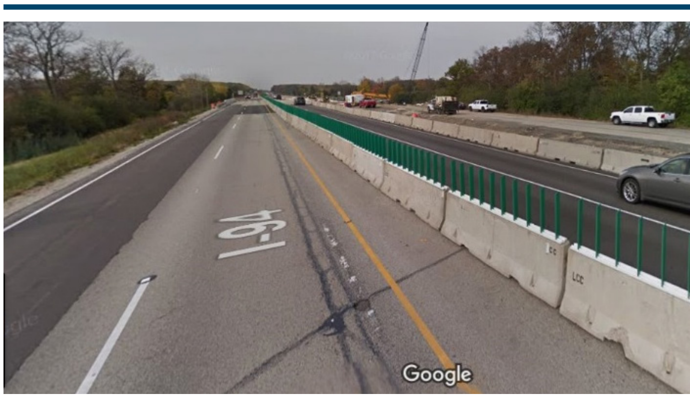
Orange Work Zone Pavement Marking Midwest Field Test

Final Report
April 2018



SWZDI
Smart Work Zone Deployment Initiative

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(TPF-5(295))
Federal Highway Administration
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About SWZDI

Iowa, Kansas, Missouri, and Nebraska created the Midwest States Smart Work Zone Deployment Initiative (SWZDI) in 1999 and Wisconsin joined in 2001. Through this pooled-fund study, researchers investigate better ways of controlling traffic through work zones. Their goal is to improve the safety and efficiency of traffic operations and highway work.

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The preparation of this report was financed in part through funds provided by the Iowa Department of Transportation through its "Second Revised Agreement for the Management of Research Conducted by Iowa State University for the Iowa Department of Transportation" and its amendments.

Front Cover Image Credits

Google StreetViews of I-94 bridge over Dousman Road (control site) on the left and I-94 bridge over Golden Lake Road (test site) on the right, © 2016 Google

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title
Orange Work Zone Pavement Marking Midwest Field Test

5. Report Date
April 2018

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.
Part of InTrans Project 18-535

9. Performing Organization Name and Address
University of Wisconsin - Madison
College of Engineering
1415 Engineering Drive
Madison, WI 53706

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Organization Name and Address

Smart Work Zone Deployment Initiative Iowa Department of Transportation 800 Lincoln Way Ames, Iowa 50010	Federal Highway Administration U.S. Department of Transportation 1200 New Jersey Avenue SE Washington, DC 20590

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code
TPF-5(295)

15. Supplementary Notes
Visit www.intrans.iastate.edu/smartwz/ for color pdfs of this and other Smart Work Zone Deployment Initiative research reports.

16. Abstract

Roadway lanes are often repositioned to accommodate highway work operations, resulting in a need to alter pavement markings. Even the most effective methods for removing old pavement markings sometimes leave "ghost" markings at the old lane line locations. The ghosts can be quite conspicuous under certain lighting conditions and viewing angles. To address this issue, some international jurisdictions use a special marking color (orange or yellow) to increase the salience of temporary lane lines; this practice appears to have originated in Germany in the 1980s and is now routine in several European countries and the Canadian province of Ontario. Special-color markings have also been used experimentally in Australia, New Zealand, and Quebec. In some jurisdictions the special-color markings override existing markings (such that the old markings are left in place), while other jurisdictions use special-color temporary marking but also attempt to remove old lane lines.

The Wisconsin Department of Transportation (WisDOT) experimented with orange work zone marking on a high-volume long-term freeway-to-freeway interchange reconstruction project in Milwaukee; surveys indicate good driver acceptance, but the complex traffic flow characteristics and frequent configuration changes at the site make it difficult to separate the effects of the orange markings from other aspects of the work zone management strategy.

To assess the driver behavior aspects of orange markings in a simpler environment, a matched-pair study was conducted on two bridge re-decking projects on I-94 near Oconomowoc, Wisconsin. Evaluation of vehicle positioning and speed data indicated very similar driver behavior with the two colors. Driver surveys and interviews with project field engineers indicated a preference for the orange marking when lateral lane shifts are required. Perhaps the most pragmatic approach is to reserve orange as an emphasis color for specific work zone locations that require difficult driving maneuvers.

17. Key Words
orange pavement markings—temporary lane markings—work zones

18. Distribution Statement
No restrictions.

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified.	Unclassified.	81	NA

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Sponsored by the Smart Work Zone Deployment Initiative and
the Federal Highway Administration (FHWA) Pooled Fund Study TPF-5(295):
Iowa (lead state), Kansas, Missouri, Nebraska, and Wisconsin

Preparation of this report was financed in part
through funds provided by the Iowa Department of Transportation
through its Research Management Agreement
with the Institute for Transportation
(InTrans Project 18-535)

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ACKNOWLEDGMENTS

This research was conducted under the Smart Work Zone Deployment Initiative (SWZDI) and Federal Highway Administration (FHWA) Pooled Fund Study TPF-5(295), involving the following state departments of transportation:

- Iowa (lead state)
- Kansas
- Missouri
- Nebraska
- Wisconsin

The authors would like to thank the FHWA, the Iowa Department of Transportation (DOT), and the other pooled fund state partners for their financial support and technical assistance.

The authors also express their gratitude to the Wisconsin DOT for providing the work zone sites, equipment for data collection, and an in-depth review of the draft reports.

EXECUTIVE SUMMARY

Construction operations on roadways frequently require adjusting the lateral position of driving lanes. Incomplete removal of old pavement markings or surface scarification from marking removal can leave “phantom” or “ghost” marks that create ambiguity for drivers, more so under certain weather and lighting conditions. Ambiguity about lateral position of the vehicle can be exacerbated on facilities that have three or more lanes open to traffic and when lane positions have been moved multiple times. Some international jurisdictions have advocated the use of special-color pavement markings to mitigate these issues. The use of special-color pavement markings for work zones appears to have originated in Germany in the 1980s and is now widespread in Continental Europe. In North America, the Canadian province of Ontario has been the most active user of orange work zone markings. Special-color markings have also been used experimentally in Australia, New Zealand, and Quebec.

One of the most extensive orange pavement marking demonstration projects began in the Zoo Interchange reconstruction project in Milwaukee, Wisconsin in 2014. In spite of initial “teething” problems with fade resistance and reflective bead retention, favorable public reaction to the trial has been reported. The Zoo Interchange project is characterized by frequent changes in lane configurations and alignments, high traffic volumes, recurrent congestion even before the project began, and extensive use of advanced work zone traffic management strategies such as the zipper merge and automated back-of-queue warning systems that overlap the orange marking area. These complexities make it very challenging to separate the driver behavior and traffic operations effects of the orange markings from those attributable to other site conditions and traffic management techniques.

To assess the driver behavior aspects of orange markings in a simpler environment, a matched-pair study was conducted on two bridge re-decking projects on I-94 near Oconomowoc, Wisconsin as part of this research project. Since orange pavement markings are not in the MUTCD, the research team prepared Request for Experimentation (RFE) in accordance with the MUTCD guidelines. Following the approval of the RFE, orange pavement marking tapes were procured and installed. Orange pavement marking tapes were installed at the I-94 bridge over Golden Lake Road work zone. This site was paired with a very similar work zone approximately 2 miles to the east on the I-94 bridge over Dousman Road, and had standard-color marking tapes to serve as an experimental control. The markings were implemented using wet-recoverable pavement marking tapes (Brite-Line Deltaline TWR), supplied in fluorescent orange and in standard white and yellow colors.

Lateral positioning sensors, site overview cameras, and approach speed radars were installed to monitor vehicle lane positioning and travel speeds at both the test and control sites. Following data cleaning, 77,757 and 137,379 lateral positioning observations were available at the control and test sites respectively. No statistically significant difference was found between the distributions of lane position data for the test and control sites. Subjective visual examination appears to indicate that some vehicles in the right lane of the test section (orange markings) tended to track slightly further to the right than vehicles in the control section; this difference was perhaps 100 to 150 mm (4 to 6 inches). Video image samples obtained from trailer mounted cameras were used to assess lane choice and the prevalence of vehicles straddling or changing lanes.

One potential benefit of orange markings is to mitigate driver confusion under low illumination (such as Dawn or Dusk) and rainy conditions. In order to evaluate this, one hour of video for both the control and test sites was analyzed for the following four conditions: dawn, mid-day, dusk, and rain. With orange markings, the percentage of vehicles straddling lanes (not vehicles changing lanes) was marginally lower under dusk and rain conditions, but essentially similar for practical purposes. Forward-fired radar units were used to collect trajectory information of individual vehicles to identify any differences in speed behavior that are potentially attributable to the marking color. Overall, the observations suggest that speeds were about 2 mph faster at the site with orange markings, but this should be interpreted cautiously. The sample size is small, and the speed differences might have been influenced by geometrics: the lane shift rate was slightly gentler at the orange marking site than at the control. An alternative explanation is that after “practicing” their lane-shift maneuvers at the first work zone (which was the control site), westbound drivers felt confident driving somewhat faster through the second work zone. Thus it is possible that the observed speed differences are related to sequencing rather than color. In summary, vehicle positioning and speed data indicated very similar driver behavior with the two colors.

A driver survey of was conducted at a rest area, a few miles downstream of the test sites. A total of 60 responses were obtained during two days (clear/sunny weather conditions) of survey distribution. Overall, almost half of the respondents said the orange markings were more visible, while less than 20% felt white markings were easier to see. The research team also interviewed two field engineers towards the end of the construction project. The two engineers interviewed felt orange tape was beneficial for this project and could be beneficial for freeway projects. Nevertheless, they felt the orange marking should be limited to projects with lane shifts or crossovers.

Based on the field data, driver survey and interviews of field engineers, there was no evidence of driver miscomprehension of the orange markings, nor did there appear to be any problems resulting from the non-use of yellow left edgeline markings at the test site. Perhaps the most pragmatic approach is to reserve orange as an emphasis color for specific work zone locations that require difficult driving maneuvers. This approach is similar to the British practice of parsimoniously using special marking colors to provide emphasis in problematic areas, and would help reduce the potential for drivers to become desensitized to the special color. This research evaluated orange markings at one study site and therefore the results are preliminary and suggestive. Future research should evaluate orange markings at multiple sites and different work zone scenarios than the one studied in this research.

1 INTRODUCTION

Construction operations on freeways and other multi-lane high-speed roadways frequently require adjusting the lateral position of driving lanes. Incomplete removal of old pavement markings and surface scarification from marking removal can leave “phantom” or “ghost” marks that create ambiguity for drivers as illustrated through Figure 1 in a Wisconsin construction project (Pike and Miles 2013).

Wisconsin DOT

Figure 1. Ambiguous pavement markings on a Wisconsin DOT construction project (circa 2010)

Under certain weather and lighting conditions ghost markings can be quite conspicuous, and peculiar contrast inversions sometimes occur as the horizontal viewing angle changes (VicRoads 2012, Magel 2014, Stevens 2016). A media report on KCCI (a television station based in Des Moines, Iowa) offered the following description of the site illustrated in Figure 2.

Figure 2. Phantom markings on a freeway construction project near Des Moines, Iowa (2014)

> The tangle of painted and unpainted lane markings on the freeway in Windsor Heights is causing problems for some drivers. The lanes were shifted on I-235 last month so crews could install new sign posts and trusses over the roadway. At certain times of the day, it's

> hard for some drivers to see which lane markings are correct. Crews had to grind off old white lines and paint new ones, but the “ghosts” of the lines are still visible. Some drivers report the old marking spots also glow and can look almost as bright as the white lines in the right lighting conditions. The DOT has received complaints about the problem. Officials said once the [sign bridge replacement] project is done they plan to come back and completely cover over all west bound lanes with asphalt and new lane markings. (Magel 2014)

These issues sometimes result in unplanned costs; for example, in the instance cited above, the Iowa DOT subsequently found it necessary to mill and overlay the surface to remove the ghost markings.

Ambiguity about desired lateral vehicle positioning can be particularly problematic when lane positions have been moved more than once, especially on facilities that have three or more lanes open to traffic (DuPont 2016, DuPont and DeDene 2017). The wide range of pavement materials, marking materials, and removal techniques can make it difficult to predict when ghosting will occur, but the problem is generally felt to be more serious on east-west roadways than on north-south roadways (Stroh 2014, Stevens 2016). Winter work zones present a particular concern for practitioners in cold climates because salt residue reduces contrast between traditional temporary markings, in particular white, and the rest of the pavement surface (Rauch 2015, DuPont and DeDene 2017). Some international jurisdictions have advocated the use of special-color pavement markings to mitigate these issues.

The use of special-color pavement markings for work zones appears to have originated in Germany in the 1980s and is now widespread in Continental Europe (Kehrein 1989, Stevens 2016, Shaw et al. 2017). In Western European countries that use all-white permanent pavement marking systems (such as Belgium, France, Germany, Italy and Spain) the special color is usually yellow. In Central European countries such as Austria, Switzerland and Slovakia, it is usually orange. In many cases the special-color overrides existing permanent markings, which are left in place. This practice avoids the cost and complexity of marking removal and is particularly expedient for projects on urban streets, where inapplicable arrows and crosswalk markings are simply crossed out with a yellow or orange X. Old markings are removed on some projects, such as Italian tollways with high speed limits (Shaw et al. 2017). Special color markings inspired by European practice have also been used experimentally on urban freeway projects in Melbourne, Australia (yellow) and Auckland, New Zealand (orange) (VicRoads 2012, Stevens 2016).

In North America, the province of Ontario, Canada has been the most active user of orange work zone markings, with extensive testing and deployment of fluorescent orange markings for major freeway construction projects since the late-2000s (MTO 2009). Ontario has also published detailed guidance on when to use orange marking as part of the Ontario Traffic Manual (MTO 2014). In Ontario, old markings are removed and the bright orange color provides high contrast. Similar orange marking has been used experimentally in the neighboring province of Québec.

One of the most extensive orange marking demonstration projects began in the Milwaukee, Wisconsin area in 2014 and is currently ongoing. The site is the Zoo Interchange, a high-volume freeway-to-freeway interchange of I-41, I-94, and I-894 that is located in the heart of the Milwaukee metropolitan area. In spite of initial "teething" problems with fade resistance and reflective bead retention, favorable public reaction to the trial has been reported (DuPont and DeDene 2017). Within the Wisconsin DOT (WisDOT), there has been much discussion and debate about the costs and benefits of orange marking, but a direct assessment of the Zoo Interchange site is difficult: the construction is fast-paced with frequent changes in lane configurations and alignments, traffic volumes are high, there was recurrent congestion even before the project began, and WisDOT is making extensive use of advanced work zone traffic management strategies such as the zipper merge and automated back-of-queue warning systems that overlap the orange marking area. These complexities make it very challenging to separate the driver behavior and traffic operations effects of the orange markings from those attributable to other site conditions and traffic management techniques.

The objectives of this study were as follows:

1. Conduct a literature review on the use of orange pavement markings (PM) in work zones, especially from Europe since there has been only one experimental application of orange pavement markings in the US, so far.
2. Conduct in-person and video based field observation to identify driver behavior in the vicinity of the orange PM, e.g. abrupt lane changes, harsh braking, or other maneuvers that can be considered crash precursors.
3. Conduct a survey to evaluate public acceptance of the orange PM during the deployment.
4. Interview agency personnel associated with the field deployments to assess their satisfaction with the orange PM.
5. Summarize project findings through preparation and distribution of this report.

Chapter 2 presents a review of literature on the use of orange PM. Chapter 3 describes the field data collection and analysis. Chapter 4 presents the results of driver survey and agency/contactor personnel. Chapter 5 presents conclusions and recommendations for future research.

2 LITERATURE REVIEW

To assess the potential benefits and risks of experimentation with orange PM, official documents from a number of countries that currently use specially-colored pavement markings in work zones were reviewed. Very little formal academic research on this topic was found, but an abundance of information was found in national standards, agency guidelines, and other "grey literature". This chapter illustrates several photographs. The colors in the photos may vary from their true colors in the field. This is particularly true for fluorescent objects, whose brightness and color contrast will be limited by the display devices, paper, and dyes used to view or print this document.

2.1 Pavement Marking Removal Techniques

Practitioners seeking to minimize ghost marking have utilized a wide range of techniques to remove old pavement markings. NCHRP Report 759 conducted side-by-side field tests comparing several methods, such as high-pressure water blasting, flailing, and orbital flailing (Pike and Miles 2013). The authors reported:

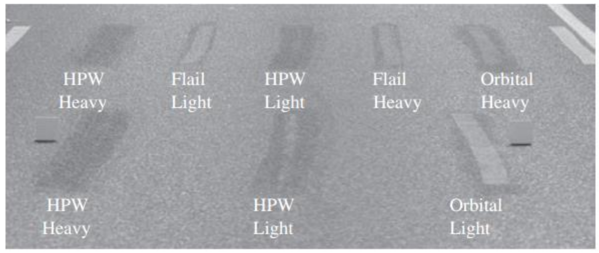
> In general, blasting systems tend to be able to remove all of the markings without leaving a deep scar but still may result in shadow lines from the removal process, whereas grinding tends to leave a scar in order to remove all of the markings. Grinding and blasting can both create dust and debris that need to be cleaned or vacuumed while marking removal is conducted to allow for a safe driving and work environment. Wet grinding and water blasting do not have issues with dust. Grinding tends to be faster and cheaper than the blasting techniques.

