVER UNDERSTANDING

As with any part of the traffic control device system, there are many factors that affect the effectiveness of a pavement marking. Certainly, visibility of a pavement marking is one of those factors. However, seeing a marking is only the first step; drivers must also know the meaning of pavement markings or the meaning must be inherently understandable in order to function at an optimal level. In fact, a study of traffic sign symbols suggested that comprehension, or understanding, is the most important criteria in the overall effectiveness of a traffic sign (*8*). Therefore, a critical element in assessing the potential impacts of implementing an all-white pavement marking system is to determine driver comprehension of the current yellow–white pavement marking system in the United States and compare that to potential driver understanding of an all-white system.

As originally proposed, this research project intended to rely upon previous research to assess driver understanding of pavement markings and the potential effectiveness of various all-white pavement markings. However, although that review did identify previous research on driver understanding of pavement markings, much of it was too old or did not address the specific issues of color understanding. Therefore, the research was modified to conduct an extensive evaluation of driver understanding of:

- the current yellow–white pavement marking system, including:
  - understanding of the direction message conveyed by yellow and white and
  - understanding of the passing restrictions conveyed by marking patterns,
- the potential effectiveness of an all-white pavement marking system, including:
  - directional messages and
  - passing restrictions,
- identification of potential enhancements that could be implemented to improve yellow–white or all-white pavement marking systems, and
- drivers' opinions of pavement marking issues, including the potential conversion to an all-white pavement marking system.

This chapter summarizes the findings from the two efforts in this area: (1) evaluation of previous research on understanding of pavement markings and (2) evaluation (through a survey) of current drivers' understanding of pavement markings.

PREVIOUS RESEARCH

Early in this study, the researchers evaluated previous research on driver understanding of pavement markings. The researchers identified 10 major studies in the last 35 years that evaluated various aspects of the extent to which drivers understand pavement markings. The results of the analysis were presented in the interim report and are included in this report as Appendix B.

The effort identified a limited number of previous studies on driver understanding of pavement markings, particularly with respect to the system-type issues. The system perspective of comprehension information was needed for this study in order to assess various elements of the yellow–white system and the identification of potential alternatives for an all-white pavement marking system. Furthermore, many of the studies that were identified were conducted in the 1970s, when the exclusive use of yellow for separating opposing traffic was relatively new. As such, data from those studies could not be generalized to represent understanding of the system today, which has been in use for 30 years. The ultimate result of the review was the finding that there is not an adequate body of recent information to determine the extent to which drivers understand the yellow–white marking code. Also, there was no information on the potential understanding of various alterative schemes for an all-white pavement marking system.

One of the most significant challenges of evaluating previous research efforts was the limited focus of many of these studies. Typically, one or two questions might be asked about pavement markings as part of a larger effort on traffic control devices or other issues. Most of the questions focused on no-passing messages of markings and did not address the meaning of pavement marking color. Another significant challenge in using various studies to make pavement marking system comparisons were the differences in evaluation techniques between studies. Differences in evaluation techniques, subject samples, and the year of evaluation can lead to differences in evaluation results. For example, the studies

that used in-context or simulated real world images of the pavement markings generally had higher levels of comprehension. The higher levels were attributed to contextual clues found in the driving environment.

Table 13 presents a generalized summary of the findings relative to understanding of a broken yellow centerline and a broken white lane line. In this table, the research studies have been arranged in chronological order. However, these results should not be compared directly with one another. Many of these research studies found that drivers who had attended driver education classes had better overall comprehension of pavement markings. Instead of directly comparing results, these findings should be used to gain a general appreciation of the extent to which drivers understand the pavement marking system.

In general, the previous research evaluated as part of the all-white marking evaluation found that significant portions of drivers do not have an inherent understanding of the color meanings associated with the yellow–white pavement marking system. The following information presents some of the researchers' conclusions about the yellow marking color as presented in eight of the 11 studies described in this chapter.

- **Evaluations for the 1971 *MUTCD***: "*Respondents are able to interpret the intended meanings of the form of road markings, but, on the basis of the examples given in this questionnaire at least, they do not apprehend the proposed meanings for colors*" (*10*).
- **Evaluations of the marking code**: "*The research findings indicate that, in fact, color coding of traffic is not "getting across" to the driver. Many respondents, in defining the markings, thought that white lines are intended to show counter traffic movement. Moreover, most drivers did not even recognize that color does communicate traffic movement. . . . Yellow should not be universally used to mark the center of two-way roads. White center markings are preferable. Yellow paint is toxic, it represents a visibility handicap under adverse weather conditions, and it is more expensive than white paint. . . . The research findings bring into question the use of yellow markings to show the separation of counter-moving traffic*" (*11*).
- **AAA 1979 Evaluation**: "*The greatest weakness in motorists' perception of traffic controls was in the area of pavement markings*" (*12*).

TABLE 13 Generalized summary of previous research findings

Study	Year	First Author	Reference	Directional Message Associated with Color Correct Response Rate (percent)	
				Yellow Centerline	White Lane Line
Ohio	1967	Taylor	9	67[1]/89[2]	
Evaluations for 1971 MUTCD	1972	Dietrich	10	29	6
Evaluations of Marking Code	1976	Gordon	11	70	59
First AAA	1979	Hulbert	12	n/a	
Second AAA	1980	Hulbert	13	n/a	
Second TTI	1981	Womack	14	87[3]	47[3]
				53[4]	45[4]
Wisconsin	1993	Palit	15	69	57
Kansas	1995	Stokes	16	88	52
Third TTI	1995	Hawkins	17	77	50
				NE	79
TTI Border	1999	Hawkins	18	72[3]	52[5]
				83[4]	48[6]

Notes: [1]Results from random-order presentation for complete marking system.
[2]Results from system-order presentation for complete marking system.
[3]Results for multiple-choice evaluation.
[4]Results rate for open-ended evaluation.
[5]Drivers from Mexico.
[6]Drivers from Texas border area.
NE=not evaluated.

- **Ohio Evaluation**: "*Significant results were found in many of the studies which indicated that pavement marking systems could be devised to convey meaningful information to the driver. . . . Also, the use of color appears to have greater potential in the long run than the use of line shape*" (*9*).
- **Wisconsin Evaluation**: "*These results suggest the need for an educational program for the general public on the meaning of the pavement markings*" (*15*).
- **TTI 1981 Evaluation**: "*In general, survey respondents indicated a lack of understanding of the meaning of the road marking code system. . . . Respondents showed little understanding of the difference between yellow and white in defining directions of travel. Additionally, although a reasonably good understanding of markings that do not permit passing was found, there was some indication that the premise drivers use was the color yellow, rather than solid versus dashed markings*" (*14*).
- **TTI 1995 Evaluation**: The researchers identified several devices where increased emphasis in driver training classes is needed. Among the recommendations was one to "*Emphasize the difference between yellow and white markings and the restrictions indicated by different marking patterns*" (*17*).
- **TTI 1999 Border Area Evaluation**: Researchers recommended several devices for emphasis in driver education: Among the recommendations was one to emphasize the "*difference between yellow and white markings*" (*18*).

Several major conclusions can be drawn from the findings of the review of previous research. They include the following:

- There is a lack of thorough research on driver understanding of pavement markings.
- In the 1970s, when exclusive use of yellow as a centerline was relatively new, research indicated that significant proportions of the driving population did not distinguish the different meaning between yellow and white lines of the same shape.
- The previous research supports the claim that the yellow–white system could be changed because drivers do not have a high degree of familiarity and understanding with it.
- Drivers are not thoroughly familiar with the meaning of yellow within the pavement marking system, but specific issues of understanding color are not adequately addressed in previous research.

The information on previous comprehension research was presented to the panel early in the research project. After reviewing this and other information, the panel agreed that the project should include an evaluation of current driver understanding of the U.S. pavement marking system. Therefore, the project was modified to devote a significant effort to this issue, including driver understanding of potential all-white pavement marking patterns. Driver understanding of yellow–white and all-white markings were assessed through a driver survey that was administered to 851 drivers at 7 general locations in the United States.

SURVEY DEVELOPMENT

The survey was developed over a series of several months. The researchers established the initial content and format for the survey, then proceeded to administer the survey in a pilot effort. Through pilot testing, the researchers found that the format of the initial survey had numerous shortcomings and the content was too long. This led to an overhaul of the survey format and content. The survey was revised and evaluated in a second pilot effort, which determined that the revised survey was effective.

Initial Survey Development

In developing the initial survey, the researchers attempted to address all of the understanding issues that needed to be answered and to present the information to survey participants in a manner that represented a real-world condition to the greatest extent possible.

Content

In developing the initial survey, the researchers identified numerous items that they felt should be addressed in the evaluation. These included:

- Drivers' ability to describe the pavement marking color code,
- Drivers' reliance on pavement marking color when interpreting marking messages,
- Drivers' reliance on pavement marking patterns when interpreting marking messages,
- Drivers' ability to discern subtle differences in pavement marking patterns,
- Drivers' understanding of the current yellow–white pavement marking system,
- Drivers' potential understanding of various alternatives for an all-white pavement marking system,
- The ability to increase understanding of yellow–white or all-white markings through minor enhancements, and
- Drivers' opinion and input on pavement marking issues.

The initial survey consisted of 55 questions, which could be divided into the following categories:

- Basic understanding of the pavement marking code and driver reliance on the code (5 questions),

- Pavement marking patterns without color (10 questions on 6 different marking patterns),
- Current yellow–white pavement markings (8 questions on 4 different marking patterns),
- Potential alternatives for all-white pavement markings (28 questions on 14 different marking patterns),
- Enhancements to the pavement marking system (2 questions), and
- General comments (2 questions).

Static graphic images were used for all questions except those addressing the yellow–white and all-white markings. Video clips were used for the 36 questions on yellow–white and all-white markings. The video clips were deemed to be necessary for two reasons: (1) the desire to present as realistic a scenario as possible and (2) the desire to evaluate different stripe and gap patterns for the all-white markings. TTI staff filmed the video clips on a local highway. The all-white markings were created by overlaying existing yellow markings with strips of white tape mounted on aluminum panels. These patterns were easily changed from one scenario to another. Table 14 presents the different all-white pavement marking patterns that were included in the initial survey as video clips.

As shown in Table 14, a variety of width and stripe/gap lengths for the all-white markings was included because of the dependence on similar patterns in other countries with all-white markings. The researchers wanted to determine if wider markings or different stripe and gap lengths might convey a sense of opposing traffic to drivers. Figure 7 illustrates the appearance of several different stripe/gap patterns. These images were taken from the video clips used in the initial survey.

Format

The initial survey was envisioned as a self-administered survey that would be presented on a laptop computer. The intent was to present a series of photographs, graphic images, and video clips to survey subjects, who would respond through keystrokes on the computer. This survey format was selected because (1) it presented a more realistic view of roadway scenarios than a static image, (2) it allowed more than one survey to be given concurrently by an administrator, and (3) it allowed automated recording of data entries.

The initial survey was created in Visual Basic so that answers would be automatically saved in a database on the computers as respondents viewed the images and responded to questions on the screen. As mentioned, this format allowed for the use of video clips as a part of the survey. Each of the video clips was 3 to 4 s long. The use of video clips enabled the researchers to display varying patterns of line lengths and spacings in a real-time view, simulating the actual driving situation more realistically than with photographs.

Pilot Testing

Once the initial survey had been prepared and approved by the NCHRP panel, the researchers initiated a pilot test to evaluate the effectiveness of the survey instrument. The initial survey was pilot tested with 15 subjects at two locations

TABLE 14 All-white pavement marking patterns included in initial survey

Line Type	Line Width (inches)	Line Length (feet)	Gap Length (feet)	In Revised Survey?
Single Broken	4	10	10	Yes
Single Broken	4	10	30	No
Single Broken	4	20	20	No
Single Broken	8	10	10	No
Single Broken	8	10	30	No
Single Broken	8	20	20	No
Single Solid	8	N/A	N/A	Yes
Double Broken	4	10	10	Yes
Double Broken	4	10	30	No
Double Broken	4	20	20	No
Double Combination (Passing Permitted)	4	10	10	No
Double Combination (Passing Permitted)	4	10	30	No
Double Combination (Passing Permitted)	4	20	20	Yes
Double Solid	4	N/A	N/A	Yes

a. 4-inch line: 10-ft stripe, 10-ft gap

b. 8-inch line: 10-ft stripe, 10-ft gap

c. 4-inch line: 20-ft stripe, 20-ft gap

d. 8-inch line: 20-ft stripe, 20-ft gap

e. 4-inch line: 10-ft stripe, 30-ft gap

f. 8-inch line: 10-ft stripe, 30-ft gap

Figure 7. Comparison of striping patterns.

in the College Station/Bryan area. During the pilot testing, researchers noted that participants were not taking the time to watch the 3- to 4-s video clips. In most cases, they answered almost immediately upon seeing a still image on the screen. It became apparent that participants could not tell the difference between various stripe and gap lengths in the video clips. Figure 7 provides several examples of striping patterns that drivers could not distinguish from one another. Further, the initial pilot tests indicated that the survey was too long and too repetitive. Because participants did not distinguish between the various scenarios, they thought they were being asked to answer the same question repeatedly. The 55 questions in the initial survey took an average of 20 min to complete.

In addition to the problems with perceived repetition and length, there were glitches in the use of the Visual Basic version of the survey. Although the survey worked well on the laptop computer on which it was developed, it did not work properly when installed on other laptop computers. This prevented the survey from being administered on multiple laptops at the same time, reducing the efficiency of the survey administration process. As a result of the negative experience with the initial survey, the researchers determined that the survey should be significantly revised.

Revised Survey Development

The revised survey was created from the initial survey by eliminating some of the questions, converting the video clips to photographs, and creating a paper-based survey format.

Content

In revising the content, the researchers eliminated 12 of the marking scenarios and combined separate questions for many of the other scenarios that were retained in the survey. The result was a survey that consisted of 20 questions. In general, the questions that were eliminated addressed some of the less common marking situations or the wide variety of stripe and gap lengths in the all-white markings. Table 14 indicates which of the all-white markings were included in the revised (and final) survey instrument. The researchers also refined the introductory questions on the pavement marking code and simplified the presentation of multiple questions that were related to a specific scenario. The content of the final survey instrument is presented in Appendix C.

Format

Once the video clips were eliminated and the number of questions was reduced, the researchers determined that a paper-based survey format would be just as effective as the computer-based format. Therefore, the survey was converted to PowerPoint and printed for presentation from a binder. Each screen was printed in color, and each page was inserted in a plastic sleeve. The sleeves were placed in a hard binder, and each surveyor had a copy of this notebook. This change also allowed the surveyors to more easily approach potential participants because the paper version was mobile: the researcher and participant did not have to move to a specific area where a laptop computer was located. Figure 8 illustrates one question from the survey binder as it was used to collect data from the participants.

The revised survey was organized into four general sections:

- Introduction and initial open-ended questions to determine if drivers mentioned pavement markings as some-

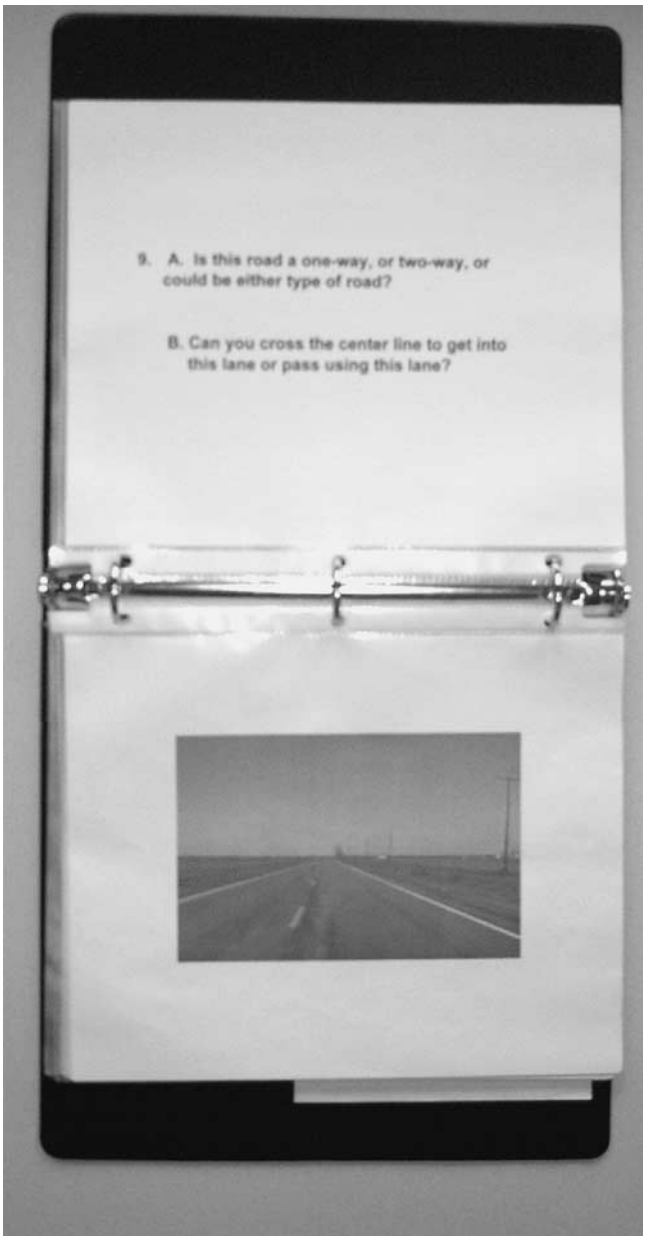


Figure 8. Survey binder.

thing they would look for when deciding which way to go in an unfamiliar situation,
- Scenarios where all pavement markings are shown in black on a gray road to determine driver understanding of patterns,
- Actual photos of road scenarios with pavement markings shown in yellow and white to determine driver understanding of color, and
- Actual photos (originally videos) of all-white pavement markings to determine interpretation of the markings.

These sections were followed by two questions about new arrow patterns and an open-ended question asking for opinions on converting to an all-white pavement system.

Pilot Testing

After developing a revised survey instrument, researchers pilot tested the revised survey instrument. Two pilot tests were conducted in the College Station/Bryan area, with a total of 30 subjects participating in the survey. The experience gained from the first pilot test found that the recorded responses indicated answers to the questions, but not the respondents' confidence in the answer. In many cases, the respondent would make statements such as "I'm not really sure, but I think it is supposed to be yellow, so that's what I'll say." In the survey results, this would be recorded as a correct response even though the respondent did not have any degree of confidence in the answer. Therefore, in the second pilot test, a follow-up question was added to the second and third questions in the survey to assess subjects' certainty of their answers.

The experiences gained from the pilot testing of the revised survey indicated that the survey instrument was effective and that the effort could move forward into the survey administration stage.

SURVEY ADMINISTRATION

The first surveys were conducted in August 2001 in Houston, Texas. In all, surveys were administered in six metropolitan areas in five states around the United States to a total of 851 subjects. Table 15 lists the survey locations and number of surveys completed at each location.

Site Selection

The survey was administered in public places where drivers could be recruited and where a waiting period was typical. The researchers selected driver licensing offices, airports, train stations, and bus stations for survey locations in order to include a wide variety of drivers. The researchers' original plan was to collect survey data in airports. Some data were collected at airports prior to September 11, 2001, but no surveys were administered in airports after this date because of security restrictions. Instead, the researchers used train and bus stations as the primary locations for collecting survey data.

TABLE 15 Survey sites

City and State	Location	Number of Surveys Completed
Atlanta, GA	Hartsfield Airport	5
Atlanta, GA	Greyhound Station	70
Chicago, IL	Amtrak Station	398
Dallas, TX	Amtrak Station	47
Dallas, TX	Greyhound Station	7
Emeryville, CA Oakland, CA San Francisco, CA	Amtrak Stations	65
Houston, TX	Amtrak Station	33
Houston, TX	Driver License Station	69
Houston, TX	George Bush Intercontinental Airport	50
Houston, TX	Greyhound Station	75
Minneapolis, MN	Human Factors & Ergonomic Society Conference	10
Minneapolis, MN	Small Social Settings	14
St. Paul, MN	Amtrak Station	8
Total Number of Surveys		851

The survey was conducted in five geographically diverse areas of the United States: Texas, Illinois, Georgia, California, and Minnesota. The intent was to avoid limiting the results to one region of the country. As the location selection expanded to include more than driver licensing offices, the net result was that the sample included drivers from almost every state and territory of the United States, with larger frequencies from the survey state sites.

Administration

Potential participants were approached and asked if they would be willing to complete a survey about driving that would take approximately 10 min. If the potential participant said no, surveyors thanked them and moved on. If the potential participant said yes, the surveyor positioned the notebook so that the participant could clearly see the images and text after first determining that the participant was a driver. The surveyor began by assuring the respondent that the survey was not a test and would in no way affect the participant's driver license.

The surveyor then read each question aloud, waited for the participant's answer, and recorded each answer on an answer sheet. The surveyor gave the participant a squeezable stress vehicle after they completed the survey in appreciation for their participation.

SURVEY RESULTS

Data from the survey consist of the responses from 851 subjects to various demographic and roadway marking questions. The results presented in this section simply address the frequency and percent responses to each question. A more detailed analysis of the results is presented at the end of this chapter. The analysis is presented according to the major sections of the survey: demographics, basic marking color code, marking patterns, yellow–white markings, all-white markings, and follow-up questions. The response percentages presented herein have a standard error of ±3.5 percent for the reported percentages, based on a sample size of 850 and a 95 percent confidence level.

Demographics

The first five questions in the survey asked the subject for demographic information. In addition to the five questions, the survey administrator recorded the gender and apparent ethnicity of the subject. While gender determination is straightforward, the values recorded for ethnicity may, by not being self-reported, involve an unknown degree of ambiguity. Table 16 presents the results of the demographic analysis. The 851 subjects that participated in the survey represented 47 states, the District of Columbia, and Puerto Rico. Table 17 presents the geographic distribution of the survey respondents.

Basic Marking Color Code

The first three questions of the survey were intended to identify driver understanding of the basic color code of the current yellow–white pavement marking system. All three questions were open-ended and subjects were allowed to give multiple responses. All subject responses were recorded in the order that they were given. All three questions presented the photograph shown in Figure 9. The second and third questions presented the graphics in Figures 10 and 11, respectively, in addition to the graphic shown in Figure 9.

Responses to Question 1 are shown in Table 18. The actual responses to this question were open-ended, and multiple responses were allowed. There were a total of 2,041 responses among the 851 subjects (an average of about 2.4 responses per subject). In tabulating the responses, the individual responses were grouped into eight distinct categories and one catch-all category (Other). Subjects were asked to continue providing answers until they could not think of any other cues to traffic direction. Therefore, Table 18 also indicates the frequency and percentage that each of these responses were given as the first, second, and third response from each subject. Presenting the results in this manner gives an indication of the primary tool that a driver would use to determine whether a street is one-way or two-way.

Table 19 presents a rank order of the responses as a function of several different considerations. This information shows that drivers tend to use signs and other traffic to determine whether a road is one-way or two-way. While drivers rely upon markings in general, they tend to be a secondary consideration if there are other cues available to provide directional information. Only about 10 percent of all the responses specifically mentioned looking at the color of the markings. About one-fourth of the subjects mentioned markings as one of their responses.

In Questions 2 and 3, a graphic was presented along with the photograph (see Figures 10 and 11). The graphic had arrows indicating one- or two-way traffic and black pavement markings. Subjects were asked to indicate the color of the broken line in the center of the street and the degree to which they were certain of their answer. They were also asked to indicate the certainty of their answer, with a 5 indicating they were positive and a 1 indicating they were guessing. Table 20 presents the responses for a two-way street (Question 2) and Table 21 presents the responses for a one-way street (Question 3). A small number of subjects gave a fractional answer (e.g. 3.5, 4.5) as their response on the certainty question. In these cases, the response was rounded down to the nearest integer.

