Evaluation of Orange Pavement Striping for Use in Work Zones

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Kentucky Transportation Center
College of Engineering, University of Kentucky, Lexington, Kentucky

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Research Report
KTC-21-03/FRT-227-1F

Evaluation of Orange Pavement Striping for Use in Work Zones

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16. Abstract

Interstate widening projects are commonplace in Kentucky, and safety is of primary concern within the project work zone. Past experience with long work zones revealed two critical safety issues: driver confusion due to unclear pavement markings and a lack of continuous work zone signage for motorists indicating they are still within a work zone. This concern is heightened in transition and taper areas. Highly visible markings in an alternative color other than standard yellow or white might better distinguish the proper travel path for motorists and prevent drivers from returning to normal driving behavior and speeds once they get through the initial transition area. To address these safety issues, the research team applied orange edge and lane lines in a work zone and studied the effects on speed, crashes, and driver behavior. Due to retroreflectivity requirements, retroreflectometer data was also collected, and researchers gathered feedback from the public and contract/construction personnel. The results of testing orange pavement markings in one work zone offer evidence that further studies should be performed, but the study was not large enough to provide conclusive evidence that orange pavement markings should be regularly employed. Retroreflectivity thresholds of the markings can be met if a high-end bead package is used. Crashes increased with the use of orange pavement markings, but there was evidence that the crashes were less severe. Specifically, wet and nighttime crashes were reduced. The speed data collected in the study indicates that very few drivers lower their speed as they travel through a work zone, even when orange pavement markings are added as a reminder. The public opinion survey revealed positive results that indicate the public would be receptive to the use of orange pavement markings in future work zones.

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Chapter 1 Introduction

1.1 Background

As Kentucky continues to update its infrastructure, roadway work zones have become common throughout the state. Interstate widening projects are especially prevalent and require effective management. It is important to ensure that these projects are as safe as possible for both drivers and construction workers. Based on past experience with interstate widening projects, there are two main concerns within long work zones: driver confusion due to unclear pavement markings and a lack of continuous work zone signage for motorists indicating they are still within a work zone.

The incomplete removal of pavement markings and/or pavement scarring in work zones may lead to confusing conditions for drivers. Pavement marking removal practices often result in ghost markings, which compete with work zone delineation for drivers' attention. This concern is heightened in transition and taper areas. Some engineers believe that highly visible markings in an alternative color other than standard yellow or white might better distinguish the proper travel path for motorists.

Furthermore, there is a desire to provide an enhanced warning to motorists alerting them that they are still within the limits of a long work zone. Drivers are more likely to return to normal driving behavior and speeds once they get through the initial transition area of a work zone and as they continue through a long work zone. The use of different colored markings may be a low-cost way to provide enhanced notice of the limits of a work zone.

The Kentucky Transportation Cabinet (KYTC) sought to address both these issues by using orange pavement markings within an interstate work zone. A team of pavement marking professionals from Central Seal and 3M developed the color, and research engineers from the Kentucky Transportation Center (KTC) analyzed its visibility and studied the effects of the orange markings on speed, crashes, and driver behavior/perception.

1.2 Problem Statement

This research studied the effect of orange edge and lane lines with wet-reflective elements and orange temporary pavement markers through work zones. The impact of the orange pavement markings was measured in terms of crash data, motorist speeds, observed driver behavior, perception from the public, and feedback from relevant contractor/construction personnel. In addition, orange pavement markings were required to meet certain visibility and durability thresholds, so retroreflectometer data was collected as well. Using this data, researchers drew conclusions about the effectiveness of the orange pavement markings. Their conclusions and recommendations are provided at the end of this report.

1.3 Tasks

The following list details the project goals that were developed at the beginning of the study:

1. Perform a literature review on the use of orange pavement markings in work zones.
2. Document the pavement marking specifications upon installation and periodically evaluate retroreflectivity and durability of the pavement markings.
3. Conduct in-person and video-based field observation to identify/quantify driver behavior when traveling through construction sites containing orange pavement markings.
4. Conduct a survey to evaluate public opinion of the orange pavement markings during their deployment.
5. Interview agency and contractor personnel associated with the field deployments to assess their experience with the orange pavement markings.
6. Evaluate speeds through the work zone using probe and crowd-sourced data.
7. Perform crash analysis before and during the implementation of the orange work zone striping.
8. Compare performance of orange pavement markings to traditional markings in a control work zone.
9. Provide semi-annual progress reports to FHWA Headquarters (August 1, 2020 and February 1, 2021).
10. Summarize project findings through development of a final report.

Chapter 2 Literature Review

Preliminary research revealed that a few agencies in North America have previously experimented with orange pavement markings. Only a small amount of formal research has been done on the subject, but some agencies include different-colored markings in their guidelines or share its use via informal documents.

2.1 Canada

Orange pavement markings are used in work zones across Canada. This is not mandated by British Columbia's work zone traffic manual, so some provinces utilize it more than others. Orange markings were first used in Ontario in 2011. Quebec has extensively experimented with it as well, but has not done formal research (Carlson et al., 2020). The Ministry of Transportation – Ontario (MTO) has since provided written guidance on when orange pavement markings should be considered, although each Regional Traffic Section can make the final decision. The MTO guidance states that "orange temporary 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 nighttime 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." (Ministry of Transportation, 2014)

The MTO currently uses spray-applied textured methyl methacrylate (MMA) for its colored pavement markings. They also previously experimented with an organic solvent-based paint and a two-coat waterborne paint, but found MMA superior in terms of visibility and durability. MMA allowed for application in cold temperatures, which had been a potential source of issue for other materials (Shaw et al., 2018).

2.2 Wisconsin

In 2014, Wisconsin utilized orange pavement markings during an interchange construction project. The construction work required many lane changes for motorists, but salt from winter maintenance treatments was obscuring the lane lines (DuPont, 2019). Orange paint was introduced as a way to increase the visibility of lane markings.

Wisconsin researchers experimented with several types of paint and shades of orange over the course of 3.5 years. All of them were applied on concrete and most were in areas with ambient light (Shaw et al., 2018). They found that the orange pavement markings needed to be fluorescent in order to be visible at night, but higher fluorescence was correlated with an increased transparency and a faster degradation during UV exposure. Their recommendation was to use waterborne paint without fluorescent materials in summer months because it resists fading under UV exposure. In winter months, they recommended using epoxy with fluorescent materials because it is more visible and holds up to wear from snowplows (DuPont, 2019).

Wisconsin researchers stated that orange pavement markings helped drivers maintain lane position throughout the project area, which was a major safety benefit. Researchers also surveyed motorists about their perceptions of orange pavement markings; about 80 percent of those surveyed preferred the fluorescent orange markings to white markings, especially when complex lane maneuvers were required (DuPont, 2019). Project field engineers were also interviewed; their perception of orange pavement markings was mostly positive, and they especially preferred orange pavement markings when lateral lane shifts were required (Shaw et al., 2018).

There was no observed change in crash rates between the work zone with orange markings and a similar work zone with white markings; however, there was not enough data for this observation to be statistically significant (Shaw et al., 2018). Researchers on this project shared that the orange markings provided adequate contrast for their vehicles with lane detection technology, but they recognized the complications that might arise as various autonomous vehicle technologies become more prevalent. Going forward, it will be necessary to determine the visual contrast threshold at which orange markings are effective at delineating the appropriate lane (Hanscom, 2018).

2.3 Texas

The North Texas Tollway Authority (NTTA) has an ongoing project evaluating temporary orange pavement markings in a work zone on the Sam Rayburn Tollway. The study began in March 2019 and its main goals are to increase lane discipline, maintain good material performance, and improve safety of construction personnel (Carlson et al., 2020).

The NTTA is using 4-inch wide, solid orange, continuous profiled thermoplastic on concrete. Researchers from Texas A&M Transportation Institute (TTI) are collecting and analyzing the data from this project. The primary measures of effectiveness will be vehicle lateral position (measured via CCTV cameras), retroreflectivity and color values of the orange profile pavement delineation, and driver opinions. Early results indicate that the orange pavement markings deteriorate about as quickly as normal white and yellow markings (Hadley and Lee, 2020).