In general, the more durable the paint or other marking material is, the harder it is to remove. For example, thermoplastic pavement marking materials may require very heavy abrasion to achieve full removal.

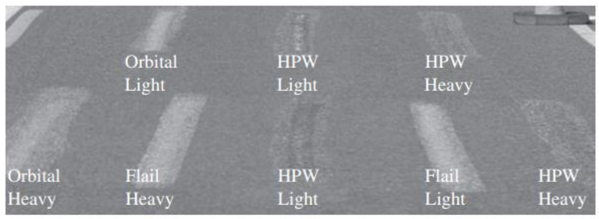
Even when complete removal of old markings is achieved, ghost lines often remain due to pavement scarification and color differences between the former lane line area and the adjoining pavement. These color contrast differences depend on pavement type:

- Asphalt surfaces generally fade with age. Areas previously under lane lines are often darker than the adjoining pavement. In addition, the texture or sheen can be quite different in areas where markings have been removed.
- Concrete pavements gradually darken with age due to tire marking. Consequently, areas formerly protected by lane lines are sometimes appear lighter than the adjoining pavement. In addition, traffic and environmental exposure abrade concrete pavement surfaces; areas protected by pavement markings often have a smoother texture than the adjoining surface, and thus reflect light differently.

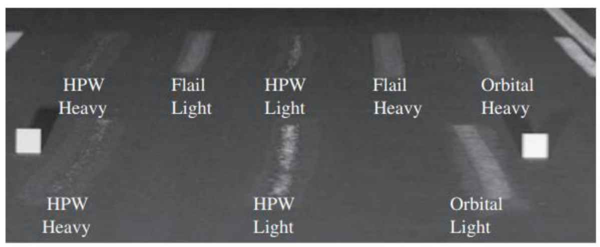
Even at a single site, the visibility of ghost lines varies greatly depending on lighting conditions, viewing direction relative to the light source, viewing angle, and pavement wetness (Figure 3).



a) Day Image Looking South



b) Day Image Looking North



c) Night Image

Figure 3. NCHRP 759 comparison of ghost markings left by different removal technologies for high-build paint on an asphaltic surface

Practitioners also report that surface conditions such as the presence of de-icing salt residue can contribute to difficulty distinguishing temporary marking from ghost lines (Rauch 2015, DuPont and DeDene 2017).

2.2 Other Methods for Obscuring Old Pavement Marking

In addition to blasting and grinding, NCHRP 759 discusses a variety of methods for obscuring old pavement markings (Pike and Miles 2013). The feasibility of these options is generally site- and project-specific. The methods include:

- **Black line-masking tape**. Flat-black non-reflectorized line masking tape is produced by various pavement marking tape vendors (Figure 4).

Figure 4. Black line-masking tape

Some agencies use these products to hide existing markings, while others consider it unacceptable. Ideally, the color and surface sheen of the tape should match the pavement, but pavement variations can make this difficult to achieve. The variability of practitioner attitudes suggests that the products work better in some situations than others. A recent Australian guideline allows blacking-out for up to one month in situations where line marking removal equipment is not immediately available or where permanent markings will be installed after the completion of roadwork (Northern Territory DOT 2015). The guideline cautions that the tape’s color and gloss can change as traffic erodes the coating. In long-term applications the tape can wear through, exposing the previous markings. On wet nights, blacked-out lines may be reflected by vehicle headlights, which can cause road users to perceive them as legitimate markings. For carry-over projects that go over the winter months, black masking tape is not feasible as snowplows will end up removing it. The guideline also recommends that when arrows or similar marks are blacked-out, the shape of the black-out area should be rectangular so that it is not mistaken for a valid mark.

- **Gray or black paint**. Gray or black paint is generally used only for shorter-duration situations because of the risk that old markings will show through when the paint wears off. An advantage over tape is that the color can be customized to match the pavement surface.

Various forms of pavement sealing and microsurfacing can be used to mask existing pavement markings, either as a stand-alone treatment or to restore a uniform surface appearance after removing old markings (Pike and Miles 2013). Examples include:

- **Sealing techniques** such as chip seal typically begin by spraying the pavement surface with an adhesive binder (Roberts and Nicholls 2008, Bateman 2016). Small aggregate (usually 1/4 to 3/8 inch, sometimes up to 1/2 inch) is then spread on the surface (Figure 5).

Georgia DOT

Figure 5. Chip seal application

Roller compaction is sometimes used to improve bonding. After the adhesive sets, excess aggregate is removed by sweeping or vacuuming. Where appropriate, skid resistance can be enhanced by using high-friction aggregate such as calcined bauxite. While the binder hardens, driving speeds must be kept low due to prevent windshield damage from loose chippings (Road Surface Treatments Association 2014).

- **Microsurfacing** (also called ultra-thin asphalt overlay) is a single-step treatment (Figure 6).

Eric Pulley/Wikimedia Commons

Figure 6. Microsurfacing paver

A polymer-modified emulsion is pre-mixed with small aggregate in the surfacing machine and then applied as a thin layer (typically about 1/2 inch thick) over the existing road surface. Typically, the roadway must be closed for 30 to 120 minutes while the material hardens.

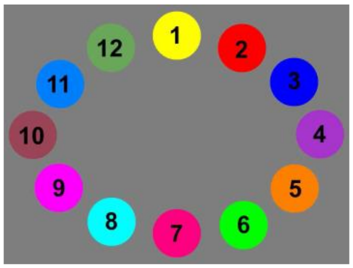
- **Micromilling.** Micromilling (also called fine milling) is similar to ordinary full-width pavement milling, but the cutter has more teeth and the teeth are more closely spaced (Brown

2012). Usually the cut is less than 1 inch deep, producing a uniform surface that is smoother than a pavement milled using standard equipment.

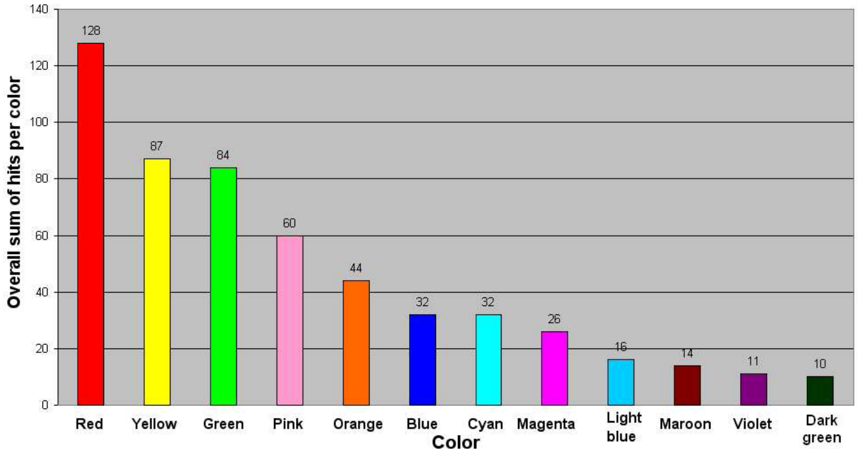
2.3 Special-Color Markings

2.3.1 Color Salience

Various methods for measuring the human response to color have been investigated. When measured with a light meter, white is typically the brightest color. Nevertheless, humans attach social and cultural meaning to various colors, for example the color red is often associated with fire, blood, and (in the traffic control context) stopping or prohibition. These effects have been explored in the psychological literature. For example, a small Swiss study developed a method to quantify the salience of 12 colors (Figure 7a) (Gelasca et al. 2005).



(a) Colors considered (1: Yellow, 2: Red, 3: Blue, 4: Violet, 5: Orange, 6: Green, 7: Pink, 8: Cyan, 9: Magenta, 10: Maroon, 11: Light Blue, 12: Dark Green)



(b) Reported salience of each color

Gelasca et al. 2005

Figure 7. Color salience study

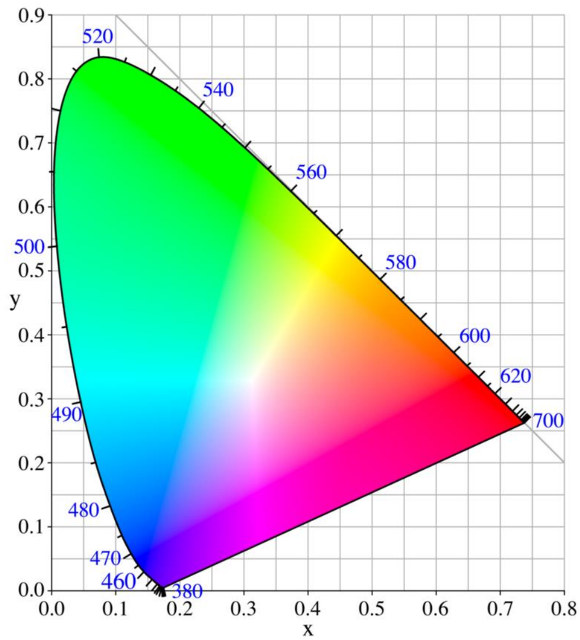
Subjects were shown various combinations of four colors and asked to identify "the most important." The study found that red, yellow, bright green, fuchsia (pink), and orange were the most salient to the subjects (Figure 7b).

Most color-blind people would see orange PMs as a shade of yellow. This would be true for all orange devices/signs used in work zones.

2.3.2 Regulatory Considerations: United States

2.3.2.1 CIE Color Definitions

A system for formal scientific and legal definition of colors was developed in the 1930s by the International Commission on Illumination, more commonly referred to as the CIE (Commission International de l' Eclairage) (Figure 8).



Reference colors shown on the chart may vary depending on the viewer's printer or monitor

PAR\Wikimedia Commons

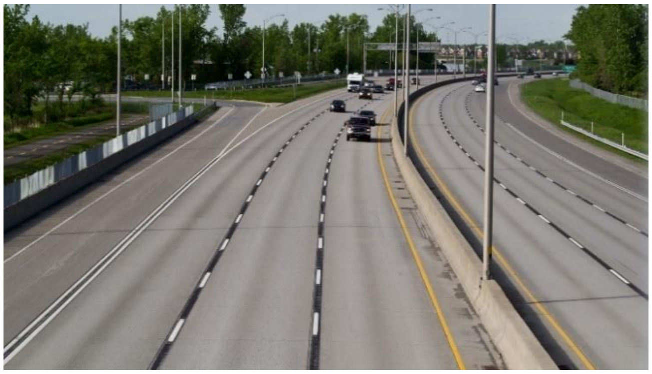
Figure 8. The CIE 1931 color space chromaticity diagram with wavelengths in nanometers

The MUTCD establishes CIE-based "color spaces" for each traffic control color, including a range of acceptable hues for fluorescent orange traffic control devices.

2.3.2.2 Authorized Pavement Marking Colors

Six pavement marking colors are authorized in the 2009 edition of the United States Manual on Uniform Traffic Control Devices (MUTCD): white, yellow, purple, blue, red, and black (FHWA 2009). Approved uses for each color indicate some colors are for specific purposes:

- **White** longitudinal markings are used to separate traffic flows moving in the same direction and to mark the right edge of the roadway.
- **Yellow** longitudinal markings are used to separate lanes traveling in opposite directions, mark the left edge divided highways and one-way streets or ramps, and separate two-way left-turn lanes and reversible lanes from other lanes.
- **Purple** longitudinal markings may be used at toll plaza approaches to supplement lane line or edge line markings in lanes reserved for electronic payment.
- **Blue** markings identify parking spaces reserved for people with disabilities.
- **Red** raised pavement markers are used to mark the wrong direction of ramps and one-way roadways. These devices must be configured so that the red color is visible only to wrong-way traffic. The use of red pavement markers is also authorized to identify truck escape ramps.
- **Black** may be used in conjunction with any other color. This is typically done to improve contrast with lightly-colored pavements or to obscure obsolete markings (Figure 9).



MTLskyline/Wikimedia Commons

Figure 9. Black pavement marking used as a contrast color on Route 132 in La Prairie, Quebec

2.3.2.3 Curb Marking Colors.

Under the general authority of MUTCD Section 3B.23, most US municipalities use painted curbs (in combination with signs) to identify stopping, standing, and parking restrictions. Typical colors for these markings are yellow, white, blue, red, and green. The specific meanings associated with each color are generally established by state or local legislation. Some of the most elaborate systems are found in California cities. For example, in Los Angles red curbs identify locations where stopping, standing, and parking are prohibited at all times (such as fire hydrants and bus stops); yellow curbs identify commercial loading zones with a 30-minute time limit; white curbs identify passenger loading zones with a 5-minute time limit; green curbs identify locations where 15 or 30-minute parking is permitted; and blue curbs identify parking reserved for people with disabilities (LADOT 2016).

2.3.2.4 Colored Pavement

Full-width colored pavement is widely used in Europe to identify special-purpose lanes and areas of conflict between motor vehicles and non-motorized road users. Colored pavement is occasionally used in the United States, most often for bus lanes (Figure 10) and bicycle lanes (Figure 11). Some of these installations have been completed as demonstration projects under the FHWA Request to Experiment process.

Hudconja/Wikimedia Commons

Figure 10. Red pavement treatment for bus lanes at Penn Station in Newark, New Jersey

Steve Morgan/Wikimedia Commons

Figure 11. Green pavement treatment for bike lanes in Portland, Oregon

The general status of colored pavement treatments (in the absence of a Request to Experiment) is somewhat ambiguous in the 2009 MUTCD. Chapter 3G of the MUTCD states that colored pavement used as purely an aesthetic treatment (such as the simulated brick crosswalk in Figure 12) is not a traffic control device, and thus not subject to regulation by the MUTCD. The MUTCD prohibits the use of colored pavements as a traffic control device, except when white or yellow are used to mark traffic channelizing islands (Figure 12).

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Figure 12. Simulated brick crosswalk and yellow marking used to increase median nose visibility in Shorewood, Wisconsin

A provision of the 2015 FAST Act allows municipalities to adopt design guidelines other than those based on the AASHTO Green Book. These potentially include the National Association of City Transportation Officials *Urban Street Design Guide*, which endorses the use of green pavement treatments for bicycle facilities. NATCO claims that colored pavement is currently used for bikeways in 15 US cities (NATCO c. 2015). The organization also issued the following statement:

> Colored pavement within a bicycle lane increases the visibility of the facility, identifies potential areas of conflict, and reinforces priority to bicyclists in conflict areas and in areas with pressure for illegal parking. Colored pavement can be utilized either as a corridor treatment along the length of a bike lane or cycle track, or as a spot treatment, such as a bike box, conflict area, or intersection crossing marking. Color can be applied along the entire length of bike lane or cycle track to increase the overall visibility of the facility. Consistent application of color across a bikeway corridor is important to promote clear understanding for all users.

2.3.3 Regulatory Considerations: Europe and Vienna Convention Countries

By policy, since 1971 the U.S. has used color to distinguish lanes moving in the same direction from those that move in opposite directions (FHWA 1971). All-white pavement marking systems are used in many European countries and other regions with marking standards based on the Vienna Convention on Road Traffic (UNECE 2006). In such countries, special-color markings (orange or yellow) are often used to draw attention to temporary conditions or other hazards.

2.3.4 Colored Pavement Lines for Wayfinding

A US patent issued in 1976 proposed a way-finding aid for complex highway interchanges using painted lines and/or shapes of various colors in the center of each lane (Sticha 1976). This technique is not authorized in the MUTCD and does not appear to have been investigated in the field.

2.3.5 Fluorescent Orange Raised Pavement Markers

A Texas study found that the shade of orange used for Raised Pavement Markers (RPMs) was important factor in drivers' ability to distinguish fluorescent orange pavement markers from yellow or red RPMs (Finley 2007). Two commercial products were evaluated in a test-track environment. Product 1 was toward the yellow end of the orange range, while Product 2 was toward the red end of the range. The study found that by day, all 12 study participants were able to distinguish Products 1 & 2 from yellow and red RPMs. At night most drivers were able to distinguish Product 1 from yellow and red RPMs, but half the drivers confused Product 2 with red RPMs. This suggests that if fluorescent orange is used as a work zone lane marking color, the shade should not be too reddish, particularly in areas where it might be confused with red pavement markings that identify runaway truck ramps, bus lanes, or parking restrictions.