TABLE 16 Demographic results

Survey Data				U.S. Population[1]
Question/Demographic	**Categories**	**Number**	**Percentage**a	
How long have you been driving? (851 responses)	Less than 1 year	21	2.47	N/A
	1 – 5 years	133	15.63	N/A
	6 – 10 years	115	13.51	N/A
	More than 10 years	582	68.39	N/A
Did you take Driver's Education in order to get your driver's license? (849 responses)	Yes	553	65.14	N/A
	No	296	34.86	N/A
What is your age group? (850 responses)	16-19	72	8.47	7.5%[2]
	20-29	218	25.65	17.7%[2]
	30-39	144	16.94	19.9%[2]
	40-49	164	19.29	19.6%[2]
	50-59	149	17.53	14.3%[2]
	60 or above	103	12.12	21.1%[2]
What is the highest grade you completed in school? (849 responses)	Less than high school	55	6.48	24.8%[3]
	High school or GED	180	21.20	30.0%[3]
	Some college or technical school	250	29.45	24.9%[3]
	College graduate	364	42.87	20.3%[3]
Where do you live?	City	See Table 17 for distribution		N/A
	State			
	Zip Code			
Observation of subject gender (838 responses)	Male	455	54.30	49.1%[3]
	Female	383	45.70	50.9%[3]
Observation of subject ethnicity (840 responses)	Anglo	604	71.90	62.6%[4]
	Black	151	17.98	12.3%
	Hispanic	55	6.55	12.5%[4]
	Other	30	3.57	10.2%

Notes: [1]Data based on the 2000 U.S. Census.
[2]Data based on percentage of total driving age population (16 and over).
[3]Data based on total U.S. population.
[4]Census data includes Hispanic with White for reporting purposes. They have been separated in this table.

TABLE 17 Summary of sample distribution by state

State	Number	State	Number	State	Number	State	Number
AK	2	ID	2	MT	11	Puerto Rico	2
AL	11	IL	150	NC	8	SC	5
AR	7	IN	19	ND	3	SD	2
AZ	8	KS	3	NH	2	TN	10
CA	95	KY	5	NJ	8	TX	185
CO	18	LA	11	NM	1	UT	1
CT	3	MA	7	NV	2	VA	12
DC	1	MD	7	NY	16	VT	1
DE	3	ME	2	OH	18	WA	3
FL	31	MI	27	OK	3	WI	29
GA	31	MN	26	OR	7	WV	1
HI	1	MO	16	PA	22		
IA	7	MS	5				

Figure 9. Photo for Questions 1 through 3.

The results of these two questions show that a substantial number of the subjects have an understanding of the use of marking color to differentiate between one- and two-way roads. About 70 percent of the subjects indicated yellow for a two-way street and about 80 percent indicated white for a one-way street. When these responses are combined with those of Question 1, it is apparent that this knowledge is not the primary tool drivers use to distinguish direction of travel on a road.

One other question in the survey addressed the color of pavement markings. Question 8 presented a graphic of a divided highway and asked drivers to indicate the color of the markings for one direction of travel. Figure 12 presents the graphic used for this question and the results are presented in Table 22. The labels identifying the specific lines were not part of the graphic image shown to survey participants. In the actual survey, the administrator would point to the line that the question was asking about.

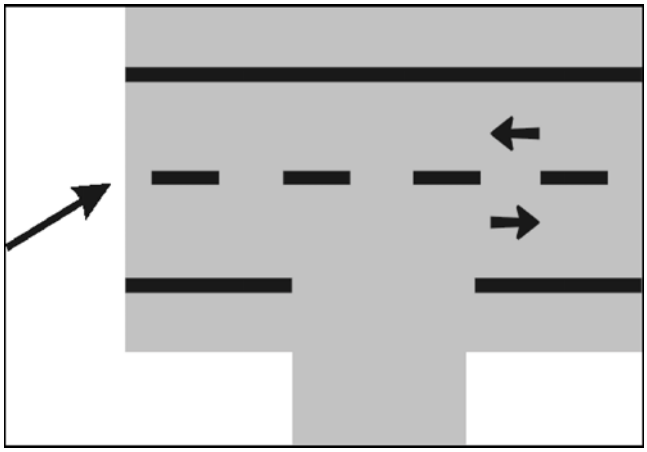


Figure 10. Graphic for Question 2.

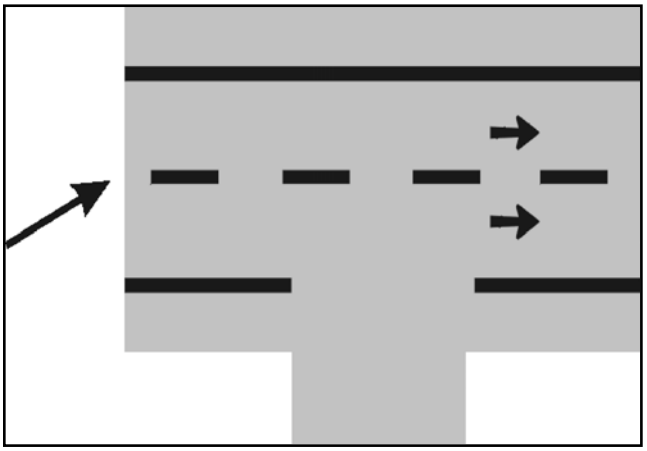


Figure 11. Graphic for Question 3.

While approximately three-fourths of the subjects correctly identified the color of the lane line, these results indicate a significant lack of understanding of the color of edge lines. Only 39 percent correctly identified the color of the left edge line and 66 percent correctly identified the color of the right edge line.

Marking Patterns

Questions 4 through 7 presented graphic images of road scenes where the pavement markings were black. The intent of these questions was to determine if drivers associate specific messages with the marking pattern alone (sans color). Two issues were addressed for each question: direction of traffic (one-way or two-way) and passing/lane changing restrictions. The graphic images presented with each question are shown in Figures 13, 14, 15, and 16.

The first part of each question addressed whether the traffic flow on the road was one-way, two-way, or either. Respondents were also allowed to indicate that they did not know or were not sure. The results for the first part of Questions 4–7 are presented in Table 23.

The second part of Questions 4–7 addressed whether the marking presented a restriction on passing or changing lanes. Respondents answered the questions based on driving the vehicle shown in the graphic image. The results for the second part of Questions 4–7 are presented in Table 24.

The results to the direction of traffic question indicate that drivers tend to associate a solid line with two-way traffic. The broken line question was correctly answered (could be either two-way or one-way) by almost 60 percent of the subjects. Another 30 percent provided the safer response of two-way traffic. The passing prohibited in one direction and the double solid line markings were strongly associated with two-way traffic (82 and 80 percent, respectively). There was no

TABLE 18 Responses to Question 1

Question: How would you know if this is a one-way or a two-way road? What would you look for that would tell you? Is there anything else you would look for? Is that everything?								
Response (open-ended)[1]	**Overall**		**First Response**		**Second Response**		**Third Response**	
	Freq.	**Percent**	**Freq.**	**Percent**	**Freq.**	**Percent**	**Freq.**	**Percent**
Look for a sign	545	26.7	310	36.4	180	23.4	51	13.5
Look for One-Way sign	187	9.2	99	11.6	68	8.8	20	5.3
Look for Do Not Enter sign	34	1.7	8	0.9	13	1.7	10	2.6
Look to see which way signs are facing	17	0.8	5	0.6	6	0.8	3	0.8
Look at direction traffic is moving	504	24.7	104	12.2	228	29.6	160	42.3
Look at the markings	294	14.4	134	15.7	121	15.7	37	9.8
Look at the color of the markings	209	10.2	129	15.2	56	15.2	22	5.8
Look for an arrow	89	4.4	17	2.0	39	5.1	29	7.7
Other	162	7.9	45	5.3	58	7.5	46	12.2
Total	2041	100%	851	100%	769	100%	378	100%

Note: [1]The response categories represent generalized aggregation of the specific responses provided by subjects.

TABLE 19 Rank order of Question 1 responses

Rank Order	**Rank Order By Types of Responses**			
	All Responses (2041)	**First Response (851)**	**Second Response (769)**	**Third Response (378)**
First	Sign	Sign	Direction of traffic	Direction of traffic
Second	Direction of traffic	Markings	Sign	Sign
Third	Markings	Marking Color	Markings	Other
Fourth	Marking Color	Direction of traffic	One-Way sign	Markings
Fifth	One-Way sign	One-Way sign	Other	Arrow

TABLE 20 Responses to Question 2 (two-way street)

Question: If this is a two-way street, what color would this dashed line be?			**Question: How sure you are of your answer?**		
Responses	**Frequency**	**Percent**	**Responses**	**Frequency**	**Percent**
White	214	25.2	1 (Guessing)	21	2.5
Yellow*	591	69.5	2	50	6.0
Either	18	2.1	3	139	16.7
Other	12	1.4	4	152	18.2
Don’t know	8	0.9	5 (Positive)	473	56.7
Not sure	7	0.8	Total	835	100%
Total	850	100%			

Note: *Indicates the correct response.

TABLE 21 Responses to Question 3 (one-way street)

Question: If this is a one-way street, what color would this dashed line be?			Question: How sure you are of your answer?		
Responses	**Frequency**	**Percent**	**Responses**	**Frequency**	**Percent**
White*	665	79.2	1 (Guessing)	31	3.9
Yellow	95	11.3	2	47	5.9
Either	11	1.3	3	151	18.9
Other	24	2.9	4	117	14.6
Don't' know	29	3.5	5 (Positive)	455	56.8
Not sure	16	1.9	Total	801	100%
Total	840	100%			

Note: *Indicates the correct response.

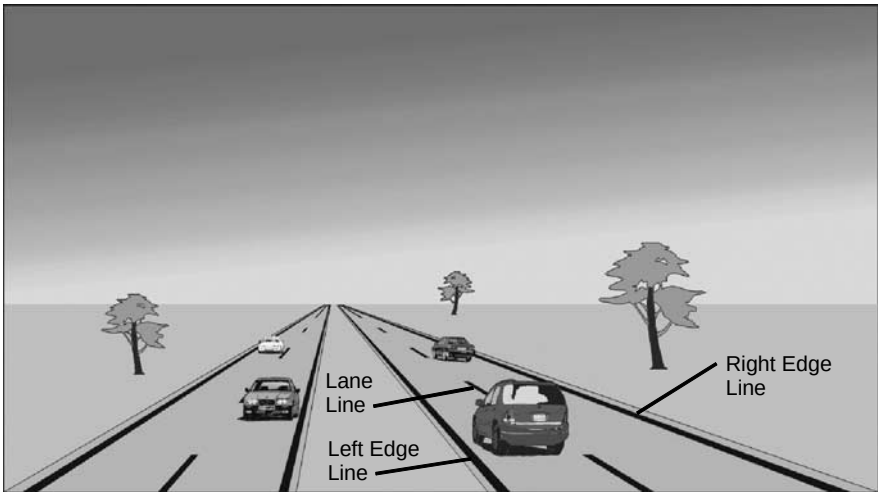


Figure 12. Divided road line color (Question 8).

TABLE 22 Question 8 results

Question: This is a sketch of an interstate highway, showing both the northbound and southbound sections. What color do you think the left edge line would be? What color do you think the lane line would be? What color do you think the right edge line would be?						
Responses	**Left Edge Line**		**Lane Line**		**Right Edge Line**	
	Freq.	**Percent**	**Freq.**	**Percent**	**Freq.**	**Percent**
Yellow	331*	39.0%*	171	20.3%	228	26.9%
White	461	54.3%	642*	76.1%*	555*	65.5%*
Other	26	3.1%	20	2.4%	34	4.0%
Uncertain	31	3.7%	11	1.3%	30	3.5%
Total	849	100%	844	100%	847	100%

Note: *Indicates the correct response.

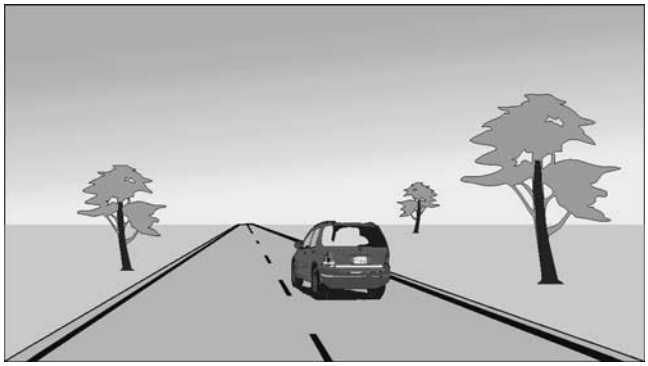


Figure 13. Broken line pattern (Question 4).

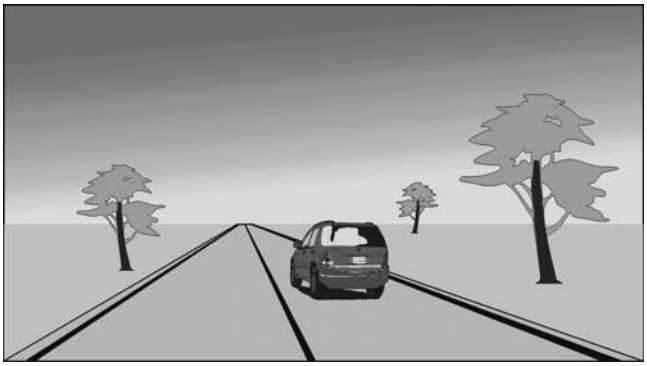


Figure 15. Single solid line pattern (Question 6).

clear consensus on the single solid line, which is not surprising, given that this marking pattern is not used as a centerline or lane line.

The second part of each question addressed the passing restrictions implied by the various marking patterns. Again, subjects associated a definite meaning to the patterns. The two solid lines that drivers normally see (double solid centerline and passing prohibited in one direction) were associated with no-passing by over 90 percent of the subjects. No-passing was also associated with the single solid line, but at a lower percentage (79 percent). Almost 95 percent indicated that passing was permitted with the broken line.

Yellow–White Markings

In the next section of the survey, subjects were presented with actual photographs of road scenes with various yellow–white marking schemes. The intent of these questions was to assess driver understanding of the current yellow–white pavement marking system. As with the marking pattern questions, two issues were addressed for each question: direction of traffic (one-way or two-way) and passing/lane changing restrictions. The graphic images presented with each question are shown in Figures 17, 18, 19, and 20.

The first part of each question addressed whether the traffic flow on the road was one-way, two-way, or could be either. Respondents were also allowed to indicate that they didn't know or were not sure. The results for the first part of Questions 9–12 are presented in Table 25.

The second part of each question addressed whether the marking presented a restriction on passing or changing lanes. The results for the second part of Questions 9–12 are presented in Table 26.

The results for these questions again show that a large percentage of drivers tend to associate the presence of a solid line with two-way traffic and with no passing. The double solid line and the solid and broken line combination (passing prohibited or permitted in one direction) all had correct response rates between 86 and 88 percent for the directional message. When only a broken line was shown, the correct response rate for the directional message dropped to 74 percent, with another 20 percent indicating the road could be either one-way or two-way.

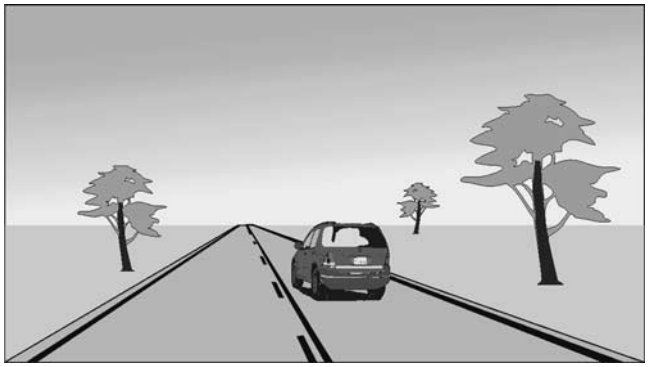


Figure 14. Passing prohibited in one-direction pattern (Question 5).

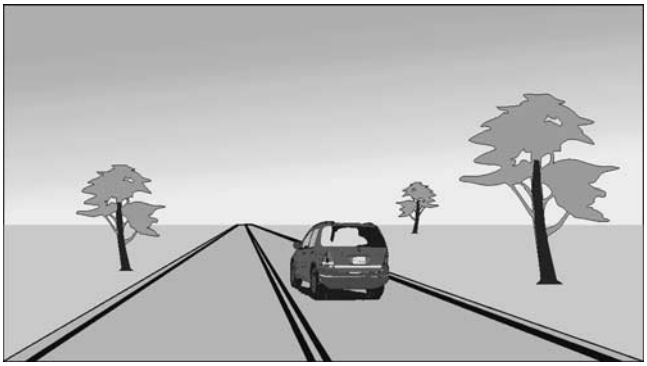


Figure 16. Double solid line pattern (Question 7).

TABLE 23 Results for directional aspect of Questions 4–7

Question: Is traffic on this road two-way, one-way, or could it be either?							
Number	**Marking Pattern**	**Response**					**Number of Missing Responses**
		1-way	**2-way**	**Either**	**Don't Know**	**Not Sure**	
4A (Figure 13)	Single Broken Line	91	258	490*	5	4	3
		10.7%	30.4%	57.8%*	0.6%	0.5%	
5A (Figure 14)	No Passing in One Direction	54	698*	89	3	6	1
		6.4%	82.1%*	10.5%	0.4%	0.7%	
6A (Figure 15)	Single Solid Line	194	378	172	39	47	1
		22.8%	46.8%	20.2%	4.6%	5.5%	
7A (Figure 16)	Double Solid Line	53	672*	91	16	13	6
		6.3%	79.5%*	10.8%	1.9%	1.5%	

Note: *Indicates the correct response.

TABLE 24 Results for passing aspects of Questions 4–7

Question: Can you cross the centerline to get into the left lane or pass using the left lane?						
Number	**Marking Pattern**	**Response**				**Number of Missing Responses**
		Yes	**No**	**Don't Know**	**Not Sure**	
4B (Figure 13)	Single Broken Line	794*	43	3	9	3
		93.5%*	5.1%	0.4%	1.1%	
5B (Figure 14)	No Passing in One Direction	48	793*	2	6	2
		5.7%	93.4%*	0.2%	0.7%	
6B (Figure 15)	Single Solid Line	153	660	17	10	11
		18.2%	78.6%	2.0%	1.2%	
7B (Figure 16)	Double Solid Line	50	786*	6	3	6
		5.9%	93.0%*	0.7%	0.4%	

Note: *Indicates the correct response.

Figure 17. Broken yellow centerline (Question 9).

Figure 18. Double yellow centerline (Question 10).

Figure 19. Yellow passing prohibited in one direction (Question 11).

Figure 20. Yellow passing permitted in one direction (Question 12).

TABLE 25 Results for directional aspect of Questions 9–12

Question: Is traffic on this road two-way, one-way, or could it be either?							
Number	**Marking**	**Response**					**Number of Missing Responses**
		1-way	**2-way**	**Either**	**Don't Know**	**Not Sure**	
9A (Figure 17)	Single Yellow Broken Line	57	626*	159	4	3	2
		6.7%	73.7%*	18.7%	0.50%	0.4%	
10A (Figure 18)	Double Yellow Solid Lines	41	746*	55	4	4	1
		4.8%	87.8%*	6.8%	0.5%	0.5%	
11A (Figure 19)	Passing Prohibited	45	736*	62	5	3	0
		5.3%	86.5%*	7.3%	0.6%	0.4%	
12A (Figure 20)	Passing Permitted	36	735*	71	3	6	0
		4.2%	86.4%*	8.3%	0.4%	0.7%	

Note: *Indicates the correct response.

TABLE 26 Results for passing aspects of Questions 9–12

Question: Can you cross the centerline to get into the left lane or pass using the left lane?						
Number	**Marking**	**Response**				**Number of Missing Responses**
		Yes	**No**	**Don't Know**	**Not Sure**	
9B (Figure 17)	Single Yellow Broken Line	793*	55	2	0	1
		93.3%*	6.5%	0.2%	0%	
10B (Figure 18)	Double Yellow Solid Lines	24	824*	2	0	1
		2.8%	96.9%*	0.2%	0%	
11B (Figure 19)	Passing Prohibited	67	777*	3	2	2
		7.9%	91.5%*	0.4%	0.2%	
12B (Figure 20)	Passing Permitted	699*	139	4	5	4
		82.5%*	16.4%	0.5%	0.6%	

Over 90 percent of the subjects responded that a solid line in their lane indicated a no-passing zone. A broken line alone was interpreted as permitting passing by over 90 percent. However, a broken line with a solid line in the other direction (passing permitted in one direction) had a correct response rate of 83 percent. While still high, these results indicate that a small percentage of drivers (9 percent) associate the solid line with a no-passing message even though the passing restriction applies to traffic in the opposing direction.

All-White Markings

In the fourth section of the survey, subjects were presented with actual photographs of road scenes with various all-white marking schemes. The intent of these questions was to assess how well drivers might understand the directional and passing messages conveyed by various patterns of all-white markings. As with the previous yellow–white questions, two issues were addressed for each question: direction of traffic (one-way or two-way) and passing/lane changing restrictions. The graphic images presented with each question are shown in Figures 21, 22, 23, 24, and 25.

Table 27 presents information on the width and stripe and gap lengths for the all-white markings used in Questions 13–17. The all-white marking scheme was created by placing aluminum covered with white marking tape on an existing roadway so that the white markings covered the existing yellow markings.

The results for the first part (direction of traffic) of Questions 13–17 are presented in Table 28. The results for the second part (passing restrictions) of Questions 13–17 are presented in Table 29. As with the previous questions, respondents were also allowed to indicate that they didn't know or were not sure.

The results for these questions indicate that only the double-line marking patterns with at least one solid line had comprehension levels where over three-fourths of the subjects indicated it was a two-way road. The double broken line had 64 percent indicating a two-way road. Only half of the subjects interpreted the single broken line and the single solid line as a two-way road.

Figure 22. Double white centerline (Question 14).

These results show that the double-line markings did a better job of conveying the two-way message than the single lines. Understanding of the double-broken line was at least 15 percent less than that of the double-line markings that contained at least one solid line. Since the subjects did not seem to attach an inherent meaning to these markings, it appears that implementation of an all-white pavement marking system would require some form of campaign to teach drivers the meaning of the lines.

Follow-Up Questions

Four follow-up questions at the end of the survey addressed various issues associated with all-white pavement markings.

Figure 21. Single broken white line (Question 13).

Figure 23. White passing permitted (Question 15).

Figure 24. Double wide white line (Question 16).

Figure 25. Double broken white line (Question 17).

Questions 18 and 19 presented supplemental marking symbols that are widely used in countries with all-white pavement marking systems to help drivers. Question 20 provided subjects with a chance to comment on all-white markings in general and any other issues they wanted to note.

Question 18 presented a two-lane road with an arrow located within the centerline as shown in Figure 26. This type of marking is used in European countries to indicate the beginning of a no-passing zone. The actual responses given by subjects were divided into general categories for analysis. Table 30 presents the summary of responses for this question.

The responses to the no-passing arrow in the centerline indicate that it has a very low inherent understanding among the survey participants. The low comprehension level might

TABLE 27 Marking dimension for all-white markings

Question	Line Pattern	Line Width (inches)	Stripe Length (feet)	Gap Length (feet)
13 (Figure 21)	Broken Line	4	10	10
14 (Figure 22)	Double Solid Lines	4	Not Applicable	
15 (Figure 23)	Passing Permitted in One Direction	4	20	20
16 (Figure 24)	Single Solid Line	8	Not Applicable	
17 (Figure 25)	Double Broken Lines	4	10	10

TABLE 28 Results for directional aspect of Questions 13–17

Question: Is traffic on this road two-way, one-way, or could it be either?							
Number	Marking	Response					Number of Missing Responses
		1-way	2-way	Either	Don't Know	Not Sure	
13A (Figure 21)	Single Broken White Line	153	424	262	5	5	3
		18.0%	49.9%	30.9%	0.6%	0.6%	
14A (Figure 22)	Double Solid White Lines	59	667	111	4	6	4
		7.0%	78.8%	13.1%	0.5%	0.7%	
15A (Figure 23)	Passing Permitted	47	692	101	5	4	2
		5.5%	81.5%	11.9%	0.6%	0.5%	
16A (Figure 24)	Single Solid Wide White Line	180	435	171	35	27	3
		21.2%	51.3%	20.2%	4.1%	3.2%	
17A (Figure 25)	Double Broken White Lines	134	542	120	29	23	3
		15.8%	63.9%	14.2%	3.4%	2.7%	

TABLE 29 Results for passing aspects of Questions 13–17

Question: Can you cross the centerline to get into the left lane or pass using the left lane?						
Number	Marking	Response				Number of Missing Responses
		Yes	No	Don't Know	Not Sure	
13B (Figure 21)	Single Broken White Line	789	52	5	2	3
		93.0%	6.1%	0.6%	0.2%	
14B (Figure 22)	Double Solid White Lines	52	788	7	2	2
		6.12%	92.8%	0.8%	0.2%	
15B (Figure 23)	Passing Permitted	703	140	5	1	2
		82.8%	16.5%	0.6%	0.1%	
16B (Figure 24)	Single Solid Wide White Line	137	674	21	5	14
		16.4%	80.5%	2.5%	0.6%	
17B (Figure 25)	Double Broken White Lines	701	107	15	17	11
		83.5%	12.7%	1.8%	2.0%	

be attributable to the lack of contextual cues when asking the question or may be due to driver unfamiliarity with this marking. The results indicate that the marking should not be implemented without further evaluation. Use of this marking in other countries indicates that it may have value as a marking symbol and deserves future evaluation.