The research team also plans to conduct driver surveys. The surveys are not complete yet, but preliminary information shows that there is a generally positive response from the public. 61 percent of motorists said that orange markings increased their awareness of the work zone and they make it easier to stay in their lane. 88 percent of respondents so far say that they would like to see orange pavement markings in other Texas work zones (Carlson et al., 2020).

Chapter 3 Testbed

3.1 Interstate Widening Project

The orange pavement markings testbed is within an established construction project on I-75. The Kentucky Transportation Cabinet (KYTC) has a construction contract to widen the interstate and provide additional travel lanes on I-75 in Laurel and Rockcastle Counties. Both of the counties fall under the jurisdiction of KYTC's Highway District 11. The construction project is divided into a northern segment and southern segment and these segments were let at different times, meaning different work zones would be created throughout the span of this widening project. There are three work zones, one of which is the orange paint work zone while the other two serve as control work zones. There are also three non-work zone segments along the study corridor and they serve as a baseline for interstate traffic characteristics. The map in Figure 3.1 shows each section on the study corridor.

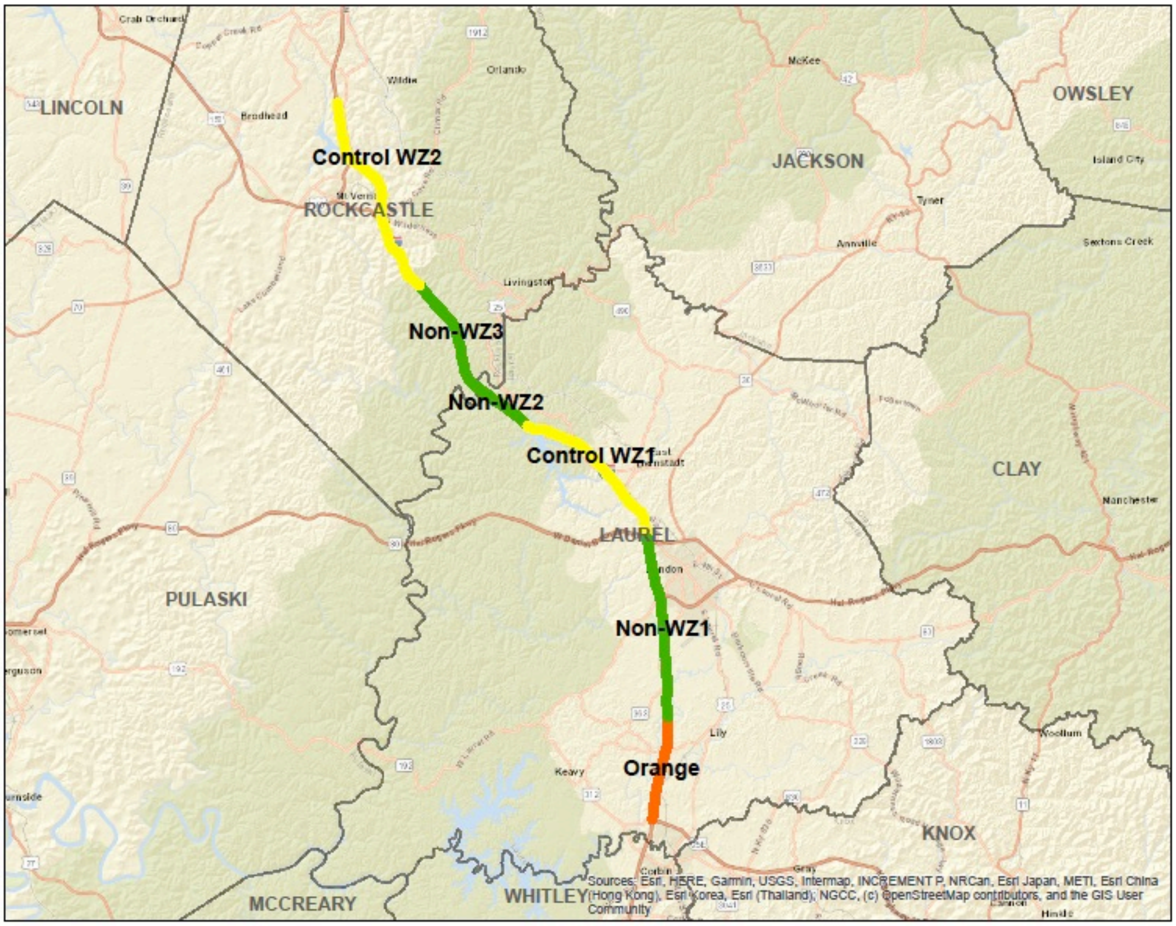

Figure 3.1 Map of Work Zones Within Interstate Widening Project

The widening project had a scheduled duration of 26 months. The construction phasing plan for the southernmost I-75 project is summarized below. The northernmost project had a similar traffic control plan.

> Phase 1: Temporary concrete barriers will be placed on the inside edge of the existing driving lanes. Traffic will be maintained on existing driving lanes narrowed to 11 feet as the median widening is constructed.
>
> Phase 2: A majority of southbound traffic (other than bridge or bifurcated areas) will be maintained on the newly constructed median area, with one lane of traffic on each side of the permanent median barrier. There will be transitions in bridge and bifurcated areas to maintain southbound traffic on two inside lanes adjacent to each other. Northbound traffic will be maintained in the same manner as in Phase 1.

Phase 3: A majority of northbound traffic (other than bridge or bifurcated areas) will be maintained on the newly constructed median area, with one lane of traffic on each side of the permanent median barrier. There will be transitions in bridge and bifurcated areas to maintain northbound traffic on two inside lanes adjacent to each other. Southbound traffic will be maintained the same as in Phase 1.

Phase 4: Phase 4 will consist of ramp work at the southern end of the project.

Phase 5: Phase 5 will consist of final surfacing.

3.2 Orange Pavement Markings Work Zone

The orange pavement markings testbed is within the southernmost segment of the interstate widening project. It is between mile points 28.9 and 33.4—approximately 4.3 miles long. This section of I-75 had an annual average daily traffic (AADT) value of approximately 42500 vehicles per day throughout the study period. Orange pavement markings were installed on November 06, 2019. The work zone was present more than a year before the orange pavement markers were installed. The analysis of this work zone includes a study of the speed and crash data for the year before the orange paint was installed (11/06/2018 to 11/06/2019) and for the year after the orange paint was installed (11/06/2019 to 11/06/2020).

Prior to the installation of the orange paint, the striping in the work zone was a typical 6 inch white right edge, 6 inch white center skip line, and a 6 inch yellow left edge. The orange paint was installed in a similar fashion, but using orange for all three stripes. Initially, temporary lines were 6 inches of waterborne paint. However, as construction phasing shifted, a variety of high-build waterborne paint and spray thermoplastic orange markings were applied to test the durability of multiple types of orange pavement markings. Wet-reflective elements were included in some of the installations of the orange pavement markings to enhance visibility during wet/night conditions. (More information about reflective elements is in Section 4.4.)

This experiment required deviation from the MUTCD in its use of a singular, non-standard color (orange) for edge lines and lane lines as opposed to the standard use of yellow and white lines FHWA, 2012). It must also be noted that the research team used yellow and white delineators on barrier walls and guardrail within the project as opposed to orange delineators. While the use of yellow and white delineators is consistent with existing language in Section 6F.80 of the Manual on Uniform Traffic Control Devices (MUTCD), it is contrary to Section 3F.03, which states that the color of delineators shall comply with the color of edge lines. Based on Wisconsin's research, there was no evidence of driver miscomprehension of the orange markings, nor did there appear to be any problems resulting from not using yellow left edge line markings at the test site (Shaw et al., 2018). As a result, the research team did not feel that the use of yellow/white delineators would be confusing. The use of traditional colors eliminates the possibility of drivers confusing orange delineators as being red.

3.3 Control Work Zone

For control sections, the Kentucky Transportation Cabinet used northern parts of the same interstate widening project. Both were on I-75; control work zone 1 was between mile points 55.7 and 64.5 in Rockcastle County (~ 38500 to 42000 AADT), and control work zone 2 was between mile points 40.7 and 48.0 in Laurel County (~ 38000 AADT). Refer to Figure 3.1 for positioning of these work zones in comparison to the orange paint work zone. These work zones had similar lane positioning and project durations compared to the test area and received comparable traffic to the orange paint work zone. However, due to the differing letting dates and construction phasing, these work zones were not present during the entire one year before period. Therefore, these control work zones are only compared directly to the orange paint work zone for the one year after period.