2.4 Agency Utilization of Orange Pavement Markings in Various Countries

2.4.1 Canada

Orange work zone pavement markings are used in some, but not all, Canadian provinces. Quebec has experimented with the use of orange work zone markings (Figure 13a and Figure 13b) and Ontario uses them extensively for construction projects on freeways (Figure 13c and Figure 13d).

a. Orange PM on Quebec Route 132 westbound near Boucherville, Quebec (May 2011)

b. Orange PM at exit ramp from Quebec Autoroute 20/25/132 to Quebec Route 132 eastbound near Longueuil (May 2011)

Scott Steves/asphaltplanet.ca

c. Orange, white, and yellow PM on the Highway 401 expansion project near Missassagua, Ontario (September 2012)

Scott Steves/asphaltplanet.ca

d. Orange PM during two-way operation on one side of a freeway at an unspecified location in Ontario

Figure 13. Orange pavement markings in Quebec and Ontario, Canada

Conversely, British Columbia's work zone traffic manual requires temporary markings to match the color of the permanent markings they replace (TranBC 2015).

Book 7 of the Ontario Traffic Manual (OTM) provides the following guidelines for selecting sites where orange markings will be used (MTO 2014):

> Orange temporary pavement markings should primarily be used on highways with a normal posted speed of 90 km/h [56 mph] or higher where there are changes in alignment to accommodate construction and there is the need to:
>
> - reduce driver confusion that results from removal of existing markings on asphalt, which can cause scarring and/or phantom marks under certain lighting conditions (e.g., low sun angle from sunrise or sunset);
> - improve the contrast on concrete (the contrast between the orange markings and light colored concrete is much better than that between white markings and concrete);
> - enhance daytime and night-time visibility;
> - provide an additional visual cue to indicate that the road user is within a construction zone;

- mitigate operational concerns as a result of multiple sets of pavement markings; or
- mitigate observed or expected driver confusion.

> On [highways under the jurisdiction of the Ministry of Transportation–Ontario], orange pavement markings are only to be used when recommended by the Regional Traffic Sections.

The Ministry of Transportation–Ontario (MTO) currently uses spray-applied methyl methacrylate (MMA) for its pavement markings (Figure 14 and Figure 15).

John Shaw

Figure 14. Spray-applied methyl methacrylate

PolyMight International/YouTube

Figure 15. Spray application of textured MMA

MMA is an acrylic resin that is often used building materials such as shatter-resistant window glazing (EPA 2000). In fall 2006, MTO tested two orange pavement marking products on major freeways: an organic solvent-based paint was tested on Highway 401, and a two-coat waterborne paint system was trialed on Highway 406 (MTO 2009). Although both types of paint improved visibility, in August 2007 MTO used Highway 427 to test a third product: fluorescent orange textured MMA. The MMA showed improved visibility and durability compared to the paints. It is applied in droplets or splatters, creating a three-dimensional wet-reflective marking surface with an intense orange color. MMA had very good adherence to milled asphalt and to concrete pavement surfaces. Its properties allow for successful application in low temperatures (which can be problematic for other materials). MMA also showed good retention of the glass beads which were embedded in the surface to improve night visibility.

2.4.2 Switzerland, Austria, and Slovakia

In Switzerland, white is used for most permanent pavement markings and yellow is used as an emphasis color at locations with significant traffic conflicts. Orange work zone pavement marking is used extensively in Switzerland (Figure 16). The orange markings override ordinary white markings; therefore, white markings are usually left in place during construction (Wir arbeiten für Sie 2014). The situation is similar in Slovakia and in Austria.

Wir arbeiten für Sie

a. Orange pavement markings override the permanent white markings in this Swiss work zone (circa 2013)

Wir arbeiten für Sie

b. Transition from orange to permanent markings at a Swiss work zone (circa 2013)

Wir arbeiten für Sie

c. Orange markings used to maintain two narrow lanes in each direction on one half of the roadway at a Swiss work zone

Figure 16. Orange work zone pavement markings in Switzerland and Slovakia

Temporary orange pavement marking tapes (Figure 17) appear to be the material preferred by agencies in Central Europe.

a. Non-wet-reflective tape

b. Wet-reflective tape

John Shaw

Figure 17. Marking materials

At least two vendors offer orange temporary pavement marking tapes to customers there. For example, 3M Stamark #A654 is a dry-reflective (Type I) tape marketed for non-freeway applications, while Stamark #A734 is a wet-reflective (Type II) tape marketed for use on freeways (3M Deutschland 2004). A competing pair of products is marketed by Brite-Line Europe (Brite-Line Europe 2011). According to the companies' sales representatives, the 3M tape is manufactured in France and the Brite-Line tape is made in the United States. Application of these materials is a two-step process: first a primer is applied to the pavement, and then the tape. For removal, the tapes are peeled off by hand.

2.4.3 Germany

Germany is one of several European countries that use all-white permanent pavement marking systems. Yellow lines have been used in German work zones since at least the late 1980s (Kehrein 1989) and are now standard practice (Figure 18). The yellow markings override white, so existing markings are often left in place during construction.

Anonymous\Wikimedia Commons

a. Yellow PM override the usual white markings at this highway work zone on the A9 Autobahn near Schnaittach, Germany (2003)

b. Traffic flows through narrow lanes on a work zone on the A6 Autobahn near Kaiserlautern, Germany (2015)

[Anonymous](#)\Pixabay

c. Temporary yellow markings at a crossover at an unspecified location on a German autobahn (2011)

[Betz](#)/TruckNet UK

d. Reallocated road space during construction on A16 bridge over the Rhine River near Speyer, Germany (2006)

[Sauer GmbH](#)

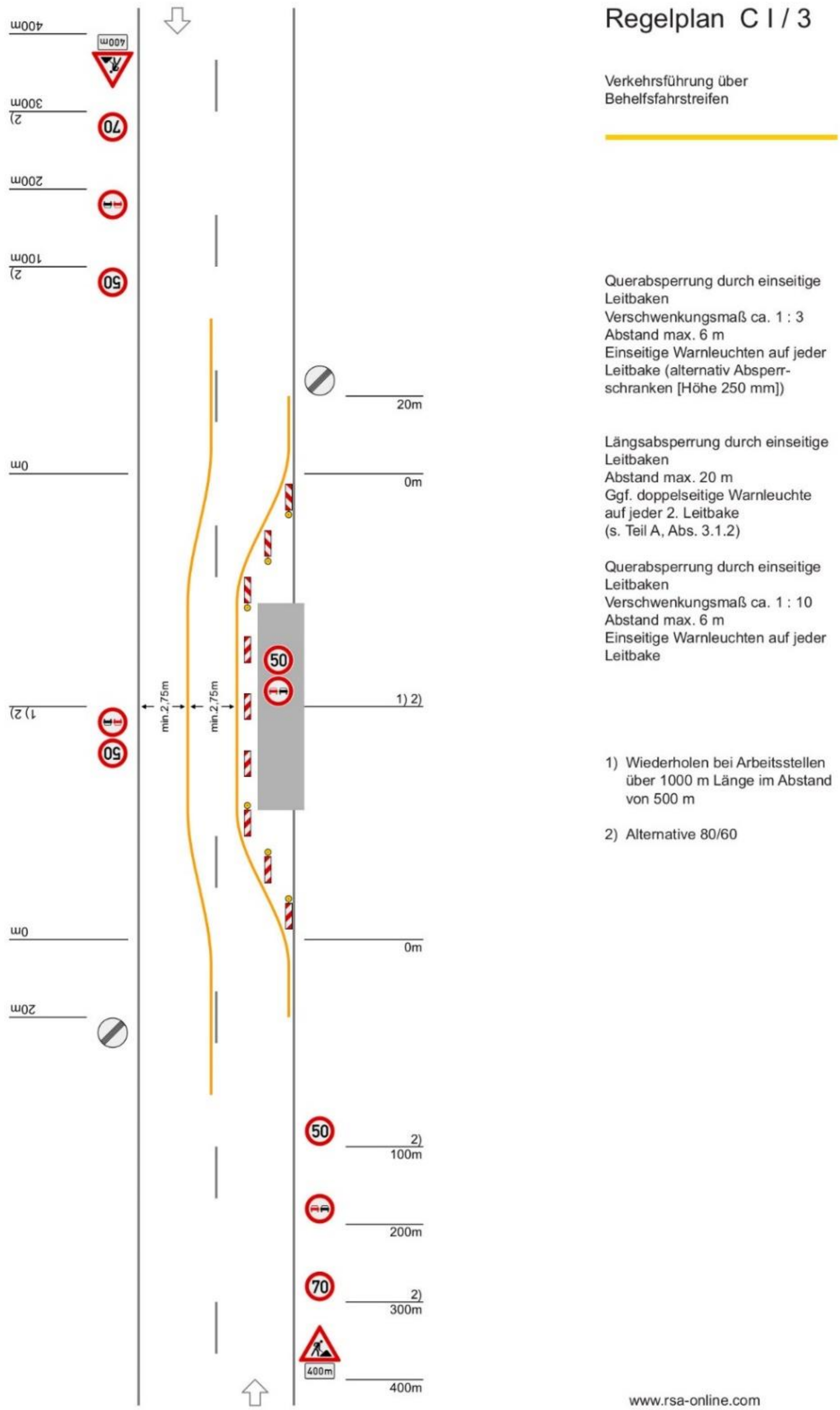
e. Yellow temporary PM for an urban bridge project in Germany (circa 2015)

Sauer GmbH

f. Temporary urban street marking at an unspecified location in Germany (2010)

Figure 18. Special-color pavement marking in Germany

A related aspect of German practice is the use of narrow lanes to reduce the need for lane closures; for example, the Typical Application drawing reproduced in Figure 19 allows the lane width to be reduced to 2.75 meters (9 feet).



[RSA Online]

Figure 19. German typical application drawing indicating the use of yellow pavement marking for a lane shift

2.4.4 Belgium, France, Italy, and Spain

Belgium, France, Italy, and Spain use all-white permanent pavement marking systems. Yellow markings are routinely used in long-term work zones on urban streets, rural highways, and freeways (Figure 20a,b). A scan of several work zone site photos suggests that old pavement markings are left in place for some long-term freeway and tollway projects (Figure 20c) and removed for others (Figure 20d). Perhaps this is related to the speed limit. Old markings generally appear to be left in place on urban street projects.

Coyau/Wikimedia Commons

a. Temporary traffic control at the Place de la République in central Paris (2012)

Akiry/Wikimedia Commons

b. Temporary traffic control on urban street in Epinay-sur-Seine, France (2012)

Rossano/Wikimedia Commons

c. Work zone near the A17/A19 freeway interchange in Belgium (2008)

[Ripley9895]/© 2018 photobucket.com

d. Yellow PM and ghost lines at a widening project on A34 in northeastern Italy (2011)

Figure 20. Special-color pavement markings in France, Belgium, and Italy

Figure 21 shows special-color pavement markings used in Spain.

Agencia de Desarrollo Local

a. Temporary one-way pavement marking during construction of a hillside street in Spain (circa 2013)

José Mª Castañares Gandía

b. Temporary yellow marking on crosswalk in an urban construction project in Spain (undated)

autofacil.es

c. Temporary yellow pavement marking on a rural two-lane highway in Spain (circa 2013)

hoy.es

d. Temporary yellow markings on an urban arterial improvement project on route EX-207 in Mérida, Spain (2014)

hoy.es

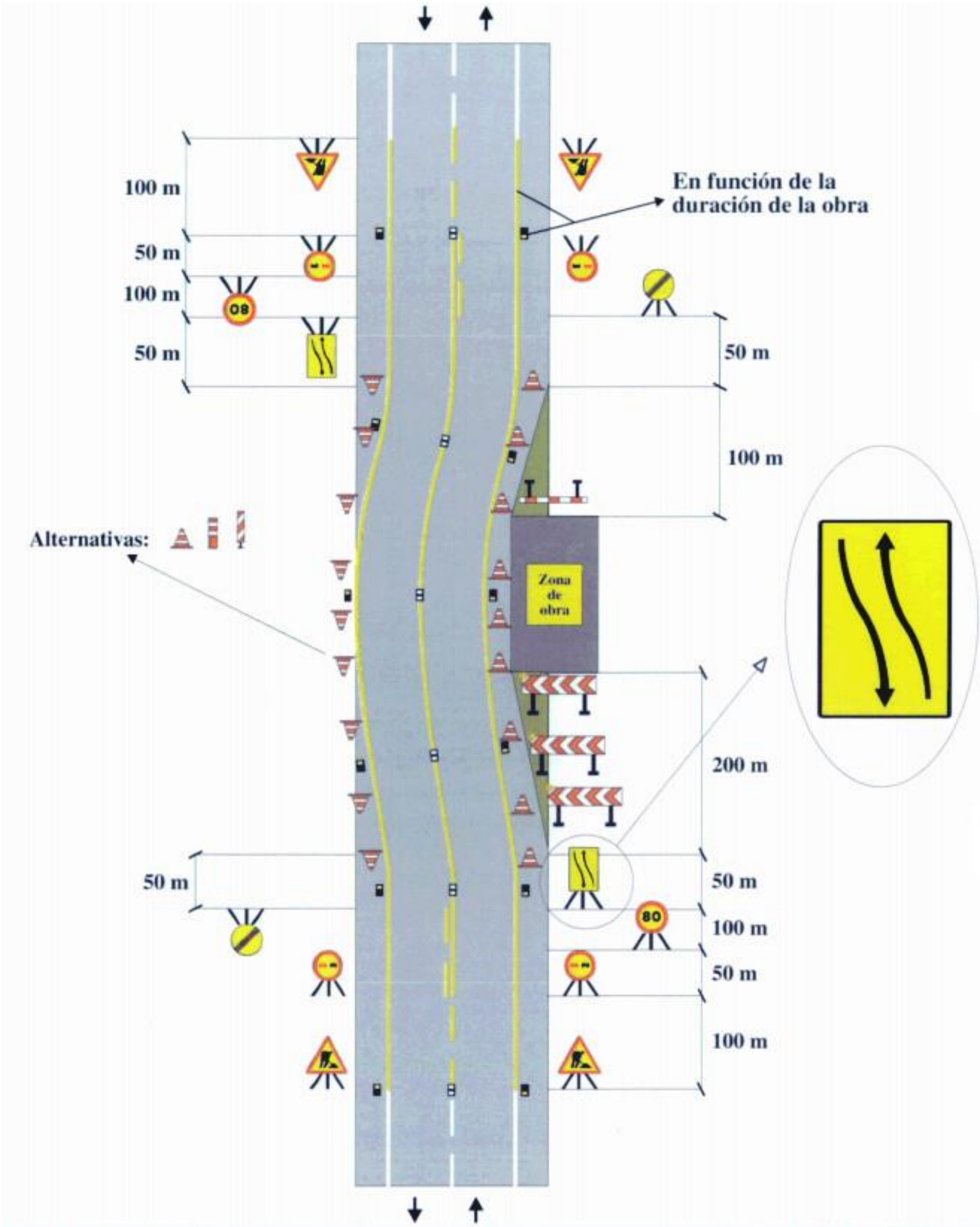
e. Summer vacation traffic passes through a work zone on a highway near the coastal city of Tarragona, Spain (circa 2008)

abc.es

f. Temporary yellow markings at a construction site in Spain (circa 2013)

Figure 21. Special-color pavement markings in Spain

Figure 22 is a Typical Application drawing from Spain illustrating the use of yellow marking.



Source: [Ministerio de Fomento](#).

Figure 22. Typical application drawing from Spain's Ministry of Development illustrating the use of temporary yellow pavement marking in an area where traffic is deviated from its normal path. Note the color coordination between the signage and pavement marking

Spain's work zone handbook provides the following guidance (Direccion General de Carreteras 1997):

Original (in Spanish)

A juicio del Director de la obra y dependiendo de las circunstancias que concurran en la misma, se podrá señalizar horizontalmente con marcas en color amarillo o naranja, las alteraciones que se produzcan sobre la situación normal de la vía.

English Translation

At the discretion of the project director and depending on the site conditions, yellow or orange colored horizontal pavement marking may be used to mark alterations to the normal situation on the roadway.

2.4.5 Australia

In 2012 the Australian state of Victoria conducted trial of special-color (yellow) temporary marking for a construction project on the M80 Ring Road, a major freeway located in the suburbs of Melbourne (Figure 23). A video produced for the project compares the conspicuity of the yellow markings with ghost markings and discusses the design of the transition section where white markings end and yellow begin (VicRoads 2012). Signs with the legend OBEY YELLOW LINES were used to emphasize that the yellow markings override the permanent white markings. White markings were left in place except in the transition area.

VicRoads 2012

Figure 23. Transition from permanent white to temporary yellow PM on M80 near Melbourne, Australia

2.4.6 New Zealand

New Zealand’s pavement marking standards are similar to the U.S. MUTCD, with double-yellow lines to mark no-passing zones and white for most other pavement marking (NZTA 2010).