Question 19 presented directional arrows on a two-lane road as shown in Figure 27. This type of marking is also commonly used in Europe to indicate direction of travel on roadways, particularly at intersections. Responses were categorized into correct and incorrect responses, where a correct response was one where the subject indicated that they needed to move from the left lane to the right lane or to stay in the right lane.

The results of Question 19 indicate a very high level of understanding associated with the directional arrows. Such arrows might have significant value in locations where drivers may be confused as to the direction of traffic flow. (See Table 31.)

Question 20 asked drivers what they thought of converting to an all-white pavement marking system. Responses were categorized into those that support the idea, those that do not, those that are undecided, and those that gave no response. Table 32 presents the summary of responses for this question. The results indicate a strong driver opposition to the concept of an all-white pavement marking system, with only one-fifth of the drivers supporting the concept. While this information may be useful in gauging public response to a change in marking color, the responses should be carefully interpreted. It may not be appropriate to ask random drivers about changing to an all-white pavement marking system. Negative responses may be a normal reaction to any change. Further, they are not likely to know or appreciate the reasons why such a change would be important.

Figure 26. End passing zone arrow (Question 18).

TABLE 30 Summary of Question 18 responses

Question: If you are driving in the left lane, what does this arrow tell you? (Figure 26)		
Response	Frequency	Percent
Merge	297	34.9%
Curve or Turn	142	16.7%
Can't Pass	135	15.9%
Other	129	15.2%
Not Sure	121	14.2%
Exit	24	2.8%
No Answer	3	0.4%
Total	851	100%

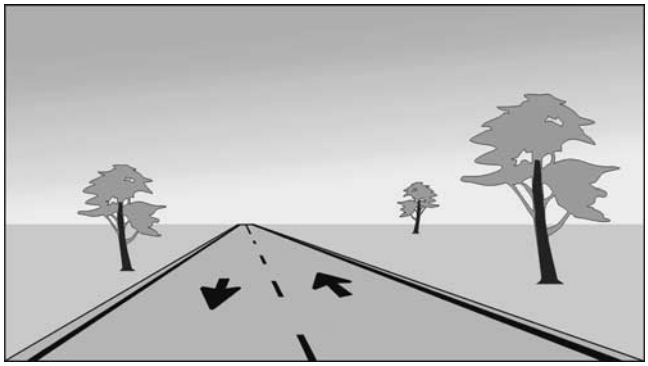


Figure 27. Directional arrows (Question 19).

DETAILED ANALYSIS OF RESULTS

While the previous section presented the basic results for the questions in the survey, this section presents a more detailed analysis of the results.

Associations Between Driver Knowledge and All-White Marking Interpretation

Drivers' comprehension of an all-white pavement marking system may be influenced by their level of understanding of the current yellow–white pavement marking system, in the sense that drivers having greater knowledge of the yellow–white marking scheme may be able to use this knowledge to their advantage when interpreting the meanings of all-white markings. Two types of questions in the survey, the first dealing with black markings (Questions 2 through 8), and the second dealing with the existing yellow–white scheme (Questions 9 though 12), provide a possible opportunity to distinguish between respondent perceptions of marking patterns and their perception of marking colors. The presentation of certain identical marking patterns across three general types of survey questions (black markings, yellow–white markings, and all-white markings) offers further information about the respondent interpretations of the meaning of certain marking patterns.

TABLE 31 Summary of Question 19 responses

Question: If you are driving in the right lane, what does this arrow tell you? (Figure 27)		
Response	**Frequency**	**Percent**
Correct	795	93.4%
Questionable	19	2.2%
Wrong	29	3.4%
No Answer	8	0.9%

TABLE 32 Summary of Question 20 responses

Question: What do you think of the idea of the U.S. using only white lines on the pavement?		
Response	**Frequency**	**Percent**
Support	172	20.2%
Don't support	487	57.2%
Undecided	186	21.9%
No Response	6	0.7%
Total	851	100%

Scoring Survey Responses

The tabulation of scored responses, or the total number of responses corresponding to an identifiably "correct" choice, is an aggregate measure that is helpful for more compact presentation of the data. This measure is especially applicable when one is interested in some general measure of knowledge, as the number of correct answers is presumably correlated with the level of a respondent's knowledge. Nineteen questions in the survey were judged to have identifiably correct or desired responses, based on the information contained in the *MUTCD* or in the proposed all-white schemes developed by the researchers. These survey questions and their corresponding "correct" responses are shown in Table 33. The direction and passing color aspects were considered to be separate questions for purpose of this analysis.

For the purposes of scoring, any response not corresponding to the correct response was judged incorrect, including missing values. The rationale behind the inclusion of missing values as incorrect responses is the assumed tendency of subjects to not answer questions they do not know the answer to or the tendency of the interviewer to forgo a survey question the respondent finds difficult in order to maintain the flow of the interview and maintain respondent interest.

Three summary measures for each respondent were tabulated:

- SCRBLK, the total number of correct answers for black-marking questions (Questions 2A, 3A, 4A, 4B, 5A, 5B, 7A, 7B, 8A, 8B, and 8C); and
- SCRYW, the total number of correct answers for the yellow–white marking questions (Questions 9A, 9B, 10A, 10B, 11A, 11B, 12A, and 12B).
- SCRBYW, the total number of correct answers for each respondent for the black-marking and yellow–white marking questions (does not include the all-white questions);

Likelihood-ratio chi-square tests were conducted to determine associations between scores and the responses to all-white marking questions. Since the all-white marking responses are nominal categorical variables, and because some

TABLE 33 Questions with an identifiably correct answer

Question	Issue	Issue	Correct Response	Count	Percent
2A	Line color	Two-way centerline	Yellow	591	69.5%
3A	Line color	One-way lane line	White	665	78.1%
4A	Direction	Black single broken line	Either	490	57.5%
4B	Passing		Yes	794	93.3%
5A	Direction	Black broken and solid line - passing prohibited	2-way	698	82.0%
5B	Passing		No	793	93.2%
7A	Direction	Black double solid lines	2-way	672	79.0%
7B	Passing		No	786	92.9%
8A	Line color	Left edge line	Yellow	331	38.9%
8B	Line color	Lane line	White	642	75.4%
8C	Line color	Right edge line	White	555	65.2%
9A	Direction	Yellow single broken line	2-way	626	73.6%
9B	Passing		Yes	793	93.2%
10A	Direction	Yellow double solid lines	2-way	746	87.7%
10B	Passing		No	824	96.8%
11A	Direction	Yellow broken and solid line - passing prohibited	2-way	736	86.5%
11B	Passing		No	777	91.3%
12A	Direction	Yellow broken and solid line - passing permitted	2-way	735	86.4%
12B	Passing		Yes	699	82.1%

Note: Question 6 not included in the list of questions with identifiably correct answers.

values of the scores occur relatively infrequently, the values of the various score variables necessarily had to be grouped into categories to accommodate subsequent chi-squared tests. For black-marking scores (SCRBLK) and yellow–white marking scores (SCRYW), this resulted in the few lowest-valued and highest-valued scores being aggregated. The total number of black and yellow–white correct answers (SCRBYW) had a larger number of values as well as low frequencies of lower-valued scores; these scores were therefore grouped into approximate quintiles. Table 34 shows the distributions of the categorized scores. For example, 176 subjects (21 percent of the sample) answered 8 of the 11 black marking questions correctly. These scores themselves are then used to assess the relationship between understanding of current marking patterns and colors and understanding of potential all-white pavement marking systems.

Chi-Square Tests for Association

Likelihood-ratio chi-square tests were conducted to ascertain associations between the various scores and the responses to white-marking questions. For these tests, non-committal responses to the all-white marking questions were excluded, as these responses were sparsely occurring and hence could compromise the tests. With few exceptions, the tests indicated highly significant evidence (p-values less than 0.01) for association between scores on the black and yellow–white questions and the all-white marking questions. Table 35 presents the test results.

Association Between Demographic Variables and Survey Responses

With the exception of driver experience, all demographic variables had highly significant relationships with the number of black- and yellow–white markings correctly answered. The likelihood-ratio chi-square test indicates that driver experience was not judged to influence total scores. Nor was age seen to influence scores except for respondents over 50 years of age. Respondents 50 years and older were less likely to achieve the highest scores compared to younger respondents, and were more likely to have the lowest scores. In particular, respondents older than 59 years had the greatest percentage of lower than average scores and the lowest percentage of higher than average scores.

Respondents who have taken a driver education course were less likely to have the lowest scores than those who have not taken the course, while also being more likely to have the highest scores. Increasing education level was clearly associated

TABLE 34 Distributions of categorized scores

Score	Number of Questions Answered Correctly by a Subject	Frequency	Percent
Black Marking (SCRBLK)	<7	122	14.3%
	7	137	16.1%
	8	176	20.7%
	9	221	26.0%
	10 or 11	195	22.9%
Yellow-White Marking (SCRYW)	<6	49	15.0%
	6	94	11.1%
	7	180	21.2%
	8	449	52.8%
Total for Black and Yellow-White Markings (SCRBYW)	<14	196	23.0%
	14 or 15	190	22.3%
	16	146	17.2%
	17	163	19.2%
	>17	156	18.3%

with increasing scores; better educated respondents were more likely to have higher scores and less likely to have lower scores.

Comparisons for Certainty

The second and third questions of the survey presented subjects with a photograph and graphic image of a two-lane road. The road was identified as a two-way or one-way road and the subjects were asked to indicate the correct color of the line between the lanes. They were then asked to indicate how confident they were with their answer (a response of 5 indicating that they were positive of their answer). Table 36 presents the relationships between the yellow or white color choices and the certainty of the answer. The certainty categories have been aggregated into three new categories, with responses of 3 or 4 combined together and responses of 1 or 2 combined together. This aggregation is motivated by the relative paucity of responses in the lower-rating categories. For the two-way and one-way road scenarios, the percentages of subjects who were positive of their responses were 43 and 48 percent respectively for the correct response. In comparison, the percentage of subjects who were positive of their response when, in fact, it was wrong is 11 percent for the two-way road and 4 percent for the one-way road. This indicates that about 10 percent of

TABLE 35 Tests for association between scores and white-marking responses

Question	Issue	Marking	SCRBLK		SCRYW		SCRBYW	
			Statistic	P-value	Statistic	P-value	Statistic	P-value
13A	Direction	White single broken line	17.5894	0.0245	66.7183	<0.0001	35.0582	<0.0001
13B	Passing		12.3390	0.0150	22.6249	<0.0001	16.0271	<0.0001
14A	Direction	White double solid lines	50.4398	<0.0001	102.8719	<0.0001	97.7704	<0.0001
14B	Passing		33.1549	<0.0001	25.4472	<0.0001	36.1400	<0.0001
15A	Direction	White broken and solid line - passing permitted	64.3913	<0.0001	197.6098	<0.0001	157.4057	<0.0001
15B	Passing		42.9155	<0.0001	152.4541	<0.0001	107.0930	<0.0001
16A	Direction	White double wide solid line	28.4341	0.0004	36.4174	<0.0001	35.7738	<0.0001
16B	Passing		54.0615	<0.0001	20.6562	0.0001	50.5396	<0.0001
17A	Direction	White double broken lines	17.2313	0.0278	55.4064	<0.0001	35.3270	<0.0001
17B	Passing		23.2098	0.0001	43.1464	<0.0001	45.4720	<0.0001

TABLE 36 Comparison of certainty

Color Chosen	Question 2 (Yellow Centerline)			Question 3 (White Lane Line)		
	Certainty[1]	Freq.	Percent	Certainty[1]	Freq.	Percent
White	5	95	11.2%	5	405	48.2%
	3 or 4	95	11.2%	3 or 4	203	24.2%
	1 or 2	24	2.8%	1 or 2	54	6.4%
Yellow	5	367	43.2%	5	30	3.6%
	3 or 4	185	21.8%	3 or 4	48	5.7%
	1 or 2	37	4.4%	1 or 2	17	2.0%
Other[2]	—	47	5.5%	—	83	9.9%
Total	—	850	100.0%	—	840	100.0%

Note: [1]For the level of certainty, 5 = certain and 1 = guessing.
[2]The other category includes color choices of either, other, not sure, or don't know. It also includes responses of white or yellow without an associated certainty.

the subjects are certain that a white line would divide opposing traffic on a two-way road while 4 percent are certain that a yellow line would divide two lanes of traffic traveling in the same direction. Another interesting interpretation of these results is that the percentage choosing the correct response increases as the certainty of the response increases.

Comparisons Across Questions

The researchers developed the survey so that comparisons could be made between questions that addressed similar marking patterns or colors. Table 37 summarizes the questions that addressed similar issues. Table 38 presents a comparison of the results for these questions. The following paragraphs compare some of the differences between the various questions.

Directional Message

Six questions addressed broken lines. Five of them related to a single broken line and one was a double broken line. When the broken centerline was yellow, about 70 percent of subjects correctly identified it as two-way. When asked the color of a lane line on a one-way street, 79 percent correctly picked white. But when shown a two-lane road with a white lane line marking, only 18 percent identified it as a one-way road, while 50 percent identified it as a two-way road. A comparison of the direction message results for the single broken line questions (Questions 4, 9, and 13) indicates variations in the response patterns. Respondents are approximately 2.4 times more likely to interpret the markings as indicating a two-way road if they are yellow–white as opposed to black (74 percent vs. 30 percent), and nearly 1.5 times as likely if they are yellow–white as opposed to all-white (74 percent vs. 50 percent). Likelihood-ratio chi-square tests bear out these findings, with a highly significant difference ($p < 0.0001$) in the pattern of responses across these questions. The results of these questions suggest that respondents rely upon color to determine the direction of traffic on a two-lane road. The difference in the pattern of responses between the black marking and all-white marking questions provokes a question as to whether the type of image presented in the questions had an effect on the response patterns.

Five questions addressed solid lines. About 50 percent identified a single solid line, irrespective of whether it was white

TABLE 37 Questions on color and pattern

Questions Addressing Pattern and Color Combinations			Color		
			Yellow	White	Black
Pattern	Single	Broken	#2, #9	#3, #13	#4
		Solid		#16	#6
	Double	Broken		#17	
		Passing Prohibited	#11		#5
		Passing Permitted	#12	#15	
		Solid	#10	#14	#7

Note: The following questions were not comparable to any others: 1, 8.

TABLE 38 Results comparison

Pattern	Line	Question	Directional Message	Passing Message
Broken	Single Yellow	2	70% - yellow for color of centerline	N/A
		9	74% - two-way	93% - permitted
	Single White	3	79% - white for color of lane line	N/A
		13	18% - one-way 50% - two-way* 31% - either one- or two-way	93% - permitted
	Single Black	4	11% - one-way 30% - two-way 58% - either one- or two-way*	94% - permitted
	Double White	17	16% - one-way 64% - two-way* 14% - either one- or two-way	84% - permitted
Solid	Single Black	6	23% - one-way 47% - two-way* 20% - either one- or two-way	79% - prohibited
	Single Wide White	16	21% - one-way 51% - two-way* 20% - either one- or two-way	81% - prohibited
	Double Yellow	10	88% - two-way	97% - prohibited
	Double White	14	79% - two-way	93% - prohibited
	Double Black	7	80% - two-way	93% - prohibited
Solid and Broken	Yellow Passing Prohibited	11	87% - two-way	92% - prohibited
	Black Passing Prohibited	5	82% - two-way	93% - prohibited
	Yellow Passing Permitted	12	87% - two-way	83% - permitted
	White Passing Permitted	15	82% - two-way	83% - permitted

*Indicates correct or desired correct response when more than response is given. If only one response is listed, it is the correct response.
Black lines were intended to address message conveyed by pattern only.
All responses were provided if there was not a single response of 70 percent or more.
Table 27 indicates the stripe and gap lengths associated with the all-white marking questions.

or black, as a two-way road, but about 22 percent identified it as a one-way road. The double solid line was associated with two-way traffic, with responses between 79 and 88 percent, regardless of color. A comparison of the results for the solid single black line and solid single wide white line (Questions 6 and 16, respectively) indicates no large differences in the pattern of responses and a likelihood ratio chi-square test indicated no significance differences in the responses. The pattern of responses to the solid double line questions (Questions 7, 10, and 14) indicates that respondents' interpretations differ, depending on whether one-color markings (black or white, Questions 7 and 14, respectively) or yellow–white markings (Question 10) are used. The use of yellow in the double solid line increases the correct response rate (88 percent for yellow, compared to 79 and 80 percent for white and black, respectively). A likelihood-ratio chi-squared test indicates this is a highly significant difference in the response patterns for the directional aspect of the question.

Four questions addressed the solid and broken line where passing is permitted in one direction and prohibited in the other. These double line markings were associated with two-way traffic, with response levels between 82 and 87 percent. The relationship between the solid line and the direction of travel did not appear to influence the results. The likelihood-ratio chi-square tests of statistical significance indicate weak significance or no significance in the direction aspects responses to the various solid-broken combination lines. This would seem to indicate that for this particular marking pattern, the choice of color for the marking has relatively little effect on respondents' interpretation of that marking.

Table 39 presents sorted results for the directional message of the markings evaluated in the survey. Overall, the results indicate that double lines and solid lines had the higher comprehension levels. All of the markings consisting of two lines, with at least one of them being a solid line, had comprehension levels of 79 percent or higher. When these

TABLE 39 Sorted results for directional message

Sorted by Direction, then Percent				Sorted by Percent			
Marking	**No.**	**%**	**Direction**	**Marking**	**No.**	**%z**	**Direction**
Double Solid Yellow	10	88	two-way	Double Solid Yellow	10	88	two-way
Yellow Passing Prohibited	11	87	two-way	Yellow Passing Prohibited	11	87	two-way
Yellow Passing Permitted	12	87	two-way	Yellow Passing Permitted	12	87	two-way
Black Passing Prohibited	5	82	two-way	Black Passing Prohibited	5	82	two-way
White Passing Permitted	15	82	two-way	White Passing Permitted	15	82	two-way
Double Solid Black	7	80	two-way	Double Solid Black	7	80	two-way
Double Solid White	14	79	two-way	Single Broken White	3	79	one-way
Single Broken Yellow	9	74	two-way	Double Solid White	14	79	two-way
Single Broken Yellow	2	70	two-way	Single Broken Yellow	9	74	two-way
Double Broken White	17*	64	two-way	Single Broken Yellow	2	70	two-way
Single Solid Wide White	16*	51	two-way	Double Broken White	17*	64	two-way
Single Broken White	13*	50	two-way	Single Broken Black	4*	58	either
Single Solid Black	6*	47	two-way	Single Solid Wide White	16*	51	two-way
Single Broken Black	4x	30	two-way	Single Broken White	13*	50	two-way
Single Broken White	3	79	one-way	Single Solid Black	6*	47	two-way
Single Solid Black	6x	23	one-way	Single Broken White	13x	31	either
Single Solid Wide White	16x	21	one-way	Single Broken Black	4x	30	two-way
Single Broken White	13x	18	one-way	Single Solid Black	6x	23	one-way
Double Broken White	17x	16	one-way	Single Solid Wide White	16x	21	one-way
Single Broken Black	4x	11	one-way	Single Solid Black	6x	20	either
Single Broken Black	4*	58	either	Single Solid Wide White	16x	20	either
Single Broken White	13x	31	either	Single Broken White	13x	18	one-way
Single Solid Black	6x	20	either	Double Broken White	17x	16	one-way
Single Solid Wide White	16x	20	either	Double Broken White	17x	14	either
Double Broken White	17x	14	either	Single Broken Black	4x	11	one-way

Notes:
* indicates correct or desired correct response when more than one response per question is presented.
x indicates incorrect or desired incorrect response when more than one response per question is presented.

double lines were yellow, comprehension levels were over 87 percent. The double yellow markings had the highest comprehension levels of any of those evaluated, with respect to the directional message.

The results for the single lines indicate that yellow was the only marking that indicated two-way traffic at a comprehension level of 70 percent or more. The one-way directional message was not addressed in detail in the survey. The one question that did assess the issue (Question 3) found that 79 percent were able to correctly identify the color of the marking as white.

The survey included several questions on all-white pavement markings in order to assess whether respondents attached an inherent meaning to specific all-white marking patterns. Five marking patterns were presented:

- Single 4-in. broken line with a 10-ft stripe and a 10-ft gap,
- Single 8-in. solid line,
- Double 4-in. solid lines,
- Double 4-in. broken lines, and
- Double lines with one 4-in. solid line and one 4-in. broken line with 20-ft stripe and 20-ft gap.

The highest comprehension level of these all-white marking patterns was the 82 percent associated with the double solid and broken line (passing permitted). The double solid line was correctly interpreted by 79 percent, and the double broken line was correctly interpreted by 64 percent. The double solid white interpretation was 8 percent lower than the double solid yellow. The double solid broken line appears to be a better all-white pattern for indicating two-way traffic

TABLE 40 Sorted results for passing message

Sorted by Action then Percent				Sorted by Percent			
Marking	**Q**	**%**	**Action**	**Marking**	**Q**	**%**	**Action**
Double Solid Yellow	10	97	prohibited	Double Solid Yellow	10	97	prohibited
Double Solid White	14	93	prohibited	Single Broken Black	4	94	permitted
Double Solid Black	7	93	prohibited	Double Solid White	14	93	prohibited
Black Passing Prohibited	5	93	prohibited	Double Solid Black	7	93	prohibited
Yellow Passing Prohibited	11	92	prohibited	Black Passing Prohibited	5	93	prohibited
Single Solid Wide White	16	81	prohibited	Single Broken Yellow	9	93	permitted
Single Solid Black	6	79	prohibited	Single Broken White	13	93	permitted
Single Broken Black	4	94	permitted	Yellow Passing Prohibited	11	92	prohibited
Single Broken Yellow	9	93	permitted	Double Broken White	17	84	permitted
Single Broken White	13	93	permitted	Yellow Passing Permitted	12	83	permitted
Double Broken White	17	84	permitted	White Passing Permitted	15	83	permitted
Yellow Passing Permitted	12	83	permitted	Single Solid Wide White	16	81	prohibited
White Passing Permitted	15	83	permitted	Single Solid Black	6	79	prohibited

Note: All responses are correct responses.

than a single broken line (64 percent vs. 50 percent, respectively). This indicates that if an all-white pavement marking system is implemented, a double line system might be the most effective means of indicating opposing traffic.

These results indicate that yellow has an important role in conveying the directional message of pavement markings. The results also indicate that there is no inherent benefit to converting to an all-white marking system from the standpoint of conveying the directional message of the road.

Passing Message

The other message evaluated in the survey was the ability to pass a vehicle (on a two-way road) or to change lanes (on a one-way road). The results for the passing message indicated a higher level of understanding compared to the directional message. As shown in Table 40, all of the responses varied between 79 and 97 percent.

For single broken lines, the correct response rate varied between 93 and 94 percent (passing permitted for all lines). Color seemed to have little impact on the interpretation of the message. The double solid line pattern had correct response rates (passing prohibited) of 93 and 97 percent. Again, color had little impact in interpretation. Both solid and broken double line combinations (passing permitted) had a correct response rate of 83 percent. The solid and broken double line combination (passing prohibited) had correct response rates of 92 and 93 percent. Within a given message (prohibited or permitted), color had little impact.

The white double broken line was correctly interpreted by 84 percent, indicating some inherent meaning to this all-white marking. However, the single solid wide white line was interpreted correctly by 81 percent, which is about the same as the solid black line.

In general, the passing restriction message of these markings seems to be well understood by the survey subjects.