3.4 Non-Work Zones

In addition to the control work zones, this study also includes some control non-work zone sections along the same I-75 corridor to serve as a baseline for the speed and crash analysis for both the control work zones and the orange paint work zone. Non-work zone 1 was between mile points 33.2 and 40.7 in Laurel County (~ 42500 to 51500 AADT), non-work zone 2 was between mile points 48 and 50.8 in Laurel County (~38500 AADT), and non-work zone

2 was between mile points 50.8 and 55.7 in Rockcastle County (~38500 AADT). Refer to Figure 3.1 for positioning of these non-work zones in comparison to the study work zones.

Chapter 4 Materials

Several different types of materials and application processes were utilized on the I-75 orange pavement markings project. Waterborne paint was installed first, spray thermoplastic was used to patch small areas when necessary and was eventually installed on longer sections, and a high-build waterborne paint was applied in one direction towards the end of the project. Striping contractors also experimented with a handful of different bead packages. This section will discuss each type of material, including when it was installed, its durability, its retroreflectivity performance, and relevant observations from researchers in the field.

Before analyzing the materials, it is important to understand the criteria for their evaluation. There are currently no guidelines for using orange pavement markings. As such, researchers used the established thresholds for yellow and white markings as a comparison. The project team of engineers and pavement marking professionals decided that orange markings must be at least as visible as yellow markings. Visibility was measured in terms of retroreflectivity, or how much light is returned to a source, and is measured in millicandelas per lux per square meter (mcd/lx/m²). Table 4.1 shows KYTC's minimum retroreflectivity values for white and yellow lane markings (KYTC, 2019). New yellow markings should have a retroreflectivity of 225 mcd/lx/m², and they should maintain a retroreflectivity of 150 mcd/lx/m² if they remain in use for longer than 120 days.

Table 4.1 KYTC Minimum Retroreflectivity Thresholds by Color (KYTC 2018 Pavement Marking Manual)

Retroreflectivity (mcd/lux/m²)				
	Permanent Stripe	Durable Tape	Thermoplastic	Maintain after 120 days
White	300	500	300	175
Yellow	225	500	225	150

In addition, guidelines from the Federal Aviation Administration (FAA) provide minimum retroreflectivity values for red pavement markings (FAA, 2018). As Table 4.2 shows, these are very low compared to white and yellow thresholds. This table suggests that orange pavement markings cannot be held to the same standards as white and yellow markings because darker colors exhibit much lower retroreflectivity values.

Table 4.2 FAA Retroreflectivity Thresholds by Color and Material

Material	Retro-reflectance mcd/lux/m²		
	White	**Yellow**	**Red**
Initial Type I	300	175	35
Initial Type III	600	300	35
Initial Thermoplastic	225	100	35
All materials, remark when less than	100	75	10

4.1 Waterborne Paint

Waterborne orange paint was installed on November 7, 2019 on I-75 between mile points 28.9 and 33.2. Supplier Ennis Flint and subcontractor Central Seal developed the color by combining existing formulas for Kentucky's yellow and white paint and mixing that with the orange paint that Wal-Mart uses for their parking lots. This combination became known as "Wal-Mart orange." A basic package of Ultra blend glass beads was applied with the paint. The waterborne paint was applied as 6-inch markings at a 15-mil thickness. It was put down at a rate of approximately 16.5 gallons per mile. In total, about 115,000 linear feet of paint was installed through the work zone. Installation of the orange paint is shown in Figure 4.1.

Figure 4.1 Initial Installation of Orange Paint

The first retroreflectivity readings were taken on November 20th, about two weeks after installation. At the time, researchers used a handheld retroreflectometer, so measurements were taken at several designated locations along the right edge line. From sixty readings, the average retroreflectivity reading was 102.3 millicandelas per lux per square meter (mcd/lx/m²). For reference, KYTC's minimum standard for yellow permanent stripe is 225 mcd/lx/ m² (see Table 4.1). There were already very few beads remaining in the paint.

A second inspection on February 19th showed that the quality decreased significantly over the winter. (Laurel County received 1.5 inches of snow throughout the season [NOAA, 2020].) The waterborne paint was very worn; in some places the original white line was clearly visible underneath the orange paint, as shown in Figure 4.2. The average retroreflectometer reading on waterborne paint at this time was 51.6 mcd/lx/m².

Figure 4.2 Waterborne Orange Paint After 100 Days

In July 2020, KTC acquired a mobile retroreflectometer unit. The mobile unit attaches to the side of any vehicle and collects retroreflectivity data at set increments. This allowed the research team to collect a significantly greater amount of data points and offered more opportunity for analysis. The mobile unit was first used on July 15, 2020. At this time, the waterborne paint had almost completely worn off since its first installation in November 2019, as shown in Figure 4.3.

Figure 4.3 Waterborne Orange Paint After 250 Days

However, by measuring the right edge line of the northbound segment, which was originally waterborne paint and had sporadic spray thermoplastic patching, data collectors could get some rudimentary information about the remaining waterborne paint. The average retroreflectivity of the right edge line was 50.6 mcd/lx/m². Again, it is important to consider that this value averages both original waterborne and spray thermoplastic patching, which were applied at different times. 31 percent of the total measurements taken on the right edge were zero; the research team inferred that most of these zero-retroreflectivity points were likely from the waterborne paint since visual inspections had concluded that most of the waterborne paint was completely worn off.

Overall, the waterborne paint effectively carried the orange color and was a clear difference from the white and yellow markings that it replaced. However, it degraded quickly and did not hold beads well. Within two weeks of its first installation, it did not meet the minimum thresholds for yellow markings. It may be best suited for short-term applications or may be used as supplemental markings only.

4.2 Spray Thermoplastic

As construction work progressed, patching was required. In mid-February, sub-contractor Central Seal began patching areas on the right edge line (both northbound and southbound) with spray thermoplastic. Spray thermoplastic is often used for longer-term applications because it is known to be very durable. The spray thermoplastic was applied at 60-75 mils with a larger gradation bead package called Missouri performance blend (MoPM). Eventually, most of the left edge lines and center skip lines were marked with spray thermoplastic as well, totaling about 50,000 linear feet of spray thermoplastic throughout the work zone. The purpose of installing spray thermoplastic was to improve retroreflectometer readings and provide more stability.

During the February 19th inspection, some locations had thermoplastic patching. At those locations, the readings averaged 135.5 mcd/lx/m². The thermoplastic looked much brighter and more durable than the waterborne paint. Figure 4.4 shows the difference between waterborne paint (on the right) and spray thermoplastic (on the left.)

Figure 4.4 Waterborne Paint and Spray Thermoplastic Side-By-Side

Retroreflectivity measurements were taken in July. The thermoplastic patches had been installed at various times so they were between 75 and 150 days old at the time of measurement. Their average retroreflectivity was 80.3 mcd/lx/m². The same thermoplastic patching was measured in September (300 to 375 days old at the time) and had an average retroreflectivity value of 74.8 mcd/lx/m². None of the spray thermoplastic met the established thresholds for yellow markings of any age.

On October 26, a continuous segment of spray thermoplastic was installed following lane shifts on the southern end of the project area. At this point, Central Seal experimented with several new bead packages. They tested three products from Potter's Industries; the names of the bead packages were Airport Type III, P20+5, and Visi-Ultra. The new spray thermoplastic had an average reflectivity value of 213.7 mcd/lx/m², but exhibited variations depending on the type of bead used. More information is given on the bead packages and their specific retroreflectivity values in Section 4.4.

4.3 High-Build Waterborne Paint

The third material that was tested was a high-build waterborne paint. The paint does not contain HD21 resin, a typical indicator of high-build; instead it is waterborne paint applied at a high-build rate of about 30 mils, making it significantly thicker than the original paint used at the start of this project. The high-build paint was applied with the high-gradation Missouri performance blend bead package and was first installed on June 1, 2020. Figure 4.5 shows the newly installed high-build waterborne paint from a vehicle, and Figure 4.6 shows a close-up of the high-build waterborne paint.