In 2014 and 2015 orange work zone pavement marking was tested on a total of six projects in Auckland, the country’s largest metropolitan area (Stroh 2014, Stevens 2016). Two were major long-term projects (9 to 14-month duration) while the others had durations of 3 to 5 months. Orange temporary marking tape was used at some sites and orange paint at others. To prevent black from showing-through, the orange paint was usually applied over a white primer. Previous markings were removed (Figure 24).

Stroh 2014

Figure 24. Orange marking trial and ghost markings on SH 16 Causeway Upgrade in Auckland, New Zealand

The primary motivation for the demonstrations was to reduce driver confusion caused by ghost lines, which was felt to be especially problematic on east-west roadways during the winter months (Stevens 2016). Most of the projects required a series of lane shifts. The existing open-graded asphalt pavement had become quite brittle, making it difficult to remove the old markings without severe scarring. Prior to the orange marking trials a significant effort had been made to develop customized black-out tapes and paints, but the results were unsatisfactory.

A report summarizing Auckland's experience was being developed at the time the literature review for this project was prepared. Although published results were not available, an Auckland Motorways representative stated that the demonstrations were highly successful and public acceptance of the special-color marking was strong (Stevens 2016). Although no formal analysis was conducted, traffic control center operators anecdotally suggested that lane discipline might have been better than usual while the orange marking was in place.

2.4.7 Japan

Japan is a mountainous country and many of its rural highways are narrow and winding, while urban arterials are often quite congested. Permanent no-passing zones are identified by solid orange or solid yellow lines (usually single lines, sometimes double) (Figure 25 and Figure 26).

SAC Murakumo

Figure 25. Permanent pavement markings on a rural highway near Hanyu, Saitama Prefecture, Japan (2015) (driving on left)

Ralph Mirebs

Figure 26. Permanent pavement markings on an urban arterial in Nagoya, Japan (2012)

The choice between yellow and orange appears to be at the discretion of each of the 47 prefectures (Figure 27).

東京都青/Wikimedia Commons (2009)

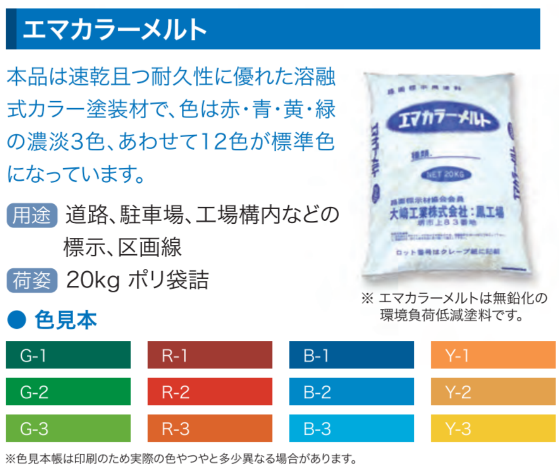
a. Yellow

Aomaru Atsugi 2013

b. Orange

Figure 27. Comparison of yellow and orange no-passing zone markings in Japan

Paints and spray-applied hot-melt thermoplastics both appear to be used for this purpose (Figure 28).



Osaki Industry Co., Ltd.

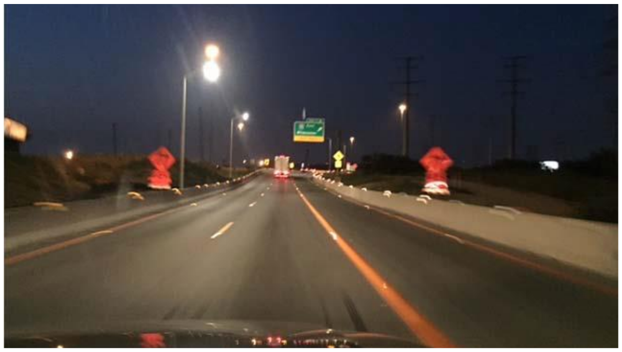
Figure 28. Typical colors for thermoplastic pavement marking in Japan (from a vendor's sell sheet)

2.4.8 Wisconsin – Zoo Interchange

In Fall 2014, Wisconsin DOT petitioned FHWA for a Request to Experiment with orange pavement markings at the Zoo Interchange reconstruction project, a high-volume freeway-to-freeway interchange in the heart of the Metropolitan Milwaukee (Figure 29).

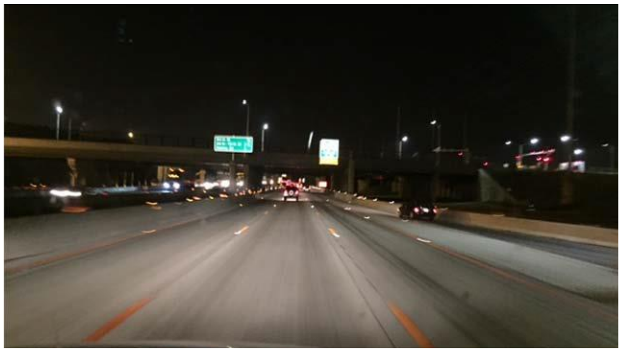
a. Zoo interchange orange markings in April 2015

b. Zoo interchange orange markings in November 2015



FHWA - Wisconsin

c. Mixed LED and high pressure sodium lighting, September 2015



FHWA - Wisconsin

d. LED lighting, September 2015

John Shaw

e. Freshly re-painted markings, July 2016

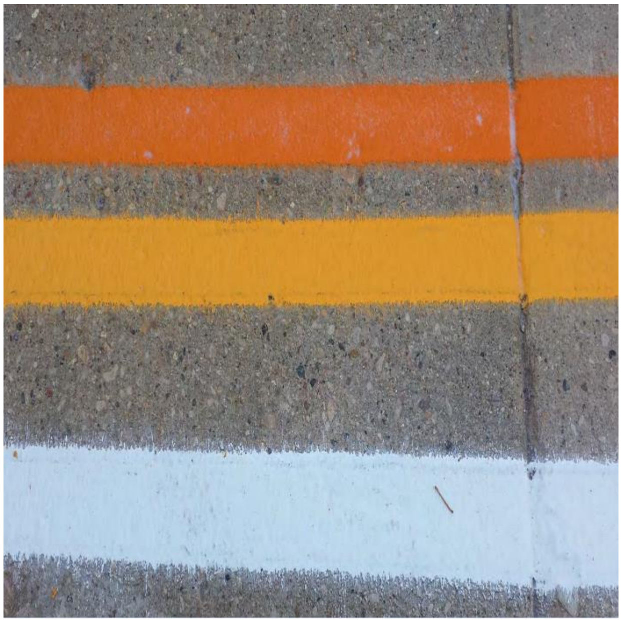
John Shaw

f. Faded markings, October 2016

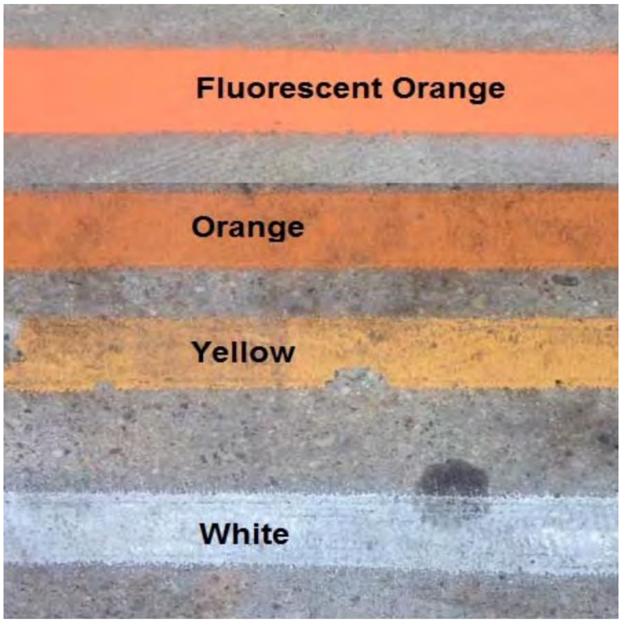
Figure 29. Photos of zoo Interchange orange marking demonstration in Milwaukee, Wisconsin

Year-round construction began in 2013 and is expected to continue through 2018. Reasons cited for the orange marking test include the large number of lane shifts in the project, very high traffic volumes, and issues with salt residue which make the white lines blend in with the pavement during the winter months (Rauch 2015). Removal of old markings during similar projects on other Milwaukee-area freeways left scars on the pavement making it hard to distinguish the correct lane lines and causing motorist confusion on the actual location of the travel lanes.

Various types and shades of orange water borne marking paints and epoxies have been utilized (Figure 30).



a. Epoxy paints.



b. Waterborne paints.

Matt Rausch/Wisconsin DOT

Figure 30. Comparison of pavement marking colors used in early Wisconsin DOT field testing

Test Rationale and Evaluation Plan. Reasons cited for the orange marking test include the large number of lane shifts in the project, very high traffic volumes, and issues with salt residue which make the white lines blend in with the pavement during the winter months (Rauch 2015). Removal of old markings during similar projects on other Milwaukee-area freeways left scars on the pavement making it hard to distinguish the correct lane lines and causing motorist confusion on the actual location of the travel lanes.

FHWA approved a Request to Experiment through June 2016, and this approval was later extended to cover the entire duration of the Zoo Interchange project. FHWA expressed some concerns which were addressed during the approval process; these included yellowing of the markings over time and the need for control sections with conventional white markings. Black-on-orange signs with the message orange pavement marking test section ahead were installed at

The evaluation plan includes video monitoring to check for evidence of unexpected driver reactions, evaluation of traffic operations (including during snow events), monthly retroreflectivity and color testing, and public opinion surveys.

Field Experience. Several types and shades of orange paints have been utilized in the Zoo Interchange. Wisconsin DOT has also experimented with various types of retroreflective beads. These tests were ongoing during the preparation of this report, so a detailed discussion of these materials tests is beyond the scope of this report. Some early experiences are summarized below.

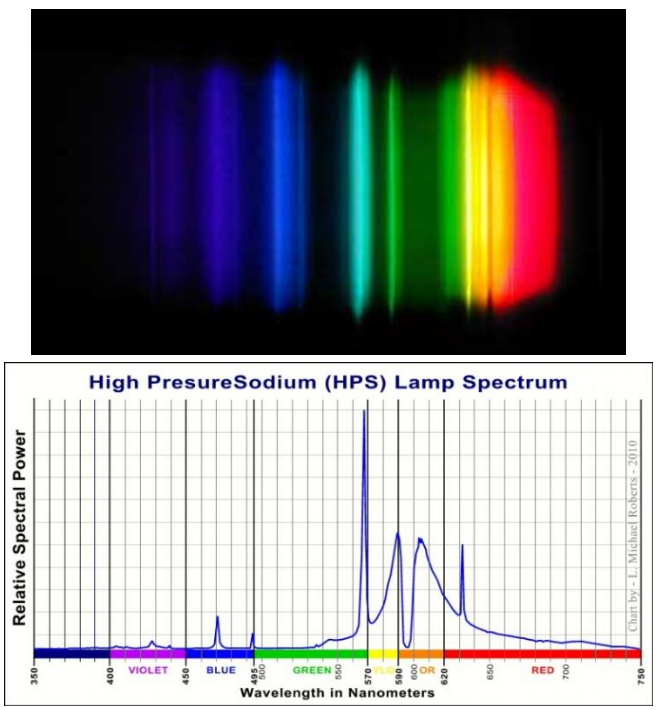
The interchange was originally equipped with High-Pressure Sodium (HPS) lighting that is being replaced with LED lighting as work progresses. The first set of orange markings were installed in December 2014 using a non-fluorescent epoxy paint that was towards the yellow end of the orange color space. Two difficulties were encountered. First, at night under the HPS lighting, the paint looked yellow. Second, the paint suffered from poor adhesion because it was not installed in accordance with the manufacturer’s specifications (the ambient temperature was too cold during installation).

Fluorescent pigments transform energy from the ultraviolet spectrum and into longer wavelengths that are visible to the human eye (Lindblom 2012). An object coated with a specific daylight fluorescent pigment reflects its visible color and absorbs and transforms UV wavelengths into this color. This creates the visual effect of greater brilliance than a non-fluorescent pigment of the same hue.

HPS lighting has a peculiar spectral distribution. Although objects appear pinkish-orange under HPS lighting (Figure 31), there is almost zero spectral power in a subset of orange wavelengths around 595 nanometers (Figure 32).

GiancarloGotta/Wikimedia Commons

Figure 31. Comparison of color effects of three roadway lighting technologies. Foreground: high-pressure sodium (pinkish orange). Crosswalk and intersection: LED (bluish white). Side street in background: Mercury vapor (greenish)



Images: Chris Heilman/Wikimedia Commons (left), LMRoberts/Wikimedia Commons (right)

Figure 32. Spectral distribution of high-pressure sodium lighting

This limits the orange hues that are visible under HPS lighting to only a portion of the MUTCD-approved color space. In addition, HPS lamps emit almost no ultraviolet light, so fluorescent pigments are not activated. As the project progressed the importance of this issue diminished due to the previously-planned replacement of HPS lights with white LED lighting (DuPont 2016).

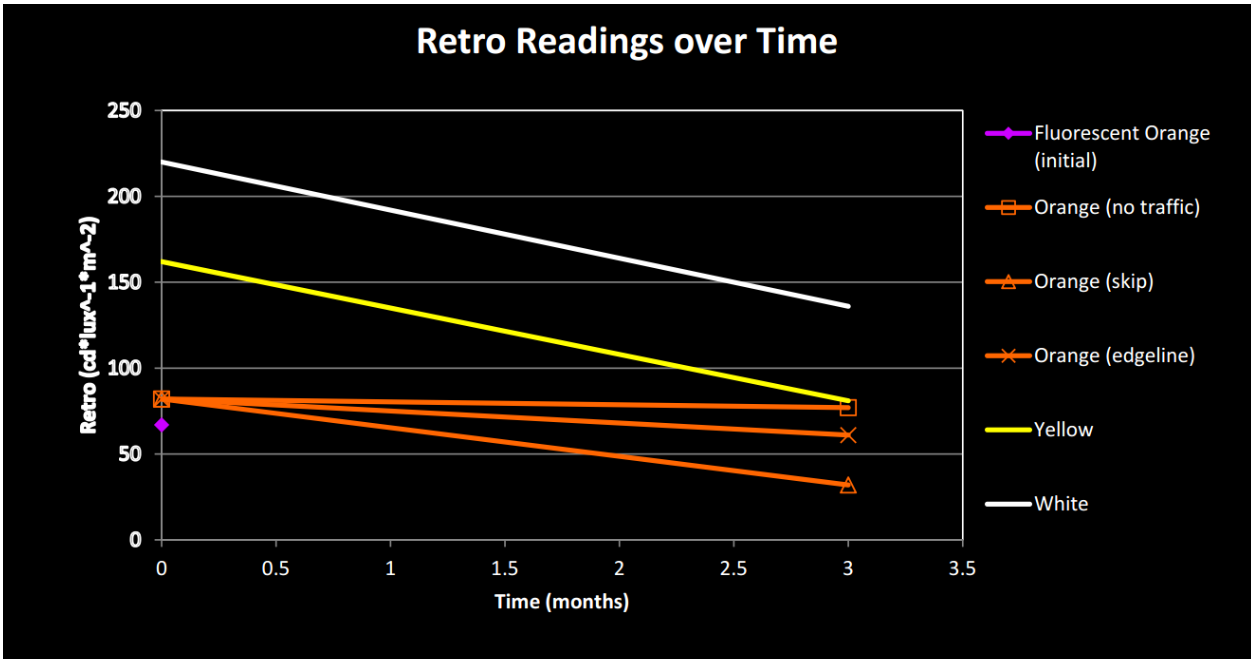
In 2015 and early 2016, Wisconsin DOT experimented with various orange pavement marking paints including two shades of orange epoxy (used primarily in the winter) and water-based fluorescent paints (used primarily during the summer) (DuPont 2016). Epoxy was used in winter because can be applied at lower temperatures and is less subject to retroreflective glass bead loss during snow plowing. Because of the high traffic volumes much of the painting is done at night, creating difficulties with assuring that the temperature and pavement moisture are within manufacturer specifications. Some of the paints used in newer trials were fluorescent, and a public opinion survey suggested most drivers preferred the fluorescent orange color (Table 1). Various types of retroreflective beads were also experimented with.

Table 1. Results of Wisconsin DOT public opinion surveys

Survey 1 (n≈1600)	**Survey 2** (n≈320)
Did the orange markings increase your awareness of being in a work zone?	**Did the fluorescent orange markings increase your awareness of being in a work zone?**
Yes: 51%	Yes: 80%
No: 49%	No: 20%
Did the orange markings seem more visible than the white pavement markings?	**Do you feel the fluorescent orange is more visible than the white?**
Yes: 56%	Yes: 83%
No: 44%	No: 17%
What is your opinion of the orange markings?	**Did the fluorescent orange help you drive safely through the work zone?**
Excellent: 12%	Excellent: 16%
Very Good: 16%	Very Good: 33%
Good: 15%	Good: 25%
Needs some improvement: 30%	Needs some improvement: 18%
Needs a lot of improvement: 27%	Needs a lot of improvement: 5%
	I didn’t notice: 3%
	Which color would you prefer to be used in a construction zone?
	Fluorescent Orange: 80%
	Orange: 5%
	White: 15%

Source: DuPont and DeDene 2017

Wisconsin DOT’s experience indicated that there are relationships between the amount of fluorescent pigment and other paint characteristics (Rauch 2015, DuPont 2016). As the amount of fluorescent pigment increased the coating became less opaque, allowing more of the underlying surface to show through (in contrast to the Auckland, New Zealand tests, white primer was not used under the orange paint in Milwaukee). Highly fluorescent paints were also less resistant to fading. Optical measurements of two versions of the orange pavement marking are summarized in Figure 33.



Rauch 2015

Figure 33. Effects of aging and traffic on zoo interchange pavement marking retroreflectivity with first-generation orange paint

Public Opinion. In 2015, WisDOT conducted two online surveys of public attitudes about the orange marking. Participants for the first survey were recruited by e-mailing drivers who signed up for electronic newsletters about the Zoo Interchange project and employees at the Milwaukee Regional Medical Center, which is adjacent to the project. The survey was also advertised on WisDOT's website. Thus, respondents to the survey were self-selected. The second survey was e-mailed directly people who responded to the first survey and agreed to receive further communications about the orange pavement marking project. It was also advertised on the WisDOT website.

The first WisDOT survey was conducted shortly after the original orange markings were installed (at the time of the adhesion and night-illumination difficulties). The second survey was conducted shortly after the site was repainted using fluorescent orange paint. The results are summarized in Table 1.

The number of respondents to the first survey was 1,546 and the responses to the second were 693. Overall, the results suggest a positive public perception of the non-fluorescent orange markings and a very positive perception of the fluorescent markings. It is important to note that in a self-selected online survey, people with strongly positive or strongly negative opinions are probably more likely to respond than those with moderate or indifferent opinions.

In 2015, some media reports criticized the orange markings used in Zoo Interchange because they were not wet-reflective and therefore had limited visibility during rain at night (Figure 34) (Hutchison 2015, Wainscott 2015).

Figure 34. The pavement marking materials used in the zoo interchange were not wet-reflective

In Wisconsin, this is not unique to orange markings: WisDOT generally does not specify wet-reflective materials for temporary applications, and the control segment on the north leg of the interchange had dry-reflective white markings. Nevertheless, the high-profile of the project attracted attention to the test section. To mitigate these concerns WisDOT added orange raised pavement markers during the latter part of 2015 and plans to continue using them during the summer months until the project is completed (DuPont 2016). An FHWA review found that the raised pavement markers “greatly enhanced the drivability of the work zone at night” but “will not last through the winter stages given snow fall and subsequent plowing operations” (Platz et al. 2015).

2.5 Literature Review Summary

Overall, the experience of agencies that have utilized special-color pavement markings appears to be positive, as indicated by its widespread adoption in standards across Europe and growing use elsewhere. Although the survey methodologies were not scientifically rigorous, public opinion data from Wisconsin DOT and the New Zealand Transport Agency indicated general support for special-color marking. Fade-resistance was problematic for the orange paints used in Wisconsin DOT work zone applications but does not appear to be a problem in permanent thermoplastic marking applications in Japan, thus it appears that fade-resistant formulations are available in some markets. Fade resistance is less likely to be a concern for short-duration projects.

Two distinct approaches to the use of special-color work zone pavement marking can be discerned from agency practices. In several European countries, yellow or orange pavement markings override existing white markings. Although existing markings are sometimes removed or obscured, in many cases agencies appear to be able to avoid the difficulty and expense of removing the old markings. This was also the case for the demonstration project in Victoria, Australia. Conversely, the orange marking applications in Ontario and the demonstration projects in New Zealand, Quebec and Wisconsin continue to remove the old markings. Ghost markings are still visible at these sites, but it appears that practitioners expect that greater color salience will improve driver guidance. These differences appear to reflect not only agency preferences, but also interpretations of statutory language related to pavement marking.

The usual approach to experimentation with new technologies is to test them gradually in increasingly demanding environments (Hughes 1983). Peculiarly, this has not been the case with the orange pavement marking demonstration projects in Australia, Canada, New Zealand, and the U.S., where the experimentation has occurred mainly in the context of major projects on high-volume urban freeways.

Although the recent demonstrations in all four countries have been freeway projects, the review of European design guidelines, agency policy documents, and site photographs suggests that special-colored marking appears to have significant benefits for projects on urban multi-lane arterials. Urban and suburban arterials often have very extensive pavement marking, such as turn arrows and crosswalks; overriding these markings with a special color (for example by placing a colored X over an existing white turn arrow as in Figure 18f) appears to be expeditious and also draws attention to the changed condition. Design standards typically require signs warning drivers well in advance as they approach freeway work zones. Conversely, urban arterial work zones usually have many access points (such as side streets and driveways) which can be difficult to sign and mark conspicuously. Specially-colored pavement marking perhaps helps remind road users approaching from secondary access points that they are entering a work zone. The special-color crosswalk treatments utilized in many European work zones also appear serve this function by warning pedestrians that they are stepping into an unusual traffic environment (Figure 20a).

Agencies have a number of alternatives to special-color marking. Black-out tapes and paints could be used more extensively at sites where durability is not a concern. Pavement sealing, microsurfacing, and micro-milling are often used as preventative maintenance treatments; additional analysis could potentially identify situations where they are more cost-effective than traditional pavement marking removal techniques. Although sealing, microsurfacing, or micromilling would not extend the life of a pavement that is scheduled to be removed in a subsequent construction phase, it could potentially contribute to ride quality and durability on a pavement that is planned to remain in service long-term, such as a detour route. As micromilling becomes more widespread, it is possible that the cost difference between full-width micromilling and grinding only the pavement markings will diminish.

The use of yellow paint for work zones has become commonplace in a number of countries that use all-white systems for permanent pavement marking. This color would not be appropriate in the United States due to the MUTCD requirement that yellow be used to designate lanes moving in opposite directions. Therefore, if a special color for work zones were to be designated, orange appears to be the most likely candidate.

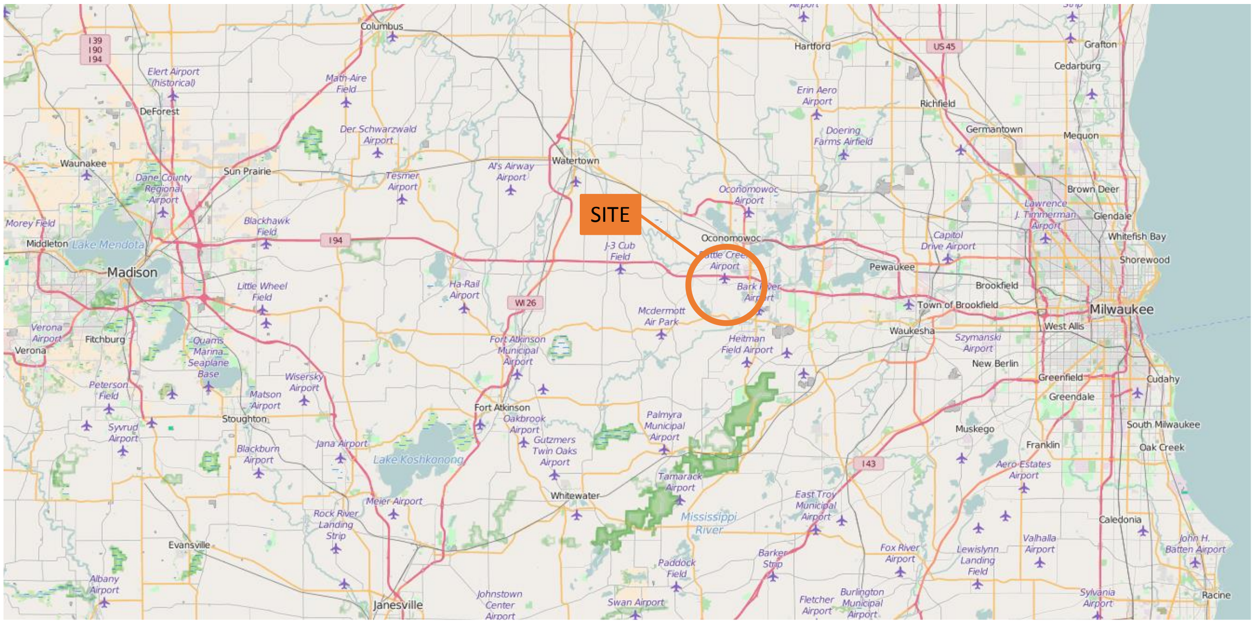
3 FIELD DATA COLLECTION AND ANALYSIS

Following the review of U.S and international literature, the research team contacted the Iowa, Pennsylvania, and Wisconsin Departments of Transportation to identify possible locations for field installation and evaluation of orange work zone pavement markings. This process resulted in selection of a test site on I-94 near Oconomowoc, Wisconsin in consultation with Wisconsin Department of Transportation (WisDOT). Since orange pavement markings are not in the MUTCD, the research team prepared Request for Experimentation (RFE) in accordance with the MUTCD guidelines. RFE was submitted by WisDOT to the Federal Highway Administration (FHWA) for approval. Following the approval of the RFE, orange pavement marking tapes were procured and installed. The details of test sites, data collection, subsequent analysis and results are presented in this chapter.

Materials availability was an important consideration for the field research. At the time of test site selection, paint vendors based in the United States were supplying epoxy and waterborne paints to the Zoo Interchange project as custom specialty items. A Colorado-based manufacturer indicated willingness to supply orange temporary pavement marking tape. A Minnesota-based multinational company offered orange marking tape in Central Europe and New Zealand, but the company's representatives in those countries were not authorized to sell the product in the US, and the American sales representative did not respond to purchasing inquiries. A Japanese vendor of orange thermoplastic marking and a Canadian vendor of spray-on methyl methacrylate were identified, but Wisconsin DOT typically does not use those materials.

3.1 Test Sites

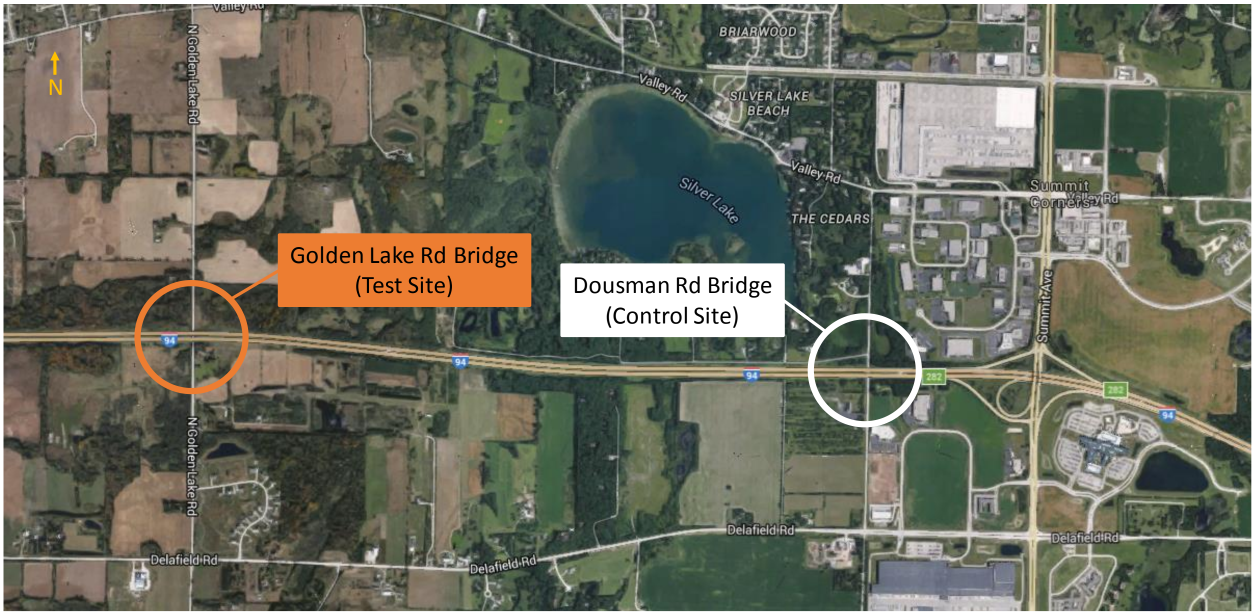
Two work zones near Oconomowoc in western Waukesha County, Wisconsin were used as test sites (Figure 35).



Open Street Map

Figure 35. Location of test sites in southeastern Wisconsin

Orange pavement marking tapes were installed at the I-94 bridge over Golden Lake Road work zone. This site was paired with a very similar work zone approximately 2 miles to the east on the I-94 bridge over Dousman Road, and had standard-color marking tapes to serve as an experimental control (Figure 36).



© 2018 Google

Figure 36. Satellite view of test and control sites

Both work zone sites had two lanes open (same as under normal conditions), each lane was 11 feet wide with lateral lane shifts in the eastbound direction and crossovers in the westbound direction. Since there are no entrance or exit ramps between the Golden Lake Road and Dousman Road sites, they carry exactly the same traffic. Thus, these sites are well suited to identifying any differences in driver behavior that are potentially attributable to the experimental pavement marking color in an operationally straightforward traffic environment. Almost no ghost marking was present at either site, which allowed observation of effects purely associated with the marking color difference.

For October 2016, WisDOT reported an average daily traffic volume of 47,412 for the segment that included the test and control sites (23,542 westbound and 23,879 eastbound). The highest reported directional hourly volume was 2,688 on Friday afternoons in the westbound direction. (Wisconsin Department of Transportation and University of Wisconsin-Madison 2016).

The markings were implemented using wet-recoverable pavement marking tapes (Brite-Line Deltaline TWR), supplied in fluorescent orange (Figure 37) for the Golden Lake Road test site and in standard white and yellow colors (Figure 38) for the Dousman Road control site. This material differs from the temporary marking paints used in other Milwaukee-area trials, which are not wet-recoverable.

John Shaw

Figure 37. Sample of experimental pavement marking tape

Figure 38. Sample of control pavement marking tape

Figure 39 illustrates the newly-installed Golden Lake Road markings in the field.

John Shaw

Figure 39. Freshly installed fluorescent orange pavement marking tape – Golden Lake Road – August 9, 2016

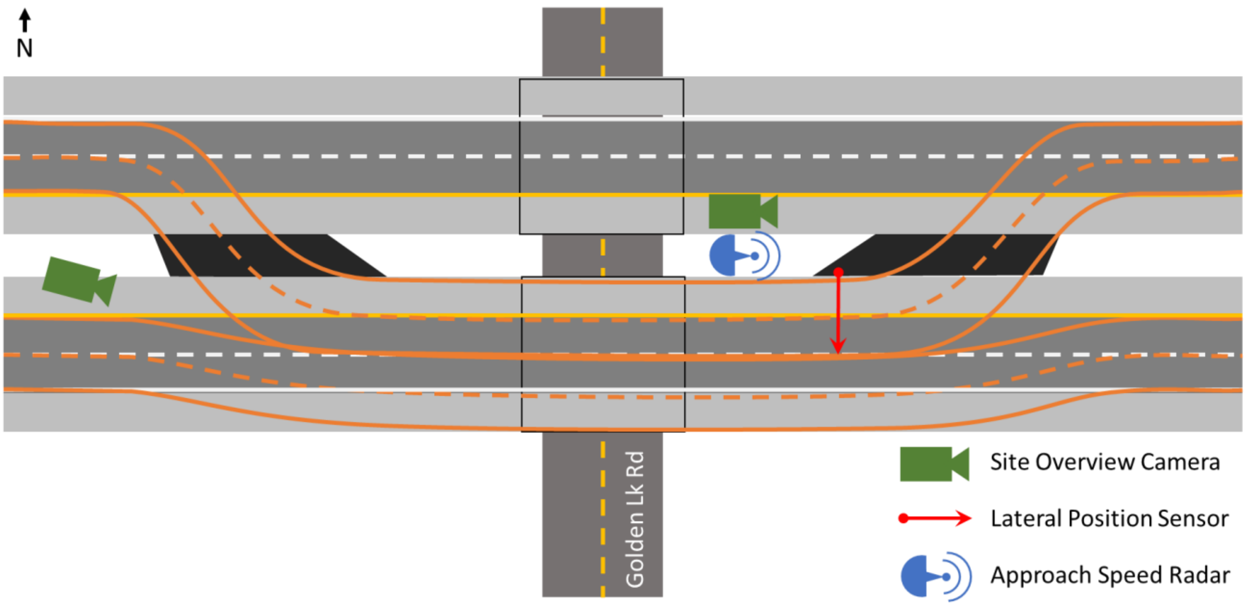
John Shaw

Figure 40 compares the colors of the unused tapes with samples collected after approximately 3½ months of the field testing: color and brightness changes were observed in all cases (yellow, white, and orange) due to fading and dirt accumulation.

John Shaw

Figure 40. Comparison of yellow, white, and fluorescent orange tapes when new (upper samples) and after approximately 3½ months in the field (lower samples)

Figure 41 illustrates the lane configuration that existed during the test phase.



Not to Scale

Figure 41. Lane configurations and data collection equipment positioning for the Golden Lake Road site

Although the geometrics at the two sites were very similar, a few differences are notable:

- Based on plans prepared before the site was selected for study, the Golden Lake Road test site (orange markings) had slightly longer lateral shift transition sections than the Dousman Road site (conventional markings).
- Westbound traffic approaching the Dousman Road control site is downstream of a moderate-volume merge maneuver associated with the STH 67 (Summit Avenue) entrance ramp.

3.2 Data Collection

Previous orange marking evaluations in Wisconsin have collected driver opinion data, but have not attempted to assess driver behavior quantitatively. To address the lack of quantitative data several field devices were installed to monitor vehicle lane positioning and travel speeds at both the test and control sites. To accomplish these objectives within the scope of the available resources, the following equipment was used:

- **Site Overview Cameras.** Portable camera trailers borrowed from the WisDOT Statewide Traffic Operations Center were placed in the vicinity of the upstream crossovers. With an overhead vantage point, these cameras provided a general overview of traffic operations at each site. Selected images from these cameras were used to evaluate driver behavior in the test (orange) and control (white) marking sections. Figure 42 shows the location of the trailer mounted camera on the approach to the work zone crossovers.

John Shaw

Figure 42. Site overview camera at the approach to work zone, November 2016

- **Lateral Positioning Sensors.** As a surrogate measure of driver awareness of the lane shift markings, lateral positioning of vehicles in the test and control segments was observed using laser distance meters (rangefinders). This was accomplished using Fluke 414D laser distance meters with a range of up to 50 meters (165 feet) and a claimed accuracy of ±2 millimeters (1/10 inch). Each unit was equipped with a Porcupine LR4 interface card connected to a custom-built data logger. The system recorded position data at a resolution of 2.5 Hz (one observation every 400 milliseconds).

- The research team developed custom data logging software using Raspberry Pi microcomputers interfaced to the Porcupine LR4. This allowed every output reading from each laser distance meter to be logged, along with a unique observation ID and a date and timestamp. Thus, each lateral positioning sensor unit consisted of one Fluke 414D, one Porcupine LR4, and one Raspberry Pi, mounted together in a watertight box (John Shaw Figure 43).

John Shaw

Figure 43. Lateral positioning sensor in the approach to work zone

These units were secured on an adjustable shelf and energy was supplied from a deep-cycle marine battery placed on a second shelf below the data collection equipment. Each unit was installed behind the concrete barrier on the right side of the travel lanes. By adjusting the shelf height, each sensor was positioned high enough to target tractor-trailers but low enough to target the body of passenger vehicles. The units were positioned in tangent sections near the upstream end of each crossover. From this vantage point, the device recorded the distance to the closest object, thus in heavy traffic the lane closest to the sensor was oversampled relative to the total volume. The position information obtained is the right edge of the vehicle.

- **Approach Speed Radar.** Forward-fired radar units were used to quantify the approach speeds at the test and control segments and identify any speed behavior differences potentially attributable to the marking color. A customized portable vehicle trajectory data collection system based on an Intersector traffic radar sensor was developed to log the position and speed of vehicles, with an upstream range of up to 800 feet. The observation rate was 2 Hz (one observation every 500 milliseconds). Figure 44 shows the approach speed radar mounted on the portable camera trailer at the work zone.

Kelvin Santiago

Figure 44. Approach speed radar mounted on portable camera trailer

As indicated in the Figure 41, the westbound traffic at the test and control sites was crossed over to road space ordinarily used by eastbound traffic. The lane and shoulder areas north of the crossovers provided ample space to position trailer-mounted cameras and other data collection equipment in space that is ordinarily used by westbound traffic. This allowed data to be collected for several weeks, including observations under various weather conditions. For the eastbound direction (the side with minor lane shifts), narrow shoulders and steep sideslopes at both Golden Lake Road and Dousman Road precluded the possibility of using trailer-mounted cameras. The original plan was to mount a camera on a temporary pole at Dousman Road and utilize an existing Traffic Operations Center traffic detector pole at Golden Lake Road, but an untimely crash knocked down the detector pole and the beam guard that ordinarily protects it. Temporary poles were subsequently installed in the median at both sites, but the resulting delays impacted the amount of data that could be collected before work on the bridges was completed. Consequently, the data analysis prepared for is report is limited to the westbound traffic.

3.3 Data Analysis

3.3.1 Lateral Position Sensor Data

The lateral position sensors collected nearest-object position information samples at a 2.5 Hz resolution on the westbound approaches of Dousman Road (control white/yellow markings) and Golden Lake Road (orange markings). Since vehicle speeds were high in relation to the sampling rate, some vehicles passed through the detection zone before they could be observed. Nevertheless, the sample size was large because position data was collected over a period of several weeks.

Extensive checks were performed on the raw sensor data to remove discrepancies and outliers. Timestamp data were analyzed to examine if there were identical values reported over extended durations of time. A few identical position values observed consecutively over an extended period of time (possibly because of a sensor fault) were removed from the analysis. Spurious observations that were not physically possible were also removed (these were verified with the video from the trailer, if available). Following data cleaning, 77,757 and 137,379 observations were available at the control and test sites respectively.

Figure 45 illustrates the lane position data obtained at the control and test sites.

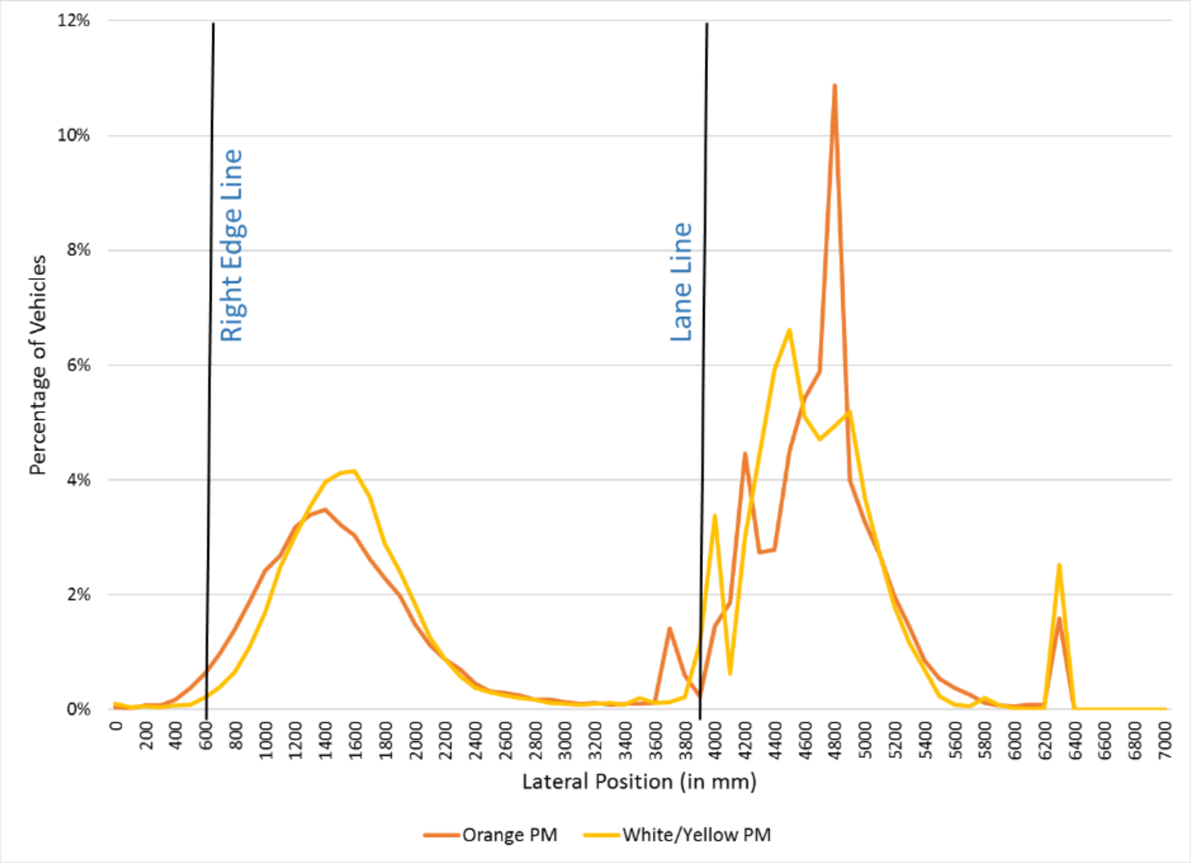


Figure 45. Lane position data

The orange curve represents orange marking test site, while the yellow curve represents the control site with conventional marking colors. Note that the lane position data is not centered within the lane, since the laser distance meter was configured to measure the distance to the right edge of the nearest vehicle. The double-hump distribution is indicative of the fact that there were two travel lanes. At both sites, vehicle position observations from the right lane were rather smoothly distributed, while vehicle positions in the left lane were less consistent. In part, this is due to sample size differences, since measuring the nearest-object distance oversampled right-lane vehicles (vehicles in the left lane were sometimes occluded by those in the right lane). Additionally, vehicle speeds in the left lane were probably higher than right-lane speeds, possibly resulting in less precise lane positioning by the drivers.

The Kolmogorov-Smirnov statistical test (K-S test) was performed to compare the two distributions. This test indicates that there is no statistically significant difference between the lane position data distributions for the test and control sites. Subjective visual examination of the histogram appears to indicate that some vehicles in the right lane of the test section (orange markings) tended to track slightly further to the right than vehicles in the control section; this difference was perhaps 100 to 150 mm (4 to 6 inches).

3.3.2 Driving Behavior from Video Data

Video image samples obtained from trailer mounted cameras (Figure 46) were used to assess lane choice and the prevalence of vehicles straddling or changing lanes.

Figure 46. Examples of images obtained from trailer-mounted cameras

The camera vantage points provided a view of several hundred feet on the approach to the crossover, providing an opportunity to distinguish lane-changing maneuvers from straddling. Straddlers were defined as vehicles that were overlapping both lanes without the intention of changing lanes. Each vehicle in the observed sample in the video was assigned to one of the following four categories:

1. Right Lane
2. Left Lane
3. Straddlers
4. Lane Changers

One potential benefit of orange markings is to mitigate driver confusion under low illumination (such as Dawn or Dusk) and rainy conditions. In order to evaluate this, one hour of video for both the control and test sites was analyzed for each of the following four conditions:

1. Dawn
2. Mid-day
3. Dusk

4. Rain

Table 2 shows the number and percentage of vehicles in each position (right lane, left lane, straddler, lane changer) under the four different conditions for the control and test sites.

Table 2. Position of vehicles under different conditions

		Orange		White/Yellow	
Condition	**Position**	**Number**	**Percent**	**Number**	**Percent**
Dawn	Right Lane	222	64.3%	186	53.9%
	Left Lane	91	26.4%	119	34.5%
	Straddlers	31	9.0%	31	9.0%
	Lane Changers	1	0.3%	9	2.6%
Midday	Right Lane	618	49.6%	522	41.9%
	Left Lane	531	42.6%	615	49.4%
	Straddlers	91	7.3%	89	7.1%
	Lane Changers	6	0.5%	20	1.6%
Dusk	Right Lane	577	52.7%	477	49.0%
	Left Lane	480	43.8%	449	46.1%
	Straddlers	29	2.6%	40	4.1%
	Lane Changers	9	0.8%	8	0.8%
Rain	Right Lane	560	48.4%	506	43.5%
	Left Lane	539	46.5%	579	49.8%
	Straddlers	50	4.3%	55	4.7%
	Lane Changers	9	0.8%	23	2..0%

Figure 47 shows the distributions of the same data.

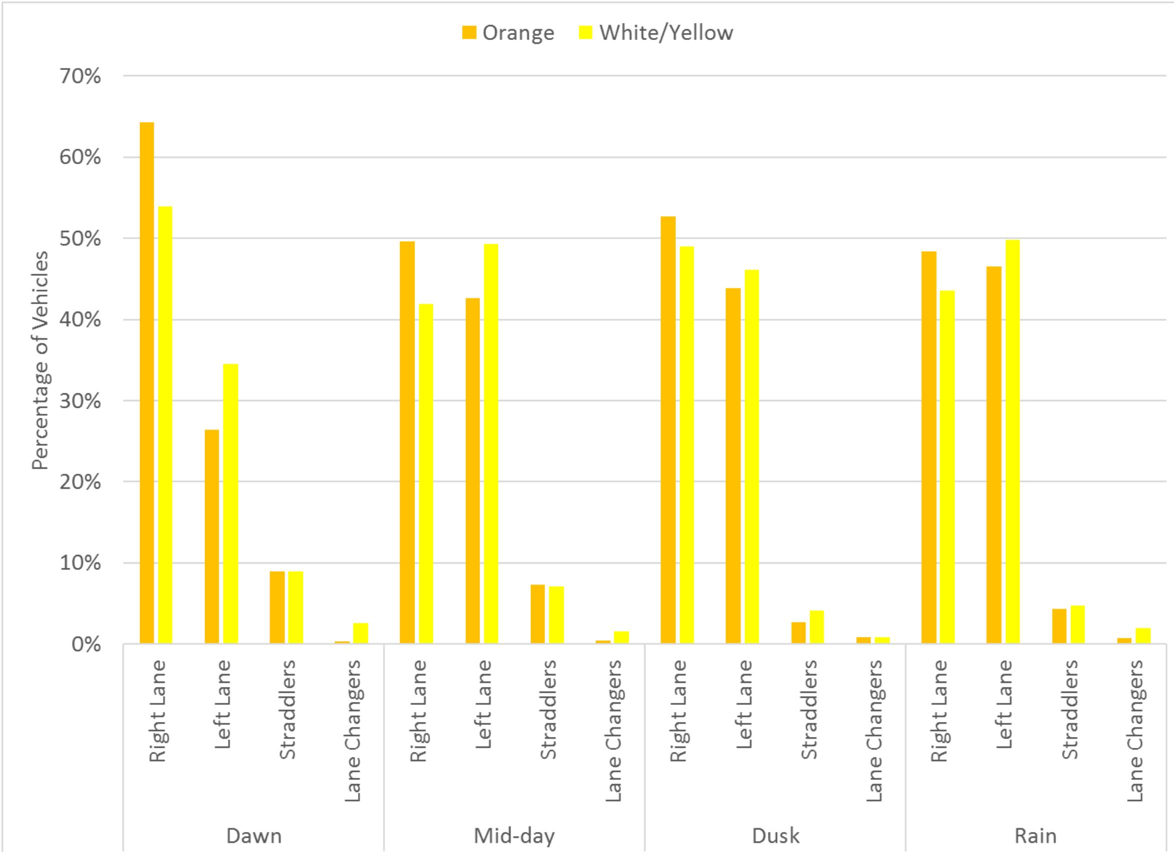


Figure 47. Distribution of vehicle positions under various conditions

The distributions are very similar, except for the dawn condition. With orange markings, the percentage of straddlers was marginally lower under dusk and rain conditions, but essentially similar for practical purposes.

3.3.3 Speed on the Approach to Work Zone

Forward-fired radar units were used to collect trajectory information of individual vehicles at the test and control segments to identify any differences in speed behavior that are potentially attributable to the marking color. Trajectory information includes speed, lateral and longitudinal distance from the radar unit collected twice every second. Data were collected under cloudy daylight conditions for about 2 hours at each location. Free flowing vehicles (defined as vehicles with headways of 4 seconds or longer) which were tracked for at least 400 feet on the approach to the work zone were included in the analysis resulting in 125 and 93 vehicles for the control and test sites respectively.

Three measures were used to quantify speed behavior:

1. Maximum speed: maximum speed of the vehicle approaching the work zone (in the distance that it was tracked)

2. Last speed: speed of the vehicle when it was closest to the radar sensor
3. Speed change: difference between the first speed and last speed of the vehicle.

Figure 48 shows the distribution of maximum speeds for free-flowing vehicles approaching the work zone.

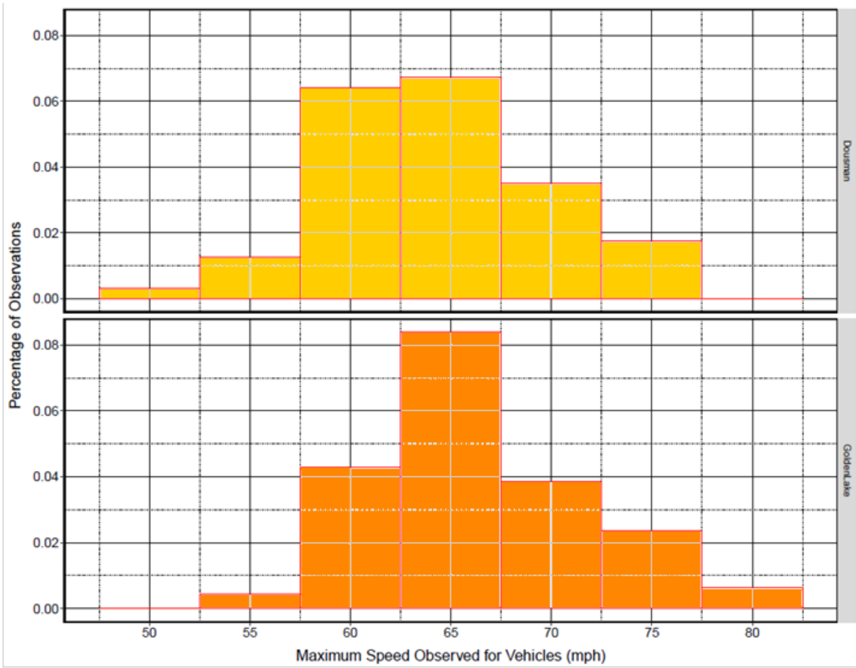


Figure 48. Maximum observed speed

To minimize any effects associated with traffic merging between the STH 67 ramp and the Dousman Road site, only free flowing vehicles were included in the analysis. The histogram indicates that speeds were slightly higher at the test (orange) site.

Figure 49 shows the distribution of speeds of free flowing vehicles closest to the radar.

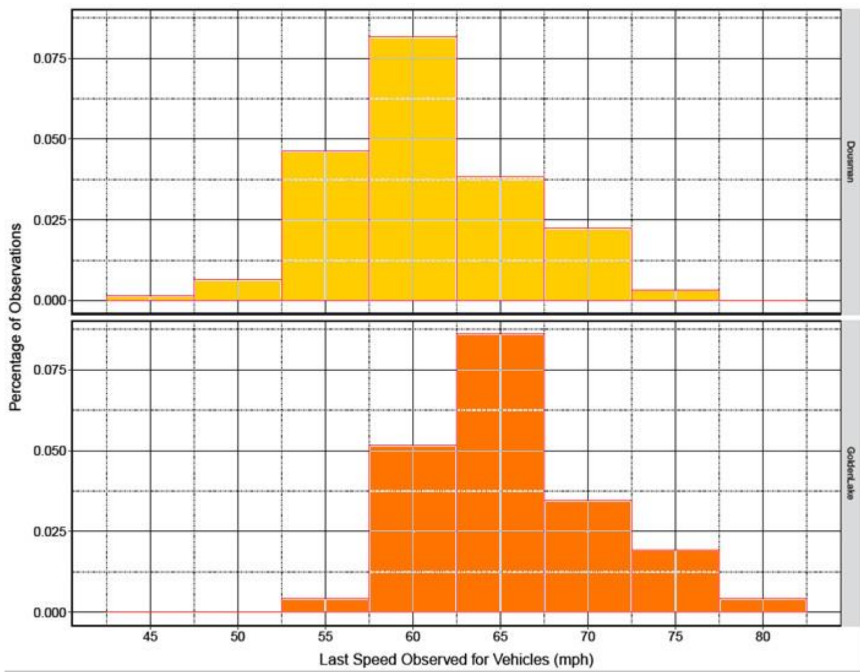


Figure 49. Last observed speed

The trend is same as noted for maximum speeds, with the last speeds being higher for the test site. Figure 50 shows the distribution of vehicle speed changes as vehicles passed through the sensor area.

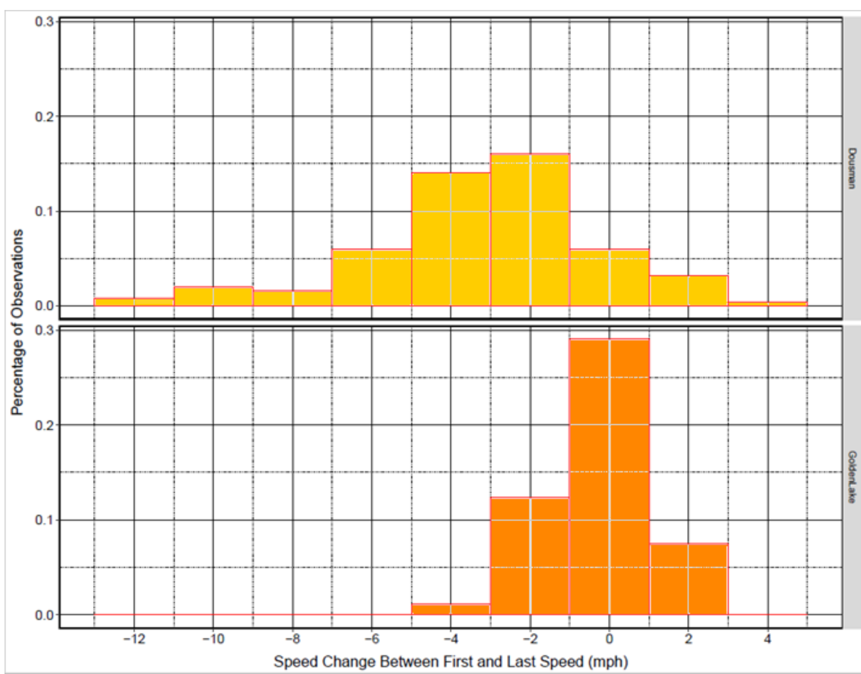


Figure 50. Observed speed change

A positive value indicates speed increase, while a negative value indicates speed reduction as the vehicle approached the work zone.

Overall, the observations suggest that speeds were about 2 mph faster at the site with orange markings, but this should be interpreted cautiously. The sample size is small, and the speed differences might have been influenced by geometrics: the lane shift rate was slightly gentler at the orange marking site than at the control. An alternative explanation is that after “practicing” their lane-shift maneuvers at the first work zone (which was the control site), westbound drivers felt confident driving somewhat faster through the second work zone. Thus it is possible that the observed speed differences are related to sequencing rather than color.

4 DRIVER SURVEY AND AGENCY/CONTRACTOR INTERVIEWS

The research team conducted a survey of drivers and interviewed agency field engineers to get their opinions and perceptions of orange pavement markings.

4.1 Driver Survey

A driver survey of was conducted at the I-94 westbound Rest Area located near Johnson Creek, a few miles downstream of the test sites. A total of 60 responses were obtained during two days of survey distribution (Table 3). All the responses were obtained under clear/sunny weather conditions.

Table 3. Demographics of survey respondents

Distribution of Responses by Gender		
Gender	**Female**	**Male**
Responses	22	38
Percentage	37%	63%

Distribution of Responses by Age Group							
Age Group	**18 – 24**	**25 – 34**	**35 – 44**	**45 – 54**	**55 – 64**	**65 – 74**	**75 – 84**
Responses	1	2	5	10	19	17	6
Percentage	2%	3%	8%	17%	32%	28%	10%

Distribution of Responses by Vehicle Type				
Vehicle	**Motorcycle**	**Automobile/SUV/Van**	**Bus**	**Semi/Commercial Truck**
Responses	0	54	1	5
Percentage	0%	90%	2%	8%

Distribution of Responses by Role of Respondent				
Role	**Driver of Personal Vehicle**	**Driver of Commercial Vehicle**	**Passenger in Personal Vehicle**	**Passenger in a Bus**
Responses	47	4	7	0
Percentage	81%	7%	12%	0%

Distribution of Responses by Weekly Hours Driven								
Hours per Week	**≤ 5**	**6 – 10**	**11 – 15**	**16 – 20**	**21 – 25**	**26 – 30**	**31 – 35**	**> 35**
Responses	6	14	16	7	2	3	1	6
Percentage	11%	25%	29%	13%	4%	5%	2%	11%

The respondent demographics can be summarized as follows:

- Nearly to two-thirds of respondents were male (63%) and slightly more than one-third were female (37%).
- The age distribution skewed towards older drivers: about 38% of respondents were over 65 years old, 32% were 55-64, and about 30% of the respondents were 18-54.

- About 90% of the respondents were driving in an automobile (Car/SUV/Van), 8% were in a commercial truck/semi and 2% were in a bus. No motorcyclists were in the sample.
- About 81% were drivers of a personal vehicle, 7% were drivers of a commercial vehicle and 12% were passengers in a personal vehicle.
- About 36% of the respondents drove 10 hours or less each week. Eleven percent of the respondents drove 35 hours or more each week, probably representing commercial/professional drivers.
- All respondents had English as their primary language.

The questions asked of the survey respondents are shown in Appendix A and a summary of the responses follows. Since the rest area was located only a few minutes downstream of the test and control sites, respondents were asked to compare the white and orange pavement markings they had just seen. As shown in Figure 51, about 27% of the respondents felt the orange pavement markings were *much* easier to see than white pavement markings, while 20% felt orange markings were *somewhat* easier to see.

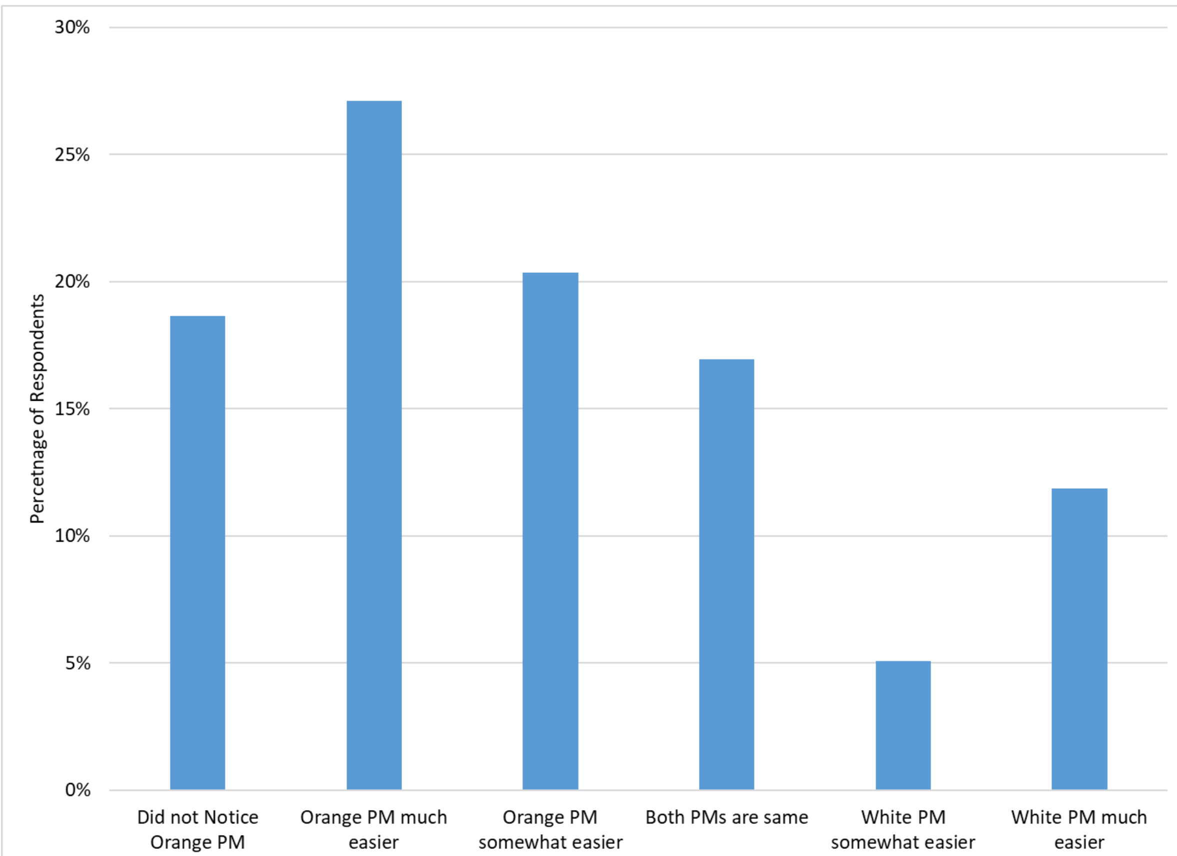


Figure 51. Respondent opinions comparing white and orange PMs in work zones

Approximately 12% felt white pavement markings were *much* easier to see, while 5% said white was *somewhat* easier. About 17% felt both were same, and 19% said they did not notice the orange pavement markings. Overall, almost half of the respondents said the orange markings were more visible, while less than 20% felt white markings were easier to see.

As shown in Figure 52, drivers who had driven through the site under other weather and lighting conditions were also asked to compare the visibility under conditions that included Daytime Sunny, Daytime Cloudy, Daytime Rain, Sunset Clear, Night Clear or Cloudy, and Night Rain.

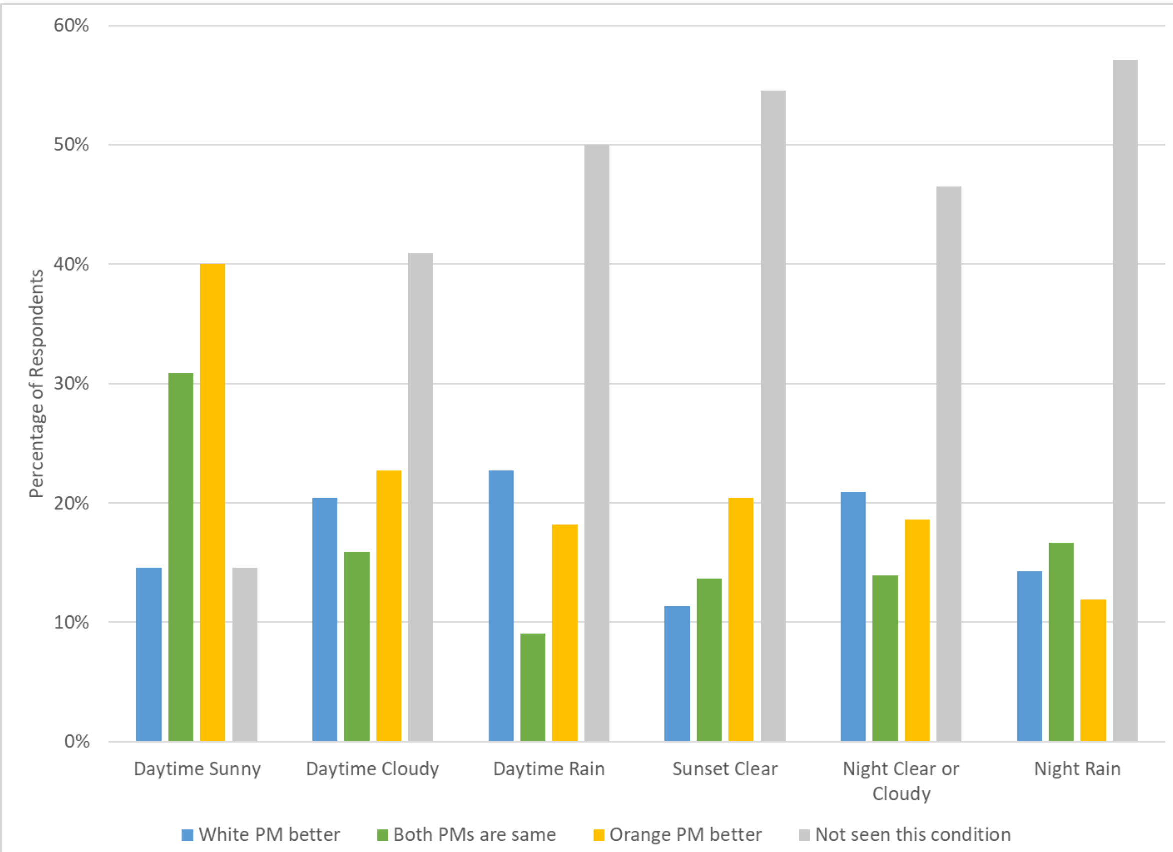


Figure 52. Respondent opinions comparing white and orange PMs in work zones under different weather/lighting conditions

More than 40% of the respondents had only seen the markings under Daytime Sunny conditions (which were the prevailing conditions during the survey distribution days). Among those who had observed the sites during other conditions, general perceptions can be summarized as follows:

- Under Daytime Sunny/Cloudy and Sunset Clear conditions, respondents generally said orange pavement markings were better than white.
- Under Rainy conditions, both Day and Night, respondents generally said white pavement markings were better than orange, although only marginally.
- Under Night conditions, white pavement markings were generally said to be better than white, although only marginally.

The Oconomowoc and Milwaukee orange marking demonstration sites used different pavement marking materials. To see if these differences were perceptible to the public, participants were also asked to compare the orange pavement markings in the two areas if they were familiar with both. As shown in Figure 53, almost one-third of the respondents had not seen the pavement markings in Milwaukee.

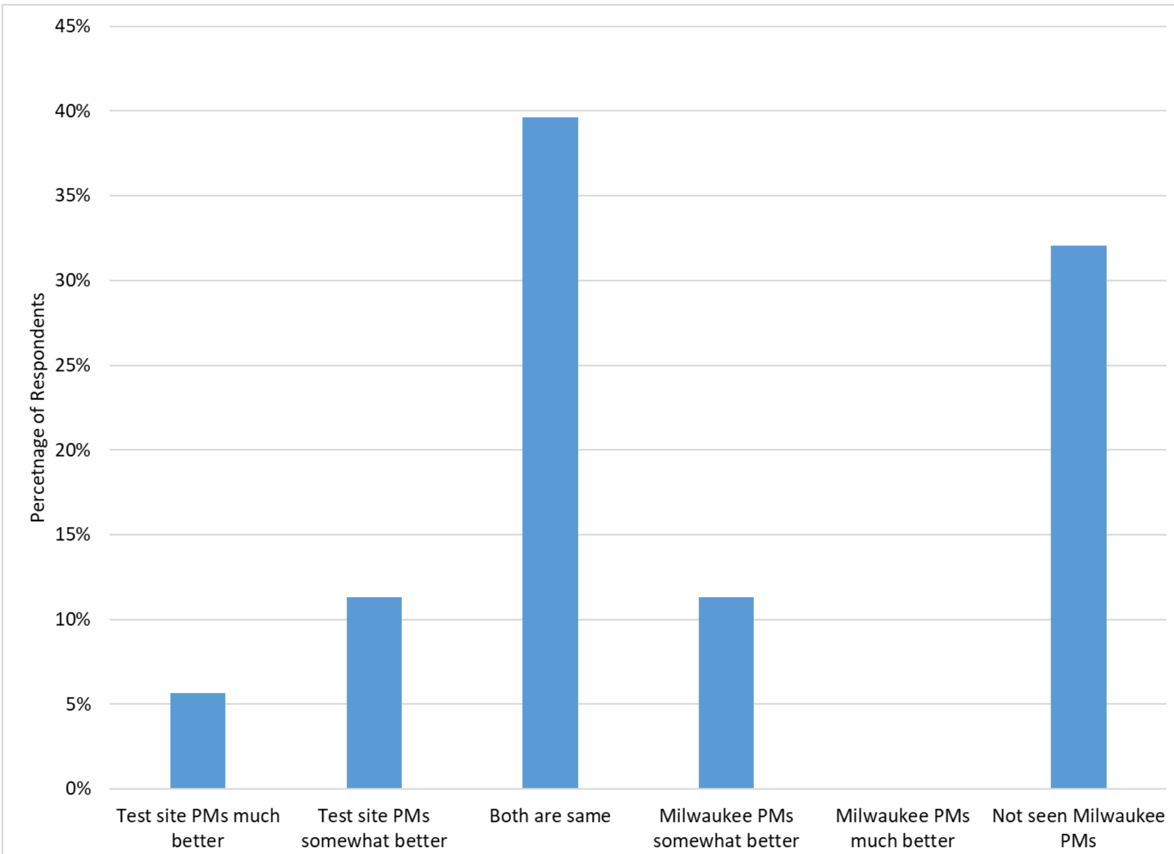


Figure 53. Respondent opinions comparing orange PMs in test site and Milwaukee work zones

Almost 40% felt the orange markings at both locations were equally visible. About 11% felt the Milwaukee orange pavement markings were somewhat or much better, while 16% felt the Oconomowoc markings were somewhat or much better.

As shown in Table 4, 15 respondents offered open-ended comments. Among these, about six responses favored orange pavement markings, three were opposed to orange markings, and six were offered neutral or general comments.

Table 4. Survey respondent open-ended comments

Response
In Milwaukee lane markings are extremely difficult to see at night and in rain. Confusing with no longer used markings. I worry about being in an accident because of this. Haven't noticed difference between white and orange.
I was passenger did not pay as much attention. Going thru to find 894 & around zoo harder because of the lane changes I must make.
I like the orange-easier to see.
I prefer the orange markings.
The orange around Milwaukee is distracting. Too much orange with the barrels.
Not sure that orange is better or worse in terms of visibility but the change of color grabs your attention. You are aware of a change.
I like orange because it reminds people that they are in a work zone.
I hate the orange lines.
From Iowa, visiting Milwaukee to see family. Your highway is always very good. No complaints.
Orange marking suck!
It's a matter of upkeep, not color.
I love the orange markings - much easier to distinguish (and follow) from all the other stuff on a road in a construction zone.
Milwaukee normally needs help along these lines.
I like clear bright clear lane markings. Very important to me.
For all pavement markings, night and rainy conditions need to improve. Thanks.
Not used to these markings. Color too dark.
Orange was better in construction areas.

4.2 Agency/Contractor Interviews

At the time the Golden Lake and Dousman Road projects were nearing completion, the research team interviewed two field engineers who had been working at the Oconomowoc field office. The interview participants were Brian Boothby, a Wisconsin DOT staff engineer responsible for overseeing the two bridge projects, and James Buggs, a consultant responsible for oversight of a nearby project on WIS 67. A summary of their comments and observations follows.

4.2.1 Differences in Driver Behavior

The engineers said the initial brightness of the orange tape markings was excellent and they were more visible than white. They felt that with many projects being conducted concurrently in urban areas, drivers get accustomed to drums and orange signs and do not mentally register them, even though they see them. The engineers felt that orange markings helped identify the Golden Lake Road site as a work zone and provided better visibility than white, especially in the lane shifts. They feel it is also important to avoid overusing orange markings. In their frequent drives through the test and control sites they noticed no differences in the lane positions selected by the drivers.

4.2.2 Visibility of Markings under Different Weather and Lighting Conditions

The engineers felt that the night performance of the markings was similar at Golden Lake Road (orange) and Dousman Road (white/yellow), with orange perhaps slightly better. All colors were dull during nighttime rain conditions. They compared this to the raised pavement markers used in the Zoo Interchange, which they feel were very helpful in delineating the lanes under adverse weather and lighting conditions. Comparing the orange marking materials used in Milwaukee and Oconomowoc, they felt that the orange tape used at Golden Lake Road performed better at night, while the orange paint used in the Zoo Interchange was better by day.

4.2.3 Performance of Marking Materials

The engineers felt that the orange tape was very conspicuous in daytime when it was new. The tape was in place for about three and one-half months. After the first month or so all tapes (orange, yellow and white) began to fade and accumulate dirt. Epoxy paint might not accumulate as much dirt. They felt that the additional cost of epoxy can be justified for many projects due to better durability. Tape was more convenient for experimentation than paint because switching paint colors is difficult due to the complexity of cleaning the spray equipment on paint trucks.

4.2.4 Engineers' Opinions of Use of Orange Markings

The two engineers interviewed felt orange tape was beneficial for this project and could be beneficial for freeway projects. They are concerned that "sign fatigue" is a major problem in urban areas because of several ongoing project at the same time: there are lots of drums and signs and they are closely spaced, and as a result people do not pay attention to signs. In the opinion of the two engineers interviewed by the research team, orange markings, if used, may be a possible solution to address sign fatigue and might reinforce driver awareness of being present in a work zone. Nevertheless, they felt the orange marking should be limited to projects with lane shifts or crossovers. They recommend supplementing orange tape with raised pavement markers and epoxy paint. Because of the differences in the performance of the paints and tapes under different weather and lighting conditions, they suggested possibly alternating between epoxy paint and orange tape for skip lines. They felt that the agency should explore alternative methods to remove old pavement markings (such as micromilling) that would leave a more uniform pavement surface.

5 CONCLUSIONS AND RECOMMENDATIONS

The use of special-color pavement marking for work zones appears to have originated in Germany in the 1980s and is now a standard practice in many Western European countries. For example, in Belgium, France, German, Italy, and Spain (which use all-white systems for permanent pavement marking) yellow marking materials are used to override permanent markings, minimizing the need to remove permanent markings. In Central Europe, orange pavement markings are increasingly used for the same purpose. In the United States and other countries that use two-color marking systems, pavement marking removal is a typical construction activity, but removal operations often leave ghost markings that can be quite conspicuous under certain lighting conditions. The marking removal process is itself a significant construction operation with inherent traffic safety and human health hazards. As a result, the concept of using orange to improve work zone marking conspicuity has attracted considerable attention from practitioners, and has become standard practice in at least one North American jurisdiction (Ontario).

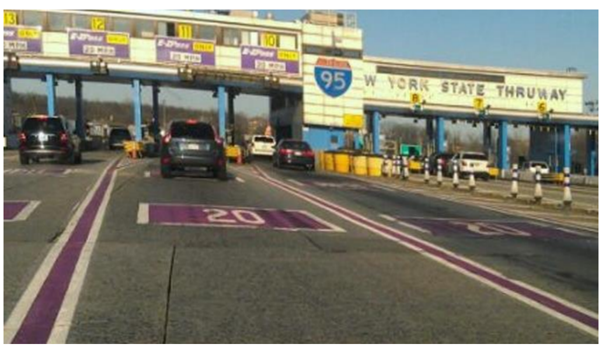
The Zoo Interchange project in Milwaukee is a multi-year construction project that has been experimenting with orange markings since late 2014. Fade-resistance of the orange paints used in long-term applications at the Zoo Interchange was troublesome, and the Zoo Interchange project team and its suppliers have been experimenting with various paint formulations to address this issue. The research conducted near Oconomowoc for this project focused primarily on driver behavior. The color of the fluorescent orange pavement marking tape used at the Oconomowoc test site was more stable than the Zoo Interchange paints, and in spite of fading and dirt accumulation the color remained similar after 3½ months of service (comparable color changes were also observed in white and yellow tapes supplied by the same vendor for the control site). Orange pavement markings are widely used for work zones in Central Europe and for permanent markings in Japan, and this suggests that fade-resistance and retroreflectivity issues have probably already been addressed by suppliers serving those markets.

This study explored driver behavior effects of orange marking using a matched-pair methodology at two nearly identical bridges near Oconomowoc, Wisconsin. The I-94 bridge over Golden Lake Road bridge was marked in orange, while the I-94 bridge over Dousman Road was marked using MUTCD standard colors. Ghosting was not a problem at either site, providing an opportunity to observe effects attributable almost entirely to color. Under these conditions, the lateral lane positions selected by drivers were very similar in the test (orange) and control (standard white and yellow) sites. Based on a limited daytime sample, vehicle speeds were somewhat higher at the orange marking site, but this might have been partially attributable to small differences in the site geometrics and other site-to-site differences. The proportion of out-of-position vehicles was similar at the test and control sites under all four lighting/weather conditions that were analyzed, suggesting that the majority of drivers who were straddling lanes did so by choice. There was no evidence of driver miscomprehension of the orange markings, nor did there appear to be any problems resulting from the non-use of yellow left edgeline markings at the test site.

This research evaluated orange markings at one study site and therefore the results are preliminary and suggestive. Future research should evaluate orange markings at multiple sites and different work zone scenarios than the one studied in this research. Potentially, more dramatic driver behavior differences would have been observed at a site where ghosting occurred, or during winter construction when de-icing salt accumulation can limit the contrast between temporary white markings and the pavement surface. Additional research is necessary to assess orange marking performance under these conditions, possibly through a simulator or test track study.

Consistent with previous survey findings (Stevens 2016, DuPont and DeDene 2017), road users surveyed as part of this project generally expressed a preference for orange markings during daytime conditions, but were less strongly in favor of orange at night and during adverse weather. Two field engineers responsible for projects near the Golden Lake Road and Dousman Road sites also felt that the visibility of orange was superior by day, but equal or perhaps marginally better than white at night and in wet weather. The performance of the orange materials under night and wet conditions could probably be enhanced through product formulation or manufacturing changes.

Perhaps the most pragmatic approach to orange markings was articulated by the field engineers, who feel that orange will be most beneficial if it is reserved for use as a special-emphasis color in work zones that require difficult driving maneuvers. This approach is similar to the British practice of parsimoniously using special marking colors to provide emphasis in problematic areas (DfT 2003), and would help reduce the potential for drivers to become desensitized to the special color. Conceivably, in freeway applications the orange lines could be used side-by-side with white/yellow markings in these emphasis areas, matching the MUTCD practice for the use of purple markings at toll plazas (Figure 54).



Jake Smith

Figure 54. Section 3E.01 of the 2009 MUTCD allows white and yellow lane lines to be supplemented with purple markings

Orange marking also appears to have potential as an override color for urban street applications. For example, similar to European practice an orange X could be placed over an existing turn arrow to indicate that restriction does not apply during construction (Figure 55).

Sauer GmbH

Figure 55. Special-color overriding existing urban street marking (Germany 2010)

In many cases this would be less costly and more expeditious than attempting to obliterate (and perhaps subsequently replace) special markings such as arrows and bus lane markings.

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APPENDIX A: DRIVER SURVEY

Work Zone Pavement Marking Survey

The Departments of Transportation from Iowa, Kansas, Missouri, Nebraska, and Wisconsin are working together to find ways to improve traffic flow and safety in highway construction zones.

If you passed through the Oconomowoc area today, you might have noticed some experimental orange pavement markings near the WIS 67 interchange. A similar work zone nearby had regular white pavement markings. Please take a moment to share your opinions about these markings.

1. What were the weather and lighting conditions during your trip today?

Weather
- ○ Clear
- ○ Cloudy
- ○ Fog
- ○ Light Rain or Drizzle
- ○ Heavy Rain
- ○ Other ________________________

Lighting Condition
- ○ Sunrise
- ○ Daytime
- ○ Sunset
- ○ Night

2. Please compare the white and orange pavement markings you saw today in the work zones **in the Oconomowoc area near WIS 67**:

- ○ I did not notice the orange markings.
- ○ White markings were much easier to see than orange.
- ○ White markings were somewhat easier to see than orange.
- ○ Both colors were about the same.
- ○ Orange markings were somewhat easier to see white.
- ○ Orange markings were much easier to see than white.

3. If you have driven through the work zones in the **Oconomowoc area near WIS 67** under other weather and lighting conditions, please indicate which color was easier to see:

Condition	White was Better	About the Same	Orange was Better	Haven't seen it in this condition
Daytime Sunny	○	○	○	○

Daytime Cloudy	O	O	O	O
Daytime Rain	O	O	O	O
Sunset Clear	O	O	O	O
Night Clear or Cloudy	O	O	O	O
Night Rain	O	O	O	O

4. Orange markings are also being tested in Milwaukee near the Zoo Interchange (the two tests use different materials). If you are familiar with both locations, please compare them:
   - O Orange markings in Oconomowoc much better than the orange markings in Milwaukee.
   - O Orange markings in Oconomowoc somewhat better than the orange markings in Milwaukee.
   - O Both locations about the same.
   - O Orange markings in Milwaukee somewhat better than orange markings in Oconomowoc.
   - O Orange markings in Milwaukee much better than orange markings in Oconomowoc.
   - O I have not seen the ones in Milwaukee.

5. What type of vehicle were you in today?
   - O Motorcycle
   - O Automobile, SUV, van, pick-up, etc.
   - O Bus
   - O Semi or other commercial truck

6. Comments (optional)

About You…

Which best describes your role today?

- O Driver of a personal vehicle
- O Driver of a semi or commercial truck
- O Passenger in a personal vehicle
- O Passenger in a bus

Age

- O 13 or Younger
- O 14-16
- O 17-18
- O 19-24
- O 25-34
- O 35-44
- O 45-54
- O 55-64
- O 65-74
- O 75-84
- O 85 or Older

What is your primary language?

- O English
- O Spanish

Approximately how many hours do you drive each week?

- ○ Hmong
- ○ Other (please specify) ____________________

- ○ Less than 5
- ○ 6 to 10
- ○ 11 to 15
- ○ 16 to 20
- ○ 21 to 25
- ○ 26 to 30
- ○ 31 to 35
- ○ 40 or more

Please indicate your gender in the box below or choose from the list:

- ○ Man
- ○ Woman

About this project:

This survey is being done by the Traffic Operations & Safety Laboratory at the University of Wisconsin–Madison. The research is sponsored by Wisconsin DOT and the Smart Work Zone Deployment Initiative. If you have questions about this project, contact Dr. Madhav Chitturi 608-890-2439.