CHAPTER **4**

FINDINGS AND RECOMMENDATIONS

During the 1990s, numerous transportation professionals began to suggest that there may be benefits to converting the U.S. pavement marking system from a yellow–white system to an all-white one. There have been several major events that have helped to foster discussion of this idea:

- A 1994 survey distributed by the Markings Technical Committee of the National Committee on Uniform Traffic Control Devices to gather input on the level of support for an all-white pavement marking system,
- An all-white pavement marking session at the 1996 TRB Annual Meeting,
- A 1998 scan trip on innovative traffic control practices in Europe which recommended an evaluation of the feasibility of an all-white pavement marking system in the United States, and
- EPA activities throughout the 1990s to develop and refine regulations for reducing the VOC and lead content of pavement marking materials.

There are several general reasons that have traditionally been mentioned as the primary reasons why the United States would benefit from implementing an all-white pavement marking system. Those reasons include (in no particular order):

- Drivers do not have an inherent understanding of the meaning of yellow markings.
- All other factors being equal (binder, beads, application, etc.), white markings have higher retroreflectivity than yellow markings. This is compounded by the fact that yellow markings receive less illumination than white markings (headlamps are oriented to the right).
- Most of the industrialized countries of the world use all-white pavement markings.
- Some of the pigments used in yellow markings are difficult to recognize as yellow in nighttime conditions.
- White markings are less expensive than yellow markings and having only one color to apply would reduce the application and supply costs.
- An all-white pavement marking system would eliminate environmental concerns related to the use of lead chromate as a yellow pigment.

The NCHRP sponsored Project 4-28, "Feasibility Study for an All-White Pavement Marking System," to look at the various factors associated with the potential implementation of an all-white pavement marking system and determine if such a system is feasible in the United States. The overall objective of this research project, as described in the proposal, was to "*conduct a feasibility study that quantifies and/or identifies the advantages, benefits, costs, drawbacks, disadvantages, risks, and implementation issues associated with converting the United States from the present yellow and white system of pavement markings to an all-white system*." A number of research activities were undertaken in assessing the feasibility of all-white pavement markings. The previous chapters describe those activities and the related results. This chapter summarizes the results of those evaluations and presents the recommendations evolving from those findings.

FINDINGS

As mentioned previously, numerous issues impact the feasibility of implementing an all-white pavement marking system in the United States. Portions of the previous chapters address several key aspects on several issues. This section summarizes the key issues associated with all-white markings and the findings of the research activities related to each issue.

Factors Affecting All-White Marking Feasibility

The research team evaluated numerous issues related to converting the current yellow–white pavement marking system to an all-white pavement marking system. The most signification of these evaluation activities included: (1) conducting a survey on driver understanding of pavement marking patterns and colors and (2) identifying pavement marking systems used in other countries, soliciting comments and practices of agencies and industry through surveys and a stakeholders workshop, and evaluating various factors that affect the feasibility of either all-white markings or yellow–white markings. The results of these evaluations are presented in the following paragraphs as they relate to each of the major issues.

Driver Understanding

Virtually everyone who has provided input on this project has identified driver understanding of the current system and of a potential all-white system as one of the most critical issues that must be addressed. The ability of drivers to understand the yellow–white and all-white marking systems have been presented as reasons supporting the change to all-white markings or to stay with yellow–white markings. Those that believe that drivers have a basic understanding of the existing yellow–white system do not believe it should be abandoned for an all-white system, while others believe that drivers do not understand the basic message conveyed by yellow markings and the overall system would benefit from using all-white markings.

As described previously in this report, there has not been a comprehensive evaluation of driver understanding of the yellow–white marking code in the last 20 or more years. Therefore, this research project was modified to include a major assessment of driver understanding of the yellow–white marking code and their inherent understanding of potential all-white marking schemes. The researchers surveyed 851 subjects at locations in 5 states. The subject sample includes drivers from 47 states, plus Puerto Rico and Washington, D.C. The focus of the evaluation was to determine how well drivers interpret the directional message and passing restriction message of markings.

As a result of reviewing the results of previous evaluations and conducting a new evaluation, the researchers identified the following issues related to driver understanding of both yellow–white markings and all-white markings:

- The current yellow–white system has been in place since the early 1970s.
  - Implementation of an all-white pavement marking system should be considered as a new system for U.S. drivers and not a return to a previously used system that some portion of the driving population is familiar with.
  - Over 55 percent of current U.S. drivers have never driven on a road in the United States where the centerline of a two-way road could be white. For the remaining portion of the U.S. driving population, it has been 30 years since they might have driven on a two-way road with white centerline markings.
- The survey results found that
  - Drivers tend to use signs and other traffic as the primary cue to determine whether a road is one-way or two-way.
  - Drivers use the yellow color of centerlines as a tool in determining the direction of traffic flow on a road.
  - Approximately 75 percent of the surveyed drivers understand the basic concept that a single broken yellow line separates opposing traffic on a two-lane road.
  - The presence of a solid line (either double solid or solid and broken) in the centerline increases comprehension of directional flow to approximately 85 percent.
  - Over 90 percent of the surveyed drivers understand that a solid line (either double solid or solid and broken) prohibits passing.
  - Drivers do not have a better understanding of any of the potential all-white marking alternatives presented in the survey, indicating that there is no inherent benefit to converting to an all-white marking system from the standpoint of conveying the directional message of the road.
  - The addition of direction arrows significantly improves understanding of a two-way road situation.
  - Drivers are not inclined to recognize the differences between various stripe and gap lengths as a means of conveying information about the direction of traffic flow.
  - The driver survey focused only on driver interpretation of pavement markings in daytime conditions. Driver use and interpretation of pavement markings in nighttime conditions may be different from daytime conditions, but it was not feasible to evaluate nighttime use and interpretation within the scope of this effort.
- Wider lines may not be a practical means of indicating opposing traffic. When retracing lines, they often become wider. In addition, many agencies are now beginning to implement wider longitudinal markings on a regular basis.
- The most effective system for all-white markings appears to be one where the centerline is a double line, which would be solid where passing is prohibited and broken where passing is permitted. There are four possible centerline combinations for the double line:
  - Double solid line for passing prohibited in both directions.
  - A solid line with a broken line for passing prohibited in one direction (there are two versions of this pattern, depending upon which direction passing is prohibited).
  - Double broken line for passing permitted in both directions.

Driver Education

Given that the alternative all-white marking schemes presented in the survey did not have inherently higher levels of understanding than the current yellow–white system, the implementation of an all-white pavement marking system would require a significant driver education commitment. Implementation of an all-white system would require a nationwide driver education media campaign and a revision of all current driver education and driver-training materials.

In comparison, a smaller effort could focus on the current yellow–white system and increase driver understanding to a greater level than the all-white system with fewer resources. There is much that could be done to improve driver understanding of the current system, and it can be done at less cost than an effort to educate drivers on an all-white pavement marking system.

Visibility

Increases in pavement marking visibility may be the most commonly cited reason for converting to an all-white pavement marking system. This reason is based on the belief that white markings are more visible than yellow markings. The researchers identified the following issues related to the visibility of pavement markings:

- Nighttime visibility of pavement markings is based on the distribution of illumination from the headlamp, the retroreflectivity of the marking, and the contrast with the pavement surface. For most pavement surfaces, the retroreflectivity of the marking is the most significant factor in the nighttime visibility of the marking.
  - The retroreflectivity of a yellow marking is typically about 65 percent of an identical white marking fabricated from the same binder and beads and applied at the same thickness.
  - Given equal illumination, white and yellow markings with the same retroreflectivity have the same level of nighttime visibility.
  - Yellow lines on the left side of a vehicle receive less illumination than white lines on the right side of the vehicle. For markings with the same retroreflectivity values, a marking on the left side of a vehicle will have a lower luminance than a marking on the right side.
  - At night, drivers focus their attention on the right side of the field-of-view and tend to rely upon the right lane line or edge line for positional guidance.
  - At typical marking retroreflectivity levels, it is possible to place yellow markings that have the same or higher retroreflectivity value as white markings. This can be achieved by improving the marking material, beads, or application process. Placing yellow markings that have the same or higher retroreflectivity values as white markings will increase the costs of the yellow markings.
  - While all-white pavement markings can improve the nighttime visibility of the overall system, the nighttime visibility of the current yellow–white system can also be improved by increasing the performance of yellow markings.
  - Changes in headlamps indicate that newer headlamp designs place more illumination on the pavement surface. A comparison of UMTRI 1997 and 2000 50th percentile headlamps indicates that at distances from 300 to 1,000 ft in front of the vehicle, the newer headlamps place approximately 15 and 20 percent greater illumination on the centerline and right edge line, respectively.
- Daytime visibility of pavement markings is based on the contrast of the marking with the pavement surface.
  - White markings have lower contrast and are less visible on concrete and faded asphalt pavement surfaces.
    - Visibility of white markings on these surfaces can be improved through the use of black contrast markings. This will increase the costs of using an all-white pavement marking system.
- An advantage attributed to yellow markings is that they may be more visible on a snow-covered road or road with blowing snow conditions.
- The FHWA is expected to initiate rulemaking for pavement marking in-service retroreflectivity and color requirements for pavement markings.
  - Minimum retroreflectivity requirements would lead many agencies to place more emphasis on providing pavement markings with higher retroreflectivity. This would improve the overall nighttime visibility of markings in many jurisdictions.
  - Establishing federal regulations for the daytime and nighttime color of pavement markings may lead many agencies to improve the color of yellow markings so that there is less confusion between the color of white and yellow markings.

International Harmony

Another commonly cited reason for converting to an all-white pavement marking system in the United States is that it would bring the country into greater conformity with international pavement marking practices. The researchers identified markings systems used in 22 countries, 17 of which use an all-white system. The evaluation of other countries' marking systems identified the following issues related to achieving international harmony in pavement marking patterns:

- The majority of countries contacted as part of this research effort use an all-white pavement marking system. Officials representing the countries contacted did not express any concerns about the effectiveness of their all-white pavement marking systems.
- A review of the actual all-white pavement marking systems used in individual countries revealed that there are important differences between countries. Countries use a variety of stripe lengths, gap lengths, and line widths to convey various messages with pavement markings with important differences from one country to another. As a result, there is no consistent system of all-white pavement markings, even within the European continent.

- While it is possible for the United States to implement an all-white pavement marking system that could be consistent with that used in one or two countries, it is not possible to achieve consistency with a large number of countries because of the variations in all-white pavement marking systems used in different countries.
- There are several aspects of the European system of traffic control devices that are different from the U.S. system. These differences make comparisons between the two systems difficult:
  - European headlamps emphasize glare reduction. As a result, less light reaches signs, requiring a greater reliance on pavement markings.
  - European countries generally place more emphasis on pavement markings and horizontal signing. They use more markings and appear to devote more resources to maintaining pavement markings.

Costs

Even if all other factors were to favor implementation of an all-white pavement marking system, agency personnel have indicated that they would not favor implementation if there is a cost increase associated with the all-white system. The researchers have not conducted a detailed economic assessment of the cost impacts of implementing an all-white pavement marking system. However, the researchers have been able to identify the following economic issues related to all-white pavement markings:

- The costs of pavement markings is highly variable across the country, depending on the marking material, whether it is applied by agency or contractor personnel, agency to agency variations, and other factors.
  - Common pavement marking costs can range from as little as $0.02/ft for paint to $0.85/ft for thermoplastic. Specialized markings such as tape and profile markings are more expensive.
- A detailed national cost analysis would be difficult to conduct without determining miles of markings on all roads in the United States, types of marking materials used on those roads, and the costs of applying markings on those roads.
- Implementation of an all-white pavement marking system in the United States would require all current yellow centerlines to be removed and/or restriped.
  - There are 160,462 mi of road on the National Highway System. At a weighted average of $0.17/ft, it would cost over $144 million to restripe the centerlines and left edge lines of the National Highway System. The National Highway System represents about 20 percent of the total federal-aid highway system.
  - The survey results indicate that a double line centerline is likely to have the best understanding of the traffic direction message. Additional evaluations should be conducted to confirm this conclusion. If a double line were to be implemented, not only would all yellow lines need to be covered with white lines, but a second line would need to be added at all locations that currently have a single yellow line for the centerline. This would further increase the costs of implementing an all-white system.
- In addition to the cost of white markings, implementation of all-white markings may require black contrast markings on many pavement surfaces.
- The contracting community may not have the capacity to restripe the entire country to all-white markings within a 1-year period. The manufacturing community (binder and beads) would need significant lead time to build sufficient reserves to prepare for such an effort.
- Implementing all-white markings may lead to a short-term increase in the cost of white marking materials for one or more of the following reasons:
  - Increased demand for raw materials, particularly TiO_2.
  - Increased demand for a large quantity of white markings.
- Two recent FHWA activities have the potential to significantly increase pavement marking costs for agencies:
  - FHWA is in the process of moving toward implementation of in-service retroreflectivity and color requirements. These requirements, if implemented, may require agencies to replace markings on a more frequent basis and/or to use higher quality (and more expensive) markings, thereby increasing the costs to agencies for installing and maintaining pavement markings.
  - The 2000 *MUTCD* contains volume warrants for edge lines and centerlines. These warrants may increase the miles of roadway requiring edge line or centerline markings for some agencies, primarily for local agencies, thereby increasing the pavement marking costs. This action does not have a significant effect upon most state transportation agencies.
- The implementation of an all-white marking system is likely to impose a significantly greater pavement marking expense on state and local agencies beyond the costs associated with the activities just mentioned.
  - If the FHWA moves forward with an all-white pavement marking system within the next 10 or so years, the FHWA should consider providing funding to state and local agencies for the initial costs of implementing an all-white pavement marking system.
- There are productivity benefits to implementing all-white markings. These cost reductions result from not having to provide two-color systems on installation equipment. The increased productivity benefits are not likely to offset the additional costs of implementing all-white markings.

Safety

Safety is a factor in any potential improvement to the transportation system. At this time, it is not possible to assess the possible reductions (or increases) in crashes that would be associated with implementing an all-white pavement marking system. Previous research has attempted to document the benefit associated with incremental improvements in pavement markings (use of wider markings, increases in marking retroreflectivity), but has been unable to do so. The crash-reduction benefits of all-white pavement markings can only be addressed through a field trial of all-white markings.

Material and Environmental Issues

The chemical properties of yellow binders and the associated environmental changes are sometimes cited as reasons to eliminate yellow as a marking color. The following issues are associated with the material and environmental aspects of yellow markings:

- EPA regulations require that pavement marking paints meet stringent requirements for lower levels of VOCs.
  - These requirements have virtually eliminated the widespread use of solvent-based pavement marking paint.
- Agencies' concerns related to worker exposure and disposal issues have lead agencies to reduce the amount of lead chromate used as a pigment in yellow pavement markings.
  - Organic yellow pigments have led to color fastness difficulties in yellow markings. Some organic yellow markings appear white or pale yellow at night.
- Removal of yellow pavement markings containing lead chromate may require special handling. This is largely an issue only with older yellow markings.
- Industry and agencies appear to have largely adjusted to the environmental demands associated with pavement markings.
  - Some agencies are not satisfied with the color of yellow markings.
- Implementing an all-white pavement marking system would eliminate the environmental issues associated with yellow pavement markings.
- NCHRP has funded a new research project to evaluate the color and specifications for yellow pavement markings (Project 5-18). This project, expected to begin in late 2002, will evaluate drivers' ability to distinguish between yellow and white markings, develop color specifications for markings, and assess the extent to which existing markings provide drivers with adequate yellow color. The results of this research, when combined with the establishment of in-service color requirements for markings, should improve the quality of yellow pavement marking color.

Implementation Issues

There are many practical issues associated with the potential implementation of an all-white pavement marking system. Many were identified in the background information chapter, and an implementation plan that addresses many issues is provided at the end of this chapter. The following implementation issues are among the most significant associated with an all-white pavement marking system.

- Implementation of an all-white pavement marking system would require that state laws be changed in many or most states.
  - There are 43 state legislatures that meet once or twice a year.
  - There are 7 state legislatures that meet every other year (Arkansas, Delaware, Montana, Nevada, North Dakota, Oregon, and Texas).
    - These states might require a significant lead time to make the necessary changes in state laws.
  - No state legislatures meet less frequently than every other year.
- In addition to state laws, the federal government would have to change the *MUTCD*.
  - Changes to the *MUTCD* must go through a rulemaking process. This process includes an opportunity for the public to comment on the proposed change. Given the lack of support for the concept as presented in the survey, the public comment would likely be opposed to the change.
- The wide range in pavement marking durability will pose challenges to converting to an all-white pavement marking system. If a short implementation period is used, then some yellow durable pavement markings will be replaced with white markings before the end of their service life.

Forced Implementation Considerations

At the present time, the decision to implement an all-white pavement marking system is a voluntary decision which is based on an evaluation of the feasibility and benefits of such a system. However, there are circumstances that could force the United States to implement an all-white system, even if the actual feasibility of an all-white pavement marking system is questionable. The researchers have identified four potential circumstances that could lead to forced implementation of all-white markings. They include (1) environmental constraints, (2) color specifications for pavement markings, (3) minimum levels of retroreflectivity, and (4) wet marking retroreflectivity. The following paragraphs describe each of these circumstances and the potential for each to lead to forced implementation. The researchers have determined that the

likelihood of any of these scenarios leading to forced implementation of an all-white pavement marking system is small.

Environmental Constraints

In the most likely occurrence of this scenario, a federal agency establishes an environmental regulation that would eliminate the ability to use yellow markings. Such a regulation would most likely address the pigments that are used to provide the yellow color of the marking. While the regulation might not prevent the use of yellow, it may make such use so expensive that it is no longer feasible. However, as mentioned previously, industry can now provide effective and environmentally friendly yellow marking materials. This makes the probability of this scenario favoring all-white markings small.

Color Specifications for Pavement Markings

In summer 2002, the FHWA was expected to establish in-service specifications for the daytime and nighttime color of pavement markings. There are several aspects of in-service color requirements that could limit the continued use of yellow as a marking color. One is the ability to measure pavement marking color. Currently, there is only one commercially available instrument for measuring marking color. And it is a handheld instrument, which limits the number of locations that can be measured in a day and requires the use of traffic control to protect the worker measuring color. The ASTM specification (*6*) recognizes the practical limitations of measuring pavement marking color with the following statement:

> *"The referenced nighttime color test method is primarily a laboratory procedure, and may not be convenient for use in the field for the measurement of material in service. More convenient field test instruments complying with this test method are expected to be available in the near future."*

Furthermore, although the challenges for marking color are greater with yellow than with white, white markings will not be exempt from meeting the color specifications. For this scenario to lead to all-white markings, the color specifications would have to be such that there are no yellow marking materials that can meet the specifications with sufficient durability to provide a reasonable life at reasonable cost. The researchers estimate that probability of the expected color specifications leading to a forced implementation of all-white pavement markings is small.

The NCHRP has funded a research project to evaluate the color of yellow pavement markings (Project 5-18). This project, which is expected to begin in late 2002, will evaluate driver needs for recognition of marking color, develop revised color specifications (if necessary), and evaluate the extent to which existing markings in the field meet the color specifications.

Minimum Levels of In-Service Retroreflectivity

Congress has mandated the FHWA to change the *MUTCD* to include a standard for a minimum level of retroreflectivity for signs and pavement markings. The minimum values would define the end-of-service life for pavement markings in the field. The FHWA has developed some initial research recommendations for minimum levels of marking retroreflectivity and is continuing research to refine the values. Other related questions are also being considered such as whether yellow retroreflectivity requirements should be higher when there are no edge lines or whether innovative centerline treatments offer improved visibility of the yellow lines at night. It is conceivable, although unlikely, that the minimum values for yellow could be high enough that it would be cost-prohibitive to provide yellow markings that would meet the end-of-service life minimum values.

Wet Retroreflectivity

The presence of water on the surface of a pavement marking can significantly reduce the retroreflectivity of the marking. Data presented in an NCHRP synthesis report indicates that wet retroreflectivity of measured samples is 42 to 52 percent the retroreflectivity of a dry marking (*4*). At present, there are no requirements for wet retroreflectivity of pavement markings. However, ASTM recently added two new specifications for measuring the wet retroreflectivity of pavement markings (*19*, *20*). If the minimum retroreflectivity values are determined to apply to wet retroreflectivity values, or if the wet methods for measuring retroreflectivity are established as the standard methods for pavement marking retroreflectivity, then agencies might have to use higher retroreflectivity markings to meet the retroreflectivity requirements. There are yellow marking materials that will meet the minimum retroreflectivity requirements, even when using wet marking measurement methods. However, these materials are more expensive than typical pavement markings. While this scenario is the most likely of the four to lead to forced implementation of all-white markings, the researchers believe that the probability of such an occurrence is small.

RECOMMENDATIONS

Using the findings described in the preceding section, the researchers developed recommendations in three areas. The primary recommendation indicates whether an all-white marking system should be implemented. The section following the

primary recommendation presents the various reasons that support the primary recommendation. The researchers also developed a series of secondary recommendations that address improvements that are beyond the immediate question of implementing an all-white system. Finally, the researchers recognized that there are factors that may, at some time in the future, force the implementation of an all-white pavement marking system. Therefore, the researchers developed a series of implementation guidelines to help agencies address the challenges associated with implementation.

Primary Recommendation

On the basis of the findings of the research activities, the researchers recommend that an all-white pavement marking system not be implemented in the United States at the present time.

Justifications for the Primary Recommendation

There is no single factor that led the researchers to recommend the continued use of the existing yellow–white marking system. Instead, it was the combination of numerous factors that together limit the feasibility of an all-white pavement marking system. The following paragraphs describe these factors and their impact upon the recommendation to keep the yellow–white marking code. These factors are not listed in any particular order.

There are many reasons why it is not feasible to implement an all-white pavement marking system in the United States at the current time. The major reasons are described in the findings portion of this chapter and briefly summarized below:

- **Driver Understanding**—The survey results indicate that the yellow–white pavement marking system is better understood than previously believed and that the potential all-white pavement markings presented in the survey do not have higher levels of understanding than the current yellow–white markings. Furthermore, the survey results indicate that driver understanding of the directional message of pavement markings could be significantly improved through the use of directional arrows in the lanes. The survey results also indicate that, while drivers have a basic level of understanding of the directional message of yellow markings, they tend to use signs and other traffic as the primary cue to determine whether a road is one-way or two-way.
- **Driver Education**—The survey results indicated that drivers have a better understanding of the current yellow–white pavement marking system than any of the potential all-white pavement marking systems evaluated in the survey. Therefore, a significant driver education and training effort would be required to implement an all-white marking system that would be understood as well as the current system. The researchers recommend that greater improvements could be achieved with fewer resources if the meaning of current marking colors were emphasized more in driver education and driver training programs.
- **Nighttime Visibility**—The higher nighttime visibility of white markings (compared to yellow) is attributed to the fact that white markings have higher retroreflectivity than yellow markings made in the same manner. While improved nighttime visibility is often cited as justification for an all-white pavement marking system, the researchers found that the nighttime visibility of yellow markings can be increased by using marking materials with higher retroreflectivity. However, increasing the retroreflectivity of yellow markings will also increase the costs of the markings.
- **International Harmony**—One of the reasons supporting the implementation of an all-white pavement marking system is that it would bring the United States in agreement with the marking systems used in most industrialized countries, especially in Europe. The researchers evaluated the use of color in pavement marking systems in other countries. While they found that many countries use an all-white system, there is significant variability in the all-white marking codes from one country to another. Because there is no single all-white pavement marking system used throughout the world, or even throughout a continent, there is little advantage in promoting a U.S. all-white pavement marking system as a means of improving international harmony.
- **Costs**—The wide range in the costs of markings makes it difficult to perform a comprehensive benefit/cost assessment of implementing an all-white pavement marking system. However, the researchers identified numerous instances of increased costs associated with all-white markings. These costs include the following: over $144 million to restripe the centerlines and left edge lines on the National Highway System—this cost would increase if a double line all-white marking system were used; black contrast markings that may be necessary for all centerlines on concrete pavements; the demand for white marking materials that may increase the costs for white materials; and an extensive driver education/media campaign that would be needed. The magnitude of these costs will not be offset by the production benefits gained by using only one color.
- **Safety**—The safety benefits of implementing an all-white pavement marking system cannot be established without a field trial of such markings.
- **Materials**—There are numerous material and environmental challenges associated with yellow markings. However, industry is overcoming these challenges and can provide effective and environmentally friendly yellow pavement marking materials.

- **Implementation**—The potential implementation of an all-white pavement marking system would involve changing laws, ordinances, and regulations in a large number of jurisdictions at all levels of government. These changes would need to be in place before implementation could proceed.