Figure 4.5 High-Build Paint

Figure 4.6 Close-up of High-Build Paint

Field observations established that the high-build waterborne markings had a distinct color and were very easy to see. They also appeared brighter at night than either the spray thermoplastic or the original, thinner waterborne paint. Researchers measured the retroreflectivity of the high-build paint three times. The first measurements were taken on July 15th, about 40 days after initial installation. About half of the markings passed the 225-threshold for new yellow markings and this segment's overall average retroreflectivity was 219.5 mcd/lx/m². A second set of retroreflectivity measurements was taken on September 23rd. The material was about 100 days old and its average retroreflectivity was 179.0 mcd/lx/m². The last set of measurements of the high-build paint was performed on November 18th. The high-build paint was 160 days old. Its average retroreflectivity value was 208.9 mcd/lx/m². This is an increase from its 100-day value, which may indicate that paint wore off over time and exposed more beads.

4.4 Bead Packages

For most of the project, the materials were applied with the basic bead package that Central Seal uses on most projects across Kentucky: Missouri performance blend. This is a blend that utilizes a portion of larger sieve size beads along with standard Type 1 beads. The larger beads in this package provide good durability, as well as relatively high dry and wet night retroreflectivity. Central Seal contractors also experimented with a basic package called Ultra, as well as three non-traditional bead packages. The three novel packages were from Potter's Industries; the names of the bead packages were P20+5, Airport Type III, and Visi-Ultra.

P20+5 beads were utilized in the high-build paint. According to the contractors, this is a higher-gradation bead package that is good for thicker pavement markings. In the high-build paint, the P20+5 beads returned a retroreflectivity value of 219.5 mcd/lx/m² 40 days after installation. This approaches but does not meet KYTC's threshold of 225 mcd/lx/m² for new markings. After 100 days, the retroreflectivity had decreased to 179.0 mcd/lx/m². 140 days after installation, it had increased again to 208.9 mcd/lx/m². A possible explanation for the increase could be that the paint wearing off exposed more of the bead, thereby increasing its retroreflectivity. Because of this increase in retroreflectivity, the P20+5 beads in high-build paint did, in fact, meet KYTC's threshold of 150 mcd/lx/m² for markings older than 120 days.

P20+5 was also tested in the spray thermoplastic. Ten days after installation, the retroreflectivity of the spray thermoplastic with P20+5 beads was 131.5 mcd/lx/m². The spray thermoplastic with P20+5 beads degraded fairly quickly, reaching a retroreflectivity value of 74.8 mcd/lx/m² after 300 days. This did not meet KYTC's standards for yellow markings and it was lower than the retroreflectivity values of high-build paint with the same beads
.

Airport Type III was installed on spray thermoplastic. These beads are very round and are advertised to provide a high index of refraction and more stable performance. The performance of Airport Type III beads was measured at three locations within the project area. All markings were about the same age when they were measured: 20-30 days old. One segment was on original asphalt; retroreflectivity of the Airport Type III beads on this surface was 184.8 mcd/lx/m². A second segment was on a surface that had been patched repeatedly, so it was a combination of old and new asphalt. The retroreflectivity of the Airport Type III beads on patched asphalt was 124.0 mcd/lx/m². On the third segment, which was new asphalt, the Airport Type III beads had a retroreflectivity value of 196.5 mcd/lx/m². These values failed to meet the standards for yellow markings set by KYTC, but they were generally better than those of P20+5 beads.

Visi-Ultra is a high-end blend of large beads with a high refraction index. This blend was tested on spray thermoplastic and was applied only to center skip lines because of its high cost. It was installed in two locations, one northbound segment and one southbound segment, and installed ten days apart. Retroreflectivity data collection returned expectedly good results. When the spray thermoplastic with Visi-Ultra beads was 20 days old, it had a retroreflectivity of 286.8 mcd/lx/m². At the other location where the markings were 30 days old, the retroreflectivity measured 368.4 mcd/lx/m². Researchers inferred that the difference is due to dissimilarity in lane positioning and the subsequent wear from vehicles. There was not time to measure how Visi-Ultra beads performed over time, but its initial readings met the thresholds for new yellow markings.

Table 4.3 summarizes Section 4. It lists each unique combination of material and bead package used during the experimentation, the type of asphalt surface it was applied to, the age of the striping material, its retroreflectivity, and whether or not it passes KYTC's thresholds for yellow markings laid out in Table 4.1.

Table 4.3 Summary of Materials and Their Performance

Material	Bead Package	Surface	Age of material (days)	Retroreflectivity (mcd/lx/m²)	Pass?
Waterborne	Ultra	Old asphalt	15	102.3	No
Waterborne	Ultra	Old asphalt	100	51.6	No
Waterborne (almost worn off)	Ultra	Old asphalt	250	50.6	No
Waterborne	MoPM	New asphalt	60	131.5	No
Waterborne	MoPM	New asphalt	110	119.7	No
Spray thermo	P20+5	New asphalt	10	135.5	No
Spray thermo	P20+5	Patching	75-150	80.3	No
Spray thermo	P20+5	Patching	300-375	74.8	No
Spray thermo	Airport Type 3	Patching	20	124.0	No
Spray thermo	P20+5	Old asphalt	20	121.6	No
Spray thermo	Visi-Ultra	Old asphalt	20	286.8	Yes
Spray thermo	Airport Type 3	Old asphalt	30	184.8	No
Spray thermo	Airport Type 3	New asphalt	30	196.5	No
Spray thermo	Visi-Ultra	Old asphalt	30	368.4	Yes
High-build Paint	P20+5	Old asphalt	40	219.5	No
High-build Paint	P20+5	Old asphalt	100	179.0	No
High-build Paint	P20+5	Old asphalt	160	208.9	Yes

Chapter 5 Speed Analysis

KYTC is in contract with HERE Traffic Analytics to obtain live traffic data on all public roads in Kentucky. HERE obtains the data in two-minute intervals by probing GPS units in vehicles and cellphones to monitor activity on roadways in 57 countries, and codes this data to their network of over one trillion nodes that define the roadway networks they monitor (HERE, 2020). As a result of this contract, KYTC receives over 49 million traffic records per week that must be stored in a user-friendly interface (Stout and Grindle, 2018). Elastic Enterprise Search is the data solution utilized by KYTC to house and interface with the HERE data (Lambert). This software package includes a tool called Kibana, which allows users to perform calculations and create visualizations from the underlying data source instantly. These calculations and visualizations pull from the historic data stored in Elastic and can be updated to include the live data provided by HERE every two minutes.

KTC researchers utilized Kibana to interface with the HERE data to calculate average speeds along the study corridor for the year before the orange paint was installed (11/06/2018 to 11/06/2019) and the year after the orange paint was installed (11/06/2019 to 11/06/2020). Speeds were averaged during daylight hours (defined as 6am-6pm) and nighttime hours (defined as 6pm-6am) on all segments in the before and after period. The study corridor along I-75 has a speed limit of 70 mph with a reduced speed limit of 55 mph in the work zones. The goal of the speed analysis was to determine driver compliance with reduced speed limits in work zones compared to non-work zones and to gauge the impact of orange paint on vehicle speed.

The speed analysis began by comparing the speeds in the orange paint work zone before the orange paint was installed to the speeds in the orange paint work zone after the orange paint was installed. The speed in the orange paint work zone in the after period was also compared to neighboring control work zones on I-75 that did not use orange paint as well as some non-work zone sections of I-75.

In order to determine any effect of the orange paint on driver speed, it was important to first note the speeds in the orange paint work zone for the time period before the orange paint was installed. Table 5.1 summarizes the average speeds for a year in the work zone before the orange paint was installed.

Table 5.1 Average Vehicle Speed in Work Zone Before Installation of Orange Paint

Zone	Direction	RT unique	BMP	EMP	Average Daytime Speed	Average Nighttime Speed
Orange	Cardinal	063-I -0075 -000	28.9	33.2	65.67	66.00
Orange	Non-Cardinal	063-I -0075 -010	28.9	33.2	64.26	63.49

The speeds in the cardinal direction in this work zone are higher than the non-cardinal direction during both daytime and nighttime hours. Both directions show speeds in the mid-60 mph range, which is faster than the 55 mph work zone speed limit.