Secondary Recommendations

In determining that an all-white pavement marking system is not feasible, the researchers identified several actions that should be taken to improve the current yellow–white pavement marking system. These recommendations are as follows:

- **Implement Directional Pavement Marking Arrows**—The survey results indicate that the addition of arrows indicating the direction of traffic flow increase comprehension of that message to over 90 percent. Section 3B.19 of the *MUTCD* should be revised to provide agencies greater flexibility and guidance on the use of directional pavement marking arrows to reduce travel in the wrong direction.
- **Increase Emphasis on Marking Color in Driver Training**—The survey results found that approximately 75 percent of the drivers understand the directional message of a single broken yellow line. While this value is higher than some thought it would be, it also indicates a need to increase understanding of the meaning of marking colors. Driver education and driver training materials and curriculums should increase the emphasis on the meaning of pavement marking color. Increasing the emphasis in current programs would be less expensive and have greater benefits than establishing a new program to educate drivers on the meaning of all-white markings.
- **Increase Retroreflectivity of Yellow Markings**—The reduced nighttime visibility of yellow markings (as compared to white markings) was cited as a major reason to implement all-white markings. Agencies should consider using yellow marking materials that have retroreflectivity values that are similar to those of white markings on the same road. This would entail using higher quality materials for the yellow markings, resulting in an increase in costs.
- **Improve Color of Yellow Markings**—The reduced use of lead chromate as a pigment in yellow markings has resulted in some yellow markings with less intense yellow color, leading to potential confusion with white markings. A new NCHRP will evaluate color aspects of yellow markings and the results should be used to improve yellow markings.
- **Provide Funding for Potential Implementation**—As mentioned previously, there are potential pavement marking changes on the horizon that may increase pavement marking costs for transportation agencies (in-service minimum retroreflectivity and color specifications). The next section of this chapter presents circumstances that may lead to forced implementation of all-white markings. If minimum retroreflectivity guidelines, color specifications, and forced implementation occur in the same time frame, the federal government should provide state and local agencies with financial support for implementing the all-white pavement marking system.

Contingency Implementation Recommendations

As indicated in the primary recommendation, the researchers do not recommend implementation of an all-white pavement marking system in the United States. However, as indicated in the findings portion of this chapter, there are circumstances that could lead to forced implementation of an all-white pavement marking system. Although the researchers do not believe that there is a significant potential for forced implementation of all-white pavement markings, they have developed a preliminary implementation plan for such a contingency. These contingency recommendations provide implementation guidance to initiate the process of implementing an all-white system should it be necessary to do so. Table 41 presents a proposed time line for conducting these implementation activities. As can be seen from this table, implementation extends over a period of 9 years. It is possible that the actual implementation may take longer than indicated. The implementation activities described below represent those that would be part of a thorough and deliberate implementation effort that attempts to provide maximum input from affected agencies and citizens. The specific circumstances associated with the impetus for the implementation may limit the ability to perform all of the activities.

- The FHWA should consider publishing an advance notice of proposed rulemaking in the *Federal Register* indicating the intent to eliminate yellow as a color for pavement markings. The notice should explain the reason(s) for eliminating yellow and identify that research is planned to determine the most effective all-white marking code. It should also identify potential implementation timelines.
  - The advance notice should be prominently publicized by all organizations that are involved with pavement markings. At a minimum, these organization should include: American Association of Motor Vehicle Administrators (AAMVA), American Association of State Highway and Transportation Officials (AASHTO), American Public Works Association (APWA), American Road and Transportation Builders Association (ARUBA), American Traffic

TABLE 41 Time line of implementation activities

Activity	Year								
	1	2	3	4	5	6	7	8	9
Advance Notice of Proposed Rulemaking – Comment Period	■								
Advance Notice of Proposed Rulemaking – Comment Analysis		■							
Go or No Go Decision		■							
Additional Research			■	■	■				
Driver Education Plan			■	■					
Field Trials				■	■	■			
Proposed Rule – Comment Period						■	■		
Proposed Rule – Analysis of Comments							■		
Go or No Go Decision							■		
Final Rule								■	
Changes to Laws and Regulations							■	■	■
Media and Driver Education Campaigns									■
All-white Marking Installation									■

Safety Services Association (ATSSA), Institute of Transportation Engineers (ITE), National Association of County Engineers (NACE), National Association of Governor's Highway Safety Reps. (NAGHSR), National Committee on Uniform Traffic Control Devices (NCUTCD), and National Committee on Uniform Traffic Laws and Ordinances (NCUTLO). Desirably, all transportation-related organizations should be involved in publicizing the notice.
  - The comment period for the advance notice should provide adequate time for organizations to distribute the notice to their members and for members to develop a response. At a minimum, the comment period should extend for 6 to 9 months.
  - Within 6 months of the end of the comment period, the FHWA should consider identifying whether it is practical to move forward with implementation of the all-white pavement marking system.
- If the decision is to continue moving forward with implementation of an all-white pavement marking system, the NCHRP or the FHWA should consider sponsoring additional research to determine the most appropriate code for all-white markings. Consideration should be given to the all-white code recommended in the current research, but other systems should also be considered.
  - On the basis of the findings of the current study, a double line for all centerlines is recommended. However, this system and other systems should be studied further.
  - The research should include simulator studies with subjects from at least three regional areas.
  - The research effort should include the development of a plan for a media and driver education campaigns to inform the public of the change to an all-white pavement marking system.
- Field trials of an all-white pavement marking system should be conducted.
  - The field trials could be part of the established research effort or a new project.
  - The field trials should be conducted in no less than three areas of the country.
  - The field trials should be areawide and represent a range of road types. The field trials should also evaluate potential schemes for installing the all-white marking system.
  - Extensive media and driver education campaigns should accompany the field trials in the affected areas.
  - Appropriate signing should be installed in the field trial areas to inform road users that may not have been reached by the media and/or driver education campaigns.
  - Upon completion of the field trials, the markings should be restored to the yellow–white system.
  - The cost of installing the all-white pavement markings and restoring the markings to yellow–white should be included as part of the research effort.
  - The results of the field trial should be evaluated to determine if implementation of all-white pavement markings should continue.
    - The field trial evaluation should address driver understanding, driver behavior, safety, costs, and implementation effectiveness.
- If the decision is to continue moving forward with implementation of an all-white pavement marking system, the FHWA should consider publishing a proposed rule in the *Federal Register* for implementing an all-white pavement marking system.

- The proposed rule should describe the changes to the *MUTCD* needed to implement the all-white pavement marking system.
- The proposed rule should include a time line for implementing the all-white pavement marking system. The time line should include specific deadlines for the following:
  - Deadlines for changing all applicable federal laws, regulations, and policies.
  - Deadlines for changing all applicable state laws, regulations, and policies.
  - Deadlines for changing all applicable local ordinances, regulations, and policies.
  - Earliest date for installation of all-white pavement markings.
  - Latest date for installation of all-white pavement markings.
- The comment period for the proposed rule should be 6 to 9 months.
- Within 6 months of the end of the comment period, the FHWA should consider determining if there is sufficient justification to move forward with implementation of an all-white pavement marking system.

- If the decision is to continue moving forward with implementation of an all-white pavement marking system, the FHWA should consider publishing a Final Rule containing the *MUTCD* language, a timetable that identifies when agencies are required to take specific action.
- During the 2-year period following the publication of the Final Rule, all government agencies at all levels will be required to revise all relevant laws, regulations and policies to convert from a yellow–white to an all-white pavement marking system.
  - All laws, ordinances, and regulations should all become effective on the same date.
  - Pertinent elements of driver education and driver training materials will be identified and revised as appropriate.
  - At the end of this implementation phase, the FHWA should review federal, state, and local activities to ensure that all the necessary steps have been taken to establish the necessary administrative structure to implement an all-white pavement marking system.
- Once all necessary laws, ordinances, and regulations have been changed, a driver education campaign should be initiated. The campaign should have a national focus.
  - The campaign should include the popular media.
  - The campaign should include all driver education and driver training materials and programs.
- Installation of the all-white pavement marking system should begin no less than 6 months after the driver education begins.
  - The initial installation of all-white marking should take place while the driver education campaign is underway.
  - The transition period should be limited to 1 year if at all possible.
  - The FHWA should consider providing funding to state and local agencies for the costs of the initial application of all-white markings.

APPENDIX A

EVOLUTION OF U.S. PAVEMENT MARKING SYSTEM

One of the earliest known applications of road markings can be traced back to ancient Mexico on a road near Mexico City (*21*) sometime about 1600 A.D. The centerline was placed to separate opposing traffic and was created using lighter-colored stones in the pavement. In more modern times, other road markings may have been used in isolated instances in the late nineteenth century on bridges. Painted road markings in the early twentieth century appeared in various cities at various times, but there is no consensus on where the first pavement markings appeared in the United States. One publication indicates that the first painted lines were Stop lines painted on roads in Portsmouth, Virginia, in 1907. New York City appears to have first used markings for crosswalks in 1911. Similar lines were used in Providence, Rhode Island, and Minneapolis, Minnesota, in 1913 and 1914, respectively (*22*).

It is not possible to ascertain where the first longitudinal pavement marking was first used in the United States. One publication indicates that in 1911 or 1912, the first lane marking was made just inside a park entrance in Cincinnati, where the most-used roadway was narrow and many collisions had occurred (*23*). However, it appears that Wayne County, Michigan (Detroit area), was one of the first areas to use centerlines on a widespread basis. These early centerlines may have been used as early as 1911, but were certainly in place by 1922 (*2*). Indio, California, also makes a claim to the earliest centerline, with the first use dating back to 1924 (*2*). At this time, there were few, if any, standards or guiding principals for markings. Where those standards or guiding principles did exist, they were on a local level and there was no coordination between local agencies.

DEVELOPMENT OF NATIONAL MANUALS

During the twentieth century, there has been a continuous evolution in the national standard for traffic control devices. Since 1935, this document has been known as the *Manual on Uniform Traffic Control Devices* (*MUTCD*). Prior to its initial publication in 1935, there were two different predecessor documents. Table A-1 summarizes the evolution of these documents. A series of articles on the history of the *MUTCD* provides a more complete description of the evolution of these documents (*24*, *25*, *26*).

Early Manuals

The American Association of State Highway Officials (AASHO) *Manual and Specifications for the Manufacture, Display, and Erection of U.S. Standard Road Markers and Signs* was published in January 1927 (*27*). This manual was the first national manual on traffic control devices, but it addressed only signs in rural areas, setting forth the design and use for each type of sign. Despite its name, pavement markings were not addressed in the document. In the earliest days of traffic control devices, some types of signs were referred to as road markers and this creates confusion with pavement markings.

During the time that AASHO was developing its rural signing manual, the National Conference on Street and Highway Safety (NCSHS) was developing a manual for the use of traffic control devices in urban areas. They published the *Manual on Street Traffic Signs, Signals and Markings* in 1930 (*28*). The urban manual conformed with the AASHO rural manual in virtually all respects, except that material addressing traffic signals, pavement markings, and safety zones was added. Among other applications, the urban manual indicated that markings could be used (1) for the centerline of a street, (2) for the centerline on a curve having a radius less than 600 ft, (3) for the centerline at and approaching hill crests, (4) for traffic lanes on streets wide enough for three or more lanes, (5) at all signalized intersections (especially opposite safety zones), and (6) for traffic lanes for turning at street intersections.

1935 *MUTCD*

The inherent conflicts created by the existence of two manuals were quickly recognized and efforts were initiated to develop a single manual for both rural and urban conditions. AASHO and NCSHS formed the Joint Committee on Uniform Traffic Control Devices (JC) in 1932 and published the original edition of the *MUTCD* in November 1935. Each part (signs, markings, signals, and islands) was subdivided into articles and sections addressing specific traffic control device aspects such as legal authority, application and location, design, and maintenance. The markings portion was further divided into divisions addressing regulatory and guidance markings and warning markings on hazardous objects. This format required the user to look at several different sections to obtain all the information about a particular type of marking.

The 1935 *MUTCD* defined markings for pavements, curbs, and objects. Lines could be marked with construction joints, paint, or pavement inserts. White, yellow, or black could be used, depending on which color would provide the greatest contrast. Lines could be between 4 and 8 in. wide. Stripes and gaps were supposed to be equal in length and between 5 and 75 ft.

TABLE A-1 Evolution of U.S. traffic control device standards

Year	Name	Month/Year Revised
1927	Manual and Specifications for the Manufacture, Display, and Erection of U.S. Standard Road Markers and Signs	4/29, 12/31
1930	Manual on Street Traffic Signs, Signals, and Markings	No revisions
1935	Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD)	2/39
1942	MUTCD - War Emergency Edition	No revisions
1948	MUTCD	9/54
1961	MUTCD	No revisions
1971	MUTCD	11/71, 4/72, 3/73, 10/73, 6/74, 6/75, 9/76, 12/77
1978	MUTCD	12/79, 12/83, 9/84, 3/86
1988	MUTCD	1/90, 3/92, 12/93, 2/98, 12/96, 6/98, 1/00

Centerlines were required only on approaches to hillcrests, short radius curves, curves with a restricted view, or pavements wider than 40 ft. When the centerline was used everywhere, a distinctive line was required at all points of hazard. The 1935 *MUTCD* was revised in 1939, and the revision included numerous refinements to the pavement marking guidelines.

1942 *MUTCD*

The onset of World War II placed many demands on highway travel and traffic control in the United States and the JC determined that a War Emergency Edition of the *MUTCD* was needed to address these conditions. To a large extent, the 1942 edition avoided changes in standards other than those needed for the prosecution of the war, recognizing that numerous changes would be desirable when peace was restored. The most significant elements of the 1942 *MUTCD* were changes in the standards to conserve materials for the war effort and the addition of material on traffic control in blackout conditions.

The 1942 War Emergency *MUTCD* continued to allow the use of white, yellow, or black markings. However, the material indicated that white paint was rapidly replacing black paint for centerline applications. This was particularly significant for blackout conditions, under which black markings were not visible. Yellow was reserved for barrier lines and curb markings. This *MUTCD* described the need for alternative yellow pigments so that chromium could be used to support the war effort. Included was a statement that earth pigments should be used for yellow instead of converting barrier lines to white.

1948 *MUTCD*

As World War II neared an end, traffic engineers began gearing up for a long-needed revision to the manual. Higher vehicle speeds had created many pressing needs for advances in size, illumination, retroreflectorization, use of symbols, and pavement markings. The 1948 *MUTCD* was the first real opportunity to widely implement the lessons learned from the experience gained from the first *MUTCD*. Unfortunately, there continued to be a lack of reliable research data and the 1948 edition was based largely on the experience and opinions of experts rather than on scientific engineering or factual data. There were many changes in content and organization in the 1948 *MUTCD*. Each of the four parts (signs, markings, signals, and islands) was reorganized so that every device was completely addressed in one location.

The changes in pavement markings were few, but evoked considerable discussion and debate. New specifications were established for centerlines and no-passing zones. White was specified for all applications (including as a broken centerline) except for double centerlines on multilane highways and no-passing zone barrier lines, where yellow was recommended (*29*). This was the most controversial question faced by the committee, and a final decision was reached only after much discussion and two special polls of the state highway departments (*30*). However, white continued to be permissible for use in these applications. The manual recommended against the use of pavement edge lines. White and yellow were the only colors permitted for markings. Figure A-1 indicates how color was specified for pavement markings. Longitudinal lines were 4 to 6 in. wide. Broken lines used a 15-ft stripe with a 25-ft gap.

Pavement markings and patterns were a controversial issue just after World War II because there was no national consensus in use. The variability in states' practices is illustrated in Figure A-1, which is a summary of the various methods used by states to mark centerline and no-passing areas on two-lane pavements in the United States in 1949.

The 1948 *MUTCD* was revised in 1954. While this revision is best known for changing the color of the Stop sign from yellow to red, it included a significant marking revision. The revision was the first *MUTCD* language to require retro-

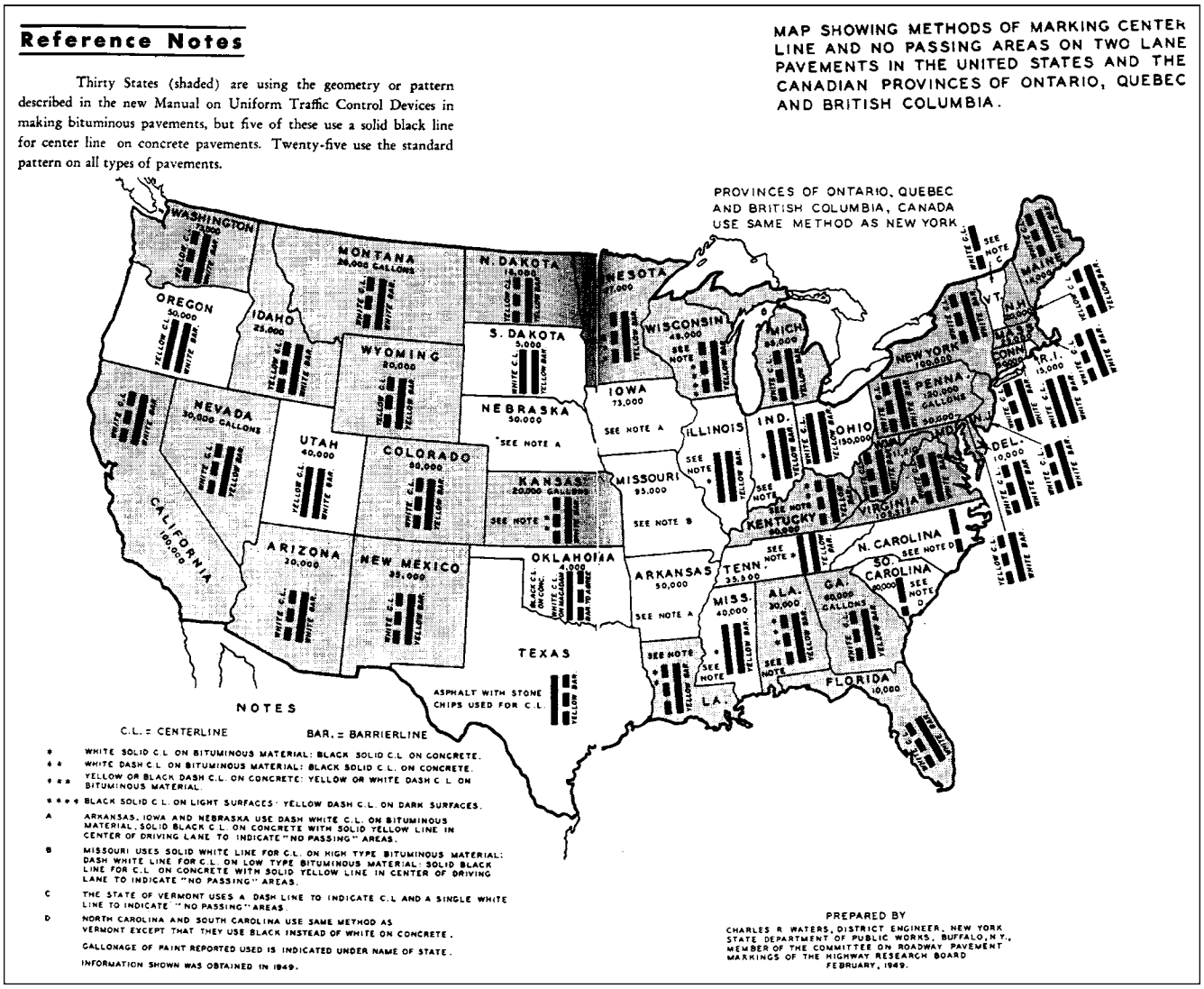


*Figure A-1. Summary of pavement marking patterns in the United States in 1949 (*31*).*

reflectorization of pavement markings, for all rural markings that had application at night.

1961 *MUTCD*

The 1961 *MUTCD* was the first to be organized in parts, chapters, and sections as used in the modern *MUTCD*. New material was added to address traffic controls for construction and maintenance operations, signing for civil defense, and freeway signing. The importance of the manual was indicated by a federal requirement that all traffic control devices used on federal-aid highways conform to the standards in the 1961 edition. The new edition tried to avoid departure from the basic standards of previous editions, but provided for much greater uniformity in traffic control devices. Many of the alternatives previously permitted for a given device were eliminated and a single standard was substituted. The value of symbols continued to be recognized, but few symbols were introduced.

In the markings part of the manual, conflicts over the color of no-passing zone markings were eliminated by specifying yellow for centerlines and eliminating the use of white, as permitted in earlier editions. Table A-2 presents the possible uses of white and yellow markings as specified in the 1961 *MUTCD*. That manual presented the following reasons for using yellow for the specified pavement marking applications:

(1) It contrasts with the normal white center or lane lines and thus gives emphasis to the hazard;
(2) Yellow has been accepted as a symbolic warning color in signs and signals; and
(3) It is consistent with the standard for no-passing-zone markings approved by the American Association of State

TABLE A-2 Meaning of pavement marking color in the 1961 MUTCD

Yellow markings shall be used for:	White markings shall be used for:
1. Double centerlines on multilane pavements. 2. No-passing barrier lines at: a. No-passing zones on two- and three-lane roads. b. Pavement-width transitions. c. Approaches to obstructions which must be passed on the right. d. Approaches to railroad crossings. 3. Curb markings: a. To show parking prohibitions covered by signs or ordinance. b. On islands in the line of traffic.	1. Centerlines on two-lane rural roads and city streets. 2. Lane lines. 3. Pavement edge lines. 4. Paved-shoulder markings. 5. Channelizing lines. 6. Approaches to obstructions which may be passed on either side. 7. Turn markings. 8. Stop lines. 9. Crosswalk lines. 10. Parking space limit lines. 11. Word and symbol markings.

Highway Officials and is in use in more than two-thirds of the States for barrier lines.

Centerlines, lane lines, and barrier lines were specified to be 4 to 6 in. wide, while edge lines were specified to be 2 to 4 in. wide. The length of stripes and gaps remained at 15 and 25 ft, respectively. The permissive use of a white edge line was added and the 1948 *MUTCD* recommendation against edge lines was eliminated. The 1961 *MUTCD* is the only peacetime manual that was never revised.

1971 *MUTCD*

The 1971 *MUTCD* is a very close relative of the current *MUTCD*. The objectives of the 1971 edition were to update the 1961 edition, provide more flexibility in application, and to eliminate contradictions. It was the first *MUTCD* to become the responsibility of the FHWA who assumed responsibility for the *MUTCD* shortly after the 1971 edition was published. It was also the *MUTCD* that introduced the large number of symbol signs in an attempt to promote international uniformity of signing. The increased significance of legal definitions were indicated by the fact that this edition was the first to include definitions for "should," "shall," and "may" requirements.

The most significant markings change in the 1971 *MUTCD* was establishing yellow as the color used to separate opposing traffic when used as a centerline. With this change, white could no longer be used for a centerline. The 1971 edition also introduced the use of red markings. The various uses of pavement marking colors indicated by the 1971 *MUTCD* were:

- Yellow lines delineate the separation of traffic flows in opposing directions or mark the left boundary of the travel path at locations of particular hazard.
- White lines delineate the separation of traffic flows in the same direction. White continued to be used for the left edge line on divided roads.
- Red markings delineate roadways that shall not be entered or used by the viewer of those markings.

The width of all long lines was specified to be 4 to 6 in. and the recommended stripe and gap length of broken lines continued to be 15 and 25 ft. Edge line markings in the 1971 *MUTCD* are the only practice that varies from current marking practices. Left edge lines were specified to be white, except where obstructions exist to restrict the area beyond the edge line from use as an emergency refuge, in which case the left edge lines were yellow.

The 1971 *MUTCD* was the first *MUTCD* to be revised on a regular basis, with eight volumes of rulings on requests for interpretations, changes, and experiments. Unfortunately, few of these revisions were actually distributed to all manual owners on a widespread basis. A few key revisions addressed the use and color of pavement markings.

The most significant of these revisions occurred in October 1973 when yellow was established as the color for all left edge lines on divided highways. The revision was based on the opinions of several state transportation agencies that differences between the use of a left yellow and a left white edge line, depending on the median design, was too subtle to be understood by the motorists.

1978 *MUTCD*

By 1978, there were over 500 rulings involving changes and interpretations to the 1971 *MUTCD*, and over 100 approved changes affecting nearly every page. Unfortunately, it was estimated that only 20 percent of *MUTCD* owners had received all eight volumes of the rulings. Therefore, the 1978 edition of the *MUTCD* was published in order to provide an up-to-date manual. The format of the manual was changed to a binder with loose-leaf pages.

Most of the changes to the markings section were intended to further clarify the meaning and application of some markings. The most significant marking change in the 1978 *MUTCD* was adoption of the current practice for the use of yellow pavement markings—as a centerline on two-way roadways and as the left edge line on one-way (divided) roadways (incorporating the 1973 revision of the 1971 *MUTCD*). The

stripe/gap ratio was also changed in the 1978 *MUTCD*, with the length of the stripe changing to 10 ft and the gap length changing to 30 ft.

The 1978 *MUTCD* was revised four times. Marking changes within these revisions included a requirement that edge lines be used on all rural multilane highways and the lowering of the driver eye height for marking no-passing zones.

1988 *MUTCD*

By 1988, FHWA had officially adopted over 130 changes to the 1978 *MUTCD*. Most of the changes were distributed in the four revisions to the 1978 edition. However, over one-half of them had not been distributed. Additionally, the concept behind the loose-leaf format had not worked well. As a result of these two factors, FHWA decided to publish a new edition of the *MUTCD* in 1988 to provide an up-to-date manual. The 1988 edition included all changes made to the 1978 edition in Revisions 1 through 4, plus a number of additional changes that were added as Revision 5. The changes to permanent markings in Revision 5 were generally minor.

The 1988 *MUTCD* has been revised seven times. The most significant change affecting markings is the last revision that established mandatory (shall) and recommended (should) use of centerline and edge line markings based on ADT and road width.

2000 *MUTCD*

In December 2000, the FHWA published the Millennium *MUTCD*. This almost 1,000-page manual contained a large number of changes to standards and guidelines for traffic control devices. Most of the changes to pavement markings do not affect the use of white and yellow colors. The 2000 *MUTCD* did revise the centerline and edge line warrants originally published as a revision of the 1988 *MUTCD*. Figure A-2 presents the centerline and edge line warrants as contained in Revision 1 of the 2000 *MUTCD* (*1*).

OTHER EVOLUTIONARY ISSUES

In addition to the evolution of *MUTCD* principles for markings patterns and the use of color, there is an evolutionary history behind other important marking issues that could affect the conversion from a yellow–white to all-white system. These include retroreflectivity requirements, color definitions, and marking materials.

Retroreflectivity

Nighttime visibility of pavement markings has been addressed in some fashion in every edition of the *MUTCD*, although it was not until the 1954 *MUTCD* revision that there was a requirement for retroreflective markings. The 1935 *MUTCD* contained an appendix that provided a standard specification for white pavement paint. Although retroreflective markings were not used at this time, a portion of this specification addressed nighttime visibility of the marking materials, stating:

> *"The night visibility of the reflected paint as measured by an Illuminometer in photometric apparatus at an angle of incidence of 88E20′ with an angle of reflection of 87E8′, shall be at least ten foot-candles when compared to a ground standard milk glass plate having an angle of diffuse reflection of approximately 77 percent and furnishing an Illuminometer reading of three foot-candles."*

The 1942 *MUTCD* was the first to describe the practice of using glass beads on the paint to provide retroreflectivity. The 1948 *MUTCD* also described the use of glass beads to provide retroreflective markings and provided the following regarding the use of retroreflective markings:

> *"Reflectorization for better night visibility is desirable for almost all markings, but it is neither practical nor necessary requirement in all cases. Reflectorization is of doubtful value on well-lighted city streets, for example, and it is not ordinarily essential for center or lane lines where there are no special hazards. At least the following markings should normally be reflectorized:*
>
> 1. *Centerlines on multilaned pavements.*
> 2. *No-passing barrier lines at:*
>   *(a) No-passing zones on two- and three-lane roads.*
>   *(b) Pavement-width transitions.*
>   *(c) Approaches to obstructions in the roadway.*
>   *(d) Approaches to railroad crossings.*
> 3. *Striping on vertical surfaces of objects in and adjacent to the roadway."*

As mentioned previously, there was no requirement (shall condition) for pavement marking retroreflectivity until the 1954 revision of the 1948 *MUTCD*. This revision required that all rural markings that had application at night be retroreflectorized. In the 1961 *MUTCD*, requirements for marking retroreflectivity were expanded so that all pavement markings having application at night were required to be retroreflectorized. Language in the 1961 *MUTCD* indicated that retroreflectorization was desirable even on streets with illumination. However, the 1971 *MUTCD* softened the retroreflectivity language somewhat and stated that markings having application at night be retroreflectorized, unless ambient illuminated assured adequate visibility. The following statement has remained the same in the 1971, 1978, and 1988 *MUTCD*s.

> *"Markings which must be visible at night shall be reflectorized unless ambient illumination assures adequate visibility. All markings on Interstate highways shall be reflectorized."*

Section 3B.01 Yellow Centerline and Left Edge Line Pavement Markings and Warrants

[Note, only the portion of the section addressing centerline warrants is presented.]

Standard:

Centerline markings shall be placed on all paved urban arterials and collectors that have a traveled width of 6.1 m (20 ft) or more and an ADT of 6,000 vehicles per day or greater. Centerline markings shall also be placed on all paved two-way streets or highways that have three or more traffic lanes.

Guidance:

Centerline markings should be placed on paved urban arterials and collectors that have a traveled width of 6.1 m (20 ft) or more and an ADT of 4,000 vehicles per day or greater. Centerline markings should also be placed on all rural arterials and collectors that have a traveled width of 5.5 m (18 ft) or more and an ADT of 3,000 vehicles per day or greater. Centerline markings should also be placed on other traveled ways where an engineering study indicates such a need.

Engineering judgment should be used in determining whether to place centerline markings on traveled ways that are less than 4.9 m (16 ft) wide because of the potential for traffic encroaching on the pavement edges, traffic being affected by parked vehicles, and traffic encroaching into the opposing traffic lane.

Option:

Centerline markings may be placed on other paved two-way traveled ways that are 4.9 m (16 ft) or more in width.

If a traffic count is not available, the ADTs described in this Section may be estimates that are based on engineering judgment.

Section 3B.07 Warrants for Use of Edge Lines

Standard:

Edge line markings shall be placed on paved streets or highways with the following characteristics:

A. Freeways;

B. Expressways; and

C. Rural arterials with a traveled way of 6.1 m (20 ft) or more in width and an ADT of 6,000 vehicles per day or greater.

Guidance:

Edge line markings should be placed on paved streets or highways with the following characteristics:

A. Rural arterials and collectors with a traveled way of 6.1 m (20 ft) or more in width and an ADT of 3,000 vehicles per day or greater.

B. At other paved streets and highways where an engineering study indicates a need for edge line markings.

Edge line markings should not be placed where an engineering study or engineering judgment indicates that providing them would decrease safety.

Option:

Edge line markings may be placed on streets and highways that do not have centerline markings.

Edge line markings may be excluded, based on engineering judgment, for reasons such as if the traveled way edges are delineated by curbs, parking, bicycle lanes, or other markings.

Edge line markings may be used where edge delineation is desirable to minimize unnecessary driving on paved shoulders or on refuge areas that have lesser structural pavement strength than the adjacent roadway.

Figure A-2. 1988 MUTCD revision on centerline and edge line warrants.

Although there has been a requirement for retroreflectorized pavement markings in the *MUTCD* for almost 40 years, this requirement has no specific values of retroreflectivity. In 1985, the Center for Auto Safety (CAS) petitioned the FHWA to initiate rulemaking on the issue of minimum standards of retroreflectivity for traffic control devices. That petition contended that the range of drivers was not being accommodated by the traffic control devices allowed in the *MUTCD* with respect to nighttime conspicuity dependent upon retroreflective illumination. In April 1985, the FHWA published a request for comments and a notice of proposed amendment to the *MUTCD* in the *Federal Register*. The *Federal Register* notice summarized the problem and asked 10 questions regarding retroreflectivity of signs and markings.

Several years later, Congress included the following requirement in the 1993 Department of Transportation Appropriations Act:

> *"The Secretary of Transportation shall revise the MUTCD to include a standard for a minimum level of retroreflectivity that must be maintained for traffic signs and pavement markings which apply to all roads open to public travel."*

The FHWA research program on the nighttime visibility of traffic control devices preceded the CAS petition for minimum levels of retroreflectivity for signs and markings. This research program continued through the 1980s and into the 1990s. This research included several different research studies, which are described in a draft FHWA report that presents research recommendations for minimum levels of in-service retroreflectivity for pavement markings (*7*). These values are presented in Table A-3.

At the present time, the FHWA is awaiting recommendations from an AASHTO retroreflectivity task force before proceeding with development of a proposed rule on pave-

TABLE A-3 FHWA research recommendations for minimum retroreflectivity values

Option 1		Non-Freeway, ≤ 40 mph	Non-Freeway, ≥ 45 mph	Freeway, ≥ 55 mph
Option 2		≤ 40 mph	≥ 45 mph	≥ 60 mph, > 10,000 ADT
Option 3		≤ 40 mph	45-55 mph	≥ 60 mph
With RRPMs	White	30	35	70
	Yellow	30	35	70
Without RRPMs	White	85	100	150
	Yellow	55	65	100

Source: Reference (*7*).
Note: Retroreflectivity values are mcd/m2/lux and measured at 30 meter geometry.
RRPMs – Retroreflective Raised Pavement Markers.

TABLE A-4 Pavement marking color in the MUTCD since 1948

MUTCD	Color Language
1948	The correct color for yellow traffic paint is the same as that specified for highway signs. Color cards showing this "highway yellow" may be obtained from the Public Roads Administration.
1961	The correct color for yellow traffic paint is the same as that specified for highway signs. Color cards showing this "highway yellow" may be obtained from the Public Roads Administration on request.
1971, 1978, and 1988	The colors for pavement markings shall conform to the standard highway colors.

ment marking retroreflectivity. The FHWA has indicated that a proposed rule on pavement marking retroreflectivity is not to be expected before 2003 at the earliest.

Color Definitions

At various times during the evolution of the *MUTCD*, white, yellow, red, and black have been used as pavement marking colors. Throughout their evolution, the various editions of the *MUTCD* have indicated that pavement marking colors should correspond to the color requirements for signs. Table A-4 summarizes the language regarding marking color in the various editions.

On December 21, 1999, the FHWA issued a proposed rule to change the specification for the color of signs and pavement markings. The proposed rule provides specifications for both daytime color of yellow, white, blue, and red pavement markings and nighttime color of yellow and white pavement markings. Although not specifically indicated in the proposed rule, FHWA staff have indicated that these color specifications are intended to represent end-of-service life values for pavement marking color. In other words, markings that are not within the defined 1931 International Commission on Illumination chromaticity coordinates, or within the daytime luminance factors limits, should be replaced. There are several controversial aspects associated with this proposed rule, one of which is that there is currently no instrument capable of measuring nighttime pavement marking color in the field.

APPENDIX B

PREVIOUS RESEARCH ON DRIVER UNDERSTANDING

Pavement markings are unlike the other types of traffic control devices (signs and signals) as there is little inherent meaning in the colors and patterns of pavement marking lines. A wider line is more significant than a narrow one, a solid line is more significant than a broken line, and a yellow line can be more closely associated with a potential hazard than a white line. The main issue is whether drivers can recognize these distinctions. Unfortunately, comprehension of pavement markings has not been addressed to the same extent that it has for signs. One FHWA-sponsored study evaluated the technical support for various standards in the *MUTCD* (*32*). The research identified 17 standards as having a significant need for additional research. Centerline markings were among those believed in need of additional research. The research indicated that there are "*serious concerns about the driving public's understanding of lane markings.*" The research also indicated a need for better visibility for pavement markings, particularly in relation to wet–night driving.

The research team was able to identify 11 research efforts that included assessments of driver understanding or comprehension of pavement markings. Much of the pavement marking research was performed as part of larger studies on traffic control devices in general. Very few sources exist that address only pavement markings and driver comprehension. This appendix summarizes the pertinent findings from the studies that can offer some insight into comprehension of the current U.S. pavement marking system and how comprehension might affect implementation of an all-white marking system. Table B-1 presents a summary of the previous research on driver understanding of pavement markings that were evaluated for this research effort.

A critical review of these previous evaluations reveals that it can be very difficult to quantify how well drivers understand a particular marking. In many instances, different studies determined different levels of comprehension for the same marking. When evaluating comprehension of a marking, the outcome of the evaluation is dependent on the research method, the specific wording of the evaluation question, the format of the answer(s), the survey procedure, the sampling process, and the year in which the study was performed.

NATIONAL STUDIES OF PAVEMENT MARKING COMPREHENSION

There have been few national evaluations of driver understanding of traffic control devices that included pavement markings in the evaluations. The research team was able to identify four studies that had information pertinent to marking comprehension. The earliest of these was done to support the development of the 1971 *MUTCD*, with the most recent being conducted in 1980.

FHWA Evaluation for the 1971 *MUTCD*

In 1972, the FHWA published a two-volume report that described research conducted to investigate new traffic signs, markings, and signals proposed for inclusion in the 1971 *MUTCD* (*10*). The devices were evaluated in the laboratory and on the road. The pavement marking issues evaluated in the research addressed the marking color code proposed for the new *MUTCD*. In the proposed scheme, yellow was used to separate opposing traffic (all centerlines) and white for separating traffic moving in the same direction.

There were two parts to the evaluations: a multiple-choice questionnaire about specific roadway situations (23 questions) and an open-ended questionnaire on the meaning of specific pavement markings (nine questions). The same 63 subjects participated in both parts. In the first part, subjects were shown four typical road diagrams that represented a variety of road geometries and use of yellow and white solid and broken lines (as proposed for the 1971 *MUTCD*). Figure B-1 presents the four diagrams. Cars making specific maneuvers were shown on the diagrams and researchers asked if the maneuvers were permitted by the markings. Subjects choose one of the following responses: clearly permitted, permitted with caution, discouraged, or prohibited. The results of the questions are presented in Tables B-2 to B-5.

In the second part of the evaluation, respondents were presented with nine questions that asked them to generalize the meanings of various markings and their colors (in an open-ended format). The same 63 drivers participated in the evaluation. The questions are listed below. The responses were categorized and are summarized in Table B-6.

1. In the road diagrams that you have just seen, what does a double solid line tell you?
2. In the road diagrams that you have just seen, what does a single solid line tell you?
3. In the road diagrams that you have just seen, what does a single broken line tell you?
4. In the road diagrams that you have just seen, what does a double line tell you when a broken line is in your lane?
5. In the road diagrams that you have just seen, what does a double line tell you when a solid line is in your lane?

TABLE B-1 Summary of previous research evaluation procedures

Type	Description	Year	Reference	No. of Questions[1]	No. of Subjects	Presentation Format	Form of Response	Testing Area
National	Evaluations for 1971 MUTCD	1972	10	31	63	graphic image	multiple-choice open-ended	One state
	Evaluations of Marking Code	1976	11	7	254	graphic image	open-ended	104 from FHWA 150 from USCG and FAA
						film	yes/no	
	First AAA	1979	12	8	3,164	film	multiple-choice	Nationwide
	Second AAA	1980	13	6	1,748	film	multiple-choice	Nationwide
State	Ohio	1967	9	36	unclear	photograph	yes/no	Seven states
	Wisconsin	1993	15	4	195	telephone survey	open-ended	Wisconsin
	Kansas	1995	16	5	502	graphic image	multiple-choice	Kansas cities
Texas	First TTI	1978	33	3	422	color photo	multiple-choice	Texas cities
	Second TTI	1981	14	8	94	color photo and film	open-ended	Texas cities
				8	375	color photo	multiple-choice	Texas cities
	Third TTI	1995	17	7	1,745	color photo and graphic image	multiple-choice	Texas cities
				1	322	graphic image	open-ended	Houston
	TTI Border	1999	18	5	490-593 Texas drivers	graphic image	open-ended	Texas-Mexico border
				5	236-417 Mexico drivers	graphic image	open-ended	Texas-Mexico border

Notes: [1]Number of questions related to pavement markings.

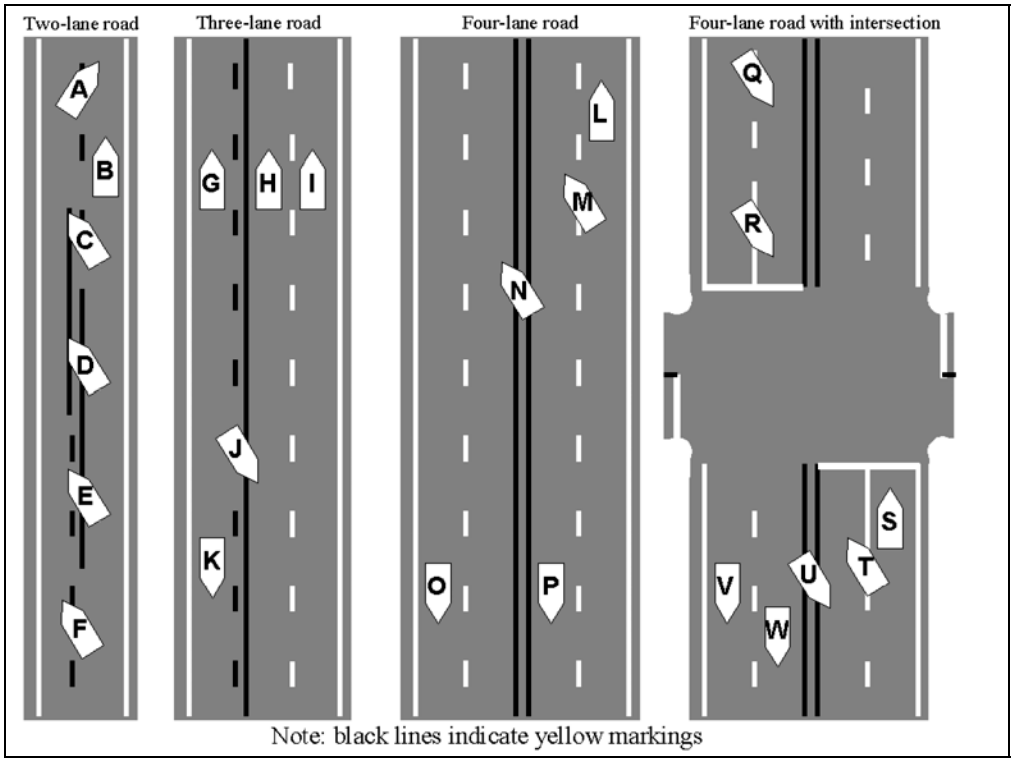


Figure B-1. Graphics from FHWA evaluation for 1971 MUTCD.

TABLE B-2 Two-lane road results

Car	Maneuver	Percent Response				
		CP	PwC	Dis	Pro	NA
A	Crossing single broken yellow	41	48	2	10	-
B	In right lane	100	-	-	-	-
C	Crossing double broken-solid yellow	16	70	5	11	2
D	Crossing double solid-solid yellow	2	-	-	98	-
E	Crossing double solid-broken yellow	-	2	3	94	2
F	Crossing single broken yellow, right to left just before double solid-broken yellow begins	10	25	30	33	2

Notes: CP=clearly permitted, PwC=permitted with caution, Dis=discouraged, Pro=prohibited, NA=not ascertained.

TABLE B-3 Three-lane road results

Car	Maneuver	Percent Response				
		CP	PwC	Dis	Pro	NA
G	In left-hand lane (wrong way) to right of solid white (edge marker) and to left of double solid-broken yellow. Passing cars H and I.	-	-	2	98	-
H	In middle lane to right of double solid-broken yellow, to left of broken white, passing car I.	70	25	2	3	-
I	In right hand lane	95	2	3	-	-
J	Crossing double broken-solid yellow	12	39	5	14	-
K	In right hand lane	100	-	-	-	-

Notes: CP=clearly permitted, PwC=permitted with caution, Dis=discouraged, Pro=prohibited, NA=not ascertained.

TABLE B-4 Four-lane road results

Car	Maneuver	Percent Response				
		CP	PwC	Dis	Pro	NA
L	In right-hand lane	97	-	-	2	2
M	Crossing broken white line	52	44	-	-	3
N	Crossing double solid-solid yellow	-	-	2	97	2
O	In right-hand lane	98	-	-	-	2
P	In center (wrong way) lane to right of broken white, to left of double solid-solid yellow	2	2	-	95	2

Notes: CP=clearly permitted, PwC=permitted with caution, Dis=discouraged, Pro=prohibited, NA=not ascertained.

TABLE B-5 Four-lane roadway with intersection results

Car	Maneuver	Percent Response				
		CP	PwC	Dis	Pro	NA
Q	Crossing broken white line	54	33	11	-	2
R	Crossing solid white line	3	13	37	48	-
S	In right-hand lane	98	-	-	2	-
T	Crossing solid white line	6	16	32	44	2
U	Crossing double solid-solid yellow	2	-	2	97	-
V	In right lane	100	-	-	-	-
W	In second lane, to right of double solid-solid yellow line, to left of broken white line	81	17	-	1	-

Notes: CP=clearly permitted, PwC=permitted with caution, Dis=discouraged, Pro=prohibited, NA=not ascertained.

TABLE B-6 Driver interpretation results

Question	Response	Percent	Question	Response	Percent
1: Double Solid Line	Crossing prohibited, do not pass	94	6: Yellow Line	Separate(s)opposite traffic lanes, divided traffic	29
	Dangerous area	2		Do not cross, pass	33
	Four-lane highway	2		Color not a factor	10
	NA	3		Caution	8
2: Single Solid Line	Use extra caution, passing discouraged	79		State road	2
	Stay to right, one-way	13		Center of road	2
	Oncoming traffic	5		Restriction in effect	2
	NA	3		Regulates traffic lanes	2
3: Single Broken Line	Cross with caution, etc.	62		Whether I may pass or not	2
	O.K. to pass, etc.	35		No parking or stopping	2
	NA	3		I am in Vermont	2
4: Double Line, Broken in your Lane	Cross with caution, etc.	60		NR	2
	May pass, etc.	16		NA	8
	Pass with caution, etc.	14	7: White Line	Outer marking, marks road	24
	May not be crossed	3		Do not pass	21
	Turn out here	2		Color not a factor	13
	NR	2		Pass with caution	10
	NA	3		Traffic going same way in next lane	6
5: Double Line, Solid in your Lane	Do not coss, stay in lane, etc.	92		Center of two-way road	5
	Discourage to cross	2		Whether I may pass or not	2
	NR	2		Divided highway	2
	NA	3		How many lanes	2
				Caution	2
				Do not have to be cautious	2
				NR	3
				NA	11

Note: Sample size is 63. NR=no response, NA=not ascertained.

6. In the road diagrams that you have just seen, what does a yellow line tell you?
7. In the road diagrams that you have just seen, what does a white line tell you?

Based on the evaluation results, the researchers concluded that drivers were able to understand and interpret the intended meanings of the line type (solid or broken) of road markings, but not the proposed meanings for colors. The researchers also found that drivers tend to consider driving maneuvers as being clearly permitted or clearly prohibited. The permitted with caution and discouraged categories were not distinguished. While the information reported in this research was useful at that time, it cannot be considered to represent the knowledge of current drivers. The 63 drivers that participated in this study were accustomed to white being used as the centerline in some roadway situations. Therefore, it is not surprising that comprehension of yellow as separating opposing traffic was low.

FHWA Evaluation of the Road Marking Code

In the mid-1970s, the FHWA conducted its own research on the effectiveness of the pavement marking system (*11*). Two evaluations were conducted. In the first, a questionnaire using graphic images of a road scene was used to test how well 254 drivers understood various markings. In the second evaluation, subjects were shown a film and asked several yes/no questions about each film clip.