After the orange paint was installed, comparisons were made among other work zones and non-work zones on the same segment of I-75. The two control work zones were present for the entire year of “after-orange” evaluation but were not present before the orange paint was installed. The three non-work zone segments between the work zones were included in the evaluation to show the speeds of motorists under normal conditions. Table 5.2 contains the average speeds on each study segment on the I-75 corridor, split up into daytime and nighttime speeds.

Table 5.2 Comparison of Speeds Throughout Several Zones in the I-75 Corridor

Zone	Direction	RT unique	BMP	EMP	Daytime Average Speed	Nighttime Average Speed
Orange	Cardinal	063-I -0075 -000	28.9	33.2	66.65	66.50
Orange	Non-Cardinal	063-I -0075 -010	28.9	33.2	64.38	64.60
Non-WZ1	Cardinal	063-I -0075 -000	33.2	40.7	67.03	66.80
Non-WZ1	Non-Cardinal	063-I -0075 -010	33.2	40.7	66.07	65.72
Control WZ1	Cardinal	063-I -0075 -000	40.7	48	66.89	66.60
Control WZ1	Non-Cardinal	063-I -0075 -010	40.7	48	65.03	64.50
Non-WZ2	Cardinal	063-I -0075 -000	48	50.8	66.00	65.30
Non-WZ2	Non-Cardinal	063-I -0075 -010	48	50.8	66.24	65.28
Non-WZ3	Cardinal	102-I -0075 -000	50.8	55.7	66.45	65.21
Non-WZ3	Non-Cardinal	102-I -0075 -010	50.8	55.7	67.45	66.06
Control WZ2	Cardinal	102-I -0075 -000	55.7	64.5	67.95	67.03
Control WZ2	Non-Cardinal	102-I -0075 -010	55.7	64.5	67.23	66.21

By relating Table 5.1 and Table 5.2, one sees that average speeds increased in the study work zone after the orange paint was installed. The increase was about 0.5 mph during the daytime and about 1.0 mph during the nighttime. This increase may be due to motorists' growing familiarity of the work zone since it had already been in place for a year before the orange paint was installed. Drivers may reduce their caution and increase speed in the work zone as they become complacent and familiar with the work zone.

Generally, the speeds among the orange paint work zone, the two control work zones, and the non-work zones are about the same. During the daytime hours, speeds are slower through the orange paint work zone compared to the two control work zones. This is true for both the cardinal and non-cardinal directions. During the nighttime hours, the average speed through the orange paint work zone was almost exactly equal to the speeds through control work zone 1, but slower than the speeds through control work zone 2.

Comparing the work zones to the non-work zones is helpful too. The orange paint work zone and control work zone 1 show lower average daytime speeds than the non-work zones. However, control work zone 2, the northern most work zone, shows higher daytime average speeds than the non-work zones. In general, the nighttime data shows a similar trend with slightly lower speeds. However, there is one exception. During nighttime hours, the average speed on the non-cardinal direction of the orange paint work zone was slightly *faster* than the average speed there during daylight hours. In the cardinal direction, average speeds in all three work zones are about equal to the non-work zone average speeds. In the non-cardinal direction, the work zone average speeds for the orange paint work zone and control work zone 1 are lower than the non-work zone average speeds in the same direction. Control work zone 2 continues to show a higher average speed in nighttime hours than the control non-work zones in the same direction.

By aggregating the data further, researchers concluded that the average speeds in the work zones were 0.2 mph slower than the speeds in the non-work zones. But during the nighttime, average speeds in the work zones were 0.2 mph faster than the speeds in the non-work zones.

Overall, the daytime and nighttime speeds through all three work zones and the non-work zones were about the same: 65.8 mph. Drivers tend to reduce their speed, at most, 1 to 2 mph as they enter a work zone. This is in spite of the 15 mph speed reduction that should occur when drivers enter the work zones. The data indicates that very few drivers lower their speed as they travel through a work zone, regardless of whether or not orange pavement markings are added as a reminder.

Speeds in the orange paint work zone were lower before the orange paint was installed. This may indicate that drivers are more willing to drive slowly in work zones when the work zone is new. But, as the longevity of the work zone increases, drivers who are familiar with it may reduce their caution. This perceived mindset and its consequence seems to be independent of what materials are used to alert them to a work zone's presence.

Chapter 6 Crash Analysis

Similar to the speed analysis, the orange paint work zone crash analysis consists of a comparison of the crash history on the orange paint work zone for the year before orange paint installation (11/06/2018 to 11/06/2019) to the crash history on the same work zone the year after installation (11/06/2019 to 11/06/2020). Additionally, the crash history in the after period of the orange paint work zone is compared to the crash history in the same period for the two control work zones in order to investigate any differences in crash trends when orange paint is used in a work zone instead of traditional white and yellow pavement markings. The three work zones are all different lengths and have varying but comparable AADT (See Section 3); therefore, crash analysis will be mostly based on a percentage of crashes in each category of analysis rather than total crashes.

Table 6.1 summarizes the length, total crashes, and percentage of crashes of each severity level in the orange paint work zone in the before period and the orange paint and two control work zones in the after period.

Table 6.1 Crash Summary By Severity

	Orange Before	Orange After	WZ1 After	WZ2 After
Length (mi.)	4.3	4.3	7.6	8.8
Total Crashes	49	60	62	65
Severity Percentage				
K (Fatal)	0.0%	0.0%	0.00%	1.5%
A (Severe Injury)	0.0%	1.7%	3.2%	1.5%
B (Minor Injury)	2.0%	8.3%	4.8%	0.00%
C (Possibly Injury)	20.4%	5.0%	12.9%	7.7%
O (Property Damage Only)	77.6%	85.0%	79.0%	89.2%

The total number of crashes increased by over 20 percent in the year after the orange paint was installed compared to the year before it was installed. Although the orange paint work zone was nearly half as long as the two control work zones, the orange paint work zone saw nearly the same number of crashes as the two control work zones in the same after period. There was a higher proportion of "property damage only" crashes in the orange paint work zone in the after period compared to the before period. The "possibly injury" crash proportion decreased, but the

"severe injury" and "minor injury" proportion increased in the orange paint work zone. The severity distribution of the crashes in the orange paint work zone was comparable to the two control work zones in the after period, with the main discrepancy being a higher proportion of minor injury crashes in the orange paint work zone.

Researchers are often interested in studying lane departure crashes and commercial vehicle crashes within work zones since lane widths are frequently restricted. Table 6.2 shows the percentage of lane departure crashes and percentage of commercial vehicle crashes in the three work zones during the after period and the orange paint work zone in the before period.

Table 6.2 Lane Departure and Commercial Vehicle Crash Summary

	Orange Before	Orange After	WZ1 After	WZ2 After
Lane Departure	53.1%	63.3%	74.2%	81.5%
Commercial Vehicle	22.5%	40.0%	33.9%	13.9%

The proportion of lane departure and commercial vehicle crashes in the orange paint work zone increased after the orange paint was installed. The two control work zones also experienced a high percentage of lane departure crashes. Control work zone 1 experienced a similar percentage of commercial vehicle crashes to that of the orange paint work zone.

To appreciate these numbers, it is helpful to understand the sequence of construction. The construction occurring in the before phase of orange paint was mainly earthwork with very minor changes to the traveled surface. The after period involved paving efforts, which required lane shifts and narrowed travel lanes on all three work zones. The lane shifts and narrow lanes likely played a larger role in the increase in lane departure and commercial vehicle crashes than the orange paint itself because the other work zones experience similar crash patterns in the after period.

The distribution of the manner of collision of crashes in each work zone is presented in Table 6.3.

Table 6.3 Crash Summary Based on Manner of Collision

	Orange Before	Orange After	WZ1 After	WZ2 After
Sideswipe-Same Direction	16.3%	33.3%	30.7%	23.1%
Rear End	36.7%	36.7%	17.7%	12.3%
Single Vehicle	44.9%	18.3%	37.1%	58.5%
Angle	0.0%	6.7%	8.1%	4.6%
Head On	2.0%	0.0%	1.6%	0.0%
Rear To Rear	0.0%	1.7%	1.6%	0.0%
Backing	0.0%	1.7%	1.6%	0.0%
Sideswipe-Opposite Direction	0.0%	1.7%	1.6%	1.5%

The proportion of sideswipe collisions nearly doubled after the orange paint was installed. This increase can likely be attributed to narrow lanes and lane shifts occurring in the after period rather than the presence of orange paint because the control work zones experienced comparable proportions of sideswipe collisions in the after period as well. Rear end collision proportions remained constant in the orange paint work zone after the orange paint was installed, but this work zone experienced much higher proportions of rear end crashes than either of the control work zones. The proportion of single vehicle collisions after orange paint installation was less than half its value in the before period. The control work zones experienced over twice the proportions of single vehicle crashes than the orange paint work zone in the after period.

This analysis indicates that the orange paint leads to a higher occurrence of rear end crashes, but a much lower occurrence of single vehicle crashes compared to a typical work zone. The presence of the orange pavement markings may have served as a distraction to some drivers since it is an unfamiliar feature for work zones in Kentucky. A distraction like this could mean that drivers lost focus on the vehicles in front of them, causing a rear end collision with another vehicle. This also explains the reduction in single vehicle crashes compared to a standard work zone.

Table 6.4 displays the proportion of collisions in each work zone occurring under each of the different roadway surface conditions.

Table 6.4 Crash Summary Based on Roadway Conditions

	Orange Before	Orange After	WZ1 After	WZ2 After
Dry	65.3%	81.7%	71.0%	36.9%
Wet	28.6%	11.7%	27.4%	58.5%
Null	4.1%	0.0%	0.0%	0.0%
Water (Standing Or Moving)	0.0%	5.0%	1.6%	4.6%
Snow/Slush	2.0%	0.0%	0.0%	0.0%
Flooded	0.0%	1.7%	0.0%	0.0%

As will be discussed in Section 7 of the report, a public opinion survey of the orange paint work zone revealed that drivers had concerns with driving through the orange paint work zone in wet conditions. Drivers complained of a dramatic drop in visibility of the orange roadway striping and said it was dangerous. Contrary to public feedback, the crash analysis showed the percentage of crashes in the orange paint work zone occurring in wet roadway conditions dropped significantly once the orange paint was installed. The orange paint work zone also showed a much lower portion of wet crashes than the control work zones during the same time period. Visibility may have been so poor through the orange paint work zone that drivers were forced to drive with more caution and awareness, likely reducing their speeds, thereby lessening the likelihood of crashing. (Speed data cannot confirm or deny a drop in speed because the HERE data from KYTC does not link speed data with weather or roadway conditions.)

Roadway condition is closely linked to weather conditions, so it is wise to evaluate them alongside each other. Table 6.5 displays the proportion of collisions in each work zone occurring in each weather condition.

Table 6.5 Crash Summary Based on Weather Condition

	Orange Before	Orange After	WZ1 After	WZ2 After
Clear	49.0%	66.7%	54.8%	27.7%
Raining	24.5%	8.3%	21.0%	61.5%
Cloudy	24.5%	21.7%	22.6%	9.2%
Snowing	2.0%	1.7%	0.0%	1.5%
Severe Crosswinds	0.0%	1.7%	0.0%	0.0%
Fog With Rain	0.0%	0.0%	1.6%	0.0%

As expected, the crash trends based on weather condition are similar to the trends based on roadway condition. There was a lower percentage of crashes in the orange paint work zone during rain events after the orange paint was installed; that value also stayed lower than the control work zones during the same time period. Again, this may be due to increased driver awareness and caution as a result of the reduced roadway visibility in the orange paint work zone.

To gauge the impact of the nighttime visibility of orange paint on crashes, Table 6.6 summarizes crash proportions in each work zone by lighting condition.

Table 6.6 Crash Summary Based on Lighting Conditions

	Orange Before	Orange After	WZ1 After	WZ2 After
Daylight	61.2%	80.0%	66.1%	66.2%
Dark (Unknown Roadway Lighting)	0.0%	5.0%	1.6%	1.5%
Dawn	4.1%	3.3%	1.6%	4.6%
Dark-Hwy Not Lighted	16.3%	10.0%	19.4%	21.5%
Dark-Hwy Lighted/Off	2.0%	1.7%	3.2%	0.0%
Null	2.0%	0.0%	0.0%	1.5%
Dusk	4.1%	0.0%	3.2%	1.5%
Dark-Hwy Lighted/On	10.2%	0.0%	4.8%	3.1%

Crashes in dark conditions decreased significantly in the orange paint work zone after the orange paint was installed. This work zone also has a lower percentage of crashes in dark conditions compared to the two control work zones. As shown in the retroreflectivity data in Section 4 and as will be discussed in Section 7 of the public opinion survey, most of the orange paint materials had low retroreflectivity and low visibility at night. This lack of visibility could lead to drivers being more cautious at night to compensate, thereby reducing crashes occurring in dark conditions. The speed analysis in Section 5 did not show a significant decrease in speed in the orange paint work zone at night, but speeds are only one aspect of cautious driving.

Chapter 7 Public Opinion Survey

Because this was an experimental project that directly affected the public, it was important to obtain their feedback. A motorist survey was created to gauge public perception. The survey is included in Appendix A. Questions on the survey were aimed at deciphering whether or not motorists noticed a difference in lane marking color and if they had a positive, negative, or neutral opinion on orange lane markings compared to traditional colors.

Originally, researchers planned to conduct the survey in person at an interstate exit ramp just past the work zone and project area. However, research restrictions due to Covid-19 prevented any in-person involvement, so the survey was moved to an online format instead. Survey Monkey hosted the survey and people were directed to it via a link on Kentucky District 11's Facebook page. The survey remained open for 50 days: August 25, 2020 to October 13, 2020. During the time of the survey, the work zone included a mix of waterborne paint, spray thermoplastic, and high-build paint with various bead packages. The survey was meant to collect information on the general response to the color orange, not the attributes of any specific type of material.

7.1 Respondent Demographics

A total of 233 responses were collected during the 50 days the survey remained open.

Figure 7.1 shows the breakdown of survey respondents based on age — 69 percent of respondents were between the ages of 30 and 60 years. 25 percent were between 18 and 29. 6 percent were over 60 years old.

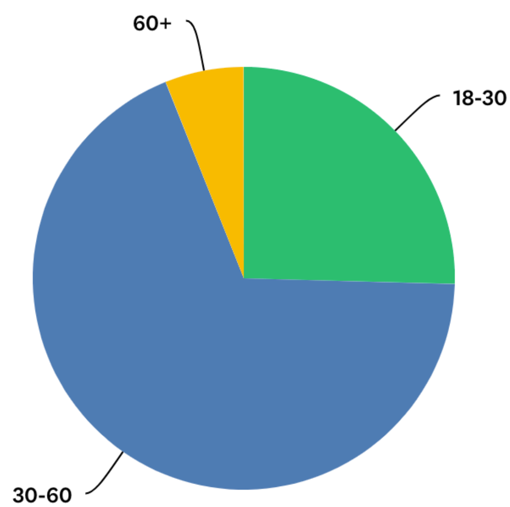

Figure 7.1 Survey Respondents by Age

Figure 7.2 illustrates survey respondents by gender. A slight majority of the survey respondents were female (53 percent); it is worth noting that this percentage reflects the average demographics of Facebook users, which is where the survey link was shared, but it does not necessarily reflect the demographics of all drivers in the study area.

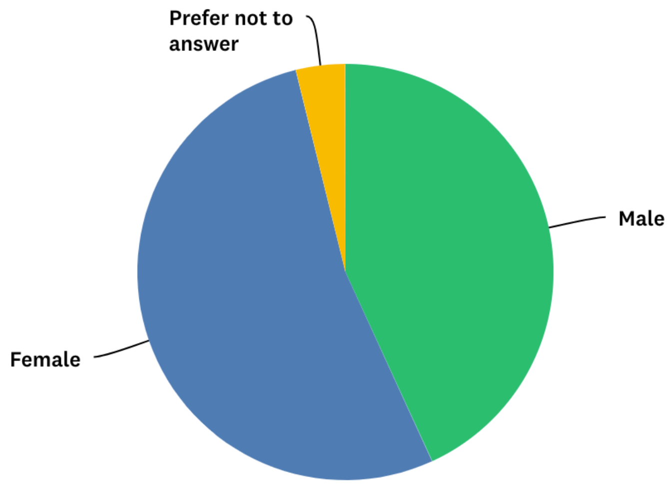

Figure 7.2 Survey Respondents by Gender

Figure 7.3 shows the type of vehicles driven by survey participants. They mostly drove passenger cars and SUVs: 39 percent and 30 percent, respectively. 19 percent drove pick-up trucks, 7 percent drove a commercial vehicle, and 4 percent drove a van. Although there was an option to choose motorcycle as the type of vehicle, no motorcyclists participated in the survey.

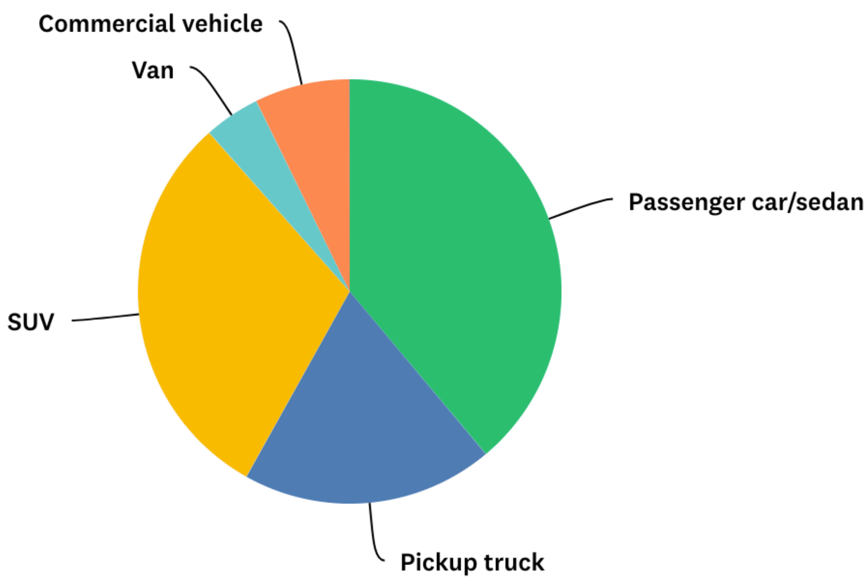

Figure 7.3 Survey Respondents by Vehicle Type

7.2 Survey Feedback

The goal of the survey was to evaluate public opinion of the orange markings during both daytime and nighttime driving.

All the survey participants had traveled through the work zone during the daylight hours. 99 percent said they noticed the change from white and yellow to orange pavement markings. 51 percent indicated that they preferred the orange markings to the original white and yellow markings. 36 percent preferred the old markings and 13 percent said it made no difference. This breakdown is illustrated in Figure 7.4.

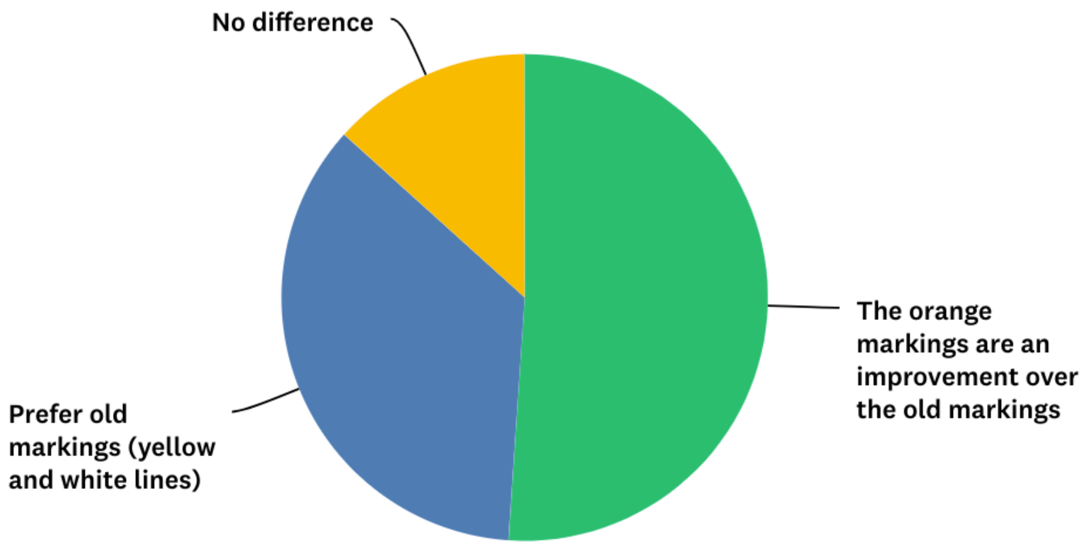

Figure 7.4 Motorist Preference for Work Zone Pavement Marking Color During Daytime

When asked about nighttime driving, respondents were less positive. 84 percent of the respondents had driven through the project area at night. Of those motorists, 49 percent preferred the orange markings over the original white and yellow markings. 43 percent preferred the original markings. 8 percent said it made no difference.

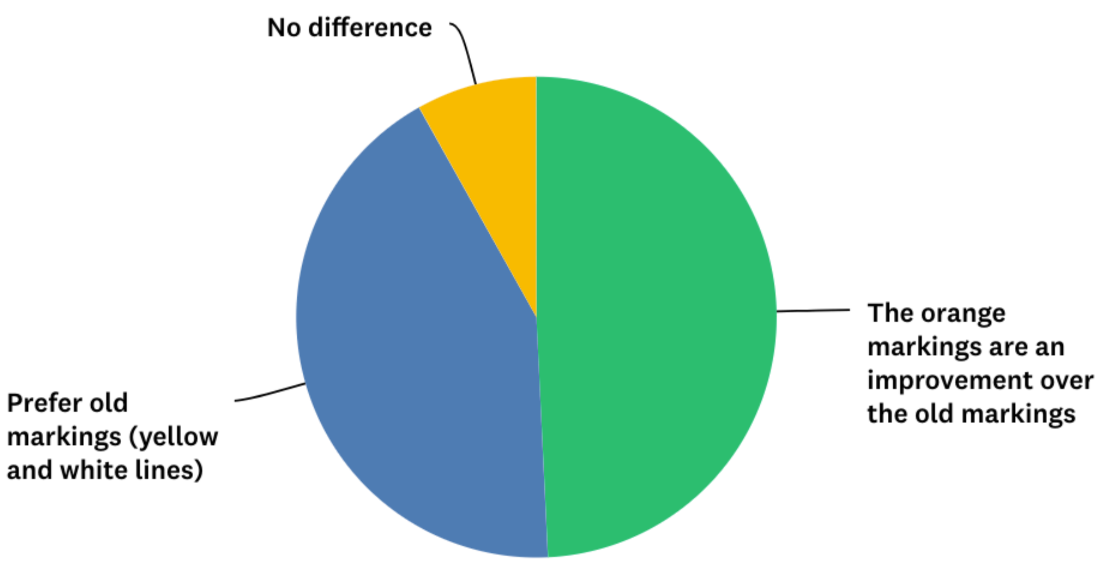

Figure 7.5 Motorist Preference for Work Zone Pavement Marking Color During Nighttime

The survey also left room for general comments from the public. Researchers read these comments individually, categorized each based on its overall message, and compiled them into tables for positive feedback and negative feedback. Positive feedback is presented in Table 7.1 and negative feedback is presented in Table 7.2. Both tables are listed in order of the frequency of those comments.

Table 7.1 Positive Comments from Motorists About the Orange Pavement Markings

Positive Comments	Frequency
Orange markings made motorist more aware of work zone and/or speed limit	11
Orange markings were easier to see	7
Orange markings were better for nighttime driving	4
Orange markings were better for driving in wet conditions	4
Orange markings felt safer	3
Orange markings made new traffic patterns easier to see and understand	2

Table 7.2 Negative Comments from Motorists About the Orange Pavement Markings

Negative Comments	Frequency
Orange markings were hard to see in wet nighttime conditions	24
Orange markings were hard to see in wet conditions	18
Orange markings were hard to see in nighttime conditions	14
Orange markings are confusing	6
Orange markings are hard to see in general / orange is too dark	6

The remarks from the public also served as a constructive source of suggestions. A couple participants mentioned that speeding remains an issue. (The speed data confirms this and researchers noticed it during field visits as well.) Commenters said it was difficult to travel at the posted speed limit when other motorists were driving much faster than the speed limit. Another commenter suggested that future work zones could use two colors side-by-side for temporary striping. This would allow orange markings during daylight hours, but could provide a way to improve the visibility during nighttime hours.

It was valuable to identify the responses of commercial vehicle drivers because they face unique challenges in work zones due to reduced lane width and lower speeds. There were seventeen commercial vehicle drivers that responded to the survey. All of them noticed the change to orange pavement markings. 47 percent of commercial vehicle drivers preferred the orange markings, 41 percent preferred the original white and yellow markings, and 12 percent said it made no difference. Sixteen of the seventeen commercial motorists had also driven through this area at night, and their opinions were the same for night driving as they were for daylight driving.

Chapter 8 Results/Conclusions

This research studied the effect of orange pavement markings through a work zone. A team of pavement marking professionals from Central Seal and 3M developed the color and tested several combinations of paint and bead packages. Then the KTC research team analyzed their visibility and studied the effects of the orange markings on speed, crashes, and driver behavior/perception.

8.1 Retroreflectivity

Researchers analyzed three different paint materials and four different bead packages. This aspect of the study presented some difficulties because it was hard to control the variables of the experiment. Materials were put down as they were needed in the work zone, as they became available to the subcontractors, and/or on different asphalts. Despite the many variables, researchers drew conclusions about the visibility of each type of material. Table 4.3 in Section 4 catalogs all materials/bead packages and their retroreflectivity, along with data about the age of the material and the type of surface it was applied to. The main conclusions are summarized here:

- Waterborne paint had poor retroreflectivity (between 50.6 and 131.5 mcd/lx/m²) and wore off quickly. Within 100 days of installation, most orange markings had faded enough to show the original pavement markings underneath them.
- Spray thermoplastic appeared brighter and was more durable than waterborne paint. Central Seal experimented with various bead packages in the spray thermoplastic, so its retroreflectivity values varied, but ranged from 74.8 to 368.4 mcd/lx/m².
- High-build waterborne paint markings had a distinct color and were very easy to see, especially at night. The retroreflectivity of the high-build paint ranged from 179.0 to 219.5 mcd/lx/m². This is the narrowest range out of all the materials used in this study.
- There were only two combinations that met KYTC's retroreflectivity standards for yellow pavement markings. They were spray thermoplastic with Visi-Ultra beads (up to 30 days old) and high-build paint with P20+5 beads (when it was older than 150 days old). Interestingly, the high-build paint did not meet the standard when it was new; it only met the thresholds set for older pavement markings because it maintained its retroreflectivity over a long period of time.

8.2 Speeds

KTC researchers used HERE Traffic Analytics data to calculate average speeds along the interstate corridor for the year before the orange paint was installed and the year after the orange paint was installed. They also compared speed data to neighboring work zones that did not use orange paint and to non-work zones on I-75. Daytime and nighttime speeds were analyzed separately.

- Daytime average speeds increased in the project work zone after the orange pavement markings were installed. The increase is small (0.5 mph) and may be due to motorist familiarity with the work zone, as it had already been in place a year before the orange paint was installed.
- The daytime average speed through the orange paint work zone was marginally lower than the average speeds through the two control work zones.
- The nighttime average speed increased by 1 mph in the project work zone after the orange pavement markings were installed. Again, this may be due to driver familiarity.
- At night, speeds in the work zones were generally higher than the speeds in the non-work zones.
- It is important to note that changes in the average speed, if there were any, were very small (about 1 to 2 mph.)
- Overall, the daytime and nighttime speeds through all three work zones and the non-work zones were about the same: 65.8 mph.
- The data indicates that very few drivers lower their speed as they travel through a work zone, even when orange pavement markings are added as a reminder.

8.3 Crashes

Safety is a critical concern in work zones, so researchers analyzed crash data to determine if there was a difference in safety with orange pavement markings. Researchers compared crash data in the orange paint work zone one year before orange paint was installed to the year after the orange paint was installed. Then the orange paint work zone was also compared to the two other control work zones over the course of one year.

- The total number of crashes increased by over 20 percent in the year after the orange paint was installed compared to the year before it was installed.
- The proportion of sideswipe collisions nearly doubled after the orange paint was installed. This increase is likely due to narrow lanes and lane shifts occurring in the after period more than the presence of orange paint because the control work zones experienced comparable proportions of sideswipe collisions in the after period as well.
- The percentage of crashes in the orange paint work zone occurring in wet roadway conditions dropped significantly once the orange paint was installed. The orange paint work zone also shows a much lower portion of wet crashes than the control work zones during the same time period. Based on feedback from the public opinion survey, researchers infer that visibility may have been so poor that motorists increased caution.
- Crashes in dark conditions decreased significantly in the orange paint work zone after the orange paint was installed. The orange paint work zone also had a lower percentage of crashes in dark conditions compared to the two control work zones. Again, the research team attributes this to more cautious driving because visibility was poor.

8.4 Public Perception

A survey hosted on Survey Monkey aimed to establish the public's reaction to using orange paint in work zones. Questions on the survey were aimed at deciphering whether or not motorists noticed a difference in lane marking color and if they have a positive, negative, or neutral opinion on orange lane markings compared to traditional colors. The survey collected 233 responses over the course of 50 days.

- The orange markings were a noticeable change in the work zone: 99 percent of respondents had noticed them.
- During daytime driving, 51 percent of motorists indicated that they preferred the orange markings to the original white and yellow markings. 36 preferred the old markings and 13 percent said it made no difference.
- During nighttime driving, 49 percent preferred the orange markings to the original. 43 percent preferred the old markings and 8 percent said it made no difference.
- Many survey respondents commented that the orange markings made them more aware of the work zone, and several noted that the orange markings were easier to see than typical white and yellow markings.
- Other comments indicated that driving in dark and/or wet conditions is much more difficult with the orange markings.

Chapter 9 Recommendations

This project served as a pilot study to test orange pavement markings in one work zone. The results were generally positive and offer evidence that further studies should be performed, but the study was not large enough to provide conclusive evidence that orange pavement markings should be regularly employed. Retroreflectivity thresholds can be met if a high-end bead package is used so agencies should evaluate how long the pavement markings will stay to determine if it is worth the extra cost. According to speed data, the average vehicle speeds through the orange work zone were not negatively affected and in fact barely differed from the nearby control work zones or the non-work zones. Crash data showed that the total number of crashes increased when orange pavement markings were installed, but there was a large decrease in wet and nighttime crashes, presumably because visibility was reduced and motorists were more cautious. The orange paint project was generally well-received by the public, but many expressed concern about visibility during wet and nighttime conditions.

Future study is needed in order to provide conclusive results. For future work, the research team offers the following recommendations and notes:

- The public needs explicit direction when orange paint is first installed. Utilize more roadside signs and/or public awareness campaigns so motorists know the meaning of the orange pavement markings and understand that they should slow down.
- Consider how the color orange is perceived by motorists. Some see it as red and think it means they are going the wrong direction (in accordance with its meaning in the MUTCD). Additionally, an orange that leans too red may present issues for motorists who have red-green color blindness. As agencies develop their own orange color, they should take care to not make it too red.
- The presence of law enforcement is a crucial aspect to safety in any work zone. Having extra law enforcement in and near the work zone would be helpful, especially when orange pavement markings are new.
- Additionally, long-term work zones may cause drivers to become overly comfortable or complacent, leading to faster speeds over time. This likely cannot be solved with novel pavement markings and instead might require law enforcement.

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Appendix A — Orange Paint Work Zone Motorist Survey

Orange Paint Work Zone Motorist Survey

Vehicle Type:
1. PC
2. PU
3. SUV
4. VAN
5. CV
6. MC

Driver Gender:
1. Male
2. Female

Driver Age:
1. 18-30
2. 30-60
3. Over 60

Did you notice a difference with this work zone?
1. YES
2. NO

If yes, what is your opinion of the work zone?
1. No Difference
2. Prefer old striping (white/yellow)
3. Improvement over old striping

Have you driven through this work zone at night?
1. YES
2. NO

If yes, what is your opinion of the work zone at night?
1. No Difference
2. Prefer old striping (white/yellow)
3. Improvement over old striping