In the static comprehension evaluation, drivers were asked the meanings of several pavement markings. Figure B-2 illustrates the diagrams presented to the subjects. For each marking, subjects were asked "*What do these road markings mean?*" Responses were open-ended and categorized by the researchers as correct or incorrect. A correct answer was defined as one containing no incorrect statements, even though the answer is not necessarily complete. A wrong answer was one that was at least partially contradicted by the *MUTCD* interpretation. An answer of "to separate lanes," by itself was

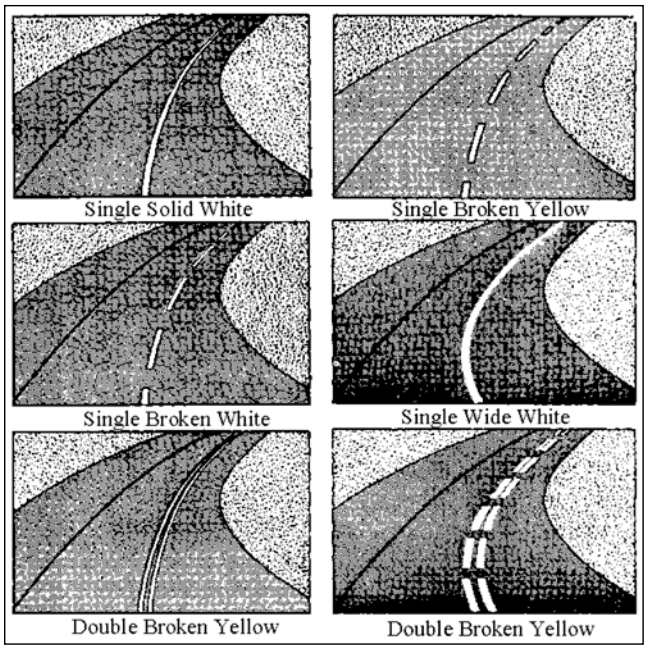


Figure B-2. Diagrams used in the evaluation of the road marking code.

considered incorrect as this is a function of many types of road markings. Table B-7 presents the results of this evaluation.

The FHWA researchers concluded that the first evaluation results indicated that the markings were not well understood, with the possible exception of the double solid yellow line. Comprehension of the broken yellow centerline was particularly low. While 70 percent of the sample gave a correct interpretation, only 11 percent indicated both of the correct meanings: separating opposing traffic and passing permitted in both directions.

The second evaluation was concerned with identifying the most logical and understandable system of markings to address common highway situations. The researchers evaluated driver understanding of common roadway markings through the use of film representations of roadway scenes. Seven scenes were shown to 96 drivers and they were asked one to five questions about each scene. The questions all required yes, no, or don't know responses. The results show that drivers understood the broken yellow line allows crossing. Drivers also understood the passing prohibition meaning of the double solid yellow and double broken yellow markings. They also were able to differentiate this meaning with crossing the line to enter driveways or cross the street. Drivers did not fully understand the meaning of the solid white line. Approximately 60 percent of drivers believed they could cross the solid white line at an intersection, and only 31 percent believed they could cross the solid white marking at a diverge area. The data also indicated that drivers are not aware that passing on the shoulder is not allowed.

Overall, the researchers concluded that drivers did not show an adequate understanding of road markings: many misconceptions were shown in the driver explanations of the markings. However, drivers did understand the meaning of the double yellow and one-direction no-passing markings. On the basis of the two evaluations, the researchers recommended that the pavement marking system be revised, but did not offer specific recommendations for changes. But the researchers did conclude that "*the research findings bring into question the use of yellow markings to show the separation of counter-moving traffic*." They further concluded that the research data "*advance no convincing evidence that the yellow–white dimension of coding is associated by the driver with the direction of traffic movement*."

AAA 1979 Evaluation

In the late 1970s, the American Automobile Association (AAA) Foundation for Traffic Safety sponsored the first of two evaluations of driver understanding of traffic control devices (*12*). This study used film of actual roadway scenes with a multiple-choice questionnaire to assess driver under-

TABLE B-7 Results of FHWA static evaluation of comprehension

Marking	Percent Correct	Percent Incorrect[1]	Percent Wrong[2]
Single broken yellow (centerline, passing permitted)	70	30	18
Double solid yellow markings (centerline, passing prohibited)	93	7	7
Double broken yellow (reversible lane)	55	45	36
Single broken white (lane line)	59	41	17
Single solid white (edge line)	28	72	58
Single wide white (lane line, passing discouraged)	19	81	61

Notes: [1]The percent incorrect column represents the sum of wrong answers and non-defined separate lanes answers.
[2]The percent wrong column represents the percentage of responses that contradict the MUTCD.

standing of various traffic control devices. This survey had a sample size of 3,164 subjects and was administered nationwide through AAA Club offices. The recruiting method used in the evaluation is not described. In order to determine understanding, the questions in this survey asked about legal driving maneuvers in a given scenario. The survey consisted of 23 questions on 16 different traffic control devices. Eight questions covered pavement markings. The eight markings are listed below. However, it should be noted that the marking referred to as the "old two-way left turn lane" was established as the marking for a reversible lane by the 1971 *MUTCD*. This reduces the value of the results for these questions because the focus of the survey questions was on an application for which the markings should not have been used at the time the survey was administered. A similar dilemma existed with the single solid yellow line centerline, as that marking was not specified by the *MUTCD*. While some jurisdictions used the single solid yellow line centerline in specific applications (typically mountain roads), the use of the line is not consistent nationwide. In fact, an interpretation of the 1971 *MUTCD* has specifically indicated that the single solid yellow line should not be used for a centerline. This limits the value of the three questions on this marking to the all-white study. As a result of these limitations, the only pavement marking questions that have value are those that relate to the two-way left turn lane. The results for these questions are shown in Table B-8.

- Two-way left turn—moving into the lane
- Two-way left turn—maneuvers that can be made from the lane
- Old two-way left-turn lane (new reverse lane) move into
- Old two-way left-turn lane (new reverse lane) move out of
- Old two-way left-turn lane (new reverse lane) use
- Single solid yellow stripe (mountain road)
- Single solid yellow stripe (urban)
- Single solid yellow stripe (construction area)

While the results shown in Table B-8 have some value for indicating driver understanding of the left turn lane markings, they have little application in evaluating the potential impacts of converting to an all-white marking system. Color comparisons cannot be made because no white pavement markings were included in the survey. The results of the evaluation are also questionable because the survey sample does not appear to be random, limiting its representativeness. The one potentially useful bit of information from this evaluation is that drivers appear to be more willing to cross a broken marking than they are a solid marking. The study did report that, among all the devices evaluated, the area of greatest weakness in driver understanding is found in pavement markings. Motorists misunderstand or are uncertain of what is permitted by markings.

AAA 1980 Evaluation

In 1980, the AAA Foundation for Traffic Safety sponsored a second evaluation of traffic control device understanding (*13*). The survey included three devices from the previous evaluation (to allow comparisons between the two) and 16 new traffic control devices. The survey had six pavement marking questions, including three from the previous survey. Except for the change in devices, the evaluation procedure was identical to the first evaluation. The markings included in the second survey are listed below. Table B-9 presents the results for the two-way left turn lane questions and the double-wide short broken white line. The results for the single solid yellow centerline are not presented because that marking did not comply with the 1971 *MUTCD*. The results for the diamond markings and double-wide short broken white line are also not presented because they are not pertinent to the all-white evaluation.

- Two-way left turn—moving into the lane
- Two-way left turn—maneuvers that can be made from the lane
- Single solid yellow stripe (mountain road)
- Diamond marking (restricted lane—buses and right turns only)—illegal maneuver
- Diamond marking (restricted lane—buses and right turns only)—legal maneuver
- Double-wide short broken white lane ends marking

The results presented in Table B-9 indicate that in 1980, motorists did not understand the meaning of the two-way left-turn lane markings.

TABLE B-8 Two-way left turn lane results from 1979 AAA evaluation

Marking	Focus of Question	Responses	Correct Response Rate (percent)
Two-way left turn lane (broken and solid yellow line on each side of lane)	Is it legal to move into the lane? (Sample size = 3,126)	Legal	18
		Not legal	82
	What maneuver is legal from the lane? (Sample size = 3,094)	Left turn	69
		Right turn	9
		Passing	21
		Backing up	1

TABLE B-9 Two-way left turn lane results from 1980 AAA evaluation

Marking	Focus of Question	Responses	Correct Response Rate (percent)
Two-way left turn lane (broken and solid yellow line on each side of lane)	Is it legal to move into the lane? (Sample size = 1,735)	Legal	26
		Not legal	74
	What maneuver is legal from the lane? (Sample size = 3,094)	Left turn	79
		Right turn	11
		Passing	1
		Backing up	< 1

STATE STUDIES OF PAVEMENT MARKING COMPREHENSION

State transportation agencies are responsible for conducting much of the traffic operations research in the United States. However, with respect to the meaning of pavement markings, the states (other than Texas, which is addressed later) have conducted little research. Three evaluations sponsored by state transportation agencies were identified, including one each in Ohio, Kansas, and Wisconsin. The Ohio evaluation was conducted to evaluate the effectiveness of systems being considered for the 1971 *MUTCD*, while the Kansas and Ohio evaluations were both conducted after the publication of the 1988 *MUTCD*.

Ohio Evaluation

In the mid-1960s, the Ohio Department of Highways conducted research to compare the effectiveness of various pavement markings (*9*). At the time of the research, the white centerline was still a standard treatment. There were five phases in the research: slide presentation, lateral placement, passing study, lane usage, and driver interview.

The first phase of the research used a slide presentation to evaluate the then-current pavement marking system (established by the 1961 *MUTCD*) and alternative systems being considered by the National Joint Committee on Uniform Traffic Control Devices. These alternate systems were being considered for inclusion in the 1971 *MUTCD*. The first alternative system used color to define direction of travel and shape to define degree of safety. This is the system that was ultimately implemented in the 1971 *MUTCD*. The second alternative system used line shape to designate travel direction and color to designate degree of safety. Table B-10 describes the meanings of the various markings that composed the two alternative systems.

The sampling procedure for this evaluation is not described in the report other than stating that responses came from seven states, making it impossible to critically evaluate the validity of the results. Nor does the report present the graphics that were used in the evaluation, making it impossible to assess what the drivers were actually responding to. Slides were used to present images representing all three systems. Subjects were asked to provide a yes or no answer to the two questions shown below. In the first presentation, slides from the three systems were presented in random order with very little explanation. Then subjects were told the rationale for each of the three marking systems. The slides were then grouped according to the marking system and drivers were asked to respond to them, answering the same two questions.

- Is the lane immediately to your left for vehicles moving the same direction?
- Is passing permitted at this location?

Table B-11 indicates the results of the random presentation for the individual types of lines. According to the researchers, the data in Table B-11 indicate that line shape and color convey a meaning to drivers. However, because over one-third of the drivers interpreted the broken white line as an indicator of opposing flow, the data may also suggest that line shape is a more important factor in determining meaning. Table B-12 indicates the results of both the random and ordered presentations according to the individuals systems presented.

TABLE B-10 Meanings of markings in alternative systems

Line	Meaning in Color Based System	Meaning in Line Shape Based System
Yellow	Separates traffic flowing in the opposite direction	Passing or lane changing not permitted
White	Separates traffic flowing in the same direction	Passing and lane changing permitted
Solid	Passing or lane changing not permitted	Separates traffic flowing in the opposite direction
Broken	Passing and lane changing permitted	Separates traffic flowing in the same direction

TABLE B-11 Results of random presentation by type of line

Response	Line Type			
	Solid Yellow	Broken Yellow	Solid White	Broken White
Indicates Opposite Direction	90%	77%	79%	34%
Indicates Unsafe to Pass	88%	37%	66%	9%

TABLE B-12 Results for individual marking systems

System	Sample Size	Random		Ordered	
		Travel Direction	Passing Safety	Travel Direction	Passing Safety
Then current	3,376	87%	89%	96%	70%
Color-Based	9,035	67	70	89	64
Line Shape-Based	6,822	81	84	92	47

The line-shape system was the most easily understood of the two alternatives. It was also more closely related to the then-current system than the color system (which was eventually adopted in the 1971 *MUTCD*). The data indicate that drivers can adapt to new systems. Overall, the researchers indicate that color alone does not convey a consistent message.

Wisconsin Evaluation

The focus of this study was to determine the opinions of Wisconsin drivers on the state's pavement markings, specifically those on the state's rural highway system (*15*). Overall, there were four phases in the evaluation: personal and focus group interviews, telephone survey, mail survey, and highway marking inspections. The telephone survey was the only phase that addressed driver understanding of the meaning of pavement markings.

In the telephone survey, 195 licensed drivers were asked to describe the meaning of four pavement markings. Answers were given in the respondents own words, then classified by the researchers as correct, incorrect, or don't know. The results are presented in Table B-13. The report does not indicate whether the solid white line is intended to represent an edge line or a solid white lane line.

The results indicate that the solid white line was the least understood marking while the solid yellow line was the best understood marking. Overall understanding was low. With the exception of the dashed yellow line, gender differences were significant. One of the unique characteristics of the telephone survey evaluation is that respondents were not viewing a diagram when they responded to the questions. While this could lead errors by the respondents misinterpreting the intent of the questions, it also has the advantage of eliminating bias introduced through the diagram. The report of the telephone survey results did not provide specific data beyond that shown in the preceding table, making it difficult to interpret the results.

Kansas Evaluation

A Kansas study used two self-administered questionnaire type surveys to determine driver understanding of various

TABLE B-13 Result from Wisconsin telephone survey

Marking	Question	Correct (percent)	Don't Know (percent)	Incorrect (percent)
Double Solid Yellow Centerline	When you see solid yellow lines between lanes, what do these indicate?	80	13	4
Dashed Yellow Centerline	When you see dashed yellow lines in the middle of the highway, what do these indicate?	69	10	8
Broken White Lane Line	When you see broken white lines between lanes, what do these indicate?	57	32	5
Solid White Line	When you see solid white lines on the highway, what do these indicate?	38	23	31

traffic control devices (*16*). The first study was a multiple-choice evaluation of 43 devices, five of which were pavement markings. The pavement markings in this survey were represented by color plan views of the pavement markings (Figure B-3). The possible responses include one correct response, two incorrect responses, and a response of "not sure." An additional answer line was included for any comments provided by the respondent. The survey questions were designed to test understanding of specific safety-related messages given by the markings. The second survey was an "open ended" questionnaire that required respondents to record their own explanation of the meaning of each traffic control device. This survey contained 10 questions, all of which were related to signs. The open-ended format was used to provide an indication of how much respondents had guessed the correct answer from the first survey.

The primary evaluation technique was a self-administered survey completed by 502 drivers in seven Kansas counties. Evaluations were conducted at various locations, including courthouses, city halls, places of employment, and selected civic and social functions. As a result of the sampling procedure, the survey sample was not random. The survey results for the five pavement marking questions are provided in Table B-14.

Three markings stood out as being poorly understood: the solid white edge line, the single broken white lane line, and the two-way left-turn lane marking. The single broken yellow centerline and the single solid yellow no-passing line

TABLE B-14 Marking results of Kansas evaluation

Marking (sample size)	Question	Responses	Percent
Two-Way Left Turn Lane (n = 494) see Figure B-3a	What is the purpose of the Center Lane of this roadway?	***The center lane is to be used for left turns only by vehicles going in the same direction as you are, and also by oncoming traffic.***	***62.8***
		The center lane is for emergency vehicle use only. No other vehicles are allowed to use this lane.	11.7
		The center lane is to be used to make left turns or to pass other vehicles.	3.0
		Not sure.	22.5
No passing zone markings in the direction of travel (n = 500) see Figure B-3b	If you are traveling in the direction of the arrow, what is the meaning of the Solid Yellow Line in the center of the highway?	***This is a two-way road where you are not allowed to pass.***	***96.2***
		This is a two-way road where you are allowed to pass.	2.0
		This is a one-way road where you are allowed to change lanes.	0.4
		Not sure.	1.4
Two-lane road with no passing zone markings (n = 497) see Figure B-3b	If you are traveling in the direction of the arrow, what is the meaning of the Solid White Line on the right side of the highway?	***To let you know where the edge of your driving lane is.***	***48.1***
		To let you know that you should not cross this line for any reason.	34.2
		To let you know there is no curb on this road.	3.2
		Not sure.	14.5
Two-lane, two-way road with no edge lines (n 499) see Figure B-3c	What is the meaning of the Dashed Yellow Line in the center of this highway?	***This is a two-way road where you are allowed to pass.***	***87.8***
		This is a one-way road where you are allowed to drive in either lane.	6.4
		This is a two-way road where you are not allowed to pass.	3.6
		Not sure.	2.2
Two-lane, one-way road with no edge lines (n = 500) see Figure B-3d	What is the meaning of the Dashed White Line in the center of this highway?	***This is a, one-way road where you are allowed to change lanes.***	***52.4***
		This is a two-way road where you are allowed to change lanes.	38.0
		This is a one-way road where you are not allowed to change lanes.	3.4
		Not sure.	6.2

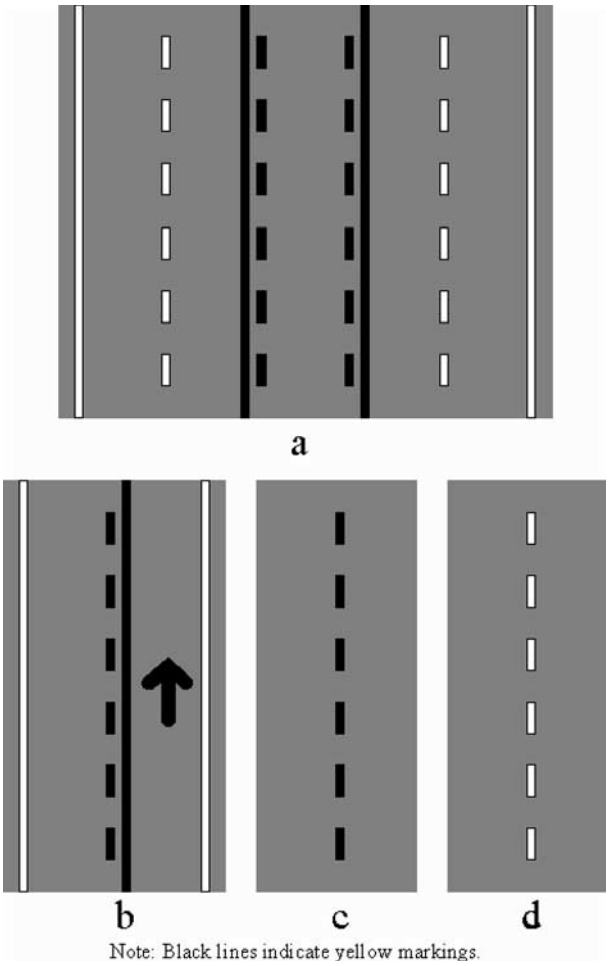


Figure B-3. Graphics used in Kansas evaluation.

were the most understood markings in the study. The correct, incorrect, and not sure response rates for these markings can be seen in Table B-14.

As with all evaluations, there were several limitations that must be considered when interpreting the evaluation results. As proven in this research, the multiple-choice format tends to overestimate actual comprehension of a traffic control device. The use of self-administered survey instruments favors responses from drivers with higher education levels. Drivers that cannot read would not be able to participate in this survey. Because of the locations where the surveys were administered (not a random sample), the results may not be representative of the general population. Finally, the images used to represent the markings removed many of the environmental clues that drivers often use to determine the meaning of a traffic control device.

TEXAS STUDIES OF PAVEMENT MARKING COMPREHENSION

Perhaps the most extensive evaluations of driver comprehension of traffic control devices has been conducted by the Texas Transportation Institute (TTI) over the course of several studies for the Texas DOT. Four evaluations have been conducted since the 1971 *MUTCD* was published. While the bulk of each of these evaluations focused on traffic signs, each of the four included some questions on driver understanding of pavement markings.

TTI 1978 Evaluation

The earliest of TTI's traffic control device comprehension evaluations was conducted in the late 1970s (*33*). Two efforts were undertaken in this research effort. In the first, researchers solicited comments from driver training professional regarding commonly misunderstood devices. With respect to markings, the driver training professionals offered more comments than for any other devices. The following represents the findings from the report on this effort:

> *The broad area of markings has received more comments than the other areas. On centerline pavement markings, 45 percent of the respondents had specific comments. Both color and continuous or broken stripes are not always understood, i.e., all-white lines are not interpreted as used in one-way lanes. Solid stripes are disregarded as restrictive crossing areas. Such questions arise as: "Do double solid centerlines prohibit left turns into driveways or entrance to businesses?" "Does the slightly raised median painted yellow have the same meaning as the double solid yellow?" "On the continuous left turn lane, where is the centerline?"*

The results of the driver training professional input information were used to design a survey that was administered to 422 drivers in 10 Texas cities. There were three pavement marking questions in the survey. The markings were the double yellow line, the pedestrian crosswalk, and the solid white line. The first and third of these are of interest to the all-white research effort. The results for these two pavement markings are shown in Table B-15.

The double yellow line was understood by the majority of the drivers; however, the marking was shown in combination with a sign that read "Do Not Cross Double Yellow Line to Pass". Drivers were able to recognize the "do not cross" restriction of the marking but were unable to distinguish why.

The solid white line was the least understood marking. A little over one-third of the drivers answered correctly. This particular question is interesting because the two incorrect responses were complimentary in nature. This meant that if a driver chose one, he or she should logically have chosen the other. This did not happen and indicates that drivers have some confusion about the ability to change lanes.

The results of this research have little application to the evaluation of all-white markings. The image for the question on the double solid yellow centerline presented a scene with a four-lane roadway, and the question focused on the passing issues, not the directional movement of traffic. The question

TABLE B-15 Marking results of 1978 TTI study

Marking	Question	Answer Choices	Responses	Percent
Yellow Double Centerline (on 4-lane roadway)	You notice a double solid yel1ow 1ine down the center of the road and a sign on the right shoulder. What do the lines and sign tell you?	Do not pass the vehicle in your lane.	43	9
		Do not cross over the centerline to pass a vehicle. (CORRECT)	348	76
		Look out for oncoming traffic if you pass.	2	< 1
		Do not cross the centerline for any reason (such as turning into a driveway).	66	14
		Not sure.	0	0
	Totals		459	100
White Right Lane Line for Left Turn Lane	You enter the left turn lane and notice a solid white line on your right. What does the white line tell you?	The line is a divider line marking lanes. Drivers may cross it if they want. (CORRECT)	165	35
		If you are in Lane A you cannot cross the line into the left turn lane.	99	21
		If you are in the left turn lane you can not cross the line into Lane A.	173	37
		Not sure.	28	6
	Totals		465	1

Note: Drivers were permitted to choose more than one response.

for the right lane line for a left turn lane has little significance in the overall scheme of pavement markings.

TTI 1981 Evaluation

The second TTI study used four different evaluation methods (three laboratory and one field) to measure driver understanding of 63 traffic control devices (*14*). The four evaluation methods included:

- Laboratory evaluations conducted only in the Bryan-College Station area of Texas. Three different procedures were used in the laboratory evaluations:
  - In-depth interview in which static images (slides) of 40 traffic control devices were presented to ascertain the ability of drivers to name and provide the meaning of the devices. The sample size was 94 drivers.
  - Shape and color identification for 25 traffic signs (no markings were included in this evaluation).
  - Film presentation of 32 driving situations with a sample size of 91 drivers.
- Field evaluation of 46 traffic control devices in which 375 drivers were asked to select the meaning of the devices in a multiple-choice format. The survey was administered at nine driver license stations in six Texas cities.

Eight of the 63 devices studied in this project were pavement markings. Three of the four evaluation methods were used (shape and color evaluation was not used). Five of the markings are pertinent to the evaluation of all-white pavement markings. Unfortunately, this report does not provide a detailed description of the results of the various evaluations (images, specific questions, and response choices). It only summarizes key aspects of the findings for each of the devices evaluated in narrative fashion. This makes it difficult to interpret the actual responses from drivers. Table B-16 presents a summary of the key findings for the five pavement markings pertinent to the all-white evaluation.

The results of the research were used to identify the 19 devices that the researchers considered as the most critical from a lack of comprehension. Three of these were pavement markings: double solid yellow centerline, broken yellow centerline, and two-way left-turn lane. The researchers determined that drivers did not have an adequate understanding of the message conveyed by yellow markings. The researchers further stated that "*Respondents showed little understanding of the difference between yellow and white in defining directions of travel.*" The researchers also found that drivers tended to associate yellow markings with passing prohibitions rather than using the broken/solid pattern of yellow lines. The researchers indicated that the driver group with the best understanding of pavement markings included drivers that had taken a driver education course, or primarily

TABLE B-16 Summary of key findings from 1981 TTI evaluation

Marking	Method[1]	Issue	Response Rate (percent)
Broken yellow centerline on two-lane road	Structured	Two-way traffic	87
		Passing permitted	87
	Unstructured	Both two-way traffic and passing permitted	53
		Either two-way traffic or passing permitted	20
		Incorrect response	28
Double solid yellow centerline on two-lane road	Structured	Two-way traffic	92
		Passing not permitted	94
	Unstructured	No passing for either direction	43
		Two-way traffic	43
No passing marking in one direction on two-lane road	Structured	Two-way traffic	93
		Passing permitted in one direction only	69
	Unstructured	Recognition of passing restriction	99
Broken white lane line on two-lane road	Structured	One-way traffic	47
		Passing permitted	92
	Unstructured	One-way traffic	45
		Both one-way traffic and passing permitted	19
		Two-way traffic	23
Solid white, double-wide line on two-lane road	Structured	One-way traffic	58
		Passing not permitted	40
	Unstructured	Lane divided that should not be crossed	65
		Incorrect response	11

Notes: [1]Structured method represents multiple-choice responses to a graphic image with a sample size of 469. It includes both the in-depth interview and the statewide survey. The unstructured method represents open-ended responses to a film with a sample size of 91.

the younger drivers. But the researchers also pointed out that, at the time the evaluations were conducted (around 1980), any driver over age 40 had been exposed to four major alterations in centerline delineation, which may account for the results that favored younger drivers.

TTI 1995 Evaluation

The most extensive of the TTI comprehension studies was conducted in the early 1990s (*17*). This project included five different evaluations of driver comprehension of 52 traffic control devices. A total of 2,414 were surveyed in the five evaluations. Of the 52 devices, seven were pavement markings.

The first of the five evaluations was a statewide comprehension survey of 1,745 drivers at driver license stations in 12 Texas cities. The survey consisted of a 17-min video presentation with questions on 46 traffic control devices. The video consisted of pictures of each device or marking and voice-over narration. The question and multiple-choice answers were read aloud to the respondent. Each device or marking was presented to the respondent in two ways: in-context and close-up. The in-context picture is a still photo taken of a device or marking in use. The close-up is a computer-generated image. The answers were presented in a multiple-choice format with one correct answer, two answers containing some truth or a common misunderstanding about the device or marking, and an answer of "not sure." The seven pavement marking questions are listed below. Of these, only five are pertinent to the evaluation of all-white markings. The two-way left-turn lane question addressed the proper use of the lane rather than the meaning of the markings. The preferential lane marking addressed the meaning of the diamond symbol, which is not related to the all-white evaluation. The questions, responses, and response rates for these five markings are shown in Table B-17.

TABLE B-17 Summary of results from 1995 TTI study

Marking	Question	Response	Percent
Single Broken Yellow Centerline	Which one of the following statements is true about the dashed yellow centerline?	***This is a two-way road where you are allowed to pass.***	***76.8***
		This is a two-way road where you are not allowed to pass.	12.2
		This is a one-way road where you are allowed to change lanes.	8.2
		Not sure.	2.8
No-Passing Zone	If you are traveling in the right lane, which of the following is true about the centerline?	This is a two-way road where you are allowed to pass.	5.8
		This is a two-way road where you are not allowed to pass.	***88.0***
		This is a one-way road where you are allowed to change lanes.	3.2
		Not sure.	3.0
Single Broken White Lane Line	Which one of the following statements is true about the dashed white line?	***This is a one-way road where you are allowed to change lanes.***	***50.3***
		This is a one-way road where you are not allowed to change lanes.	4.2
		This is a two-way road where you are allowed to pass.	42.2
		Not sure.	3.3
Solid White Edge Line	What is the purpose of the solid white line on the right side of the roadway?	To let you know there is no curb on this road.	9.6
		To let you know that you should not cross this line for any reason.	10.4
		To let you know where the edge of your driving path is.	***74.7***
		Not sure.	5.3
Double Solid White Lane Line	Which one of the following statements is true about the double white lines on the pavement?	***It is illegal to change lanes across these lines.***	***61.0***
		You may change lanes across these lines with caution, if necessary.	22.1
		You may change lanes across these lines from left to right, but not from right to left.	6.9
		Not sure.	10.0

Notes: Correct responses shown in ***bold italics***.
Survey administered to 1,745 drivers, sample size for each question varied, but was close to the total number of drivers participating in the survey.

- Single Broken Yellow Centerline
- No-Passing Zone
- Single Broken White Lane Line
- Solid White Edge Line
- Two-Way Left-Turn Lane (not pertinent)
- Double Solid White Lane Line
- Preferential Lane (diamond) (not pertinent)

The results of the statewide survey are among the most pertinent to the issue of pavement marking color. In the survey, two of the questions showed identical road scenes except for the color of the pavement markings. When the road was marked for two-way operation, only 8 percent thought it was a one-way road. When the roadway was marked for one-way operation, 42 percent thought it was a two-way road. These results seem to suggest that when exposed to yellow markings, driver recognize that they separate opposing traffic. However, in the absence of yellow markings, they have difficulty discerning the difference between a one-way and two-way roadway. The statewide survey findings relative to the broken white markings led the researchers to include the marking in one of the follow-up evaluations.

In the follow-up evaluation, researchers designed an open-ended question to address driver understanding of pavement marking color. This follow-up evaluation was conducted at a Houston Auto Show and included 322 subjects. Table B-18

TABLE B-18 Results from 1995 TTI follow-up evaluation

Stimuli	Question	Responses	Percent
One-Way sign (R6-1)	You have just turned onto a road with this sign. What color would the center dashed line on the pavement be?	***White***	***79.4***
		Yellow	12.7
		Some other color	2.9
		Not sure.	4.9

Notes: Correct response indicated by ***bold italics***. Response format was open-ended.

TABLE B-19 First-year Mexican driver survey results for pavement markings (percent)

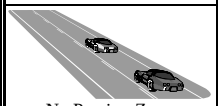
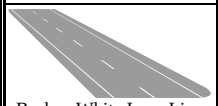
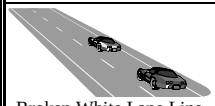
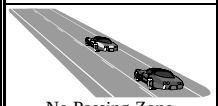
Device	Question	Correct Response Concept	Partially Correct Response Concept	Correct	Partially Correct	Incorrect	Not Sure	Unknown	Sample Size
 Broken Yellow Centerline Pavement Marking	Is this a one-way road or a two-way road?	Two-way road or cars going in both/ opposing/different directions	No acceptable response	72.2	N/A	25.3	1.5	1.0	593
 Broken Yellow Centerline Pavement Marking	Is the blue car allowed to pass the red car?	Yes, if there is enough room to pass safely	Yes without identifying the safety element	36.8	38.0	22.8	0.5	1.9	589
 No Passing Zone Pavement Markings	Is the blue car allowed to pass the red car?	No	No acceptable response	84.1	N/A	12.2	1.9	1.8	573
 Broken White Lane Line Pavement Marking	Is this a one-way road or a two-way road?	One-way or cars going in same direction	No acceptable response	51.5	N/A	45.2	2.6	0.8	505
 Broken White Lane Line Pavement Marking	Is the blue car allowed to pass the red car?	Yes	No acceptable response	81.8	N/A	14.3	1.4	2.4	490

TABLE B-20 Second-year Texas driver survey results for pavement markings (percent)

Device	Question	Correct Response Concept	Partially Correct Response Concept	Correct	Partially Correct	Incorrect	Not Sure	Unknown	Sample Size
 Broken Yellow Centerline Pavement Marking	Is this a one-way road or a two-way road?	Two-way road or cars going in both/opposing/ different directions	No acceptable response	83.2	N/A	16.3	0.5	0.0	417
 Broken Yellow Centerline Pavement Marking	Is the blue car allowed to pass the red car?	Yes, if there is enough room to pass safely	Yes, without identifying the safety element	30.3	48.1	20.9	0.5	0.2	416
 No Passing Zone Pavement Markings	Is the blue car allowed to pass the red car?	No	No acceptable response	89.0	N/A	9.6	1.0	0.5	408
 Broken White Lane Line Pavement Marking	Is this a one-way road or a two-way road?	One way or cars going in same direction	No acceptable response	48.3	N/A	48.7	2.1	0.8	236
 Broken White Lane Line Pavement Marking	Is the blue car allowed to pass the red car?	Yes	No acceptable response	92.9	N/A	5.6	1.2	0.2	410

presents the question, responses, and response rates. The results showed that 79 percent of the drivers were able to indicate that a one-way road uses white markings. The data summarized in Table B-18 suggest that Texas drivers understand that broken white lanes lines are associated with one-way operation. This finding is understandable when one considers that Texas uses multilane one-way frontage roads more than any other state. Consequently, Texas drivers seem to be more familiar with the meaning of broken white line markings than drivers in other states.

There are three factors that can be attributed to these vast differences in driver understanding of broken white markings between the two evaluations. First, and probably the most influential, is the bias introduced through the evaluation diagrams. The first survey showed a roadway scene with lane and edge markings. The follow-up survey used a diagram that showed only a ONE-WAY sign (W1-6). The second factor is the difference between the response formats (multiple-choice versus open-ended). Multiple-choice surveys typically have higher correct responses because subjects tend to guess at a response rather than select a "not sure" response. The third factor is the difference in the sample of each survey. The statewide survey represented a random, and representative, sample of a large number of Texas drivers because it was administered at driver license stations. Its size provides a small margin of error. However, the sample represents only Texas drivers and has limited national implications. The follow-up survey sample is of limited value for two reasons: (a) the sample represents only Houston drivers and (b) the survey was administered at an auto show, where drivers may have greater understanding of the meaning of traffic control devices.

TTI 1999 Border Area Evaluation

In the most recent TTI evaluation of driver understanding of traffic control devices, researchers surveyed drivers from Texas and Mexico on 33 different devices (*18*). Five of the devices were pavement markings. All of the surveys were conducted on bridges at the Texas-Mexico border. Drivers were shown a flashcard image containing an enlarged version of a traffic control device and asked to indicate its meaning. The questions to be asked by the surveyor were printed on the back of the flashcard in both Spanish and English. Drivers had a choice of responding in Spanish or English. Responses were recorded on tape and analyzed later. Answers were coded as correct, partially correct, incorrect, not sure, and unknown. The unknown category represented responses that could not be understood. In the first evaluation, researchers surveyed drivers of vehicles with license plates from Mexico. Sample sizes for any particular question varied between 490 and 593 drivers. In the second evaluation, drivers of vehicles with Texas license plates were surveyed. Samples sizes varied from 236 to 417 drivers.

It is worth noting that although Mexico formally uses an all-white pavement marking system, the researchers learned that many of the border areas on the Mexico side of the border use a yellow–white marking system. Two reasons were offered by Mexican officials for the use of yellow–white: a) the frequent cross-border traffic of citizens from both the United States and Mexico, and b) the availability of yellow pavement materials.

Tables B-19 and B-20 present the images, questions, response concepts, and response rates for the drivers from

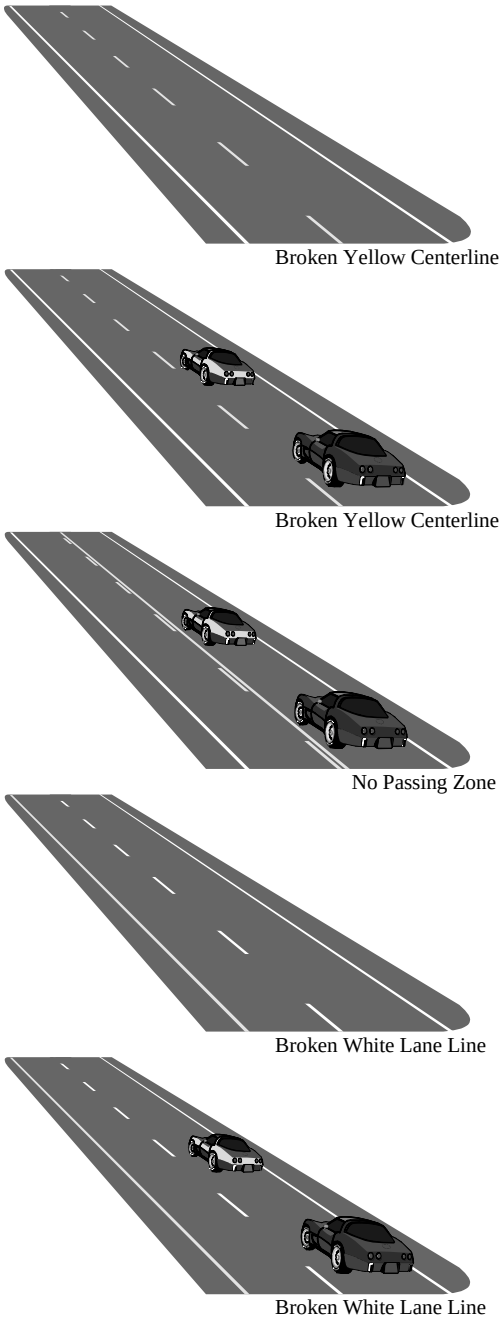


Figure B-4. Graphics from TTI border evaluations.

TABLE B-21 Comparison of understanding between border area driver samples

Driver Sample	Correct Understanding (percent)			
	Two-lane, two-way road with yellow centerline	Two-lane, one-way road with white lane line	Passing on two-way road with broken centerline	Passing on two-way road with barrier line
Mexican	72	52	37	84
Texan	83	48	30	89

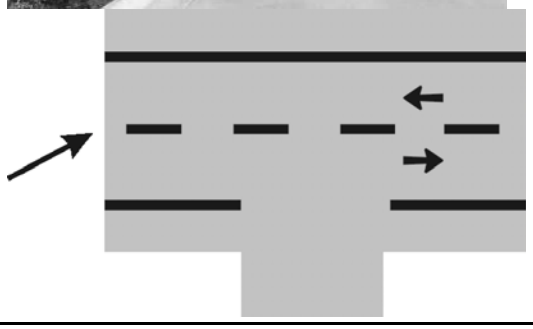
Mexico and Texas, respectively. Figure B-4 displays the graphics from these tables in a larger size. Table B-21 provides a comparison of the comprehension between the two driver groups. Based on the results of this evaluation, the researchers recommended that pavement markings receive greater emphasis in driver education/training programs.

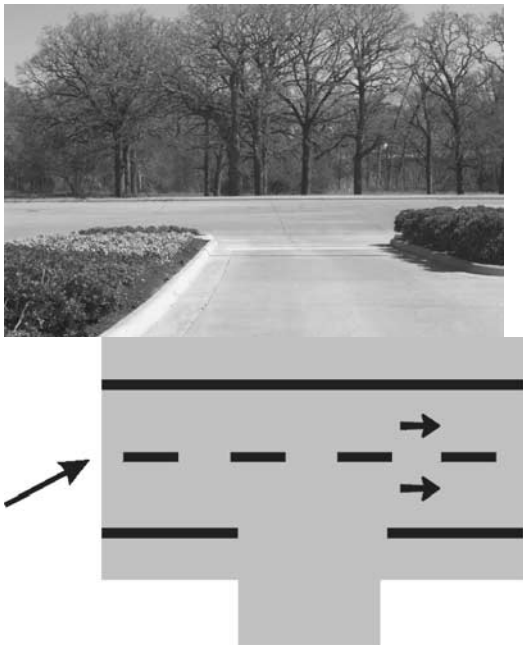
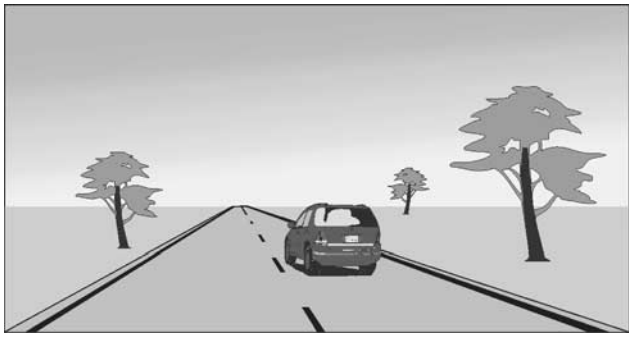
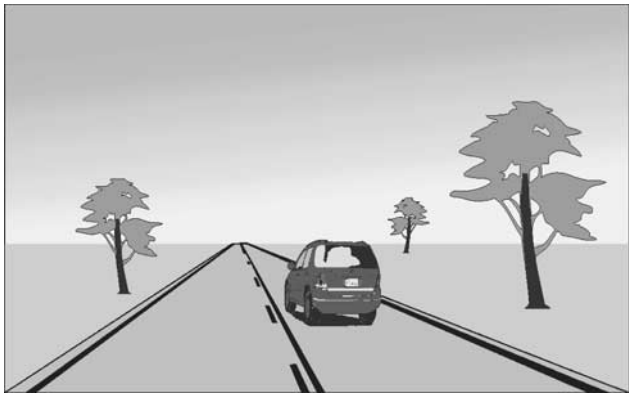
The results of this research are of particular value to the all-white issue because the questions are the closest to truly addressing how well drivers understand the color of pavement markings. However, because the survey was administered only at Texas border areas, the results cannot be generalized to the rest of Texas or any other part of the United States.

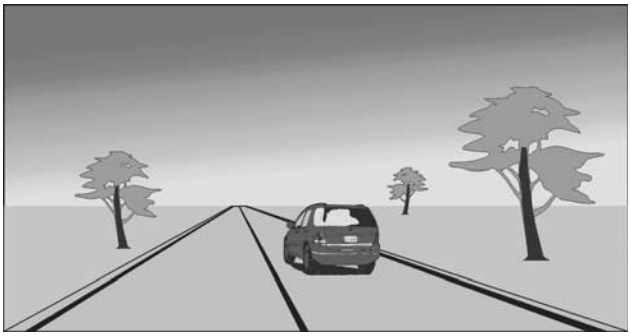
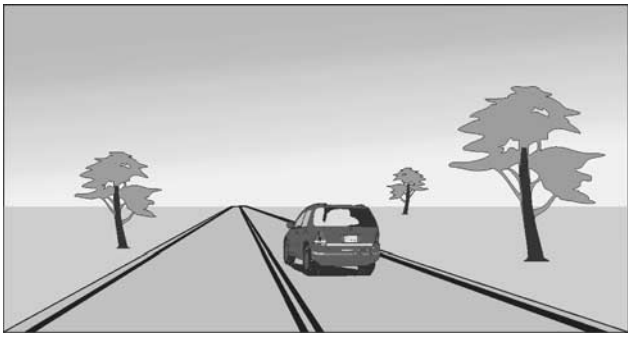
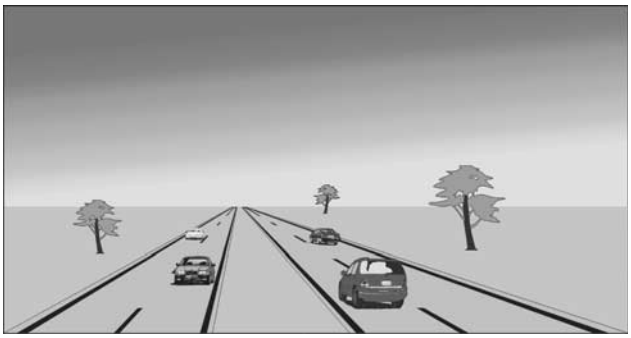
APPENDIX C

COMPREHENSION SURVEY

This appendix presents the questions and the graphic images shown to participants in the comprehension survey. The questions and images presented herein are the same as those presented in the survey, but the format/appearance has been condensed for inclusion in this appendix. Figure 8 presents a photo of the survey format.

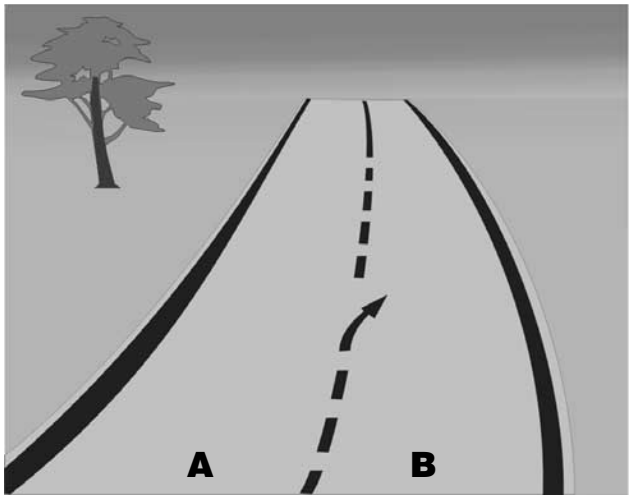
No.	Question	Image
SECTION 1 – OPEN ENDED QUESTIONS RELATED TO DIRECTION OF TRAVEL ON A TWO-LANE ROADWAY		
1	You have arrived by plane in a city where you have never been before. You pick up your rental car and drive out of the airport parking lot, and you come to this intersection. You want to go East (West) as you leave the airport, so you want to make a Left (Right) turn. How would you know if this is a one-way or a two-way road? What would you look for that would tell you? Is there anything else you would look for? Is that everything?	
2	If this is a two-way street, what color would this dashed line be? Using a scale of 1-5, tell me how sure you are of your answer, with 5 being positive and 1 is you're guessing.	 

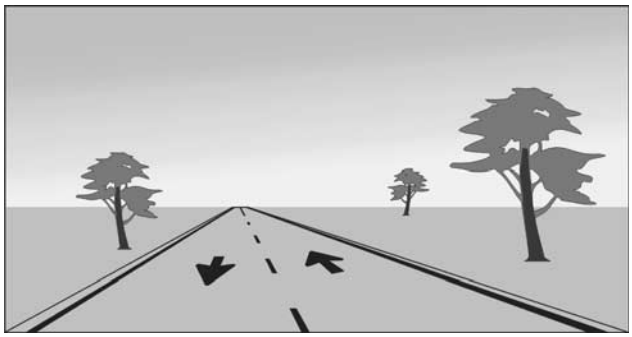
No.	Question	Image
3	If this is a one-way street, what color would this dashed line be? Using a scale of 1-5, tell me how sure you are of your answer, with 5 being positive and 1 is you're guessing.	
SECTION 2 – DRIVER INTERPRETATION OF MARKING PATTERN		
4	Would the traffic on this road be two-way (going in both directions), or one-way traffic (all going in the same direction), or either (could be one-way or two-way)? Can you cross the centerline to get into this lane or pass using the left lane?	
5	Is this a road for two-way, one-way or either type of traffic? Can you cross the centerline to get into this lane or pass using the left lane?	

No.	Question	Image
6	Is this a road for two-way, one-way, or either type of traffic? Can you cross the centerline to get into this lane or pass using the left lane?	
7	Is this a road for two-way, one-way, or either type of traffic? Can you cross the centerline to get into this lane or pass using the left lane?	
8	This is a sketch of an interstate highway, showing both the northbound and southbound sections. What color do you think the left edge line would be? What color do you think the lane line would be? What color do you think the right edge line would be?	
SECTION 3 – UNDERSTANDING OF YELLOW-WHITE MARKINGS		
9	Is this road a one-way, or two-way, or could be either type of road? Can you cross the centerline to get into this lane or pass using the left lane	

No.	Question	Image
10	Is this road a one-way, or two-way, or could be either type of road? Can you cross the centerline to get into this lane or pass using the left lane?	
11	Is this road a one-way, or two-way, or could be either type of road? Can you cross the centerline to get into this lane or pass using the left lane?	
12	Is this road a one-way, or two-way, or could be either type of road? Can you cross the centerline to get into this lane or pass using the left lane?	

No.	Question	Image
SECTION 4 – POTENTIAL UNDERSTANDING OF ALL-WHITE MARKINGS		
13	Would you think this would be a one-way or a two-way street, or either, if there were only white lines? Would you be allowed to cross the centerline to get into this lane or pass using the left lane?	
14	Would you think this would be a one- way or a two-way or either type of street? Would you be allowed to cross the centerline to get into this lane or pass using the left lane?	
15	Would you think this would be a one- way or a two-way or either type of street? Would you be allowed to cross the centerline to get into this lane or pass using the left lane?	

No.	Question	Image
16	Would you think this would be a one- way or a two-way or either type of street? Would you be allowed to cross the centerline to get into this lane or pass using the left lane?	
17	Would you think this would be a one- way or a two-way or either type of street? Would you be allowed to cross the centerline to get into this lane or pass using the left lane?	
SECTION 5 – MARKING ENHANCEMENTS AND GENERAL COMMENTS		
18	If you're driving in Lane B, what does this arrow tell you?	

No.	Question	Image
19	What do these arrows tell you?	
20	What would you think of the idea of the U.S. using only white lines on the pavement?	No Graphic Image

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Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation