REMOVING RESIDUAL LANE MARKINGS TO REDUCE DRIVER CONFUSION

Draft Final Report

SPR 855

Oregon Department of Transportation

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By

David S. Hurwitz, Ph.D., Professor
Hisham Jashami, Ph.D., Assistant Professor (Senior Research)
Jane Weber, Graduate Research Assistant
Oregon State University
101 Kearney Hall
Corvallis, OR 97331

Christopher M. Monsere, Ph.D., P.E., Professor
Sirisha Kothuri, Ph.D., Senior Research Associate
Elizabeth Yates, Graduate Research Assistant
Portland State University
P.O. Box 571
Portland, OR 97207

for

Oregon Department of Transportation
Research Section
555 13th Street NE, Suite 1
Salem, OR 97301

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16. Abstract

This research studied the relationship between removal methods used to remove pavement markings and driver confusion when encountering ghost lines. The study included field based and driver video experiments. Video data was collected at five locations in Oregon to examine the frequency with which drivers did not follow the correct markings when encountering ghost lines. The 40 participants video experiment was used to determine which removal method affected drivers' perception of which markings were the correct ones to follow. Hydroblasting was found to be the method that participants most frequently looked at when encountering the removed pavement markings versus the grinding method in all weather and lighting conditions. The study results suggest that the hydroblasting method should be used in conjunction with restriping methods that ensure that the correct pavement markings are followed.

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APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	millimeters squared	mm^2	mm^2	millimeters squared	0.0016	square inches	in^2
ft^2	square feet	0.093	meters squared	m^2	m^2	meters squared	10.764	square feet	ft^2
yd^2	square yards	0.836	meters squared	m^2	m^2	meters squared	1.196	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	kilometers squared	km^2	km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	ml	ml	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^3
~NOTE: Volumes greater than 1000 L shall be shown in m^3.									
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C	°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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DISCLAIMER

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1.0 INTRODUCTION

When lane markings need to be reconfigured, but available budgets will not allow for roadway resurfacing and installation of new lane markings, old lane markings can be removed, and new reconfigured markings can be applied to the existing roadway surface. Presently, the Oregon Department of Transportation (ODOT) uses hydroblasting, sandblasting, and shot blasting techniques to remove roadway markings for either temporary or permanent lane reconfigurations. There are several newer technologies and methods available that have not yet been implemented in Oregon such as CO_2 LASER-based removal. These processes may not remove all the marking from the pavement surface or scar the pavement in the process. These partial markings or pavement scars are sometimes referred to as "ghost lines." Ghost lines can provide faulty delineation information to road users, leading road users to incorrectly position their vehicles on the roadway's cross section, which may negatively impact both roadway operations and safety. Engineers are often tasked with reconfiguring these lane markings on roadway segments and are sometimes asked to do so without sufficient budgets for resurfacing. Identifying the performance criteria for removing old lane markings or when to resurface and add new markings will help engineers and decision-makers design and deliver projects with greater safety and efficiency for road users.

While the current methods of removing pavement markings have been working, limited research has been conducted on quantifying the effectiveness of each process. This research quantitatively determines which of the several pavement marking removal strategies result in the highest level of driver comprehension and compliance with longitudinal pavement markings. The primary project goal is to assess drivers' behavior when encountering ghost lines. This was accomplished by field and laboratory data collection and analysis sourced from both control and treatment locations.

The rest of this report is organized in the following way:

- Chapter 2 provides a literature review of previous research related to the removal of pavement markings to better understand the research topic. Reviewed topics included but were not limited to types of pavement markings, removal methods, human factors and driver lane keeping.

- Chapter 3 provides an overview of the site locations that were used for this project located throughout western Oregon.

- Chapter 4 provides information on the methodologies that were suggested, the pros and cons for each and ultimately the one that was chosen to be the best fit for this project.

- Chapter 5 provides information on the field data collection and analysis collected at five different locations in Oregon.

- Chapter 6 provides the completion of the video experiment conducted with 41 participants to investigate which removal method used in Oregon affects drivers' ability to determine the correct lane to stay in when encountering ghost lines.

- Chapter 7 provides the study findings summary, recommendations for practitioners related to the removal methods used on pavement markings and limitations and directions for future research.

2.0 LITERATURE REVIEW

Pavement markings can be removed by various blasting methods, grinding, and other newer methods such as chemical removal. The literature review presented in this report focuses on the types of pavement markings being used in Oregon and the different removal methods. This review also discusses human factors involved in drivers' perception of removed roadway markings and how those perceptions impact road user safety. While the reviewed research articles focus on removal methods for pavement markings, it should be noted that none of the previously conducted research explored driver performance when encountering ghost lines.

This literature review includes peer-reviewed journal articles, technical reports, and guidebooks produced by state transportation agencies. These documents were obtained by searching through online journal archives such as the ASCE Library and Google Scholar, general search engines (i.e., Google), and Transportation Agency websites (e.g., ODOT).

2.1 PAVEMENT MARKINGS

According to the American Association of State Highway Transportation Officials (AASHTO), pavement markings are used to control traffic for the purpose of encouraging safe and expeditious operations (Sitzabee, 2009). These pavement markings can be made of a variety of materials and can take multiple forms. This section will provide an overview of pavement markings covering topics such as the type of materials they are made from, common performance measures, and pavement marking requirements in Oregon.

2.1.1 Types of Pavement Markings

There are currently seven different types of pavement markings (paint, thermoplastic, tape, epoxy, polyurea, urethane, and methyl methacrylate (MMA) being used in the United States. These markings are used on both flexible (asphalt) and rigid (concrete) pavements and are placed on top of surface treatments. The seven different pavement marking types can be further categorized into durable and nondurable pavement markings. Paint, due to its shorter service life, is the only marking type commonly classified as nondurable. The commonly used forms of pavement markings are those made of paint and thermoplastic materials with waterborne paint being the most favored due to its low cost and wide availability (Mohamed et al., 2020). A study on pavement markings was conducted for the Idaho Transportation Department entitled Materials Acceptance Risk Analysis: Pavement Markings (Sadid et al., 2010). Table 2.1 highlights the advantages and disadvantages found in the study of the most popular types including paint, thermoplastic and MMA.

TABLE 2.1 ADVANTAGES AND DISADVANTAGES TO PAVEMENT MARKING TYPES

Marking Type	Advantages	Disadvantages
Conventional Paint Marking	• Installation costs are low. • Alkyd paints are fast drying and retroreflectivity is high at first but decreases after 6 to 7 months. • Water-based paints are fast drying and can be formulated for low temperature application. • They are more durable than VOC compliant solvent-borne paint systems. • Conventional paints generally provide equal performance on asphalt and concrete pavement. • Paints can be applied at a faster rate than most other markings and under non-ideal conditions. • Installed costs range between \$0.04 to \$0.06/lf	• Short service life (6 to 7 months) • Sensitive to temperature during application • Latex paint is sensitive to high humidity which can increase drying time drastically. • Wear off quickly and lose retroreflectivity after exposure to high traffic volumes and winter-maintenance activities. • After some time (1 to 1 ½ years) it has lower visibility at night in comparison to epoxy and thermoplastics
Thermoplastics	• New materials can be reapplied over old thermoplastic markings. • Forms a mechanical bond with a concrete surface and a thermal bond with asphalt. • More durable than conventional paints • Service life found to be around 3 to 5 years. • Inlaid thermoplastics offer better wear resistance	• Requires special installation equipment. • Higher cost with installation falling in the range of \$0.41 to \$1.50/lf • Less visible during the day because of grayish color
Methyl Methacrylate (MMA)	• Performs well in low temperatures and heavy snowfall areas. • Has good visibility in both night and wet conditions. • Bonds well to both concrete and asphalt • Typical service life ranges from 2 to 4 years but can have a longer service life of 6 to 8 years	• Limited use in the United States • Requires special installation equipment. • High cost of installation at \$2.00 to \$3.00/lf

2.1.2 Performance Measures

There are three performance measures that pavement markings must meet to be usable: retroreflectivity, marking surface color, and durability. Retroreflectivity performance is described as, "the amount of light returned back to a driver from a vehicle's headlights as it is reflected from the pavement marking." (Sitzabee et al., 2009). This reflectivity is created by embedding glass beads into the pavement marking surface through a marking binder material and can be found in three different sizes (TxDOT, 2004). Further detail on how road user's reaction to retroreflective markings during the daytime will be addressed in the human factors section of this literature review. Marking surface color is based on the purpose for which the markings are being used and to enhance the visibility of the markings for road users. The color should be monitored during and after application to ensure that the color is visible and not degraded to a point that causes road user confusion. Finally, durability is determined based on how long the service life is and how it deteriorates over time based on factors such as material type, weathering process, and marking location (Mohamed et al., 2020).

2.1.3 Oregon Standards

In the state of Oregon, there are certain standards that must be met when applying pavement markings to roadway surfaces. ODOT outlines the standards through the Traffic Line Manual containing guidelines for each type of pavement marking design and application as well as the Oregon Standard Specifications for Construction. When it comes to the design of pavement markings it is necessary to ensure that the designs are uniform and consistent. This ensures that the information that the markings are meant to convey are understood by all road users. Any deviation that occurs from the design parameters can only happen when it is deemed necessary by the engineer on the project. These deviations might also require the approval of the Federal Highway Administration (FHWA) if the risk of the deviation is determined to be high by the region traffic engineer or manager. A guide provided by ODOT for the design of the longitudinal pavement markings can be found below.

Marking colors are required to be yellow, white, red, blue, or green depending on the application, with black only being allowed when it is used as a border color to contrast the pavement marking with the road or to cover existing markings in a temporary setting. The different pavement marking colors are necessary to convey the proper message to road users at a particular location on the roadway. For longitudinal lines, which are presented in Figure 2.1, the type of pavement markings that will be investigated in the present study, they typically are applied in a solid, double, broken, or dotted pattern and must consist of a certain width depending on the type of roadway facility and the message being conveyed. These line patterns must also maintain a width to length ratio of 1:3 (ODOT, 2021). Additional standards for other types of pavement markings and their different uses are found in the ODOT manual (ODOT, 2021).

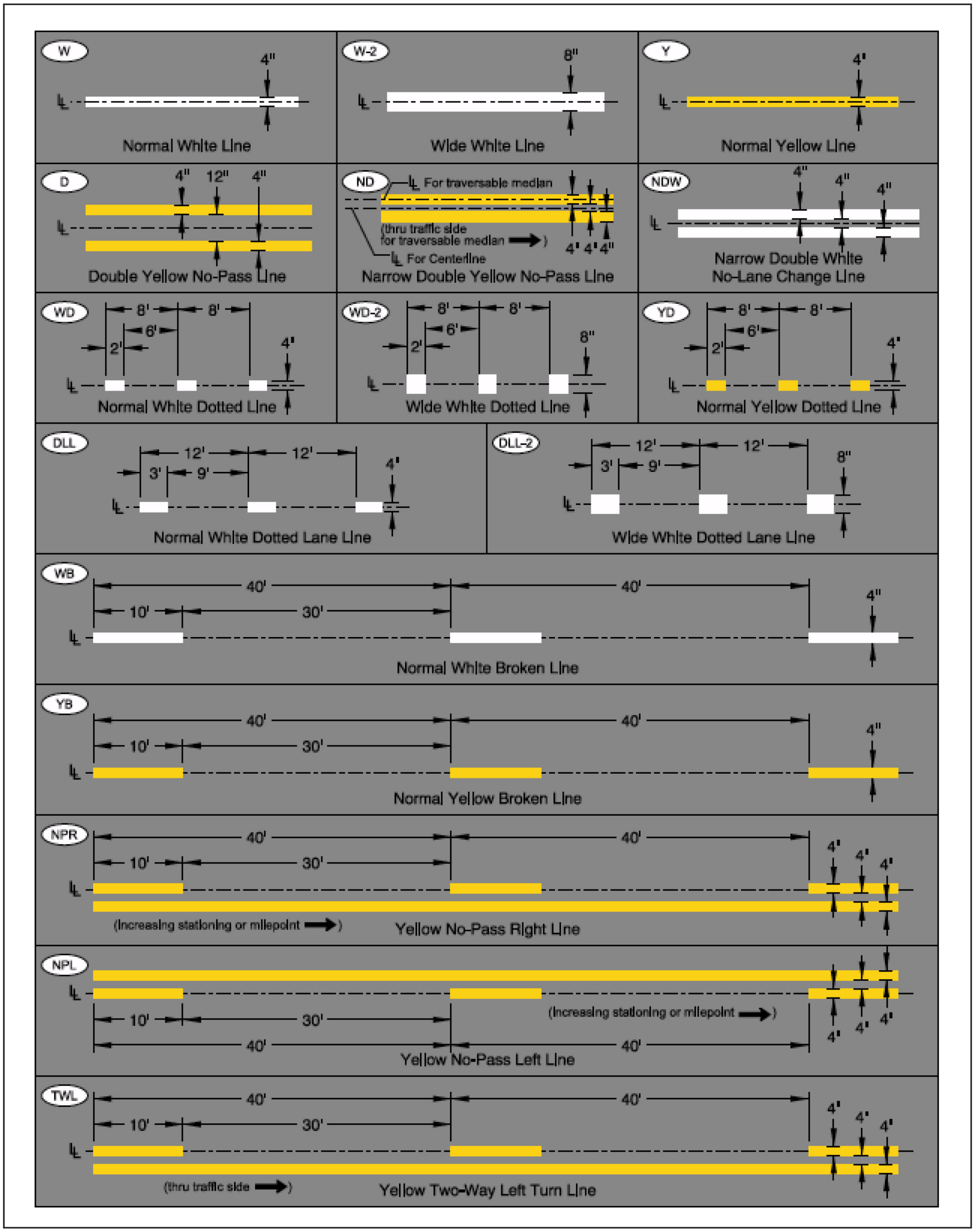


FIGURE 2.1: LONGITUDINAL LINE TYPES (ODOT, 2021)

2.2 METHODS OF PAVEMENT MARKING REMOVAL

There are multiple ways to remove pavement markings with the two most used being grinding and blasting. Other forms of pavement marking removal include chemical removal, which has become more available in the past few years, and CO_2 Laser removal, a relatively novel technique. The amount of force and time required to remove a pavement marking is dependent on the durability of the pavement marking. This section focuses on the different methods currently being used and describes their advantages and disadvantages along with the cost of each method.

2.2.1 Blasting

There are several different forms of blasting including high-pressure water blasting, hydroblasting, soda blasting, dry ice blasting, sand blasting, and shot blasting. Of these different forms the most used are high-pressure water blasting, sand blasting, and shot blasting with high-pressure water blasting being the most popular.

High-pressure water blasting has become popular in recent years due to the mobility of the method. It requires large mobile trucks that are mounted with the water blasting system and have a vacuum attachment that can suck up any debris and excess water that is produced. It can be used on all pavement markings and is considered quick at a removal speed of 2-mph. The drawbacks to this method are that it does not perform well in colder weather as the water can freeze and has issues with open-graded asphalt surfaces. It can also strip the top layer off pavement surfaces and polish the aggregate, contributing to the prominence of ghost lines. Figure 2.2 gives an example of a high-pressure water blasting truck used for this method.

Hydroblasting is different than high-pressure water blasting in that it combines sand and water rather than just water. It is effective on thin pavement markings, but the drawbacks are numerous as it can produce significant debris, scar the pavement surface, and remove the asphalt binder.

FIGURE 2.2: HIGH-PRESSURE WATER BLASTING TRUCK (GOOGLE, 2021)

Sand blasting uses a combination of high-pressure air and sand particles to remove pavement markings. It is most effective against thinner markings such as paint and has a low risk of scarring the pavement surface. The drawbacks of this method include the production of significant debris and a polishing of the pavement's surface, which can also contribute to ghost markings. There are also health and safety issues for road workers that have been raised due to the silica present in sand.

The performance of soda and dry ice blasting is consistent with the positives and negatives of sand blasting, but the two methods do not utilize sand. Additional issues for these blasting methods that have been documented include the requirement of multiple personnel needed to implement the two methods, and they must be performed on foot rather than through a moving vehicle (NCHRP, 2013).

Shot blasting is similar to sand blasting in that it uses blast material to remove the pavement markings using a conveyor instead of high-pressure air with a velocity of approximately 175 mph. It is a mobile system that can be mounted on a truck and is effective in removing thin pavement markings. The drawbacks to this method are that it can only be used under dry conditions and on smooth road surfaces.

2.2.2 Grinding

The term grinding can cover various methods, including grinding, milling, flailing, and scarifying. These techniques can be used to remove all types of pavement markings. These methods can be mobile and are a time efficient approach to removing markings. All four methods use similar form of equipment, shown in Figure 2.3, that uses an abrasive surface such as a disk that rotates against the pavement surface, with the only differences being what kind of abrasive surface is used and how long it is applied to the surface. The primary drawback to the grinding method is that it scars and damages the pavement surface (NCHRP, 2013).

FIGURE 2.3: GRINDER TO THE LEFT AND A SCARIFIER TO THE RIGHT (CHO ET AL., 2013)

2.2.3 Chemical

The removal of pavement markings through chemical means has been gaining interest in the past few years as it has become more of a viable option. It is a chemical remover that, following EPA guidelines, does not contain any form of methylene chloride (MeCl) which is considered an air pollutant and hazard to public health (Cho et al., 2013). The non-MeCl chemical remover is applied to thinner pavement markings, such as waterborne paint, and is successful in removing almost all of the paint while not damaging the pavement surface. Figure 2.4 shows the application and removal of pavement markings using a chemical remover. Drawbacks to this removal method include a longer implementation time as the chemical remover needs to remain on the markings for 10 to 30 minutes to be effective and the potential need for multiple passes over the pavement surface to remove the markings to an acceptable degree (NCHRP, 2013).

FIGURE 2.4: APPLICATION OF CHEMICAL REMOVER TO THE LEFT AND REMOVAL TO THE RIGHT (CHO ET AL., 2013)

2.2.4 Other Methods of Removal

A few other methods are available when removing pavement markings, but they are either still considered novel methods or not used as frequently as the other methods for various reasons. These methods include burning, masking, and CO_2 LASER-based removal.

Burning can be performed in two ways, either through hot compressed air or through an excess-oxygen system. Both methods use propane as an accelerant to create the needed heat, but while the hot-compressed air system has an internal combustion system, the excess-oxygen approach uses an external combustion system. The heat produced from these two methods is used to remove the pavement markings and is effective on temporary and thin paint markings. The drawbacks to this method are that if the heat is left in one spot for too long it can damage the pavement and a secondary vacuum system is needed to collect the debris (NCHRP, 2013).

Figure 2.5 shows masking which is a temporary solution that does not remove the pavement markings but instead is used to obscure and cover the existing pavement markings. It is only used when the markings need to be covered temporarily and must match the road surface and act as a blender between the surface and the marking. This method is not employed often as it can only be used when a roadway needs to be resurfaced or towards the end of construction.

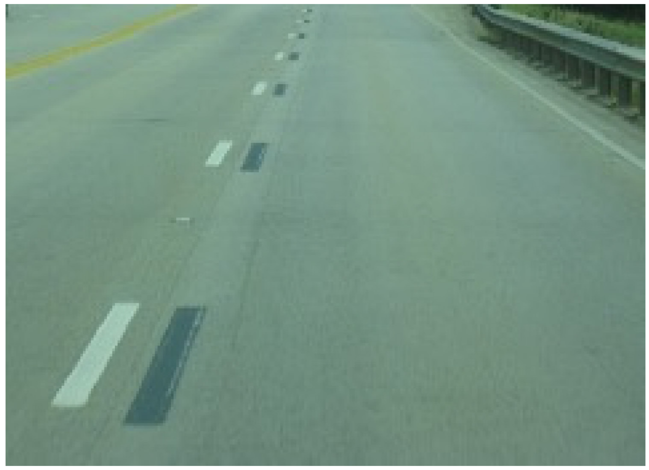


FIGURE 2.5: MASKING BEING USED TO COVER UP PAVEMENT MARKING (NCHRP, 2013)

CO_2 LASER removal is a novel method that has become more discussed in recent years. It is still considered an experimental method and has only been used in laboratory settings. It appears promising as it is effective at removing high percentages of waterborne paint markings without damaging the pavement surface. It has also been found to be an environmentally friendly option and due to how well it removes the markings, it could potentially lead to a reduction in pavement repairs. As this method is still so new, there are several drawbacks including a higher upfront cost, slower pavement marking removal times, and increased difficulty in procurement (Regentova, 2014).

2.2.5 Cost

The cost of each method is a factor that needs to be taken into consideration as this will influence why an effective method might not be used as frequently as others. Overall, it is cheaper to perform pavement marking removal at a large scale due to lower unit costs when removal is conducted in larger quantities. This can be problematic as smaller projects can incur higher per unit costs.

While grinding has been found to damage pavement surfaces, it remains one of the most popular methods to use due to its comparatively lower cost. Water blasting and dry-ice blasting remain the most expensive forms of removal. When it comes to the removal of waterborne paint or tape pavement markings it was found that shot blasting and dry-ice blasting were the most expensive method of removal.

Table 2.2 displays the different costs for the types of removal methods depending on the pavement and marking material types. The cost for grinding has been calculated at approximately $2,000/line-mi. For blasting it was found that shot blasting had a similar cost at $2,050/line-mi while sand blasting was significantly higher at $3,150/line-mi. Water blasting was found to have a 40% increase in price over grinding at a cost of $2,750/line-mi. These costs were all documented in NCHRP report 759 on effective removal of pavement markings which has a comprehensive table featuring typical removal costs for the different methods of removal and the pavement that it is performed on (NCHRP, 2013). This table was created through a survey that was sent throughout the United States to different state departments of transportation with average prices estimated from the responses.

TABLE 2.2 TYPICAL REMOVAL COSTS, LISTED BY REMOVAL TECHNIQUE/ROAD SURFACE TYPE/MARKING MATERIAL FOR DOT (NCHRP, 2013)

Type of Removal	Type of Pavement	Types of Marking Materials Removed	Estimated Removal Cost Prices vary due to the construction quantities		
			Line-mile	Linear foot	Square Foot
All	All	All			$1.50
Weighted average for all types of PM removal					$0.60
All			Avg $1,267.2	$0.24	
All	All		$3,850		
Any	PCC	Any	$1,214.4	$0.23	
All					
Bid item for marking removal	All	All	$1,953.6		
All	All	All	$1,108.8	$0.21	
Overall avg.			$1,800		
General removal of permanent markings (all removal and markings combined)			$1,742.4	$0.33	
Removal of temporary markings (paint removal)			$1,214.4	$0.23	
	All	Paint	$2,112		
	All	Thermo, Tape, MMA	$2,851		
	All	All	$2,376	$0.45	
Hand grinder					$4.15

Type of Removal	Type of Pavement	Types of Marking Materials Removed	Estimated Removal Cost Prices vary due to the construction quantities		
			Line-mile	Linear foot	Square Foot
Truck-mounted grinder			$2,376	$0.45	
Grinding			$643-$792	$0.12-$0.15	
Grinding	Concrete, Bituminous		$1,848	$0.35	
Grinding	HMA	Paint, Thermo	$2,060 for 4-inch line		
Grinding	Concrete, Asphalt	Paint, Polyurea, Tape, Thermo	$1,584	$0.30	
Grinding	All	All	$1,425.6		
Grinding	Chip Seal, Class I-1, Modified Friction Course	Epoxy	$158.4	$0.03	
Grinding	Concrete or Asphalt	Paint, Thermo, Tape Epoxy, Polyurea, MMA, Multi-Component	$1,320		
Grinding		Solid Paint	$958-$2,192		
Grinding		Broken Tape	$3,300		
Grinding		Solid Tape	$6,700-$7,200		
Grinding or Shot Blasting	HMA, PCC	Paint, Thermo, Tape	$3,960	$0.75	
Shot Blasting	Concrete, Bituminous		$2,376	$0.45	
Sand Blasting	Concrete, Bituminous		$2,376	$0.45	
Sand Blasting	All	Liquid Marking	$1,742.4		

Type of Removal	Type of Pavement	Types of Marking Materials Removed	Estimated Removal Cost Prices vary due to the construction quantities		
			Line-mile	**Linear foot**	**Square Foot**
Water Blasting			As low as $264 for very large district-wide contract, not cost effective for small jobs due to mobilization fees	$0.05	
Water Blasting	Concrete	Paint, Polyurea, Tape	$2,640	$0.50	
Water Blasting	Concrete, Bituminous		$2,376	$0.45	
Water Blasting			Up to $5,280	$1.00	
Water Blasting	Concrete or Asphalt	Paint, Thermo, Tape Epoxy, Polyurea, MMA, Multi-Component	$1,636		
Water Blasting	HMA, PCC	Thermo, Tape	$1,850		

2.2.6 Environmental and Safety Concerns

When working on a project, there is always a need to consider the environmental impacts and safety hazards that are involved for those working on the project. Each pavement marking removal method produces some form of environmental, health or safety outcome that must be addressed to ensure a safe work environment.

When applying grinding to pavement marking removal on asphalt surfaces, the main environmental concern is the waste material produced after the pavement marking has been removed. This waste material could contain contaminants such as aliphatic or polycyclic hydrocarbons that can be hazardous (NCHRP, 2013). The waste material should be tested before being properly disposed of. There are minimal environmental issues with grinding on concrete surfaces, but the waste should still be tested before disposal to ensure that it will not negatively affect the surrounding environment. Safety concerns for grinding include potential contaminants in the air that could be inhaled, e.g., lead and silica. Noise exposure for workers is also a safety concern.

For high-pressure water blasting, the main concern for pavement marking removal on asphalt surfaces is the same as that of grinding, hazardous contaminants mixed with water that will need to be tested and properly disposed of. There is minimal concern for removal performed on concrete surfaces other than the contaminants from the pavement marking. Safety concerns are consistent with grinding (NCHRP, 2013).

For blasting, that includes shot or glass, the environmental concerns are the same as with grinding but with the addition of the material being used to facilitate the blasting, i.e., shot or glass. As with grinding, the waste material will need to be tested before being properly disposed of. The safety concerns are the contaminated air particles that could include chromium and asbestos as well as noise exposure for workers (NCHRP, 2013).

For chemical removers, environmental concerns can be mitigated by choosing an environmentally friendly remover that does not contain MeCl. Prior to using the chemical remover, proper use guidelines should be followed. The waste material produced will contain pavement markings, the chemical remover, and some contaminants from the asphalt or concrete surface and will need to be tested prior to proper disposal. The safety concerns include the handling and exposure to chemicals and waste material (NCHRP, 2013).

The NCHRP document *Effective Removal of Pavement Markings* contains a comprehensive table on environmental issues that was recreated in Table 2.3 featuring the different removal methods and corresponding environmental acts.

TABLE 2.3 SUMMARY OF ENVIRONMENTAL ISSUES RELATED TO REMOVAL TECHNIQUES (NCHRP, 2013)

Removal Techniques	Hazardous Waste & Toxic Substances Control Act (TSCA)	Clean Water Act (CWA)	Clean Air Act (CAA)	National Environmental Policy Act (NEPA)
Grinding	Solid waste generated subject to regulation	Water runoff from waste products subject to regulation	Airborne material produced subject to regulation	Site-specific determination of requirements
High-Pressure Water Blasting	Solid waste and wastewater generated subject to regulation	Water runoff from waste products subject to regulation	Limited air quality concerns	Site-specific determination of requirements
Media Blasting	Solid waste generated subject to regulation	Water runoff from waste products subject to regulation	Airborne material produced subject to regulation	Site-specific determination of requirements
Chemical Removal*	Solid and chemical waste generated subject to regulation	Water runoff from waste products subject to regulation	Limited air quality concerns	Site-specific determination of requirements
Combination Grinding & Chemical Removal	Solid and chemical waste generated subject to regulation	Water runoff from waste products subject to regulation	Airborne material produced subject to regulation	Site-specific determination of requirements

**Chemical removal currently is only used on paint markings in 2013.*

2.2.7 Summary of Methods

As shown throughout this section there are many different methods of pavement marking removal that currently exist. Some of these options are easily available while others are in the beginning stages of implementation. The advantages and drawbacks of each method were shown throughout the section, including how well the method removed the markings, what damage was caused to the pavement surface, and how it affects environmental and safety concerns. A table from the NCHRP document *Effective Removal of Pavement Markings* that provides a summary of the advantages and disadvantages was recreated in Table 2.4.

TABLE 2.4 SUMMARY OF ADVANTAGES AND DISADVANTAGES FOR EACH REMOVAL METHOD (NCHRP, 2013)

Removal Method	Advantages	Disadvantages
High-Pressure Water	• Byproduct does not create dust and is contained within the equipment. • Little to no scarring on concrete pavements. • With the exception of drying time, the pavement surface is prepped for pavement marking installation. • Relatively fast for a blasting method. • Large vehicle mobile systems available with additional utility carts for smaller nearby areas.	• Limited to above-freezing conditions. • May polish surface aggregate and/or clean the surrounding pavement, creating a color contrast. • May remove some surface asphalt and fines that could lead to water penetration. • Potential for damage to pavement joints. • Currently not widely available, higher costs. • Proper equipment operation critical to achieve good results.
Grinding	• Fast and economical. • Depending on the system configuration (effective vacuum system installed to remove dust), dust created by removal can be contained. • High availability.	• Damage to pavement surface. • Scarring with full marking removal, minimizing damage to roadway may leave marking material behind. Orbital flailing may result in less noticeable scarring than drum flailing due to tapered edges. • Non-vacuum systems can create dust clouds and be hazardous.
Sand Blasting	• Minimal pavement degradation. • Little to no scarring. • Hand-operated precision.	• Creates considerable byproduct. • Creates considerable dust. • No current large vehicle mobile system, therefore slower than mobile methods. • Health hazards depending on blast media.
Shot Blasting	• Minimal byproduct. • Byproduct does not create dust and is contained within the equipment. • Minimal pavement degradation. • Little to no scarring.	• Shot recovery can be problematic especially on uneven surfaces. • Cannot be used in wet conditions. • Can be slow especially for thicker markings. • Can cause pavement damage on non-smooth surfaces. • Limited availability of equipment.
Soda Blasting	• Minimal pavement degradation.	• Creates a moderate amount of byproduct.

Removal Method	Advantages	Disadvantages
	• Little to no scarring. • Hand-operated precision.	• Creates considerable dust. • No current large vehicle mobile system. • Can be slow especially for thick markings. • Only useful on some markings.
Dry Ice Blasting	• Minimal environmental concerns with respect to debris generated. • Minimal pavement degradation. • Marking can be completely removed. • Hand-operated precision.	• Dry ice is a difficult medium to handle and store. • Very noisy. • Slow. • No current large vehicle mobile system. • Only useful on some markings.
Hydroblasting	• Similar advantages to high-pressure water and sand blasting. • Minimal pavement degradation. • Limited scarring.	• Similar disadvantages to high-pressure water and sand blasting. • Creates considerable byproduct. • No current large vehicle mobile system. • Limited to above-freezing conditions.
Excess-Oxygen Burning	• Minimal pavement degradation	• Requires at least one additional pass to remove residue. • Slow. • No current large vehicle mobile system. • Only useful on some markings.
Laser	• Non-contact and should have little to no wear, which reduces maintenance costs. • Minimal pavement degradation. • Minimal environmental concerns.	• Slow • Requires at least one additional pass to remove residue. • No current large vehicle mobile system. • Only useful on some markings.
Chemical	• Byproduct does not create dust. Can get complete removal without scarring.	• Potential to damage pavement surface if incorrect removing agents are used. • Requires at least one additional pass to remove residue. • Slow, need to wait for chemical to react then proceed with removal. • No current large vehicle mobile system. • Only useful on some markings.

Removal Method	Advantages	Disadvantages
Hand Removal	• Detailed Removal	• Slow. Typically, only for removable tapes.
Masking	• No damage to road surface. • Existing markings can be temporarily covered with tape that matches the road surface color and texture, and later reused when the tape is removed. • Removed areas can be masked to help blend in scarring or surface color changes. • Can be used in lane-shift areas to reduce driver confusion due to ghost markings or scarring.	• Can be expensive. • Material may wear away exposing the markings being covered. • Difficult to match color and texture with tape. • Tape is for temporary purposes only. • Cannot use marking materials other than tape to cover a marking.

2.3 HUMAN FACTORS AND DRIVER LANE KEEPING

Pavement markings are only useful to road users when they are easily visible and understandable. Pavement markings are used as a guide to facilitate the driving task (i.e., control, navigation, and guidance) as drivers need visual cues to operate their vehicles safely and efficiently. It has been determined that about 90 percent of the driving task is facilitated from receiving visual information about the lane that the driver is in (ODOT, 2021). If anything is changed from what the driver expects then there is an increase in the risk that driving errors will occur. The visibility of markings relies on multiple factors including color contrast, preview time, retroreflectivity, and marking width. These are all needed to ensure that the pavement markings remain visible to the driver.

2.3.1 Contrast Sensitivity & Preview Time

Contrast sensitivity is considered key when it comes to visibility as it makes it easier to discern the differences between the road and the marking with Figure 2.6 showing an example of a contrasted marking. It is stated to be, “the ability to detect small differences in brightness between an object and its background.” (ODOT, 2021). As drivers increase in age, pavement markings become less visible due to changes in the eye lens and the prominence of ocular disease within the age group. Maintaining a noticeable contrast is important when considering these road users.

FIGURE 2.6: BLACK BORDER ON WHITE STRIPE TO INCREASE CONTRAST BETWEEN MARKING AND PAVEMENT (GOOGLE, 2019)

Preview time is derived from distance and is stated to be “the amount of time that drivers look ahead on the roadway.” (Campbell et al., 2012). For road users to behave properly on the road they must be able to see and understand pavement marking from a distance that allows them to react in a timely fashion. There is some general disagreement on the minimum preview time, but overall, there is consensus that 5 seconds is the proper value (Campbell et al., 2012). A 5 second preview time provides an opportunity for the road user to react to the environment and maintain control over the vehicle.

2.3.2 Retroreflectivity

When driving, particularly at night, pavement markings need to be visible to drivers. Improved night-time visibility is due in part to retroreflectivity. Figure 2.7 shows the difference between a low reflective marking and a high reflective marking on a roadway. As discussed in Section 2.1.2, retroreflectivity is measured as “the amount of light returned back to a driver from a vehicle’s headlights as it is reflected from the pavement marking.” (Sitzabee et al., 2009). For nighttime driving this is a crucial element for visibility, and it has been found to increase nighttime safety when properly maintained (ODOT, 2021).

Multiple factors influence driver performance relative to the retroreflectivity of pavement markings. Factors associated with the driver include visual capabilities, cognitive processing capabilities, and motor skills (TxDOT, 2004). These factors decline with age but not all drivers will need the same amount of light to see the pavement markings. In the NCHRP study titled *Human Factors – Guidelines for Road Systems* it was found that for younger drivers a retroreflectivity value of 93 mcd/m^2/lux was considered adequate for nighttime driving whereas a value of 100 mcd/m^2/lux was considered the minimum adequate brightness for those 60 years or older (Campbell et al., 2012). These minimums are not to be confused with the necessary values of acceptability among all road users for retroreflectivity as it was found that a value of at least 300 to 400 mcd/m^2/lux was needed for a decent user performance (Campbell et al., 2012).

FIGURE 2.7: CONTRAST BETWEEN LOW RETROREFLECTIVITY PAVEMENT MARKINGS TO THE LEFT AND HIGH RETROREFLECTIVITY MARKINGS TO THE RIGHT (GOOGLE, 2021)

When looking at factors associated with the road these include speed of vehicle, presence of continuous roadway lighting, and presence of retroreflective raised pavement markings (TxDOT, 2004). When speeding occurs, there is a need for the pavement markings to be detected earlier and as such there needs to be light to ensure that they are seen. Pavement markings can also be easily obscured by weather conditions including darkness, fog, rain, glare, dirt and debris, ice, and snow (ODOT, 2021). This makes it considerably harder for drivers to react and keep control of their vehicle which can lead to deviation from the pavement markings. The issue of glare also needs to be taken into consideration as it has been found to cause visual impairment when encountered along with discomfort and fatigue. It is especially detrimental for older road users due to their reduced visual capabilities (Campbell, et al., 2012). To compensate for glare coming from other vehicles on the road an increase in brightness by 300% for pavement markings is recommended (Campbell, et al., 2012).

2.3.3 Pavement Marking Width

As stated in previous sections, the visibility of pavement markings is paramount in ensuring driver safety. One way that visibility can be improved is by increasing the width of the pavement marking. The current standard for pavement marking width, including longitudinal markings, is 4 inches. Multiple studies have been conducted to see if wider markings have any impact on the safety of road users. It was found that with an additional two inches there is an increase in safety. When the pavement markings are increased to 6 inches there is a noticeable increase in recognition on the part of the road user where, “mean lateral placement was more centered, fewer lane departures on curves were observed, and lane keeping in low-contrast situations improved.” (Campbell et al., 2012). While there is an overall improvement the wider pavement marking was found to work best in situations where there are horizontal curves, roadways that are narrow or have no shoulder, and in construction work zones (Campbell et al., 2012). A comparison study was conducted to see if wider is in fact better with a 6-inch lane marking being compared to an 8-inch marking. The 6-inch width was found to perform the best as there was a noticeable increase in safety once the markings were widened from a 4-inch to a 6-inch. When the markings were further widened to 8 inches the benefits were not as noticeable as those of the 6-inch markings (Campbell et al., 2012). Outside of visibility improvements there can be other reasons as to why the pavement marking should be widened. A report titled *The Use of Wider Longitudinal Pavement Markings* conducted a survey to find the most common reasons which correspond to improving safety on the roadway.

2.4 SUMMARY

This literature review considered previously conducted studies and standards documents relevant to removing residual pavement markings to reduce the occurrence of driver confusion. The review provided a synthesis of topics including different types of pavement markings, the variety of removal methods, and finally some of the human factors that are associated with how road users perceive pavement markings on the roadway. This research project will include an empirical field study to determine how road users react to pavement markings removed with a variety of techniques. The review of the literature has suggested several methods that could be employed in research design and site selection. Some of the key literature review findings include:

Pavement marking removal methods:

- High-pressure water blasting is useful in removing all pavement markings and in general has become more widely available throughout the country. When using the truck mounted option, a vacuum attachment is used to suck up the waste material reducing the need to clean up afterwards. It has the chance of creating ghost lines but is efficient and quick.

- Grinding is the most commonly used, but its harsher removal method can create more prevalent ghost lines. It is a cheap and effective method of removal that can be used easily.

- The other forms of blasting are effective but can lead to ghost lines and at times can be more expensive than grinding or high-pressure water blasting.

- Chemical removal is the newer removal method that is efficient and removes paint-based pavement markings well without leaving any damage to the roadway surface. There is no recent literature on what chemical removal can do and should be looked at more closely.

Human factors:

- When removing pavement markings, human factors need to be considered as road users can become prone to errors when given incorrect visual information.

- Pavement markings need to be visible at all times of the day, especially for the older driving population. The correct colors, contrast, and retroreflectivity need to be implemented on the pavement markings to provide the correct visual cues.

- Contrast between the pavement marking and the roadway is imperative when it comes to older drivers as their contrast sensitivity decreases. This can be accomplished through borders that can highlight the marking.

- Preview time of pavement markings on the roadway can be a minimum of 3 seconds with any less hindering the road users' chance of reacting on time. A preview time of 5 seconds is the general recommendation.

- Retroreflectivity is incredibly important as it allows road users to see the pavement markings, especially at night when visibility is reduced. It can have a long service life if it is well maintained.

- Pavement marking width affects the visibility of the pavement marking with the current standards being set at 4 inches. When the width is expanded to 6 inches there has been a notable increase in safety.

Most of the available information on this topic was related to the various marking removal techniques' cost, benefits, and advantages. Only two peer-reviewed journal articles addressed pavement marking removal, with just one focusing on ghost lines. While the removal methods were addressed neither of these articles looked at field driver performance when encountering ghost lines. This research aims to fill in that gap in the literature and provide empirical evidence to create a deeper understanding of how drivers perceive ghost lines after pavement markings have been removed. Recommendations will be developed from this knowledge as to which pavement marking removal techniques produce the best driver performance outcomes.

3.0 SITE SELECTION

A set of projects were identified through communication with ODOT project management staff, who were most familiar with project activities occurring during the SPR 855 project timeline. Each project was approached with a set of criteria to evaluate if the project would be practical for this research effort. The criteria included whether construction would begin during the summer and fall of 2022 and whether pavement marking removal would be included in the project.

3.1 SITES

While many potential study sites were identified by ODOT staff only five were found to be viable due to the criteria mentioned above. These sites are located throughout Oregon on the west side of the Cascades that include Albany, Ashland, Springfield, and Warrenton. These locations can be seen in Figure 3.1 depicting the project location sites throughout Oregon. All of these were projects in which construction had either begun or had already been completed by the time that video footage was being collected.

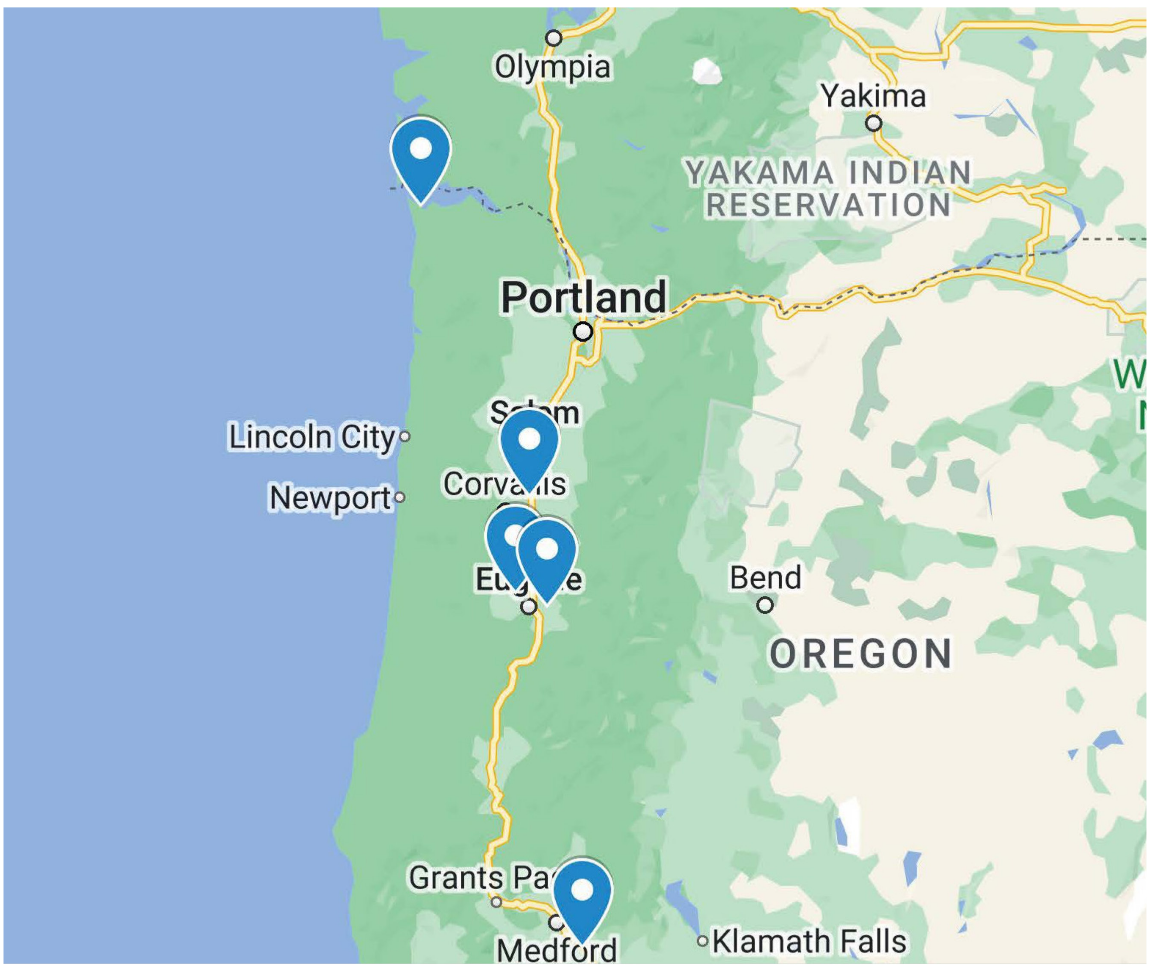


FIGURE 3.1: PROJECT LOCATIONS THROUGHOUT OREGON

3.1.1 Albany

Two project locations were identified in the city of Albany with one being at Santiam Highway, shown in Figure 3.2, and the crossing of Highway 99 and Airport Road, as shown in Figure 3-3. Both projects were scheduled for construction throughout the summer and into the fall, which would allow for video capture of the roadways prior to and after construction had been finished. The project's efforts included pavement marking removal rather than a complete repaving of the roadways. The removal method for both locations was identified as hydroblasting.

For the Santiam Highway project, the purpose was also to improve safety for this four-lane corridor. The original facility featured a painted median strip, crosswalk stripes and lane markings depicting where each lane was along with a bike lane to the right of each lane. In the updated configuration a raised median was added along with turning lanes incorporated into these medians. The speed limit for this location is 35 mph. For the Highway 99 and Airport Road project the purpose was to improve safety as it was noted to be a high crash location. The previous markings featured only one stripe for the left and right-side lane markings while the update included a double stripe for those markings as well as an added turn lane and a bike lane. The speed limit for this location is 30 mph.

FIGURE 3.2: ALBANY – SANTIAM HIGHWAY REFERENCE IMAGE (TOP IMAGE IS PRIOR TO CONSTRUCTION AND BOTTOM IS AFTER CONSTRUCTION)

FIGURE 3.3: ALBANY – AIRPORT ROAD AND HIGHWAY 99 REFERENCE IMAGE (TOP IMAGE IS PRIOR TO CONSTRUCTION AND BOTTOM IS AFTER CONSTRUCTION)

3.1.2 Ashland

The project identified in Ashland had been completed in 2012 as part of a road diet for Siskiyou Boulevard, the main roadway through the city. This roadway features four lanes, two in the northbound and two in the southbound direction along with a left turning lane, a bike lane to the right of each rightmost lane in both directions and a speed limit of 25 mph. The turning lane had been added as part of the road diet project back in 2012. While the project was older than the other featured projects in this chapter it was the only one that had removed pavement markings using the grinding removal method. Since there had been no repaving in the following years the removed markings were still visible at this location it was included as part of the sites selected for this experiment. The figure depicting the Ashland project, Figure 3.4, shows only the current facility as an image prior to construction could not be found.

FIGURE 3.4: ASHLAND – SISKIYOU BOULEVARD REFERENCE IMAGE

3.1.3 Springfield

The Springfield project featured pavement marking removal on Main Street, shown in Figure 3.5, which is the primary street that spans the entire length of Springfield with a speed limit of 20 mph. While the project stated that it featured the removal of pavement markings along Main Street the markings were only removed in the downtown area. The removal method was identified as hydroblasting and was performed for the markings in the center of the roadway. While the other projects featured a complete overhaul of original marking placement, for this project the markings were updated to be more visible for drivers which meant placing them in the same lateral position as the previous markings. This meant that it was harder to see the difference between the before and after construction in the area.

FIGURE 3.5: SPRINGFIELD – MAIN STREET REFERENCE IMAGE (TOP IMAGE IS PRIOR TO CONSTRUCTION AND BOTTOM IS AFTER CONSTRUCTION)

3.1.4 Warrenton

The project identified in Warrenton was along US 101 just outside of Astoria. The project featured pavement marking removal due to some issues that had occurred with newer markings that had been placed. Figure 3.6 shows the roadway which is a two-way highway with a turning lane in the middle, along with a bike lane to the right side of each lane located near a shopping area and the bridge connecting Warrenton to Astoria with a speed limit of 45 mph. Hydroblasting marking removal was used for this project, as was the case for most projects. The before condition did not feature the current left turn lane.

FIGURE 3.6: WARRENTON - US 101 REFERENCE IMAGE (TOP IMAGE IS PRIOR TO CONSTRUCTION AND BOTTOM IS AFTER CONSTRUCTION)

4.0 METHODOLOGY

This section evaluates a variety of methods for conducting this study that were proposed and l the alternative that was recommended. It focuses on the strengths and weaknesses of each option as well as their alignment with the possible case studies that were identified throughout the course of the investigation of possibly study sites.

4.1 INSTRUMENTED PROBE VEHICLES ON ODOT HIGHWAYS

The original method that was proposed in the scope of work consisted of using ODOT projects with scheduled lane marking removal as study sites. It would also include onsite participation from local human subjects. The participant would use a vehicle provided to them through the OSU motor pool and drive through the project locations where the pavement markings had been removed with two or more alternative methods such as hydro blasting or grinding. After the experimental drive, the participant would take a survey to determine the level of comfort that they experienced when following longitudinal markings that were removed with alternative methods. This experiment would need to be conducted in various weather conditions (e.g., sunny, rainy, cloudy, and dark) to understand how road users respond to removed pavement markings under a variety of weather conditions. Measures of speed, lateral position, lane line incursions, and the visual attention of drivers would be recorded longitudinally across each treatment. This approach would require the approval of the Institutional Review Board (IRB).

4.2 INSTRUMENTED PROBE VEHICLES ON TEST TRACK

For this proposed method a closed test track would be utilized to ensure that those participating would not encounter daily traffic or construction crews during their drive. On this test track, pavement markings would be added and then removed through various alternative methods. Participants would be recruited from the OSU and PSU communities to take part in the experiment and would be provided with a vehicle from the OSU motor pool to drive on the test track. The participant would then drive through the section of the track featuring the removed pavement markings, followed by responding to an online survey to detail their level of comfort with the roadway. Measures of speed, lateral position, lane line incursions, and the visual attention of drivers would be recorded longitudinally across each treatment. This approach would require the approval of IRB (human subjects).

4.3 PARTICIPANT OBSERVATION OF HIGH-RESOLUTION VIDEO

This method would use two approaches to obtain data collection. The first would be that instead of the participant driving through the roadway in which pavement markings have been removed, a member of the research group would drive through it and capture the drive on a video camera positioned from the driver's point of view (Foster, 2015). There would be multiple videos capturing the different types of lighting and weather that would include daylight, nighttime, and rain for at least one type of lighting condition. Participants would then be recruited to watch the videos while wearing eye-tracking glasses to capture what is being looked at on the roadway when pavement markings have been removed using the various methods (Monsere, 2020). A survey would then be filled out detailing the level of comfort with following the correct pavement markings for each section with a different removal method.

4.4 OVERHEAD VIDEO STUDY

This method would involve data collection primarily through the temporary placement of video cameras or other sensors at the roadside without the need for directly recruiting participants or receiving Institutional Review Board approval. The project locations suggested by ODOT that feature at least one novel pavement marking removal method would be used. The research team would set up either a video camera or a drone alongside the road to capture the road users' movements as they encounter the removed pavement markings. Measures of speed, lateral position, and lane line incursions would be recorded with point sensors for comparison of the pre-post-performance between the different removal methods. Figure 4.1 shows the setup of the camera used for the project. The camera would be attached to a sign pole or stand at a height of approximately 9 to 10 feet to capture the vehicles driving on the roadway.

FIGURE 4.1: SETUP OF CAMERA

4.5 SUMMARY OF METHODS

This chapter reviewed several alternative experimental methods that could be implemented to complete this study. The original method described in the scope of work was found to be less desirable based on potential issues related to participant safety, IRB authorization, and the control of variables in the field. As such, several alternatives were evaluated. The second method looked at a closed test track to eliminate traffic and construction and would include a participant driving a vehicle through an area with removed pavement markings. The third method, in which surveys, videos, and eye-tracking equipment would be used, also included participants through two different methods. The final method considered roadside measurements of naturalistic traffic under different pavement marking removal types. Each method that was considered, along with its strengths and weaknesses, is shown in Table 4.1.

TABLE 4.1 STRENGTHS AND WEAKNESSES OF THE DIFFERENT METHODOLOGIES FOR DATA COLLECTION

Method	Strengths	Weaknesses
Instrumented Probe Vehicles on ODOT Highways	• Immediate reaction of participant is captured that is driving through project locations. • Direct contact between roadway and participant	• Participant exposed to traffic. • Contingent on approval from the IRB • May not be approved
Instrumented Probe Vehicles on Test Track	• Immediate reaction of participant is captured that is driving through project locations. • Direct contact between roadway and participant	• Contingent on approval from the IRB • May not be approved. • Cost
Participant Observation of High-Resolution Video	• Captures gaze of participants when encountering videos of roads with removed pavement markings • Tracks comfort level of participant immediately after viewing the videos	• Experiencing the roadways through video capture and not in field
Overhead Video Study	• Captures local road users' reactions to the roadway with removed pavement markings. • Greater number of observations	• Not as detailed in capturing road users' reactions to the removed pavement markings

4.6 RECOMMENDED RESEARCH METHODS

These last two methods in Table 4.1 (i.e., participant observation of high-resolution video and overhead video study) were found to work best for this project and were the ones that were implemented. The first is the overhead video study which captured video of vehicles at the project locations. These videos were captured from above and included the different movements that drivers make as they encounter the lane markings. The second method utilized for this project is the experimental design of participant observation of high-resolution video, which included eye-tracking and surveys, and was found by the research team to be the one that would produce the best results for data collection. It consisted of measuring the tracking of the eye movements of participants and their responses to the provided surveys in a laboratory setting.

The experimental methods identified with the greatest possible benefit were those proposing the collection of high-resolution first-person perspective videos from the field and the overhead video study. Those videos were incorporated into survey items that were viewed by participants wearing eye tracking equipment in a laboratory environment. These methods allowed for data to be collected efficiently without the need for participants to be placed at study sites in the field that would feature traffic and construction.

5.0 FIELD DATA COLLECTION AND ANALYSIS

The objective of the field data collection using video was to observe and document driver behavior at the transition zone of the marking removals to establish the distribution of vehicle path trajectories. This method involved data collection primarily through the temporary placement of video cameras at the roadside without the need for directly recruiting participants or receiving Institutional Review Board approval. The project locations suggested by ODOT that feature at least one novel pavement marking removal method were selected. The research team set up a video camera alongside the road to capture the road users' movements as they encounter the removed pavement markings under different weather and lighting conditions. Measures of lane line incursions were recorded for comparison between the different removal methods.

5.1 SITE DATA SUMMARY

The data collected and analyzed at the five locations for field data collection, are listed in Table 5.1, followed by a description of each site.

TABLE 5.1 VIDEO DATA COLLECTION SITES

Location	Type of Marking Removal	Dates of Video Data Collection	Hours Analyzed	Number of Observations (Vehicles) Recorded
US 20, Albany	Hydro blasting	11/7/2022-11/9/2022	6.5	3,166
US 99, Albany	Hydro blasting	11/22/22	6.0	3,086
OR 126B, Springfield	Hydro blasting	10/19/22-10/20/22	6.0	3,845
US 101, Warrenton	Hydro blasting	10/24/22-10/25/22	17.0	3,131
OR 99, Ashland	Grinding	11/1/22-11/2/22	5.0	5,042

5.1.1 US 20, Albany

This study site is located on US 20 between SE Geary St and Waverly Drive SE in Albany, OR. Along this section, US 20 has two travel lanes in each direction. Video data was collected for 48 hours at this site between 11/7/2022 and 11/9/2022. The method of pavement marking removal used at this location was hydro blasting. Over six and half hours of video was watched at this location across different weather and lighting conditions encompassing dawn, day, and night, as well as wet and dry conditions. Figure 5.1 shows the pavement markings removal at this location.

FIGURE 5.1: PAVEMENT MARKING REMOVAL ON US 20, ALBANY, OR

5.1.2 OR 99E, Albany

This study site is located on 99E at Airport Road in Albany, OR. Along this section, OR 99E has one travel lane in each direction. Video data was collected for 10 hours at this site on 11/22/22. The method of pavement marking removal used at this location was hydro blasting. Approximately six hours of video was watched at this location across different weather and lighting conditions encompassing day, and night, as well as wet and rainy conditions. Figure 5.2 shows the pavement markings removal at this location.

FIGURE 5.2: PAVEMENT MARKING REMOVAL ON OR 99 E, ALBANY, OR

5.1.3 OR 126B, Springfield

This study site is located on OR 126B at Main Street in Springfield, OR. Along this section, OR 126B is one-way and has two travel lanes along with parking. Video data was collected for 48 hours at this site between 10/19/22 and 10/20/22. The method of pavement marking removal used at this location was hydro blasting. Approximately 6 hours of video was watched at this location across different weather and lighting conditions encompassing dawn, day, dusk, and night, as well as dry and foggy conditions. Figure 5.3 shows the pavement markings removal at this location.

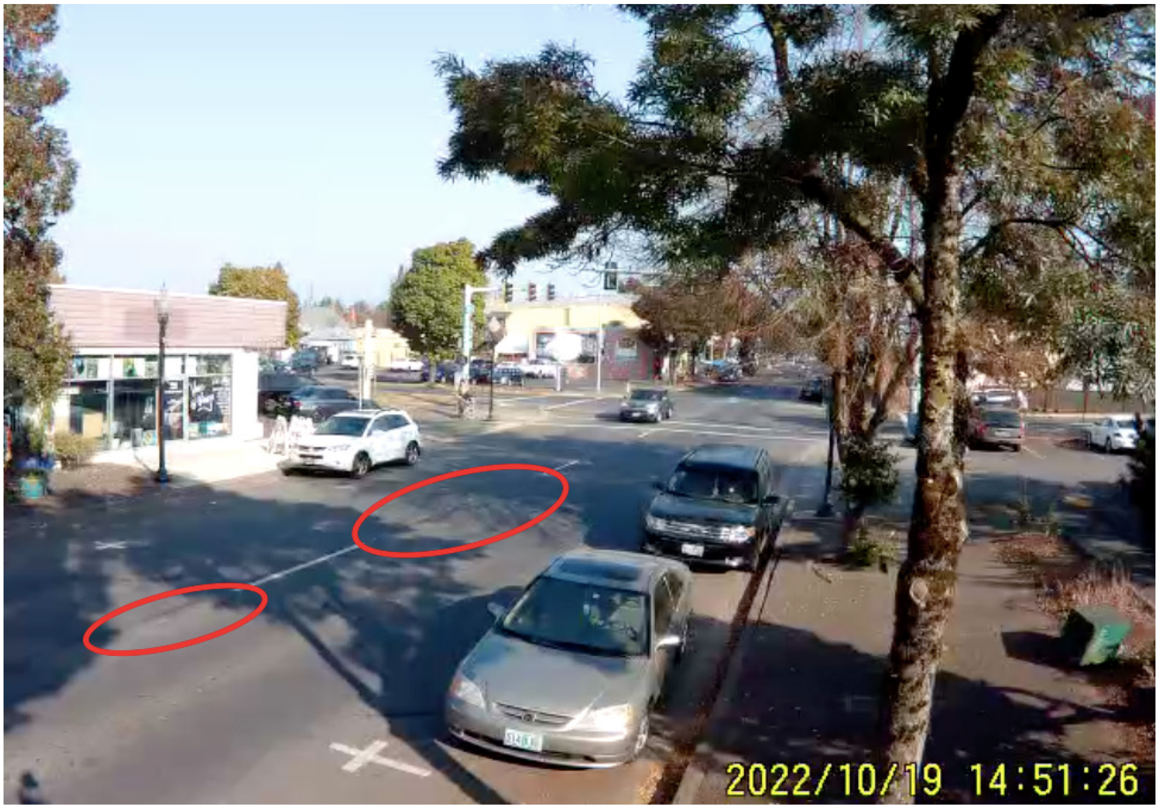


FIGURE 5.3: PAVEMENT MARKING REMOVAL ON US 126B, SPRINGFIELD, OR

5.1.4 US 101, Warrenton

This study site is located on US 101 between New Bay to Neptune in Warrenton, OR. Along this section, US 101 has two travel lanes in one direction and one travel lane in the other direction as shown in Figure 5.4. Video data was collected for 48 hours at this site between 10/24/22 and 10/25/22. The method of pavement marking removal used at this location was hydro blasting. Approximately 17 hours of video was watched at this location across different weather and lighting conditions encompassing dawn, day, dusk, and night, as well as wet and dry conditions.

FIGURE 5.4: PAVEMENT MARKING REMOVAL ON US 101, WARRENTON, OR

5.1.5 OR 99, Ashland

This study site is located on OR 99 on Siskiyou Blvd. northbound in Ashland, OR. Along this section, OR 99 has one travel lane in each direction and center turn lane as shown in Figure 5.5. Video data was collected for 48 hours at this site between 11/1/22 and 11/2/22. The method of pavement marking removal used at this location was grinding. Approximately 5 hours of video was watched at this location across different weather and lighting conditions encompassing dawn, day, dusk, and night, as well as rainy, wet, and dry conditions. The temporary road work sign seen in the figure was not placed by the research team, instead it was part of the construction effort at the site location during the time of video data collection.

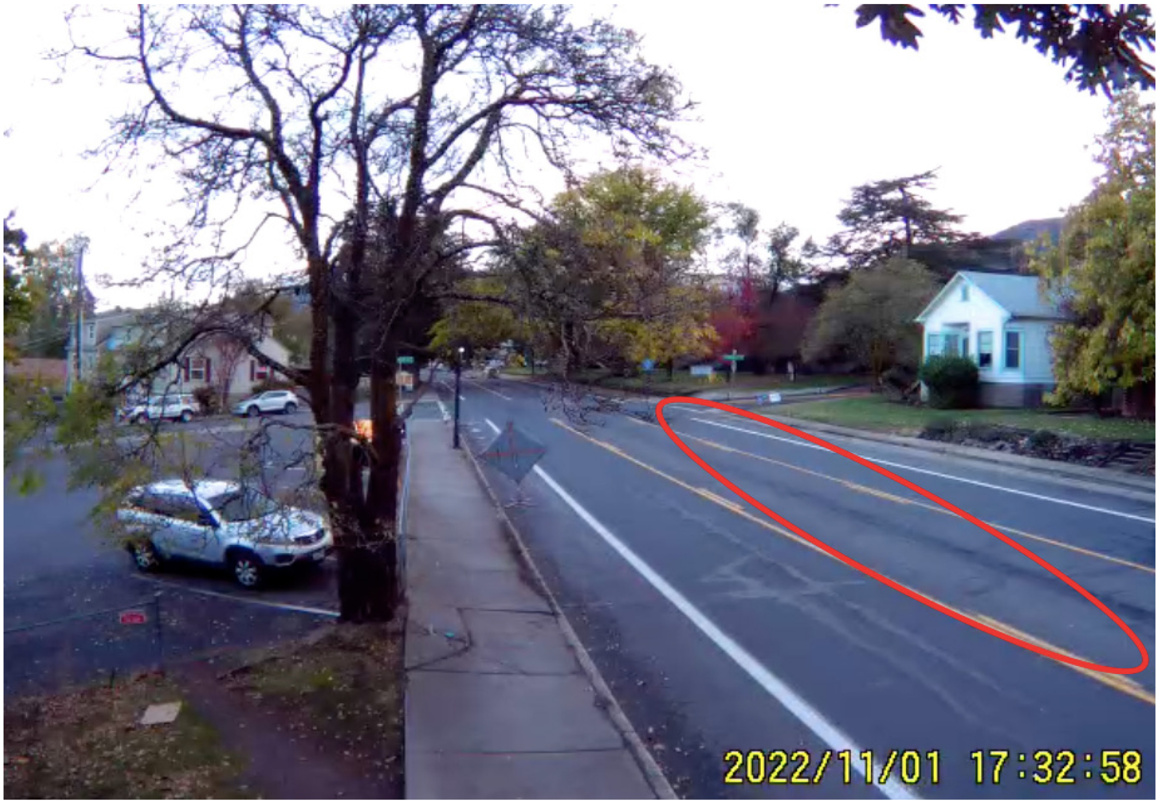


FIGURE 5.5: PAVEMENT MARKING REMOVAL ON OR 99, ASHLAND, OR

5.2 VIDEO DATA TRANSCRIPTION

The collected video was watched by researchers and several performance measures were extracted based on the Society of Automotive Engineers (SAE, 2000). During the selected observation periods that encompassed the varying weather and lighting conditions, each vehicle that traversed the section of the roadway under observation was recorded along with the date, timestamp, lighting condition, and weather condition. The researchers also recorded if each vehicle that was observed departed the lane they were traveling in, type, duration, and direction of the lane departure if it occurred. Eleven types of lane departure were considered, and these are listed below. Researchers also recorded notes regarding the lane departure description.

- A – The widest part of the vehicle touches the middle of the boundary of the lane that the vehicle is in. The widest part includes the side mirror of the vehicle. The boundary is the lane lines on either side of the lane that the vehicle is in.

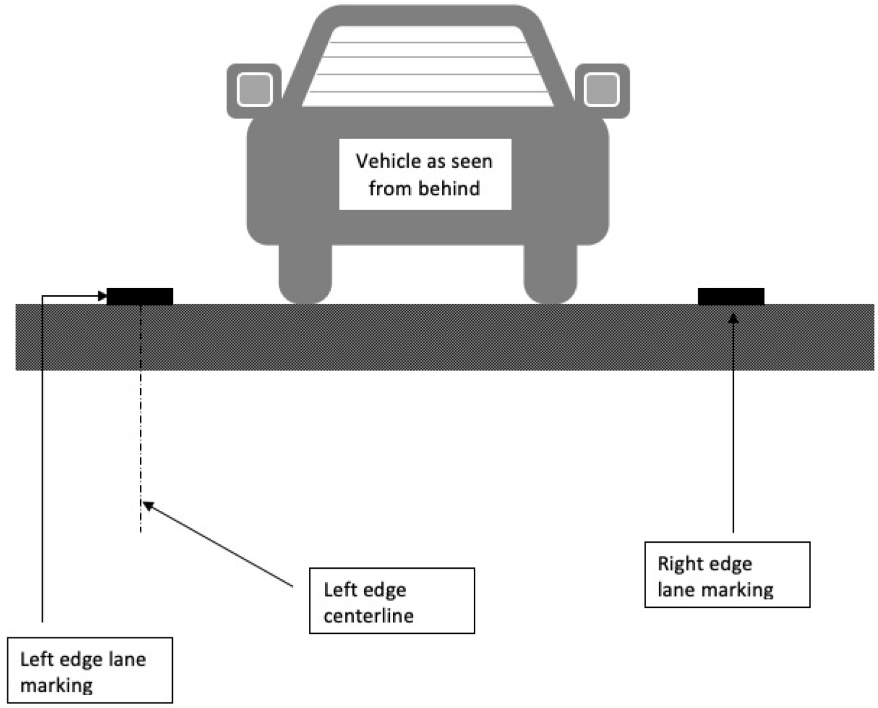
- B – The front tire of the vehicle touches the inside edge of a lane boundary. This lane boundary is the part of the lane line closest to the vehicle.

- C – The front tire touches the outside edge of the lane boundary. This lane boundary is the part of the lane line that is farthest from the vehicle.

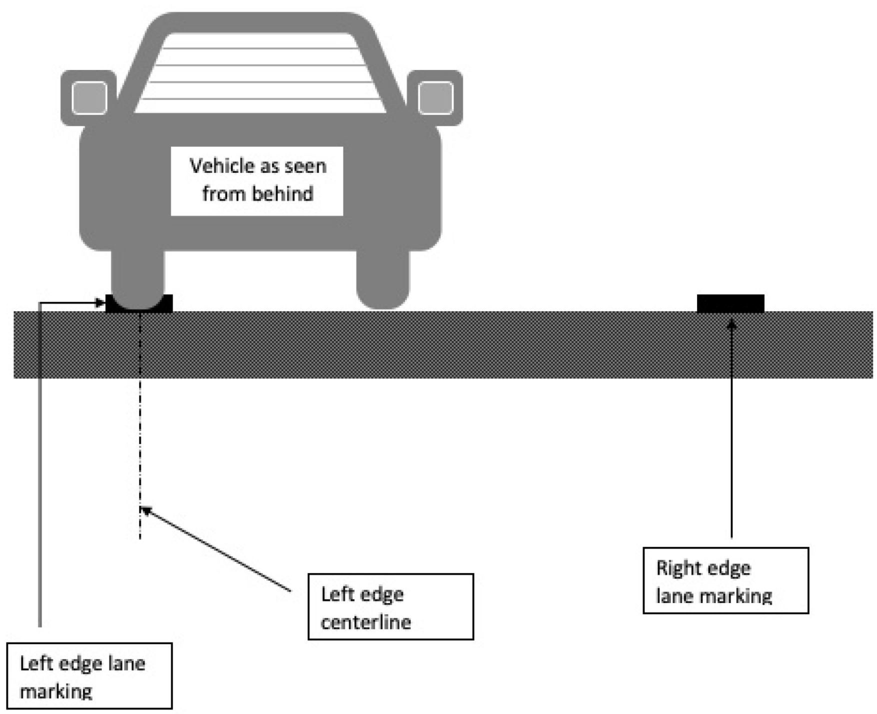
- D – The front tire of the vehicle goes beyond the outside edge of the lane boundary.

- E – Any tire of the vehicle touches the inside edge of the lane boundary.
- F – Any tire of the vehicle touches the outside edge of the lane boundary.
- G – Any tire goes beyond the outside edge of the lane boundary.
- H – The bounding box of the body of the vehicle of the vehicle touches the inside edge of the lane boundary.
- I – The bounding box including the mirror of the vehicle touches the inside edge of the boundary lane.
- J – The bounding box of the vehicle touches the outside edge of a lane boundary.
- K – The bounding box including the mirror of the vehicle touches the outside edge of the lane boundary.

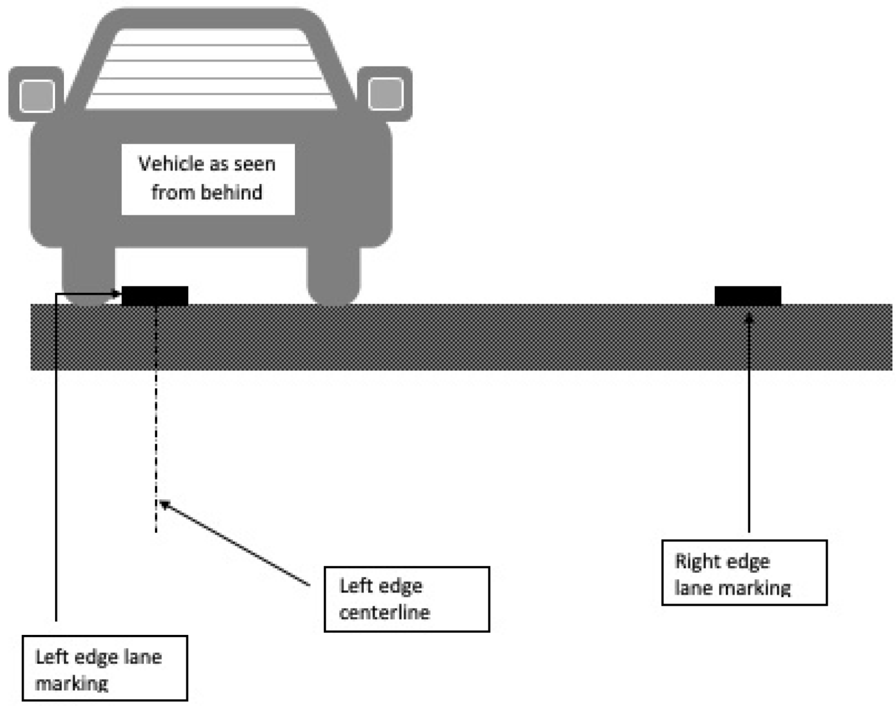
For most types, A – G tires on the vehicle will be inside the lane that the vehicle is driving in but does feature types in which the tires go just beyond the lane marking. If the vehicle that is departing the lane comes to a full stop before continuing to the lane of travel, then it is also included in this section. For H – K this typically includes vehicles that are large or are a vehicle-trailer combination that needs more space to maneuver in when making turns. The bounding box looks at the entirety of the large or combination vehicle and if it needs a wider radius and is split into the body and the body plus the mirror. If the vehicle needs a wider radius to make a safe turn and goes over the pavement markings, then this is considered acceptable and not a real departure from the roadway markings. Figure 5.6 provides reference on what the vehicle lane departure can look like in different scenarios. These scenarios show the vehicle not experiencing any form of lane departure, driving on top of the lane marking, and going beyond the lane marking.



a) Vehicle in center of driving lane



b) Vehicle on top of lane marking



c) Vehicle crossing over lane marking

FIGURE 5.6: REFERENCE FOR LANE DEPARTURE MOVEMENTS

5.3 ANALYSIS RESULTS

A descriptive analysis was conducted by observing driver behavior during the different field conditions captured in the video data. The following sections present the results of the descriptive analysis.

5.3.1 Lane Departure Rate

Lane departure rates at each site were calculated by dividing the number of observed departures by the total number of observed vehicles during each time period. Table 5.2 and Figure 5.7 show the departure rates by lighting condition across the five sites. Lane departures occurred at all lighting conditions and the highest departure rates were observed at the Ashland site. Departure rates vary by light conditions across all sites. At two sites (Ashland, Springfield), nighttime departure rates were higher than daylight rates.

TABLE 5.2 LANE DEPARTURE BY LIGHTING CONDITION

	Lighting Condition	Observations	Departures	Departure Rate
Albany (OR99)	Daylight	1688	56	0.033
	Dusk	746	24	0.032
	Nighttime	652	18	0.028
Albany (US20)	Dawn	487	55	0.113
	Daylight	2155	171	0.079
	Nighttime	524	36	0.069
Ashland	Dawn	423	67	0.158
	Daylight	4083	574	0.141
	Dusk	148	29	0.196
	Nighttime	388	104	0.268
Astoria (US101E)	Dawn	180	16	0.089
	Daylight	1780	35	0.020
	Dusk	135	8	0.059
	Nighttime	1035	43	0.042
Springfield	Dawn	287	13	0.045
	Daylight	2605	284	0.109
	Dusk	542	78	0.144
	Nighttime	411	54	0.131

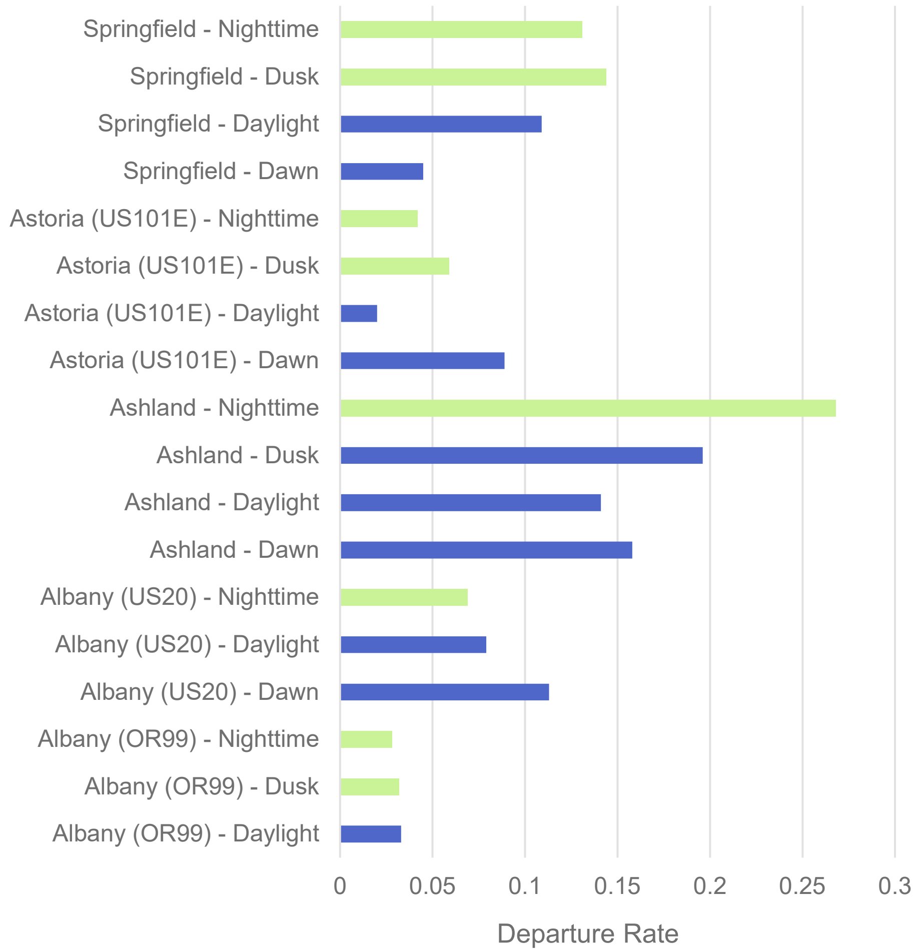


FIGURE 5.7: DEPARTURE RATE BY LIGHT CONDITION

Table 5.3 and Figure 5.8 show the departure rates by weather condition. Departure rates varied by weather condition across the sites and lane departures were observed at all weather conditions. No discernible trend was observed in the departure rates based on weather condition.

TABLE 5.1 LANE DEPARTURE RATE BY WEATHER CONDITION

	Weather Condition	Observations	Departures	Departure Rate
Albany (OR99)	Rainy	385	14	0.036
	Wet	2701	84	0.031
Albany (US20)	Dry	2855	233	0.082
	Wet	311	29	0.093
Ashland	Dry	892	178	0.200
	Hail	87	18	0.207
	Rainy	793	77	0.097
	Wet	3270	501	0.153
Astoria (US101E)	Dry	804	21	0.026
	Wet	2326	81	0.035
Springfield	Dry	2397	349	0.146
	Foggy	1448	80	0.055

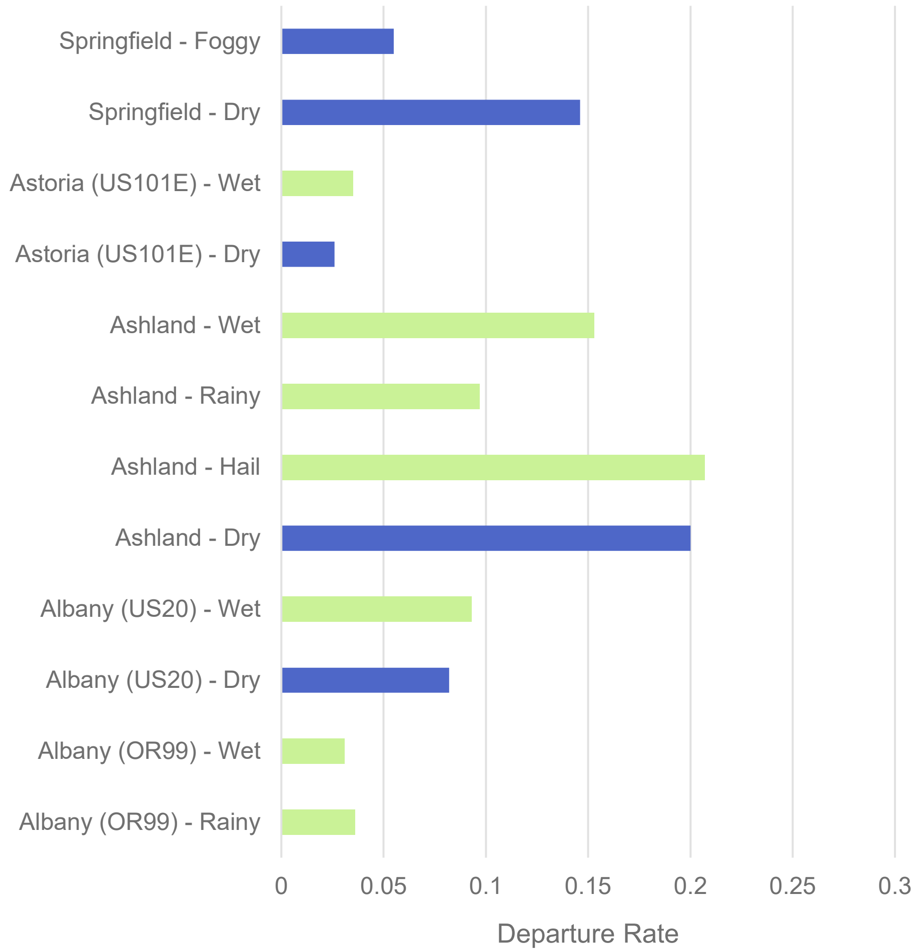


Figure 5.8: Departure Rate by Weather Condition

5.3.2 Lane Departure by Percentage

Table 5.4 shows the distribution of the lane departure events observed across all five sites. Overall, across the five sites, 18,270 vehicles and 1,664 lane departures (9.1%) were observed during the observation periods. Among the sites, the highest proportion of lane departures were observed at OR 99 in Ashland (15.3%), OR 126B in Springfield (11.2%), US 20 in Albany (8.2%), US 101 in Warrenton (3.3%), and OR 99E in Albany (3.2%). Overall, the highest proportion of lane departures were type A (32.7%), followed by type G (27.2%), type B (13.5%) and type E (12.6%). The proportions of the types of lane departures at each site varied.

Two sites from the study, OR 99 in Ashland and OR 126B in Springfield, stood out with lane departure rates exceeding ten percent of the total observed vehicles within the study area. Upon analyzing site characteristics, both locations displayed obstacles on the shoulder and a lack of oncoming vehicles on the opposite side of the removed lane marking during the data collection period.

In Ashland, traffic flow comprises two lanes traveling in opposing directions, separated by a turn lane. Notably, a temporary road work warning sign (e.g., W20-1) is positioned within the bike lane of the northbound (oncoming) traffic lane, as illustrated in Figure 5.5. The presence of this sign, combined with the availability of a turn lane as a potential refuge, likely contributed to the observed higher frequency of lane departures at this site. The lane markings that were removed at the Ashland site are situated in the center turn lane. Analysis of data collection showed that vehicles most likely to interact with the removed lane markings were those categorized as type G. Out of a total of 5,042 observations, 171 (3.4%) received this code. Among them, 26 had comments in the review notes indicating that the vehicle remained to one side of the turn lane, suggesting an attempt to avoid the removed lane marking. Furthermore, three entries coded as G had comments indicating that the vehicle entered the turn lane and then corrected its movement by swerving back into the traffic lane, possibly due to being confused by the residual marking.

Similarly, in Springfield, both lanes of one-way traffic were accompanied by on-street parking within the shoulder area. Vehicles passing through this location frequently made lateral movements to circumvent parked vehicles, especially those engaged in arrival or departure activities. This was facilitated by the fact that both lanes were traveling in the same direction.

In contrast, the site with the lowest recorded lane departure occurrences, OR 99E in Albany, featured clear shoulders and oncoming traffic on the opposite side of the absent lane marker. Consequently, the center of the lane became the preferable path for vehicles navigating through the study area. As this location differs from others, and not having a lateral buffer between opposing traffic, it is hypothesized that driver response is affected by the presence of an adjacent opposing lane which could cause drivers to be more cautious.

TABLE 5.4 LANE DEPARTURE DISTRIBUTION

Location		US 20, Albany		OR 99E, Albany		OR 126B, Springfield		US 101, Warrenton		OR 99, Ashland		Total	
Vehicles		3,166		3,086		3,845		3,131		5,042		18,270	
% Lane Departures		8.2%		3.2%		11.2%		3.3%		15.3%		-	
Type of Lane Departure	A	6	2.3%	17	17.3%	242	56.4%	40	39.2%	239	30.9%	544	32.7%
	B	12	4.6%	16	16.3%	39	9.1%	28	27.5%	129	16.7%	224	13.5%
	C	0	0.0%	0	0.0%	0	0.0%	9	8.8%	32	4.1%	41	2.5%
	D	0	0.0%	5	5.1%	0	0.0%	8	7.8%	29	3.7%	42	2.5%
	E	24	9.2%	1	1.0%	31	7.2%	5	4.9%	148	19.1%	209	12.6%
	F	73	28.0%	3	3.1%	3	0.7%	1	1.0%	26	3.4%	106	6.4%
	G	115	44.1%	53	54.1%	114	26.6%	0	0.0%	171	22.1%	453	27.2%
	H	6	2.3%	0	0.0%	0	0.0%	1	1.0%	0	0.0%	7	0.4%
	I	5	1.9%	0	0.0%	0	0.0%	10	9.8%	0	0.0%	15	0.9%
	J	17	6.5%	0	0.0%	0	0.0%	0	0.0%	0	0.0%	17	1.0%
	K	3	1.1%	3	3.1%	0	0.0%	0	0.0%	0	0.0%	6	0.4%
		261	100.0%	98	100.0%	429	100.0%	102	100.0%	774	100.0%	1664	100.0%

Table 5.5 a) – e) shows the lane departure distribution by time of day (i.e., dawn, daytime, dusk, nighttime). Figure 5.9 a) – e) shows the proportions of lane departures at each site across the different time periods. Across all sites, proportions of lane departure type A, where the widest part of the vehicle goes over the lane boundary line, occurred mainly during the daytime. Proportions of lane departure types H-K, which represented the larger vehicles touching the lane boundary also occurred mainly during the daytime except at US 101 at Warrenton.

Table 5.5 Lane Departure Distribution by Time of Day

Location		**US 20, Albany**									
TOD		**Dawn**		**Daytime**		**Dusk**	**Nighttime**		**Total**	
Type of Lane Departure	A	1	1.8%	5	2.9%	-	0	0.0%	6	2.3%
	B	7	12.7%	5	2.9%	-	0	0.0%	12	4.6%
	C	0	0.0%	0	0.0%	-	0	0.0%	0	0.0%
	D	0	0.0%	0	0.0%	-	0	0.0%	0	0.0%
	E	10	18.2%	13	7.6%	-	1	2.8%	24	9.2%
	F	16	29.1%	43	25.3%	-	14	38.9%	73	28.0%
	G	9	16.4%	85	50.0%	-	21	58.3%	115	44.1%
	H	1	1.8%	5	2.9%	-	0	0.0%	6	2.3%
	I	1	1.8%	4	2.4%	-	0	0.0%	5	1.9%
	J	8	14.5%	9	5.3%	-	0	0.0%	17	6.5%
	K	2	3.6%	1	0.6%	-	0	0.0%	3	1.1%
	Total	55	100.0 %	170	100.0 %	-	36	100.0 %	261	100.0 %

a) US 20, Albany

Location		**OR 99E, Albany**								
TOD		**Dawn**	**Daytime**		**Dusk**		**Nighttime**		**Total**	
Type of Lane Departure	A	-	16	28.6%	1	4.2%	0	0.0%	17	17.3%
	B	-	7	12.5%	4	16.7%	5	27.8%	16	16.3%
	C	-	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	D	-	5	8.9%	0	0.0%	0	0.0%	5	5.1%
	E	-	1	1.8%	0	0.0%	0	0.0%	1	1.0%
	F	-	2	3.6%	1	4.2%	0	0.0%	3	3.1%
	G	-	22	39.3%	18	75.0%	13	72.2%	53	54.1%
	H	-	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	I	-	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	J	-	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	K	-	3	5.4%	0	0.0%	0	0.0%	3	3.1%
	Total		56	100.0 %	24	100.0 %	18	100.0 %	98	100.0 %

b) OR 99E, Albany

Location		OR 126B, Springfield									
TOD		Dawn		Daytime		Dusk		Nighttime		Total	
Type of Lane Departure	A	6	46.2%	168	59.2%	42	53.8%	26	48.1%	242	56.4%
	B	1	7.7%	22	7.7%	8	10.3%	8	14.8%	39	9.1%
	C	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	D	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	E	1	7.7%	17	6.0%	9	11.5%	4	7.4%	31	7.2%
	F	0	0.0%	2	0.7%	0	0.0%	1	1.9%	3	0.7%
	G	5	38.5%	75	26.4%	19	24.4%	15	27.8%	114	26.6%
	H	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	I	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	J	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	K	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	Total	13	100.0%	284	100.0%	78	100.0%	54	100.0%	429	100.0%

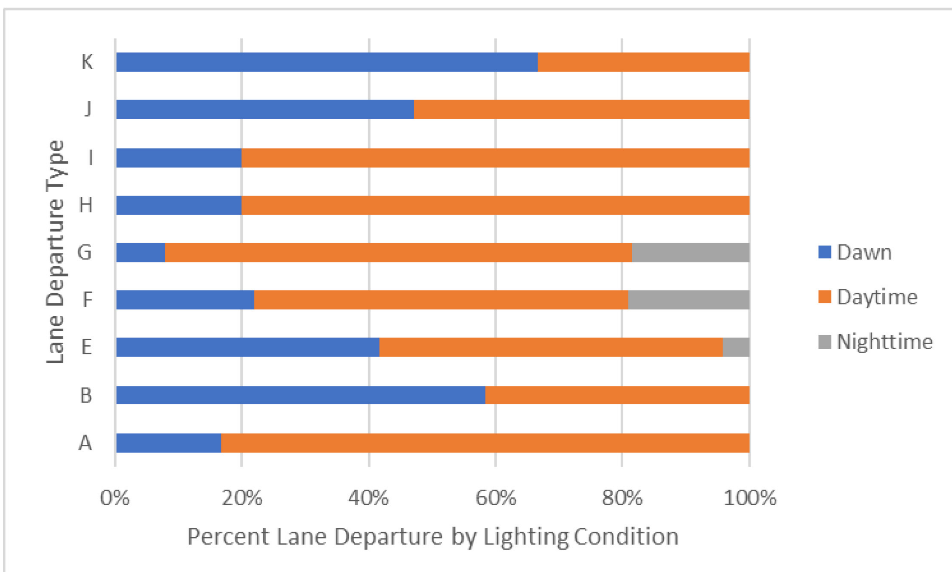
c) OR 126B, Springfield

Location		US 101, Warrenton									
TOD		Dawn		Daytime		Dusk		Nighttime		Total	
Type of Lane Departure	A	7	43.8%	12	34.3%	1	12.5%	20	46.5%	40	39.2%
	B	3	18.8%	12	34.3%	3	37.5%	10	23.3%	28	27.5%
	C	1	6.3%	4	11.4%	1	12.5%	3	7.0%	9	8.8%
	D	2	12.5%	3	8.6%	2	25.0%	1	2.3%	8	7.8%
	E	2	12.5%	2	5.7%	0	0.0%	1	2.3%	5	4.9%
	F	0	0.0%	0	0.0%	1	12.5%	0	0.0%	1	1.0%
	G	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	H	0	0.0%	0	0.0%	0	0.0%	1	2.3%	1	1.0%
	I	1	6.3%	2	5.7%	0	0.0%	7	16.3%	10	9.8%
	J	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	K	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	Total	16	100.0%	35	100.0%	8	100.0%	43	100.0%	102	100.0%

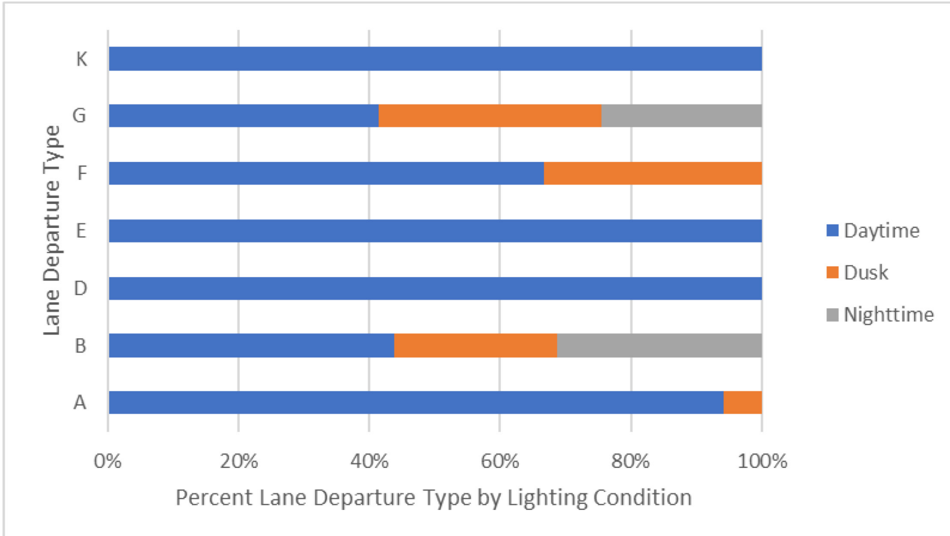
d) US 101, Warrenton

Location		OR 99, Ashland									
TOD		Dawn		Daytime		Dusk		Nighttime		Total	
Type of Lane Departure	A	10	14.9%	171	29.8%	10	34.5%	48	46.2%	239	30.9%
	B	7	10.4%	96	16.7%	7	24.1%	19	18.3%	129	16.7%
	C	2	3.0%	26	4.5%	0	0.0%	4	3.8%	32	4.1%
	D	1	1.5%	24	4.2%	0	0.0%	4	3.8%	29	3.7%
	E	26	38.8%	94	16.4%	5	17.2%	23	22.1%	148	19.1%
	F	2	3.0%	21	3.7%	2	6.9%	1	1.0%	26	3.4%
	G	19	28.4%	142	24.7%	5	17.2%	5	4.8%	171	22.1%
	H	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	I	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	J	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	K	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
	Total	67	100.0 %	574	100.0 %	29	100.0 %	104	100.0 %	774	100.0 %

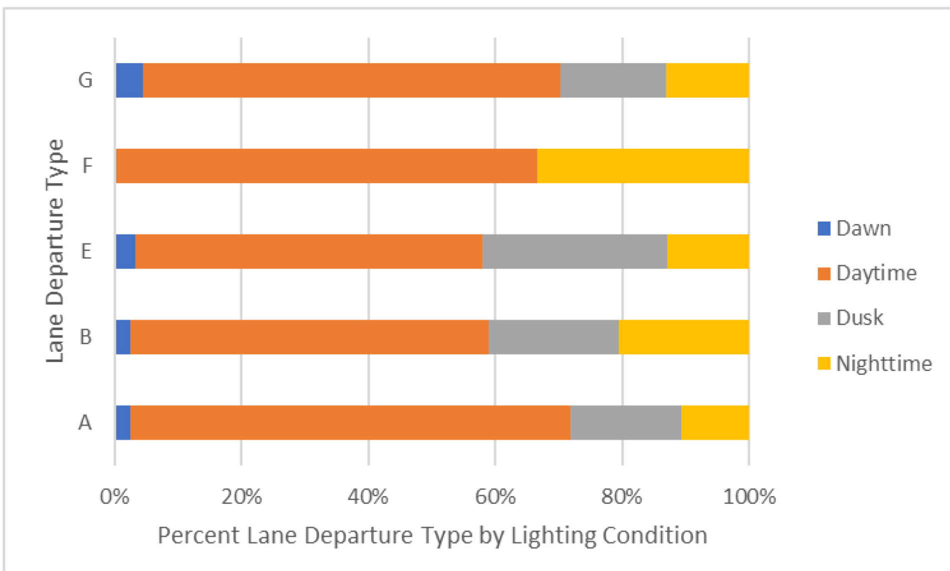
e) OR 99, Ashland



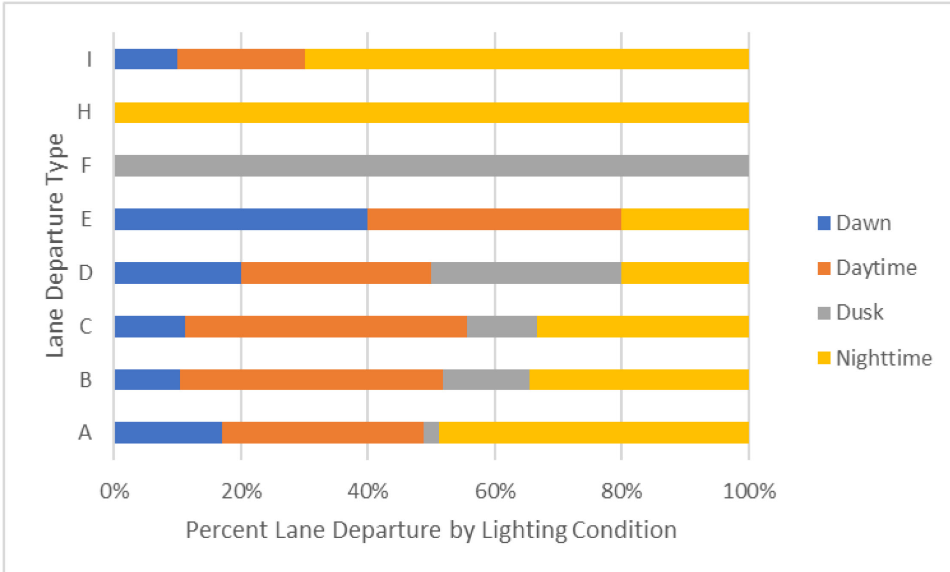
a) US 20, Albany



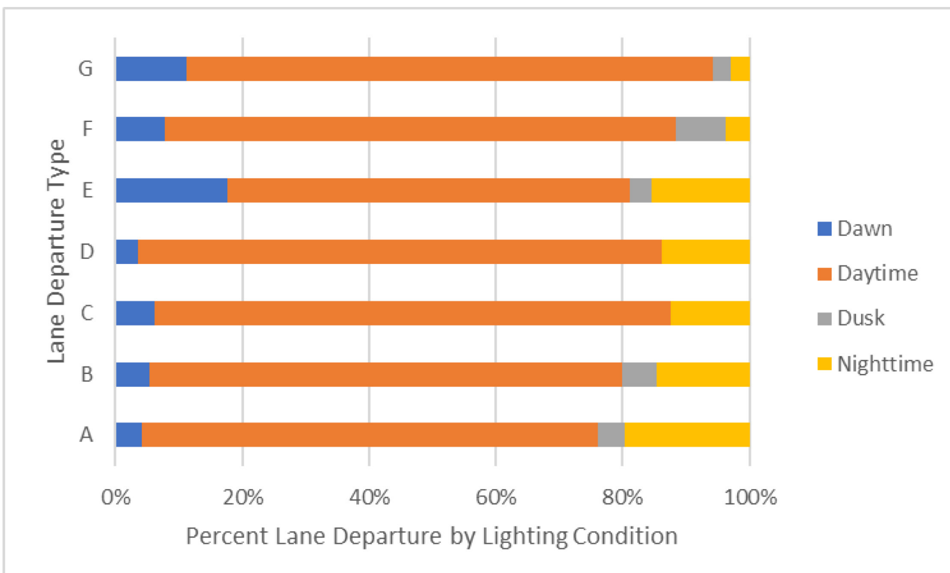
b) OR 99, Albany



c) US 126B, Springfield

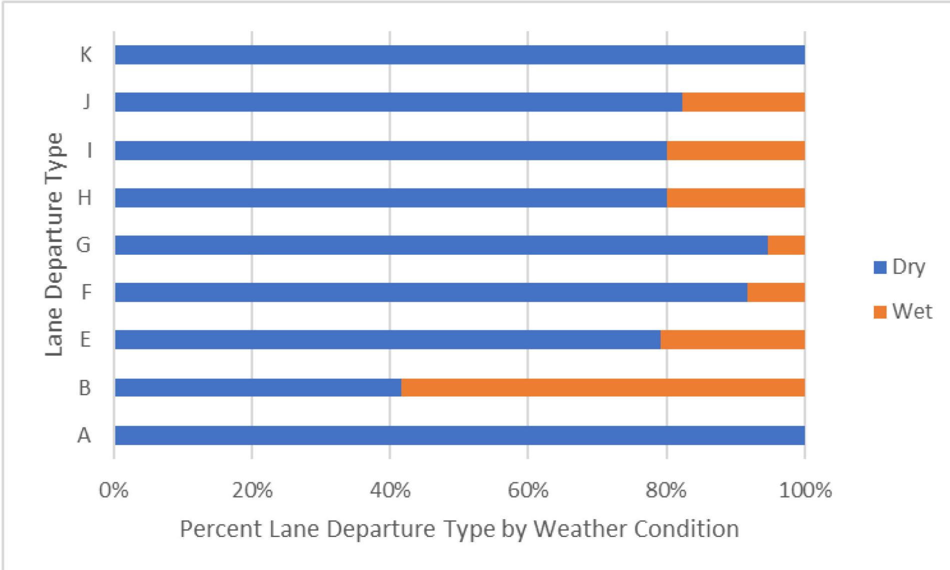


d) US 101, Warrenton

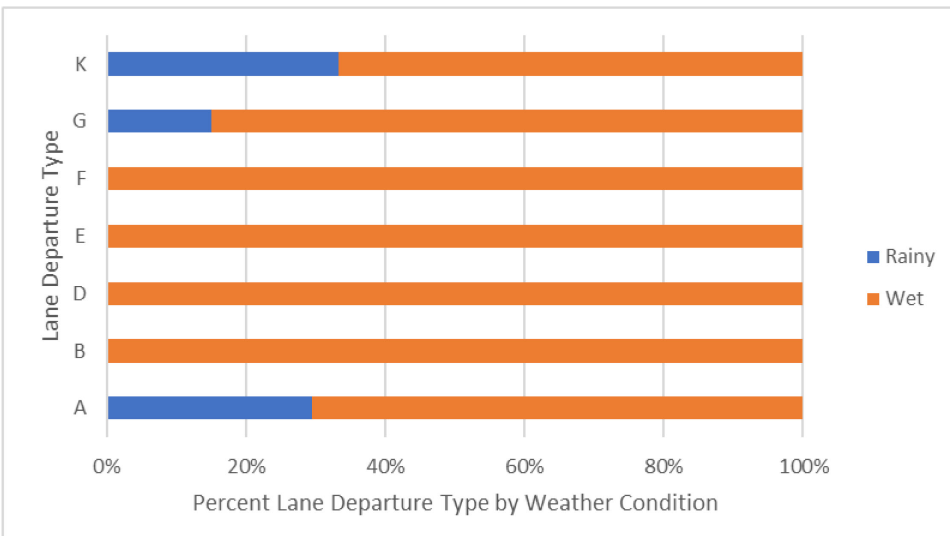


e) OR 99, Ashland

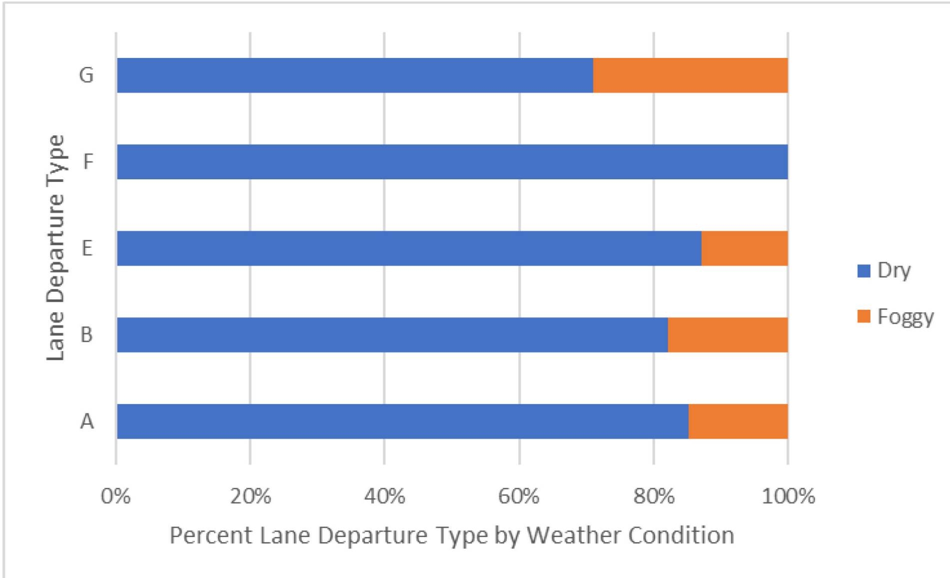
FIGURE 5.9: PROPORTION OF LANE DEPARTURE TYPE BY LIGHTING CONDITION



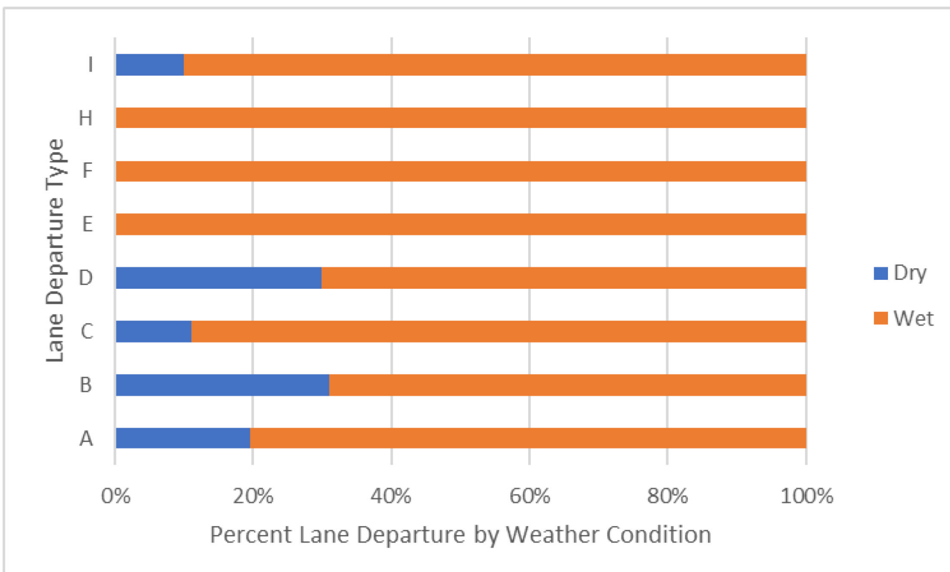
a) US 20, Albany



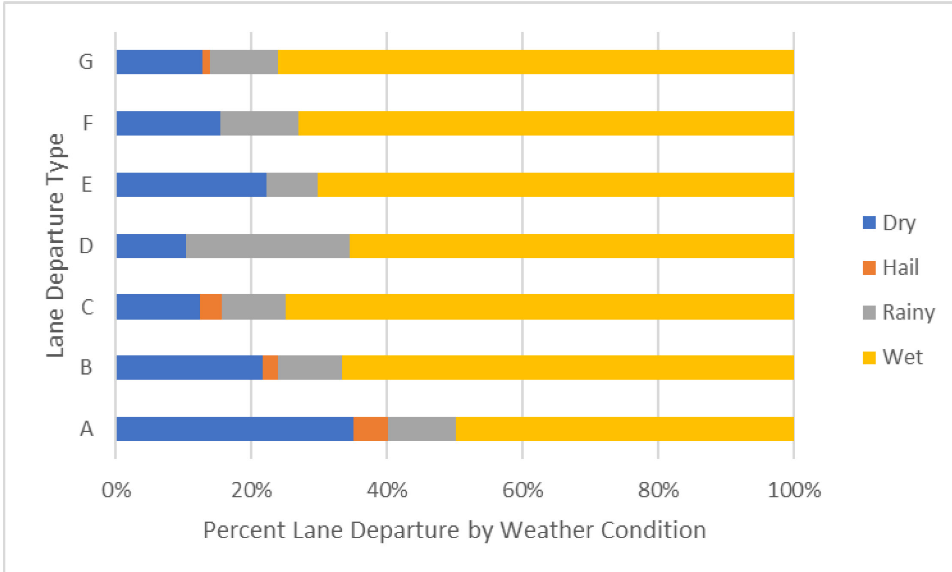
b) OR 99, Albany



c) US 126B, Springfield



d) US 101, Warrenton



e) OR 99, Ashland

FIGURE 5.10: PROPORTION OF LANE DEPARTURE TYPE BY WEATHER CONDITION

Figure 5.10 shows the proportions of lane departure type at each site by weather condition. At three of the five sites (OR 99, Albany; US 101, Warrenton; OR 99, Ashland) the proportions of lane departures were higher when it was wet.

5.3.3 Lane Departure Duration

Table 5.6 shows the statistics for lane departure duration at each site. Overall, the average lane departure durations were between 2.0 and 3.3 seconds. The minimum durations across all sites were 1 second, while the maximum ranged between 5 and 34 seconds. At the OR 99 in Ashland site, higher durations of lane departures were observed due to the vehicles shifting left through the study area. At the US 101 site in Warrenton, a high duration of lane departure was observed because the vehicle was stopped in that position due to the presence of traffic.

TABLE 5.6 LANE DEPARTURE DISTRIBUTION BY TIME OF DAY

	US 20 Albany			OR 99 Albany			US 126B Springfield			US 101 Warrenton			OR 99 Ashland		
	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max
A	1.8	1	3	3.8	1	7	1.9	1	5	2.0	1	4	3.5	1	7
B	1.8	1	4	1.8	1	4	1.6	1	4	3.4	1	34	3.3	1	15
C	-	-	-	-	-	-	-	-	-	2.3	2	4	4.0	1	17
D	-	-	-	3.2	2	6	-	-	-	4.2	2	16	3.7	2	6
E	1.6	1	3	3.0	3	3	2.6	1	6	2.2	2	3	3.6	1	7
F	2.4	1	5	2.0	1	3	3.0	1	6	3.0	3	3	3.7	2	8
G	1.6	1	5	3.1	1	6	2.5	1	7	-	-	-	2.6	1	8
H	3.5	3	5	-	-	-	-	-	-	2.5	2	3	-	-	-
I	2.4	1	4	-	-	-	-	-	-	2.8	1	6	-	-	-
J	2.4	1	4	-	-	-	-	-	-	-	-	-	-	-	-
K	2.0	2	2	3.7	3	4	-	-	-	-	-	-	-	-	-
Total	2.0	1	5	3.0	1	7	2.1	1	7	2.7	1	34	3.3	1	17

5.4 STATISTICAL MODELING

The research team additionally computed the departure rate for each site, taking into consideration various conditions. This rate was calculated by dividing the number of vehicles that departed over the total number of observations. To better understand the relationship between the independent variables (weather and lighting conditions as well as the removal method) and the dependent variable (departure rate in percentage), a linear mixed effects model (LMM) was utilized to analyze the data. LMM was used because of (1) its ability to manage errors generated from repeated sites variable as the departure rate was calculated based on the independent variables within each site, (2) its ability to manage fixed or random effects, (3) its consideration of categorical and continuous variables, and (4) its low probability of Type I error occurrence (Jashami et al., 2019). Thus, LMM was chosen to model and analyze the data using the following formula:

$$\boldsymbol{y_{ij} = \beta_0 + \beta_1 X_{ij} + b_{i0} + \varepsilon_{ij},\ b_{i0} \sim iidN\left(0, \sigma_0^2\right),\ \varepsilon_{ij} \sim iidN(0, \sigma_\varepsilon^2).} \tag{5-1}$$

Where β_0 is the intercept and β_1 is the slope (for fixed effect). b_{i0} is the random intercept of the i^{th} site which follows a mean normal distribution with a variance of σ_{b0}^2. ε_{ij} is the error term. Therefore, there is an assumption that b_{i0} and ε_{ij} are independent.

This model was developed to consider the independent variables of weather and lighting conditions as well as the removal method. These variables were included in the model as fixed effects, while the locations were included as random effects. Pearson's correlation coefficient was used to determine if any variables correlate to each other. Additionally, custom post hoc contrasts were performed using Fisher's Least Significant Difference (LSD) to do multiple comparisons. All statistical analyses were conducted at a 95% confidence level, and the Restricted Maximum Likelihood estimates were used to develop this model (Jashami et al., 2019). All analysis was conducted using R software.

The outcomes of the LMM analysis are presented in Table 5.7. Notably, lighting conditions (p = 0.024), weather conditions (p = 0.005), and the removal method (p = 0.033) all showed statistically significant associations with the departure rate. Specifically, for the lighting conditions, it was observed that during daytime hours, the departure rate was lower by 3.5% compared to other lighting conditions (i.e., night, dusk, dawn), all other variables being held constant. Regarding weather conditions, it was found that when the pavement was dry, the departure rate was approximately 5% higher in comparison to other weather conditions. Moreover, an interesting finding was revealed concerning the removal method. Locations where hydroblasting was employed yielded the lowest departure rate, at 11%, compared to those where the grinding method was utilized while maintaining all other variables constant. Though interaction terms were tested within the model, none showed statistical significance. Nevertheless, to visually depict these findings, Figure 5.11 shows the two-way interactions between the dependent and independent variables as well as their associated levels.

TABLE 5.7 RESULTS OF ESTIMATED LINEAR MIXED MODEL OF DEPARTURE RATE (%)

Variable	Levels	Estimate	S.E.	P-Value
Site Location random effect (Var)	-	2.150	3.894	0.290
Constant	-	17.767	2.117	**0.005**
Lighting Condition	Daytime	-3.435	1.415	**0.024**
	Otherwise	*Baseline*		
Weather Condition	Dry	4.784	1.542	**0.005**
	Otherwise	*Baseline*		
Removal Method	Hydroblasting	-11.261	2.224	**0.033**
	Grinding	*Baseline*		
Summary Statistics				
R-Squared	77.16%			
2Log Likelihood	139.42			
AIC	143.99			

Bold: statistically significant at α = 0.05

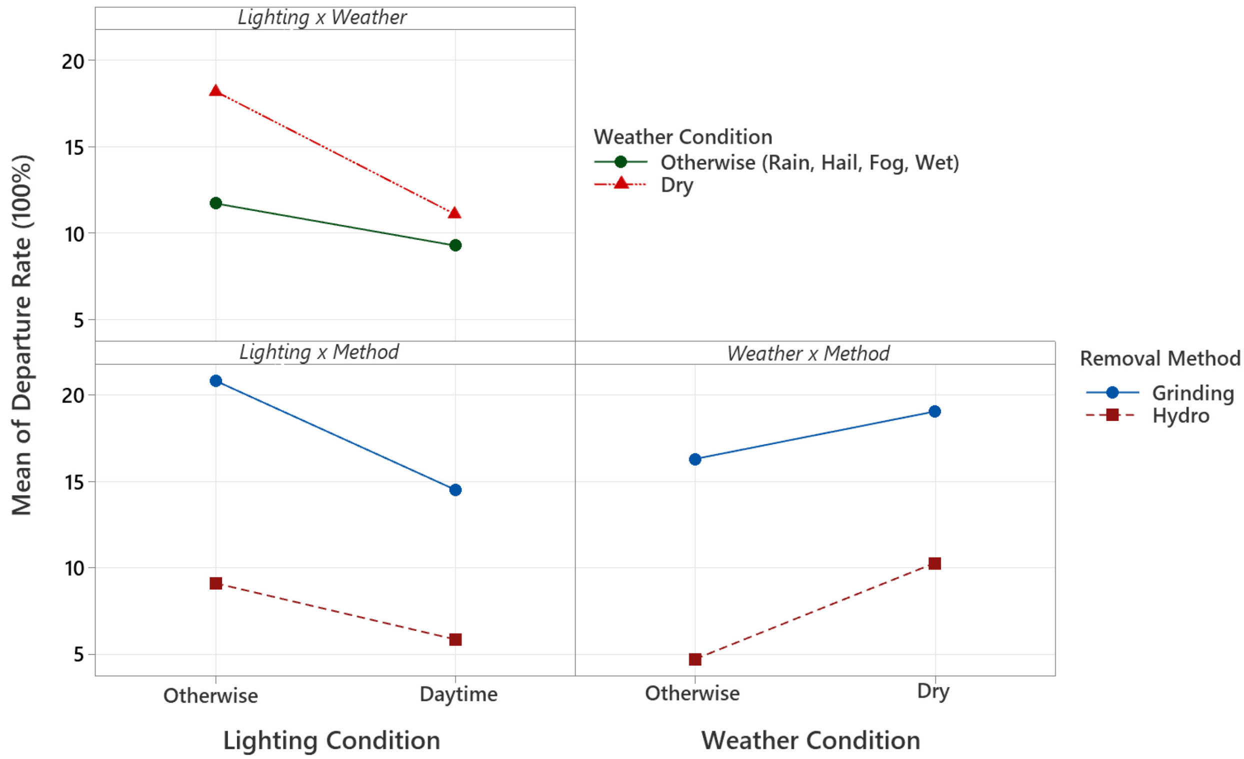


FIGURE 5.11: TWO-WAY INTERACTIONS OF INDEPENDENT VARIABLES ON MEAN DEPARTURE RATE (%)

5.5 SUMMARY

This chapter summarized the field data collection process using video, whose objective was to observe and document driver behavior at the transition zone of the marking removals to establish the distribution of vehicle path trajectories. Five sites with varying methods of pavement marking removal were selected and video was collected across different weather and lighting conditions. Portions of the video data collected at each site representing varying weather and lighting conditions were analyzed to determine the lane departure rate, frequency and type. Lane departures occurred at all lighting conditions and the highest departure rates were observed at the Ashland site. Departure rates varied by weather condition across the sites and lane departures were observed at all weather conditions. The proportions of lane departures ranged between 3.2% and 15.3% with proportions of lane departure suggesting no clearly discernible pattern. Statistical analysis showed that departure rates were lower by 3.5% during daytime hours when compared to other lighting conditions (i.e., night, dusk, dawn). The departure rate was approximately 5% higher when the pavement was dry in comparison to other weather conditions. Locations where hydroblasting was employed yielded the lowest departure rate, at 11%, compared to those where the grinding method was utilized.

6.0 PAVEMENT MARKING REMOVAL METHOD EXPERIMENT

This chapter provides a detailed description of an experiment conducted in the OSU Driving and Bicycling Research Laboratory. A combination of watching videos and eye tracking equipment was used to analyze driver attention for different removal methods used on pavement markings to understand which causes the greatest amount of driver confusion.

6.1 VIDEO EXPERIMENT

According to previous research and best-practice it was decided that eye-tracking data would work best for this experiment and as such was collected. This method relies on the Tobii Pro Glasses 3 eye-tracker that assessed driver attention when presented with videos featuring different removal methods in a variety of lighting and weather combinations. This section provides the details of the equipment used for this experiment.

6.1.1 Eye Tracker

An eye-tracking system was used to record participant visual attention, specifically where participants would look while viewing the different scenarios. The Tobii Pro Glasses 3 eye tracker was used to collect the eye tracking data through live integration into iMotions, where iMotions is a platform to process biometric data. The Tobii Pro Glasses 3 is an efficient eye tracker that is easy to use and collect precise data. It contains a 50Hz or 100Hz sampling rate with an accuracy of 0.6°. Gaze and eye position are calculated using a sophisticated 3D eye model algorithm based on the pupil center corneal reflection technique. The glasses contain a light source to illuminate the eye for reflections, and the reflections were captured by the mounted camera for further calculations. The Tobii Pro Glasses 3 uses a wide-angle scene camera that provides wider view and slippage compensation technology with persistent calibration, which allow user unconstrained eye and head movements throughout the recording ("Tobii Pro Glasses 3", n.d.).

Eye movement consists of fixations and saccades. Fixations occur when the gaze is directed towards a particular location and remains still for some period. Saccades occur when the eye moves between fixations. The eye tracking system records a fixation when the participant's eyes pause in a certain position for more than 100 milliseconds. Quick movements to another position (saccades) are calculated indirectly from the dwell time between fixations. Total dwell times are recorded by the equipment as the sum of the time of fixations and saccades consecutively recorded within an area of interest (AOI) (Hurwitz et al., 2018). Figure 6-1 shows the eye-tracking equipment and an OSU researcher demonstration of how the equipment is outfitted on the participant.

FIGURE 6.1: TOBII PRO GLASSES 3 (LEFT) AND OSU RESEARCHER DEMONSTRATION (RIGHT)

6.1.1.1 Eye-Tracking Data

Eye-tracking data describes the eye movements of participants as a combination of fixations and saccades. The participants' eye fixation and dwell data were extracted within areas of interest and were analyzed with iMotions. The results were exported to other types of files, e.g., Excel and RStudio, for statistical analysis to measure participant visual attention during the experiment.

6.1.2 Computer Screen

A Dell UltraSharp 34-inch Curved Monitor was to display the videos that the participants viewed while wearing eye-tracking glasses. A curved monitor was used as it provides a more immersive experience for viewers along with improving field of vision and reducing glare. The resolution of the monitor is 3440 x 1440 which allowed for the 4K videos to show in sharp definition. Figure 6.2 shows the monitor utilized for this experiment.

FIGURE 6.2: DELL ULTRASHARP 34-INCH CURVE MONITOR

Figure 6.3 shows the complete setup for the experiment. The monitor was placed in front of a steering wheel to provide extra authenticity to the experiment and participants were guided to hold onto the steering wheel if it felt comfortable. A laptop was set up next to the monitor for the participant to take the concurrent survey.

FIGURE 6.3: PARTICIPANT USING THE SETUP DURING THE EXPERIMENT.

6.1.3 Advantages and Risks

The primary advantages of conducting this experiment included having complete control of all independent variables such as collecting footage of the varying weather and lighting conditions, detailed demographic characteristics of participants by having them take surveys before, during and after the experiment, and collection of the different quantitative and qualitative data from the eye tracking equipment. The primary disadvantages of this experiment included lack of participant attention at various points and that it was not a true real-world application. Without a need to focus on the roadway as an active driver it was found through the eye tracking equipment and participant comments that they would look elsewhere while viewing the footage.

6.2 EXPERIMENTAL DESIGN

An experiment was designed by using a video camera, eye-tracking equipment, and a survey to better understand driver confusion when presented with roadway markings that had been removed using different methods. The footage used in this experiment came from projects that were currently in progress or had been completed that used two different methods of removal. The survey was based on those from previous experiments that would help produce a better understanding of participants' reactions.

6.2.1 Footage

The footage that was obtained and provided to the participants consisted of the following locations in Oregon:

- Airport Road and Highway 99 in Albany
- Santiam Highway in Albany
- Siskiyou Boulevard in Ashland

At these locations a variety of weather and lighting conditions were captured to see how the different combinations affected the different removal methods used. The two removal methods used were grinding (one location) and hydroblasting (two locations). Each location featured a combination of different lighting and weather conditions that led to 12 scenarios.

A brief description for each location with method used, length of removed marking and lane configuration can be found in the next subsections.

6.2.1.1 Airport Road and Highway 99 in Albany

At this location hydroblasting was used to remove the centerline markings as well as markings on the right side of the driving lane. Figure 6.5 shows the roadway which featured one lane in each direction with a predominant centerline and a right-side pavement marking for only a portion of the lane. During the period captured for the project the markings used to designate the separate lanes were raised reflector road markings.

The total length of the centerline is approximately 500 feet long while the right-side pavement marking in the westbound direction is approximately 200 feet long and the right-side pavement marking in the eastbound direction is also approximately 200 feet long. All weather conditions and lighting conditions were captured which were rainy, wet, dry for the weather types and daytime and nighttime for lighting. During the daytime portion there was no glare as there was a cloud cover.

FIGURE 6.4: ALBANY - AIRPORT ROAD AND HIGHWAY 99 DURING WET DAYTIME CONDITIONS

6.2.1.2 Santiam Highway in Albany

At this location hydroblasting was also used to remove multiple markings for a significant portion of the highway as it was a major project in upgrading the location. Figure 6.5 shows the roadway which are two lanes in either direction of the highway with a concrete divider separating the lanes. For the initial videos reflective road markers were used to designate the individual lanes while in the later videos freshly painted markings were evident. The removed markings were the centerlines, right-side pavement markings and left-side pavement markings. The total length of the different markings is a total as there was an intersection that split the project. As the markings were generally lined up together the total length for the centerline, right-side pavement markings and the left-side pavement markings are similar in length. The length for each type of pavement marking is approximately 1250 feet long. All weather and lighting conditions were captured at this location with the daytime conditions also featuring no glare due to the cloud cover.

FIGURE 6.5: ALBANY - SANTIAM HIGHWAY DURING WET NIGHTTIME CONDITIONS

6.2.1.3 Siskiyou Boulevard in Ashland

For this location it featured grinding as the removal method from a road diet project performed a few years ago. Figure 6.6 shows the project location with two lanes in either direction and the location of the removed markings being in-between the two lanes with yellow paint designating the new lanes. This was to the left of the driving lane with the video capturing it in the northbound direction. The length of the removed markings that were featured in the different scenarios is around 4600 feet long. As with the other two locations a combination of different weather and lighting conditions were captured but due to the late in the year season there was no sunshine.

FIGURE 6.6: ASHLAND - SISKIYOU BOULEVARD DURING DRY DAYTIME CONDITIONS

6.2.2 Experimental Variables

6.2.2.1 Independent Variables

Three independent variables were proposed for the experiment: location, lighting condition, and weather condition. This experiment explored the interaction between the independent variables that affect the confusion of a driver when encountering pavement markings that have been removed using different removal methods. Table 6.1 shows each independent variable and its corresponding condition. Regarding the location variable, there were three and at each location there were two different lighting conditions (daytime, nighttime) and two weather conditions (dry, rainy/wet).

TABLE 6.1 EXPERIMENTAL INDEPENDENT VARIABLES

Variable	Condition
Location	Albany – Airport Road and Highway 99 Ashland – Siskiyou Boulevard Albany – Santiam Highway
Weather	Dry Wet/Rainy
Lighting	Daytime Nighttime

6.2.2.2 Dependent Variables

The dependent variable for this experiment was associated with where the driver looked when viewing the videos of the locations with the varying lighting and weather conditions across different locations. The dependent variable included is:

- Eye-tracking fixations: The time spent fixating on the pavement marking to define the distribution of visual attention.

The fixation data was collected with separate equipment and analyzed using iMotion software to evaluate drivers' visual attention when watching the different scenarios.

6.2.3 Factorial Design

The factorial design for the three independent variables yielded a total of 12 scenarios (3x2x2). Out of the 12 scenarios created, the participants were given 9 scenarios to view in 4 different variations. The scenarios were assigned to groups of 10 participants to provide control.

6.2.3.1 Presentation of Video Scenarios

Table 6.2 shows the 12 different scenarios that were generated and distributed among 4 sets, each comprising 9 scenarios. Each set was presented to a total of 10 participants. To measure the influence of the experimental factors, participants were exposed to a variety of different configurations.

TABLE 6.2 VIDEO SCENARIOS

Scenario	Location	Weather	Lighting	Removal Type
1	Albany – Airport Rd and Hwy 99	Dry	Day	Hydroblasting
2	Ashland	Dry	Day	Grinding
3	Albany – Santiam Highway	Dry	Day	Hydroblasting
4	Albany – Airport Rd and Hwy 99	Dry	Night	Hydroblasting
5	Ashland	Dry	Night	Grinding
6	Albany – Santiam Highway	Dry	Night	Hydroblasting
7	Albany – Airport Rd and Hwy 99	Wet	Day	Hydroblasting
8	Ashland	Wet	Day	Grinding
9	Albany – Santiam Highway	Wet	Day	Hydroblasting
10	Albany – Airport Rd and Hwy 99	Wet	Night	Hydroblasting
11	Ashland	Wet	Night	Grinding
12	Albany – Santiam Highway	Wet	Night	Hydroblasting

These 12 scenarios were filmed using a camera capable of 4K quality footage mounted on the dashboard of a vehicle. Figure 6.7 shows an example of what participants watched when given a set of scenarios along with the camera used to capture the footage which was the DJI Osmo Action Pro. A series of vehicles were used depending on availability when data collection occurred at the different locations with the one shown in Figure 6.7 being a white VW Beetle. Other vehicles used for the project included two midsized SUVs and one sedan.

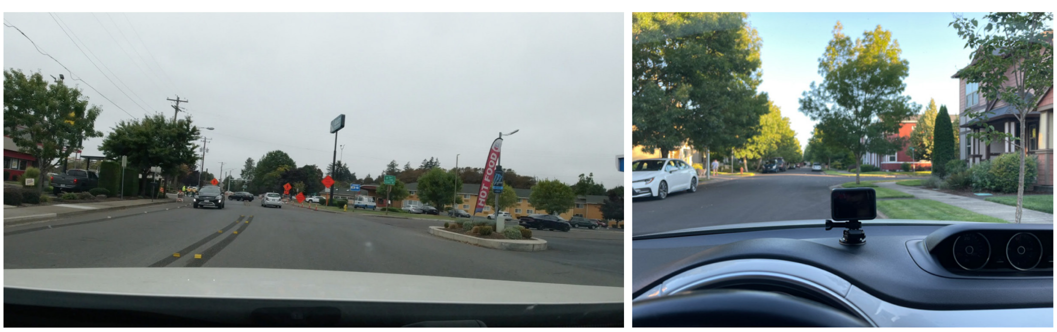


FIGURE 6.7: VIEW FROM THE DASHBOARD CAMERA FOR SCENARIO 1 AND OF THE CAMERA USED FOR THIS EXPERIMENT MOUNTED ON A VEHICLE DASHBOARD

The participants were instructed to take a survey following each scenario to collect their thoughts on the roadway.

6.2.4 Survey

A survey was conducted at various points throughout the experiment to gain insight into driving experience, eligibility to participate in the experiment, demographics and to understand what participants thought of each location in different scenarios. Open-ended, multiple-choice, and Likert scale questions were developed to elicit each user's understanding and self-reported response to removed markings on the roadway with the objective being to understand what the participants thought were more obvious removed markings or ghost lines. The entirety of the survey was conducted in-person during the experiment.

6.2.4.1 Design and Refinement

The first step in designing the survey was the development of a generic template for a survey using the Qualtrics website. The survey questions were based on eligibility to participate, and demographics was based on previous research surveys conducted at the OSU Driving and Bicycling Simulator Laboratory. For the survey questions that were concurrently given with the provided video scenario every effort was made to present questions neutrally, allowing respondents to provide meaningful answers reflecting their views on what they had just seen. Several rounds of review and refinement followed the internal development of the survey questions with feedback being provided by transportation graduate students and researchers at OSU and PSU. The finalized survey, distribution methods, and record handling were determined exempt by the IRB of OSU.

6.2.4.2 Instrument

The survey consisted of 32 questions, which included a mix of open-ended, close-ended questions. The survey design was created so that open-ended questions could be presented in an unbiased manner. Figure 6.8 illustrates the flow of the survey.

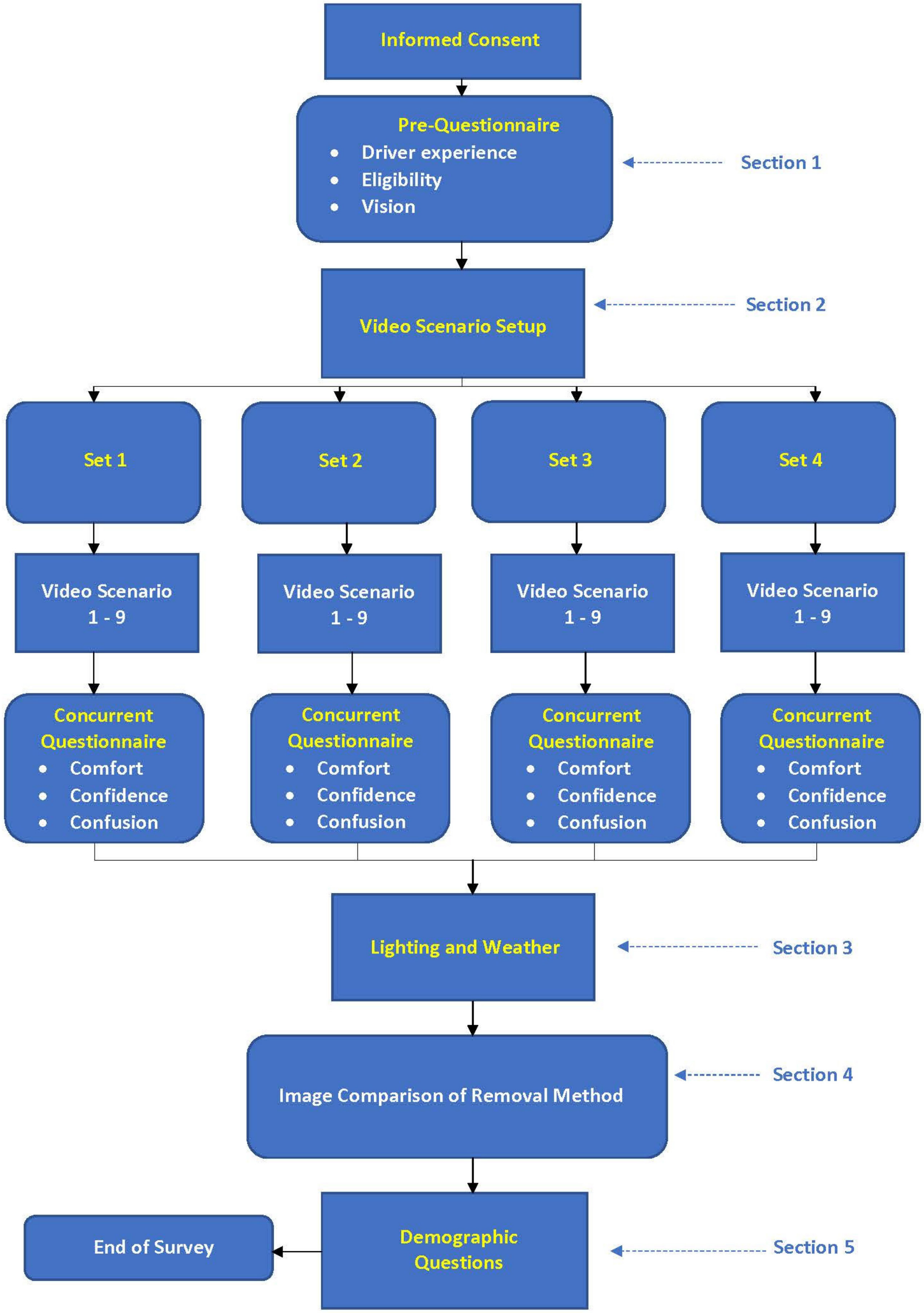


FIGURE 6.8: FLOW OF THE SURVEY USED IN THE EXPERIMENT.

Before being shown the questions, all respondents had to provide informed consent for the survey, certifying that they are over 18 years of age and have a valid license. In section 1 the pre-questionnaire included questions looking at eligibility, driver experience and vision of the participant. The concurrent questionnaire occurred in section 2 in which participants viewed the nine different scenarios that was provided within each set of videos with each participant receiving one set of videos. At this point the participant would fill out the questionnaire after each scenario that looked at comfort, confidence, and confusion of the roadway that they had just viewed. In section 3 the participant was asked questions on the lighting and weather that was occurring during the scenarios given and to determine which conditions induced the highest level of discomfort and confusion. For section 4 image comparison was performed in which participants were given two sets of photos with one featuring hydroblasting removal and the other grinding. They were then tasked with determining which image featured markings that were clearer to follow. In the final the participants finished out the survey with demographic questions regarding age, gender, education level, and income.

6.3 EXPERIMENTAL PROTOCOL

The locations chosen to be featured in the video sets given to the participants were based on experimental factors which consisted of 12 scenarios. A total of five locations and the combination of differing weather and lighting conditions were collected for this experiment, three of the locations were used for the data collection portion in which eye tracking equipment was used. Each location featured a combination of daytime, nighttime, dry, and rainy/wet conditions. Therefore, participants experienced a total of 9 scenarios during the experiment duration. The video set order was partially randomized to reduce as much bias and survey fatigue as possible.

6.3.1 Recruitment

A total of 41 individuals, primarily from the community surrounding Corvallis, OR, were recruited as test participants in the driving simulator experiment. Only licensed drivers who were at least 18 years of age were recruited for this experiment. Participants also needed to be deemed competent to provide written, informed consent. Recruitment of participants was accomplished through posting of the experiment on the OSU Today newsletter and through the email listserv that the laboratory keeps.

Researchers did not screen interested participants based on gender. Although it was expected that many participants would be OSU students, an effort was made to incorporate participants of all ages within the range of 18 to 75 years of age. Throughout the entire study, information related to the participants was kept under double lock security in compliance with accepted OSU Institutional Review Board (IRB) procedures although this experiment was granted an exemption from the board. Each participant was assigned a number to remove any uniquely identifiable information from the recorded data.

6.3.2 Informed Consent and Compensation

Consent was obtained from all participants prior to beginning any experimental procedures. The IRB approved consent document was presented and explained to the participant upon arrival to the simulator laboratory. This consent document provides an overview of the study, and the objectives of the study. The document also explains the potential risks and research benefits associated with using the simulator. Participants were given $20 compensation in cash for participating in the experimental trial after signing the informed consent document. If participants experienced simulator sickness or they could no longer continue after signing the consent document, they were allowed to leave without penalty.

6.3.3 Pre-drive Questionnaire

The pre-drive questionnaire was administered after consent had been obtained and before the participant began viewing the video portion of the experiment. This survey targets the eligibility and driving experience of the participants. Additionally, this survey included questions from the following areas:

- Vision: Participants needed to answer whether they use corrective glasses or contact lenses while driving. The eye tracker contains adjustable lenses up to prescription of five. Participants are required to clearly see the videos and read the visual instructions displayed on the screen.

- License: Participants were provided with an open answer question to provide the details of when they had obtained their license and from where.

- Vehicle type: Participants were requested to input the make and model of the vehicle that they are currently using to drive.

The pre-drive questionnaire was aimed to help assess if a participant meets the requirements to participate in the experiment.

6.3.4 Eye Tracking Calibration

The Tobii Pro Glasses 3 eye-tracker was calibrated for each participant after the participant met the inclusion experiment criteria. The participant was asked to wear the glasses and look straight at a target card. The eye tracking recording could proceed if the calibration was successful. Figure 6.9 shows a view from the eye tracking glasses of a successful calibration.

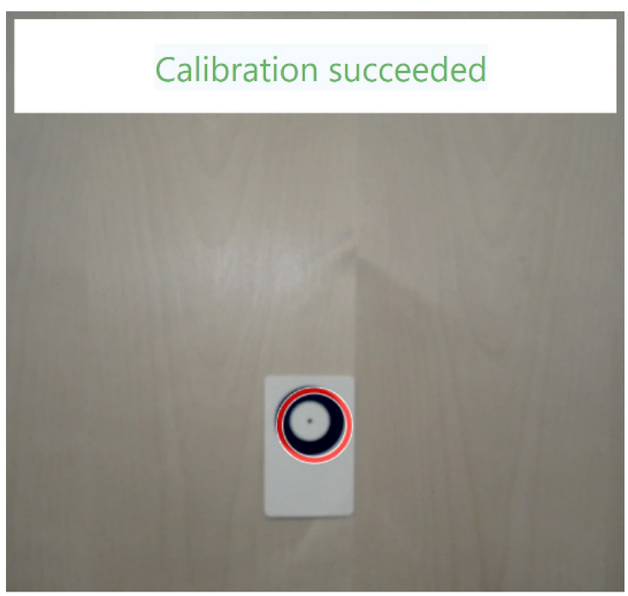


FIGURE 6.9: EYE-TRACKING CALIBRATION IMAGE

The calibration process took less than 10 seconds. Recalibration was needed if the initial calibration failed. If the eye-tracker was unable to complete the calibration after multiple attempts, the experimental trial would be conducted but the eye tracking data would not be used. After the eye-tracking equipment had been calibrated, the participant was asked to sit in front of the computer screen to watch the videos.

6.3.5 Concurrent-drive Questionnaire

After having viewed a scenario presented in the video set, the participant was asked to respond to questions regarding their perception on the roadway that they had just viewed. These questions used a Likert scale response method and included aspects such as: the participants confusion with the roadway markings, comfort level with the roadway and their confidence in driving on the roadway. In addition to the Likert scale questions some were left open to the participant to respond on anything that was noticed about the roadway.

6.3.6 Post-drive Questionnaire

After completing the experiment, the participant was asked to respond to questions regarding lighting conditions, weather conditions and comparison of images for different locations with the same lighting and weather condition combinations. They were also given a survey that targeted the demographics of the participants (e.g., age, gender, highest level of education, and salary). This was the last portion of the study; participants were then debriefed, and the purpose of the study was stated.

The entire experiment, including the consent process, pre-drive questionnaire, eye-tracker calibration, experimental video viewing, concurrent-drive questionnaire, and post-drive questionnaire, lasted approximately 45 minutes. Most participants were able to complete the experiment within twenty minutes with some finishing as quickly as 15 minutes.

6.4 DATA REDUCTION

6.4.1 EYE-TRACKING DATA REDUCTION

The eye-tracking data was reduced to find dwell times for each area of interest (AOI). Dwell time can be defined as the amount of time a participant spends viewing a certain area, made up of fixations and saccades (Bergstrom and Schall, 2014). An AOI is a designated region which describes zones that are of importance to researchers. The data collected by the eye tracker was wirelessly sent to a host computer that contained the iMotions software, and this software allows for AOIs creation for each scenario and provides the total time that participants spent viewing these areas when shown videos of roadways with removed pavement markings.

The interest period of each scenario started approximately 10 feet before the removed marking line started on the roadway and lasted until the scenario finished. This resulted in 30 seconds to 1.5 minutes of clip length per scenario depending on the location. Researchers manually coded polygons over the AOIs, and the polygons were adjusted incrementally to fit the AOIs frame by frame. The two AOIs defined in this study were removed markings to the left of the lane the video capturing vehicle was in and removed markings to the right of lane. Figure 6.10 is the screenshot of the AOIs during the reduction process. For scenarios in which only one removed marking line was featured, only one AOI was captured.

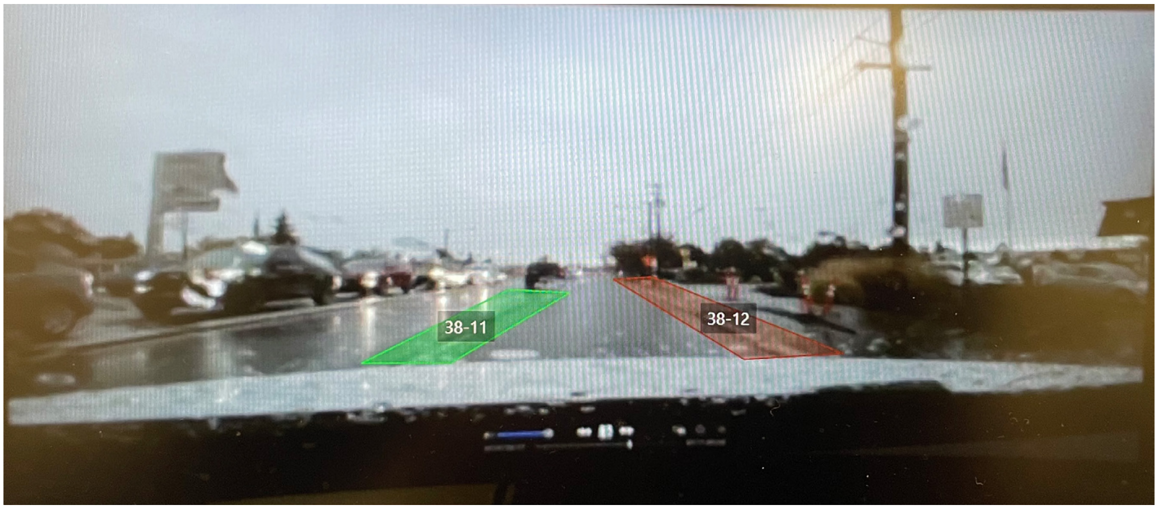


FIGURE 6.10: AOIS EXAMPLE

6.5 ANALYSIS AND RESULTS

As mentioned in the previous section, 12 scenarios were used in total for this experiment at three locations. These three locations were chosen due to the removal method used and ease of transition between videos. The study contains multiple variables and levels to investigate how drivers react to the removed pavement markings prior to and after the pavement markings had been restored.

6.5.1 Participants

Table 6.3 records the overall participants and final sample sizes of the desired data sets for this experiment. A total number of 41 participants were recruited from Corvallis and the surrounding area, including 14 males, 25 females and 2 participants who identified as non-binary or preferred not to answer. The participant ages ranged from 19 to 76 years old with an average age (AA) of 35.9 years and a standard deviation (SD) of 15.2 years. Only 1 (2.5%) participant's data was unable to be reduced which brought the total sample size to 40 (AA = 35.7, SD age = 15.2) participants, including 14 males (AA = 34.2, SD age = 15.7), 24 females (AA = 37.5, SD age = 15.2) and 2 non-binary participants (AA = 24, SD age = 15.2). This sample was found to skew slightly young and female in relation to population demographics in Oregon.

TABLE 6.3 PARTICIPANT BASE

	Total	Male	Female	Non-Binary
Total Enrolled	41 (100%)	14 (34.1%)	25 (60.9%)	2 (4.8%)
Data Not Collected	1 (2.5%)		1 (2.5%)	
Total Usable Sample	40 (97.5%)	14 (35%)	24 (60%)	2 (5%)
Age Range	19-76			

6.5.2 Visual Attention

The visual attention data were collected using the iMotion Tobii Glasses 3. As mentioned, data from 40 participants were captured and usable for analysis. Boxes were drawn on two AOIs: left side of driving lane and right side of driving lane to obtain the average total fixation duration (TFD) of participants. The AOI of the left side of the driving lane showed if participants were looking at the pavement marking line on that side; AOI of the right side of the driving lane showed if participants were focusing on the pavement marking lines found there.

The total fixation duration (TFD) of the participants for each scenario was used to compare the three independent variables and combinations of the variables to understand what caused the participants to focus on the pavement markings most frequently. In Figure 6.11 the total fixation duration is shown with the average amount of time focused on a pavement marking being approximately 2.9 seconds with the longest amount of total time spent fixating on an area at 33 seconds.

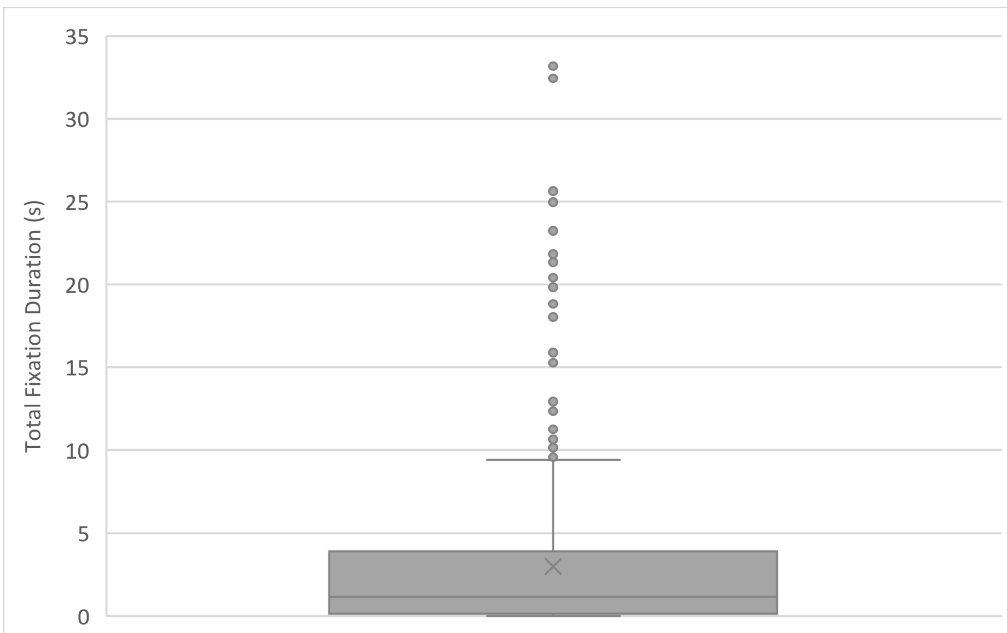


FIGURE 6.11: TOTAL FIXATION DURATION (TFD) IN SECONDS

When looking at weather conditions the total fixation duration was used to compare the difference between both dry and wet/rainy conditions overall for the three different locations. It was found that participants fixated for a longer amount of time in dryer conditions on average rather than in wet/rainy conditions. Figure 6.12 shows the results between the two weather conditions.

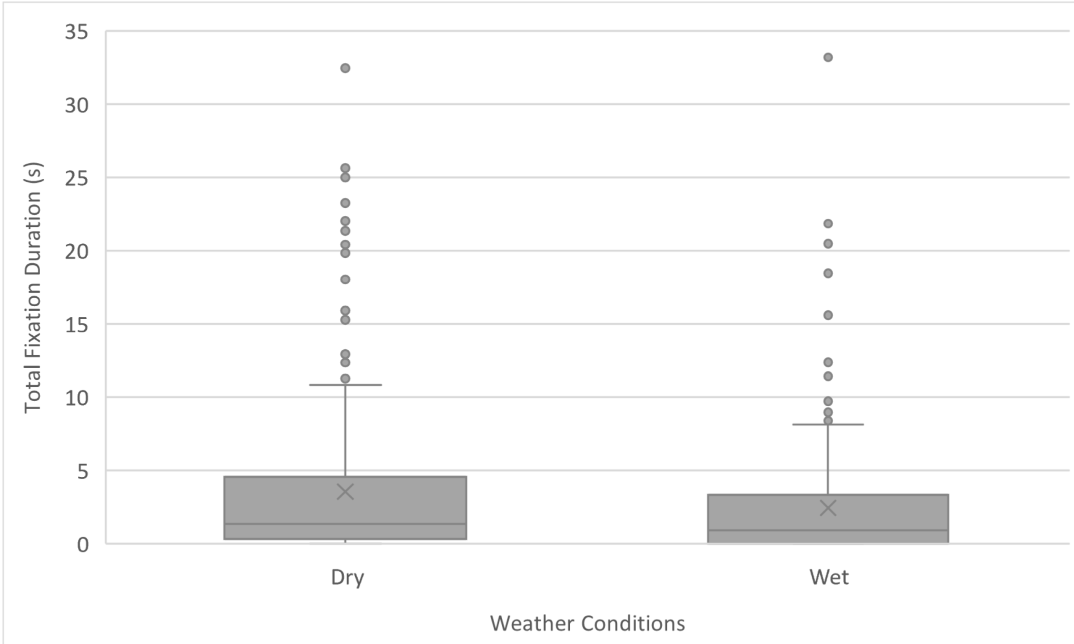


FIGURE 6.12: TFD BY WEATHER CONDITIONS

For lighting conditions, the total fixation duration was compared between daytime and nighttime conditions at the three locations. It was found that the participants focused significantly more on the pavement markings during nighttime conditions over daytime conditions. The average duration of focus on the markings for nighttime is 3.37 seconds whereas for the daytime conditions it is 2.57 seconds. Figure 6.13 displays the results for the two different lighting conditions.

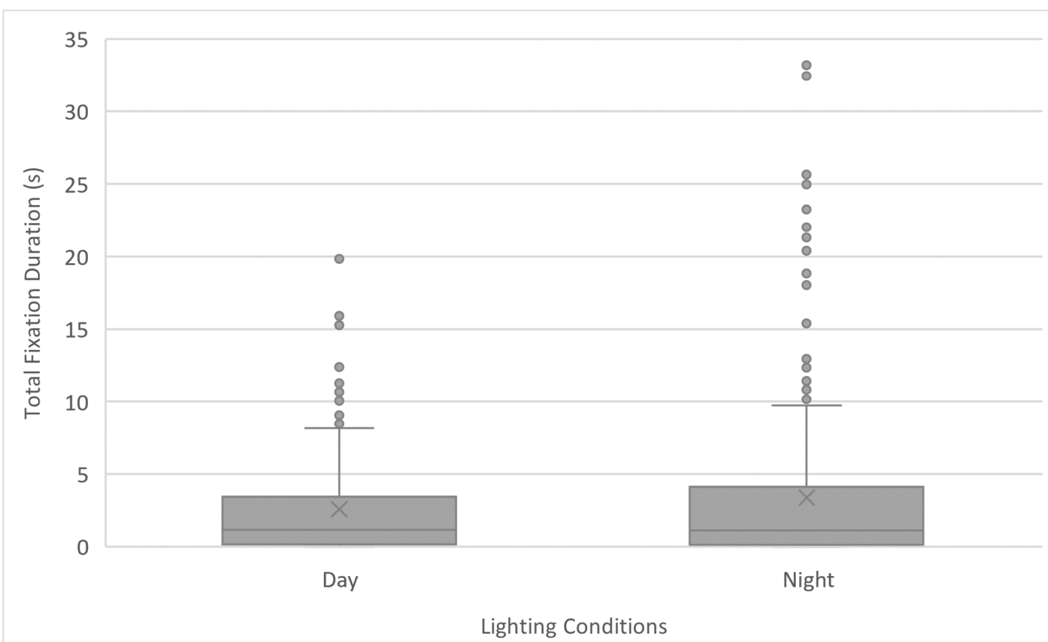


FIGURE 6.13: TFD BY LIGHTING CONDITIONS

The total fixation duration was used to compare how long the participants focused on the different removal methods that were used at the three locations. It was found that the participants on average focused on hydroblasting more often than on the grinding removal method. The average duration for hydroblasting is 3.48 seconds whereas for grinding the average duration spent looking at the removed markings is 0.93 seconds. Figure 6.14 shows the results between the two different removal methods.

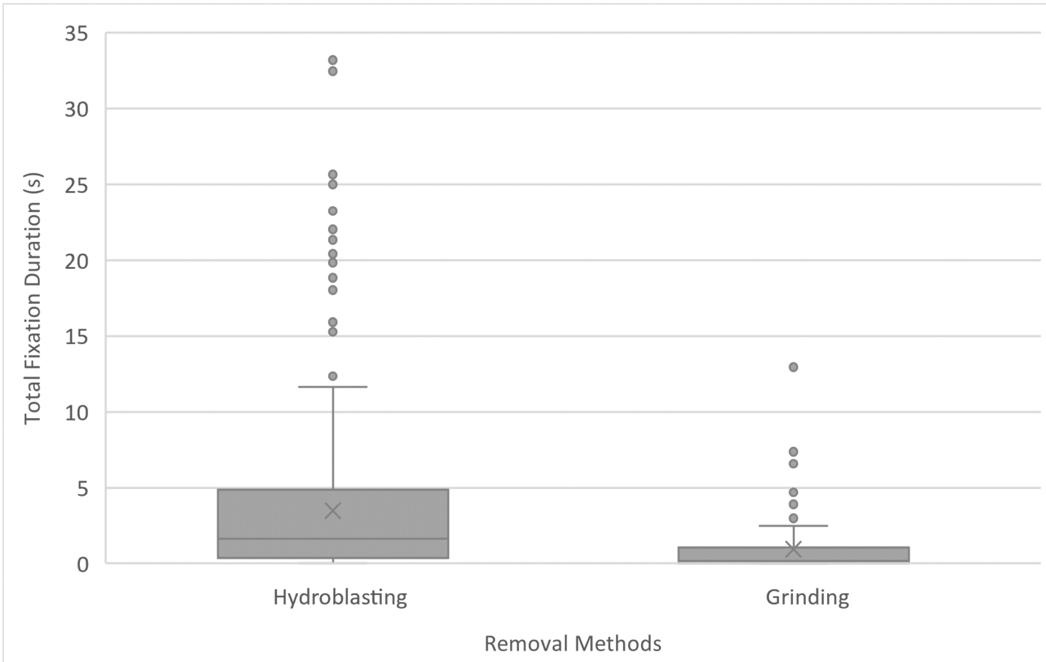


FIGURE 6.14: TFD BY REMOVAL METHOD AT STUDY LOCATIONS

The following figures were used to compare each independent variable against the location at which the videos were collected which as stated above are Airport Road and Highway 99 in Albany, Siskiyou Boulevard in Ashland, and Santiam Highway in Albany. In Figure 6.15 the total fixation duration is compared against each location with a significant amount of fixation occurring at the Santiam Highway in Albany location with an average of 5.3 seconds.

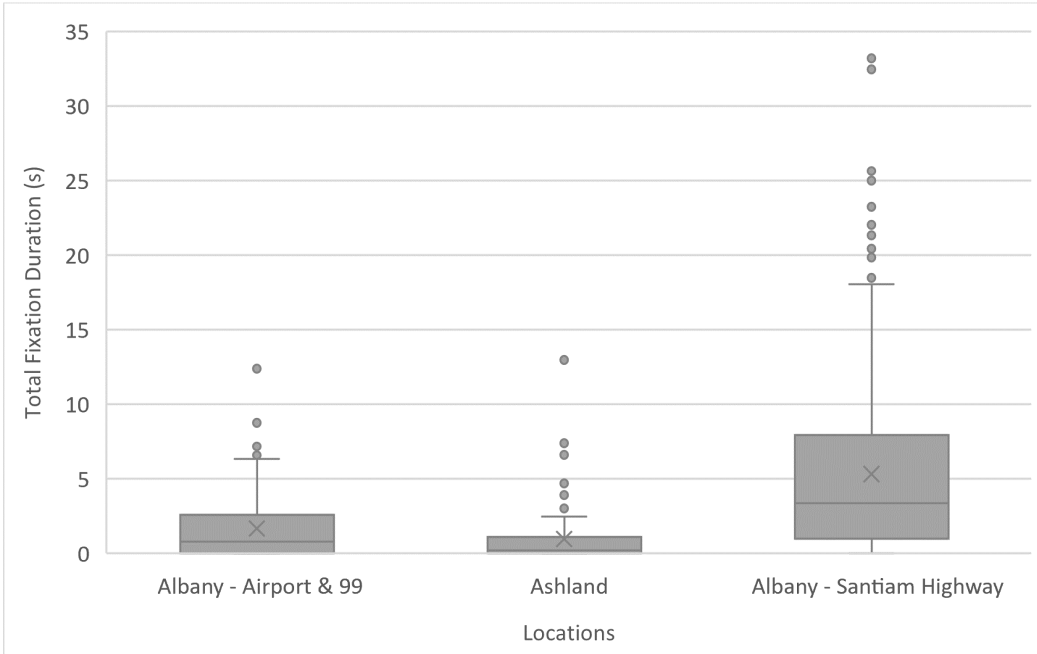


FIGURE 6.15: TFD AT STUDY LOCATIONS

In Figure 6.16 the weather at each location was compared to the total fixation duration. This was done for both the dry and wet/rainy conditions with the Santiam Highway in Albany location still showing the most fixation time for both weather conditions.

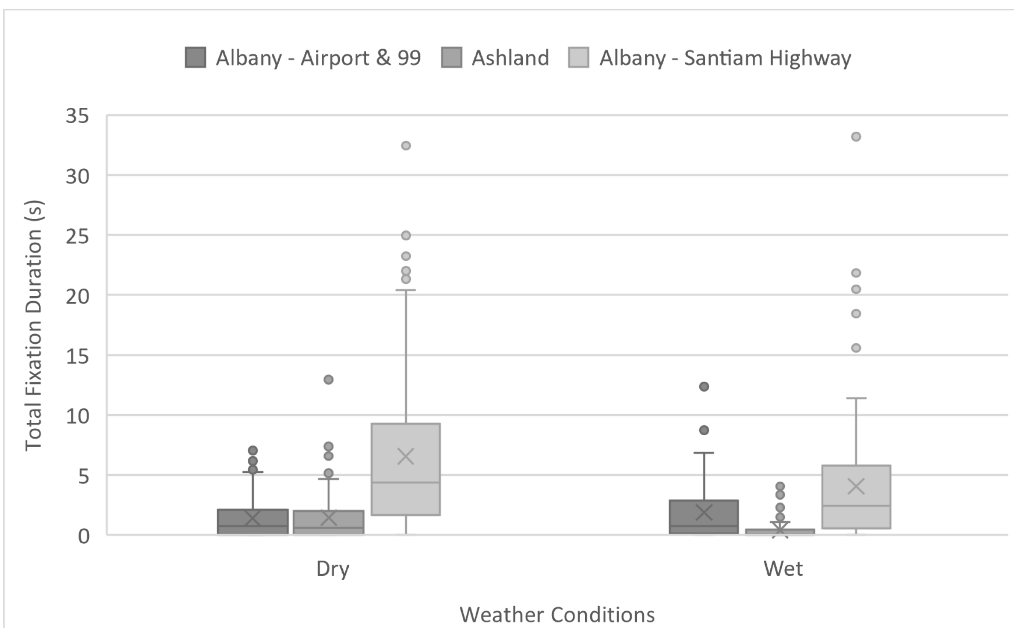


FIGURE 6.16: TFD BY WEATHER AT STUDY LOCATIONS

Figure 6.17 shows the comparison of the lighting conditions at each location to the total fixation duration. It was found that the Santiam Highway in Albany location continued to show the most duration spent on the pavement markings with those at Airport Road and Highway 99 in Albany at the second most duration but at a significantly lower value.

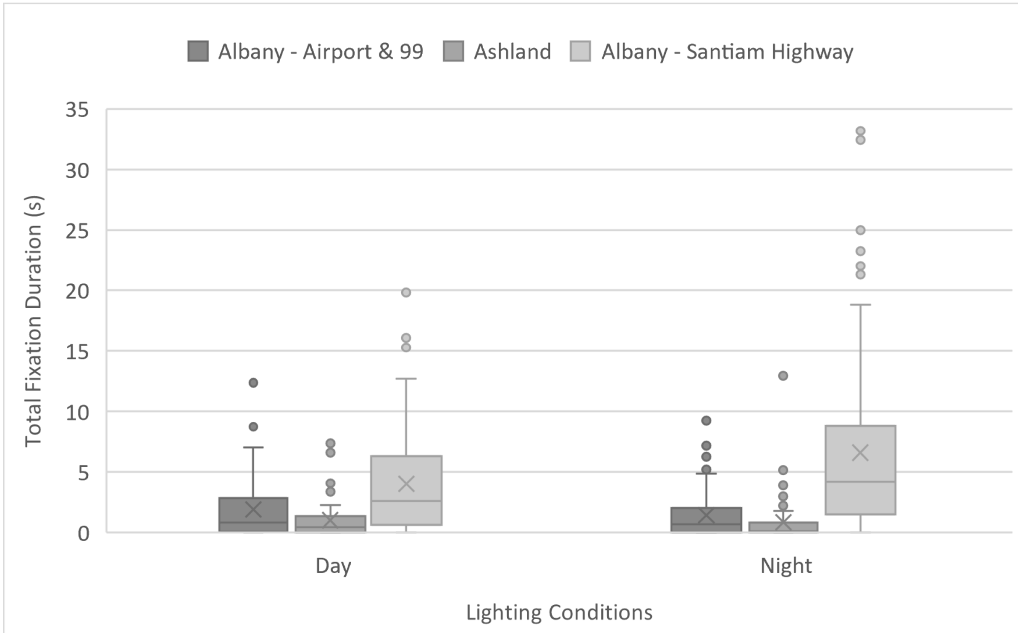


FIGURE 6.17: TFD BY LIGHTING AT STUDY LOCATIONS

The last comparison occurred between the removal method used at each location and the total fixation duration. At Airport Road and Highway 99 in Albany and Santiam Highway in Albany the hydroblasting removal method was used whereas at Siskiyou Boulevard in Ashland the grinding method was used. In Figure 6.18 the duration spent focusing on the pavement markings for the Santiam Highway in Albany location was the highest.

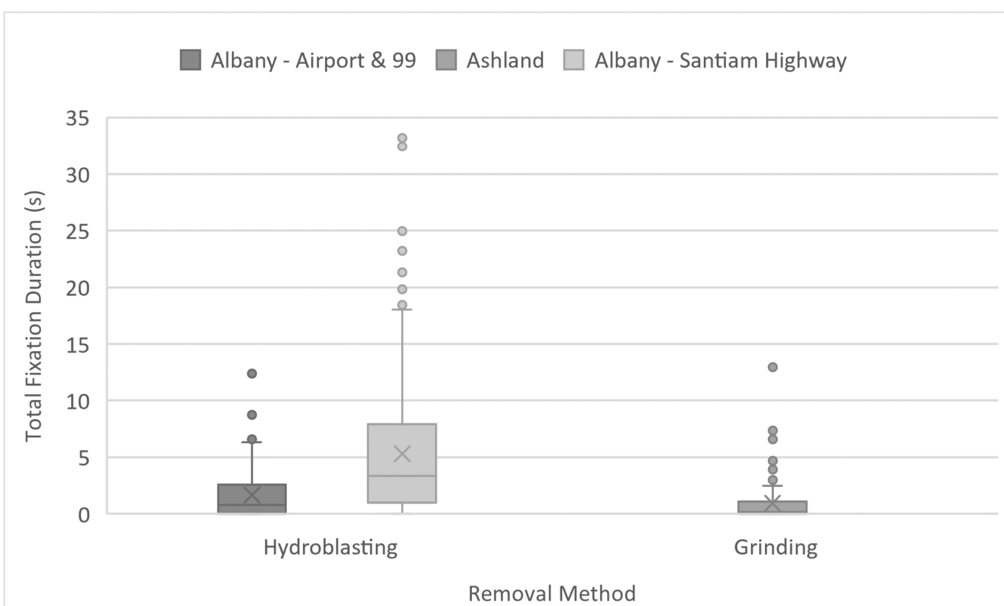


FIGURE 6.18: TFD BY REMOVAL METHOD AT STUDY LOCATIONS

6.5.3 Questionnaire Results

The study contained a pre- and post-video questionnaire along with a post-scenario questionnaire which the below section will provide the results for both questionnaires. The pre-video questionnaire focused on eligibility and driver experience while the post-video questionnaire focused on demographic based questions. The post-scenario questionnaire included questions on comfort and confidence of the roadway that had just been viewed in the different weather and lighting conditions.

6.5.3.1 Pre-video Questionnaire Results

The pre-drive questionnaire targeted participants eligibility and driving experience information. The participants ranged in age from 19 to 76 years of age and were all licensed to drive within Oregon. The questions also looked at where their license had been issued, what type of vehicle was driven and if they required any form of corrective eyewear or had astigmatism. The license location and vehicle type were collected to determine if there were any significant data points with this information whereas corrective eyewear questions were included due to the eye tracking equipment that was used. Overall, most participants received their license in the state of Oregon with around a third from other states or countries. Most participants drove either a sedan or SUV and it was fairly evenly split with those who required corrective eyewear over those who didn't require it. Table 6.4 presents the detailed results of the survey for the total sample of 40 participants.

TABLE 6.4 PRE-VIDEO ELIGIBILITY QUESTIONNAIRE RESULTS

Category	Variable	Count	Percentage
License Issue Location	Oregon	29	72.5
	Georgia	1	2.5
	Hawaii	2	5.0
	Minnesota	2	5.0
	Texas	1	2.5
	Montana	1	2.5
	California	1	2.5
	Washington	1	2.5
	Singapore	1	2.5
	Did not respond	1	2.5
Vehicle Type	SUV	19	47.5
	Sedan	17	42.5
	Pickup	2	5.0
	Unknown	2	5.0
Eyewear	Glasses	13	32.5
	Contacts	8	20.0
	None	19	47.5
Astigmatism	Yes	12	30
	No	28	70

6.5.3.2 Concurrent-video Questionnaire Results

This portion of the survey contained both Likert and open-ended questions that were designed to assess the participants confusion, comfort level, and confidence in the roadway that they had just been presented with, the responses needed to be categorized for further analysis. For the open-ended questions the research team reviewed each open-ended response, and the responses were then coded based on what was mentioned in the comments with a value of 1 through 4 depending on the answer. Table 6.5 shows the coding convention that was used for this portion of the survey.

TABLE 6.5 CODING OF OPEN-ENDED RESPONSES

Response	Value
Lane related	1
Weather	2
Combination	3
Lighting	4
Other	0

For any responses that featured a lane related comment such as on the pavement markings it was given a value of 1, whereas if only the weather such as dry or wet was mentioned then it was given a value of 2. For a combination of different things such as lane related, weather, lighting it was given the value of 3, lighting comments on daytime or nighttime were given a value of 4 and any other comments that did not include any of the above was given a value of 0.

Table 6.6 shows the responses for each scenario that was presented to the participants based on these open-ended questions which looked at confusion and a combination of lighting and weather conditions.

TABLE 6.6 OPEN-ENDED RESULTS

Response	Scenario (% out of 100%)											
	1 Dry/Day/Hydroblasting	2 Dry/Day/Grinding	3 Dry/Day/Hydroblasting	4 Dry/Night/Hydroblasting	5 Dry/Night/Grinding	6 Dry/Night/Hydroblasting	7 Wet/Day/Hydroblasting	8 Wet/Day/Grinding	9 Wet/Day/Hydroblasting	10 Wet/Night/Hydroblasting	11 Wet/Night/Grinding	12 Wet/Night/Hydroblasting
Lane Related	6.7	6.7	6.7	6.7	6.7	6.7	10.0	13.3	16.7	16.7	13.3	10.0
Weather	20.0	20.0	20.0	20.0	20.0	20.0	16.7	13.3	16.7	13.3	16.7	16.7
Combination	6.7	6.7	6.7	6.7	6.7	6.7	13.3	13.3	13.3	13.3	13.3	13.3
Lighting	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	10.0	10.0	10.0	6.7
Other	33.3	33.3	33.3	33.3	33.3	33.3	23.3	20.0	20.0	20.0	23.3	23.3
Blank	26.7	26.7	26.7	26.7	26.7	26.7	30.0	33.3	26.7	26.7	23.3	30.0

Most responses, regardless of the scenario, focused on other aspects of such as construction or signage instead of the roadway markings at around mid-20% to 30% for all scenarios, many also left this question blank. For scenarios 1 through 7, which featured a combination of dry weather conditions during the daytime and nighttime with scenario 7 featuring the only wet weather condition during the daytime at the Albany Highway 99 location, it was found that a significant number of remarks, at around 20%, focused on the weather condition whereas scenarios 8 through 12, which were all during wet weather conditions featuring both daytime and nighttime lighting conditions, had participants commenting more frequently on the lane related aspects of the scenario that was presented at around 16%.

Multiple choice and Likert scale questions were provided to each participant regarding their thoughts the scenario provided to them. After each scenario was presented to the participants, they were asked a series of questions on a scale that allowed them to rate their confusion, confidence, and comfortability on the roadway.

For question 1 which looked at if the participant noticed anything unusual about the roadway, the response was a simple multiple choice of yes or no. The second question asked about confusion similarly was a yes or no question but, in this case, if yes was selected, then further questions were asked regarding what had caused the confusion. The third and fourth questions were based on the Likert scale in which confidence level and comfortability regarding the scenario were rated with a value of 1 being very comfortable or confident all the way to a value of 5 indicating very uncomfortable or low confidence. Table 6.7 summarizes the questions asked and the responses to them below with Table 6.8 providing additional information on weather and lighting conditions for each scenario.

TABLE 6.7 MULTIPLE CHOICE RESULTS

Response	Scenario (% out of 100%)											
	1 Dry/Day/Hydroblasting	2 Dry/Day/Grinding	3 Dry/Day/Hydroblasting	4 Dry/Night/Hydroblasting	5 Dry/Night/Grinding	6 Dry/Night/Hydroblasting	7 Wet/Day/Hydroblasting	8 Wet/Day/Grinding	9 Wet/Day/Hydroblasting	10 Wet/Night/Hydroblasting	11 Wet/Night/Grinding	12 Wet/Night/Hydroblasting
Q1: Is there anything unusual about the roadway lane markings that you noticed?												
Yes	16.7	10.0	56.7	50.0	20.0	56.7	73.3	23.3	40.0	50.0	10.0	46.7
No	83.3	90.0	43.3	50.0	80.0	43.3	26.7	76.6	60.0	50.0	90.0	53.3
Q2: At any point when watching the videos, did you experience any confusion as to where you should be positioned on the roadway?												
Yes	13.3	0.3	33.3	26.7	0.0	10.0	30.0	0.3	10.0	26.7	0.3	13.3
No	86.7	96.7	66.7	73.3	100.0	90.0	70.0	96.7	90.0	73.3	96.7	53.7
Q3: Rate your confidence level in determining which lane the car was supposed to be in.												
Very Good	60.0	90.0	46.7	36.7	80.0	50.0	33.3	80.0	46.7	36.7	70.0	40.0
Good	30.0	10.0	33.3	33.3	20.0	36.7	26.7	20.0	43.3	30.0	23.3	46.7
Acceptable	6.7	0.0	16.7	30.0	0.0	13.3	36.7	0.0	10.0	23.3	6.7	10.0
Poor	3.3	0.0	3.3	0.0	0.0	0.0	3.3	0.0	0.0	10.0	0.0	3.3
Very Poor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q4: How comfortable would you be driving through a real-life scenario similar to this one?												
Very Comfortable	43.3	86.7	43.3	30.0	70.0	40.0	30.0	70.0	50.0	30.0	63.3	43.3
Comfortable	43.3	13.3	36.7	40.0	30.0	43.3	30.0	23.3	36.7	40.0	30.0	40.0
Neither	3.3	0.0	10.0	16.7	0.0	13.3	23.3	6.7	10.0	16.7	6.7	10.0
Uncomfortable	10.0	0.0	6.7	13.3	0.0	3.3	13.3	0.0	3.3	13.3	0.0	3.3
Very Uncomfortable	0.0	0.0	3.3	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	3.3

For the multiple-choice questions that looked at confusion, confidence, and comfortability in the roadway that was presented in the scenario there was a wide variety of answers. In response to noticing anything regarding the roadway without specifically asking about removed markings for scenarios 1, 2, 5, 8, and 11, which features the spectrum of the different lighting and weather conditions with scenarios 1, 2, and 5, featuring dry weather conditions during daytime and nighttime lighting whereas scenarios 8 and 11 feature wet weather conditions during the day and night, most participants did not notice anything out of the ordinary whereas the other scenarios presented at least 50% of the participants did notice something unusual. Regarding confusion, most participants did not feel any confusion as to which lane was the correct one with only scenarios 3, 4, and 7, which featured both wet and dry weather conditions along with daytime and nighttime lighting, presenting a slightly higher number of responses that selected yes. When looking at confidence levels many felt confident in the majority of scenarios presented other than scenarios 4, 7 and 10, which were during dry and wet weather conditions with scenarios 4 and 10 featuring nighttime lighting conditions and scenario 7 with daytime, in which there was a greater range of confidence levels for the participants. Lastly, regarding comfortability in the roadway scenario presented many participants responded similarly as the confidence levels with scenarios 4, 7, and 10 once again presenting lower comfort levels.

Lastly lighting and weather conditions were looked at for the scenarios with multiple choice and open-ended responses asked in the survey. This tasked the participant with answering questions based on which lighting and weather condition made it harder to follow the correct lane markings and finally which combination made it hardest. Table 6.8 summarizes the results for this section of the survey.

TABLE 6.8 LIGHTING AND WEATHER CONDITION RESULTS

Response	Scenario (% out of 100%)											
	1 Dry/Day/Hydroblasting	2 Dry/Day/Grinding	3 Dry/Day/Hydroblasting	4 Dry/Night/Hydroblasting	5 Dry/Night/Grinding	6 Dry/Night/Hydroblasting	7 Wet/Day/Hydroblasting	8 Wet/Day/Grinding	9 Wet/Day/Hydroblasting	10 Wet/Night/Hydroblasting	11 Wet/Night/Grinding	12 Wet/Night/Hydroblasting
Q1: Which lighting condition made it harder to follow the correct lane markings?												
Day	10.0	10.0	10.0	10.0	10.0	10.0	10.0	3.3	0.0	0.0	6.7	10.0
Night	90.0	90.0	90.0	90.0	90.0	90.0	90.0	93.3	100.0	100.0	93.3	90.0
Q2: Which weather condition made it harder to follow the correct lane markings?												
Dry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wet/Rainy	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Q3: Which combination of lighting and weather conditions made it the hardest to follow the correct lane markings?												
Daytime Dry	3.3	3.3	3.3	3.3	3.3	3.3	3.3	0.0	0.0	0.0	3.3	3.3
Daytime Wet	6.7	6.7	6.7	6.7	6.7	6.7	10.0	6.7	6.7	6.7	10.0	10.0
Nighttime Dry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nighttime Wet	90.0	90.0	90.0	90.0	90.0	90.0	86.7	93.3	93.3	93.3	86.7	86.7

Looking at the lighting and weather conditions that were presented to the participants an overwhelming majority selected night as the lighting condition that made it harder to follow the correct lane markings with a response rate of 90% or higher. Regarding the weather conditions presented, the participants all selected wet/rainy at a 100% rate for the scenarios presented. When asked which combination of lighting and weather condition made it the hardest to follow the correct markings the majority responded to the combination of nighttime and wet/rainy conditions with a response rate of almost 90% or higher.

6.5.3.3 Post-video Questionnaire Results

All participants were asked to respond to a post-video questionnaire after they completed the experiment. These questions targeted participant demographic information including gender, age, race, income, and education level. Most participants were female and under 45 years of age but there was still some representation for those over the age of 45. Most participants identified as white or Caucasian and had at least a four-year degree or higher. Within income level it was dispersed throughout the range given with most having a household income between less than $25,000 to $100,000. Table 6.9 presents the detailed responses by the participants.

TABLE 6.9 POST-VIDEO DEMOGRAPHIC QUESTIONNAIRE RESULTS

Category	Demographic Variable	Count	Percentage
Gender	Female	24	60.0
	Male	14	35.0
	Non-binary/Third gender	2	5.0
	Prefer not to answer	0	0.0
Age	18 – 24	11	27.5
	25 – 34	12	30.0
	35 – 44	7	17.5
	45 – 54	4	10.0
	55 – 64	4	10.0
	65+	2	5.0
Race	American Indian or Alaska Native	0	0.0
	Asian	9	22.5
	Middle Eastern	0	0.0
	Black or African American	0	0.0
	Hispanic or Latino/a	0	0.0
	White or Caucasian	29	72.5
	Other	2	5.0
	Prefer not to answer	0	0.0
Annual Income	Less than $25,000	9	22.5
	$25,000 to less than $50,000	5	12.5
	$50,000 to less than $75,000	9	22.5
	$75,000 to less than $100,000	5	12.5
	$100,000 to less than $200,000	10	25.0
	$200,000 or more	1	2.5
	Prefer not to answer	1	2.5
Education Level	High school diploma or GED	2	5.0
	Some college	7	17.5
	Trade/vocational school	0	0.0
	Associate degree	2	5.0
	Four-year degree	13	32.5
	Master's degree	13	32.5
	PhD degree	3	7.5
	Prefer not to answer	0	0.0

Table 6.10 also includes results from the post-video questionnaire that focused on the driving experiences of the participants. These questions focused on how often the participant drove in a week with an even dispersion between the options with most selecting 2-4 times per week. A large portion of the participants drove 10,000 miles or less and the majority did not have a lane

deviation feature for their vehicle. For those who did it was found that they used it when driving. The survey also looked at if participants carpooled with about half answering yes.

TABLE 6.10 POST-VIDEO DRIVING QUESTIONNAIRE RESULTS

Category	Demographic Variable	Count	Percentage
Drives per Week	1 time per week	4	10.0
	2 – 4 times per week	15	37.5
	5 – 10 times per week	11	27.5
	More than 10 times per week	10	25.0
Yearly Miles Driven	Less than 5,000	12	30.0
	5,000	8	20.0
	10,000	12	30.0
	15,000	4	10.0
	More than 15,000	4	10.0
Lane Deviation Feature (LDF)	Yes	4	10.0
	No	34	85.0
	Don't know	2	5.0
LDF Use	Always	3	7.5
	Often	1	2.5
	Don't have	36	90.0
Carpool	Yes	18	45.0
	No	22	55.0

6.6 SUMMARY

This chapter summarized the video experiment conducted in the OSU Driving and Bicycling Simulator Laboratory. The experiment consisted of multiple scenarios of footage from three different locations in a combination of different weather and lighting conditions that was captured from a dashboard camera. These weather and lighting conditions consisted of dry and wet weather conditions and daytime and nighttime lighting conditions. There were 12 scenarios in total that were shown to participants in a variety of combinations for the three different locations that featured hydroblasting and grinding as the removal method used on the pavement markings. These combinations were compiled into four different sets featuring nine scenarios each. Participants were tasked with viewing a set of the scenarios while wearing eye tracking equipment to track the duration of time that passed when focusing on any removed pavement markings titled total fixation duration (TFD). A survey was provided pre- and post-video footage along with a concurrent survey that was taken after each scenario was viewed. These surveys focused on demographics, experience with driving, and comfortability and confidence in the roadway that the participant had just seen. The demographics of the participants ranged in age from 19 to 76 years of age with an average age of 35.7 years. Overall, the hydroblasting removal method was found to have a significantly higher TFD than that of the grinding removal method in all weather and lighting conditions although it should be noted that the quality of the hydroblasting removal is dependent on equipment, training and experience of operators, and the care taken by contractors on-site during construction. When looking at weather conditions it was found that during dry weather condition participants focused on the removed markings more often than during wet weather conditions.

7.0 CONCLUSION AND RECOMMENDATIONS

The purpose of this research was to identify the differences between two different pavement marking removal methods to determine which would cause the least driver confusion when encountered on the roadway. There is a clear gap in our understanding of which method would work best to reduce driver confusion as there is not much in terms of literature or research available. Therefore, this research provides empirical evidence to better understand the relationship between drivers and the pavement markings they encounter on the roadway after removal.

To achieve the research goals, the following experiments were conducted:

- Field video data collection at 5 locations in Oregon which included dashboard video and CountCam video. The data collection captured different lighting and weather conditions such as daytime, nighttime, dry, and rainy/wet conditions. The field data was used to create the different video clips that participants viewed to determine driver confusion when encountering pavement markings that had been removed using hydroblasting or grinding.

- A total of 41 participants were tasked with viewing videos of the different scenarios containing the different lighting and weather conditions at three locations. The collected data were used to investigate how often the drivers looked at the removed pavement markings.

From this experiment, the following primary findings were observed:

- The participants looked at the hydroblasting markings significantly more than the markings created by grinding.

- The combination of nighttime and rainy/wet conditions made it harder for participants to see the roadway.

- Observed lane departures occurred more frequently during the wet/rainy conditions.

- Participants focused on the removed pavement markings more often during dry weather conditions.

An extended summary of the primary findings and results from the experiment is included in the subsections below.

7.1 FIELD STUDY

The collected video at the five sites was watched by researchers and several performance measures were extracted based on the Society of Automotive Engineers (SAE, 2000). During the selected observation periods that encompassed the varying weather and lighting conditions, each vehicle that traversed the section of the roadway under observation was recorded along with the date, timestamp, lighting condition, and weather condition. Additionally, lane departure type, duration and direction were also recorded.

Overall, across the five sites, 18,270 vehicles and 1,664 lane departures (9.1%) were observed during the observation periods. Among the sites, the highest proportion of lane departures were observed at OR 99 in Ashland (15.3%), OR 126B in Springfield (11.2%), US 20 in Albany (8.2%), US 101 in Warrenton (3.3%), and OR 99E in Albany (3.2%). At two sites OR 99 in Ashland and OR 126B in Springfield, higher lane departure rates (greater than ten percent), were observed possibly due to obstacles on the shoulder and a lack of oncoming vehicles on the opposite side of the removed lane marking during the data collection period.

The highest proportion of lane departures were type A (32.7%), followed by type G (27.2%), and type B (13.5%) and type E (12.6%). The proportions of the types of lane departures at each site varied. At three of the five sites (OR 99, Albany; US 101, Warrenton; OR 99, Ashland) the proportions lane departures were higher when it was wet. The average lane departure durations were between 2.0 and 3.3 seconds. Higher durations of lane departures were observed at the OR 99 in Ashland site, due to the vehicles shifting left through the study area and at the US 101 site in Warrenton due to a vehicle that was stopped in that position due to traffic.

7.2 LABRATORY EXPERIMENT

An experiment was conducted in the OSU Driving and Bicycling Simulator laboratory to further investigate the relationship between drivers when encountering removed pavement markings. The chosen scenarios were used based on how the different locations would work well together to reduce issues.

A total of 41 participants were recruited from the Corvallis, Oregon and surrounding area including 14 males, 25 females and 2 non-binary identifying persons. The participant ages range from 19 to 76 years of age with an average of 35.9 years and a standard deviation of 15.2 years. The participants were asked to view the video clips containing 9 different scenarios and to take a survey. With the eye tracking equipment malfunctioning for one participant, the final analyzed sample was 40 participants with 14 males, 24 females and 2 non-binary identifying persons. The participants completed a pre- and post-drive questionnaire along with a questionnaire that was provided after each scenario was viewed. These questionnaires collected eligibility and driving experience before the experiment, comfort, and confidence level in the roadway during the experiment, and demographic information after the experiment.

According to the study results, the hydroblasting removal method was found to be the one that drivers looked at most often when encountering on the roadway indicating that the markings were more prominent after removal. The eye movement data was used to examine participants' visual attention on the roadway when observing the removed markings and determine the total amount of time that was spent looking at the markings. The results obtained show that the TFD was significantly longer for both locations that featured the hydroblasting removal method over the one location that featured the grinding removal method. This was true for each different weather and lighting condition along with the combination of weather and lighting. The longer TFD time paired with the high conspicuity of the visual presentation indicated that participants were able to focus on the roadway and determine which lane markings were the correct ones to follow. This TFD may also be related to the location and age of the project where these were implemented, as the projects utilizing hydroblasting were much newer and more prominent on the roadway versus the projects involving the grinding removal method, which were older and farther over to the left side of the driver view. As many of the locations used for data collection featured temporary pavement markings that had been placed in the same lateral position as the removed pavement markings, differentiation was difficult to quantify. Participants were provided with scenarios that featured the pre- and post-construction separately which allowed for differentiation of the TFD and participant reaction to the two configurations at the same location.

The weather condition that was found to have a higher TFD was dry which was surprising as it contrasted with survey answers which predominantly featured wet weather as the one that participants found to be more distracting. When regarding this contrast between what was observed with the eye tracking equipment and answered by participants in the survey it can only be speculated that participants based their answers on driver confidence rather than on what they noticed of the roadway more frequently.

7.3 LIMITATIONS OF THE RESEARCH

This research delivers data-driven results to investigate the relationship between drivers and different methods used to remove pavement markings. The results aim to provide valuable recommendations for transportation practitioners to consider when deciding which removal method to use when removing pavement markings. These recommendations should be considered in the context of the limitations of this research.

The observed lane departure data does not provide the context of why the lane departure occurred and it may or may not be a related errors in navigation and control due to the pavement marking removal.

There were some limitations related to the data collection that occurred as it was conducted with a driver vehicle instead of having the participant drive through a location themselves. This reduced the authenticity of the participant encountering the removed pavement markings and reacting as a driver instead of as a viewer.

The number of locations and types of removal methods available was limited during the video collection period due to the limited availability of project sites, which resulted in only two different types of removal methods with most of the locations having the same method performed. As such it cannot be determined if hydroblasting is the best method available of all methods that are used to remove pavement markings.

Having participants watch the different scenarios followed by the same set of survey questions may have introduced bias as the participants started to recognize that they should look for something that might have been wrong with the roadway and began at times to actively do so. The potential limitation of fatigue in viewing the videos and survey taking might have influenced participant performance over the course of the experiment if they felt bored or tired due to the repeated measures.

7.4 RECOMMENDATIONS FOR PRACTICE

Based on the findings of this research which explored hydroblasting and grinding removal methods, the following recommendations are made for the Oregon DOT to consider:

- Prioritize adoption of the hydroblasting pavement removal method over the grinding method, since the hydroblasting method had a notably lower departure rate and a substantial increase in total fixation duration. While a higher TFD might seem counterintuitive in determining that hydroblasting was the better performing removal method, it was found that projects featuring the method also exhibited a notably lower departure rate when evaluating field behavior. These findings for the hydroblasting removal method highlight the potential for improved safety and operational efficiency in pavement removal projects, which is pivotal for the agency's objectives and long-term implementation.

- The hydroblasting removal method could be considered as an allowance on the final layers based on the ODOT standard which limits grinding to the final layer for pavement marking removal.

- Considering the observed increase in departure rates and elevated visual scanning by drivers during nighttime scenarios, the research team recommends considering the use of supplemental road reflectors. These measures may improve lane keeping behavior of drivers during nighttime driving.

- Despite the lower rate of departure incidents during rainy weather, the visual attention data indicated that when subjects were exposed to the grinding method, scanning patterns decreased due to reduced visibility. As such, the use of portable changeable message signs (PCMS) might alert drivers of the pavement removal and potential confusion. Any high conspicuity markings, such as a reflective polarizer mirror (RPM), that attract greater visual attention will result in better driver positioning along the roadway.

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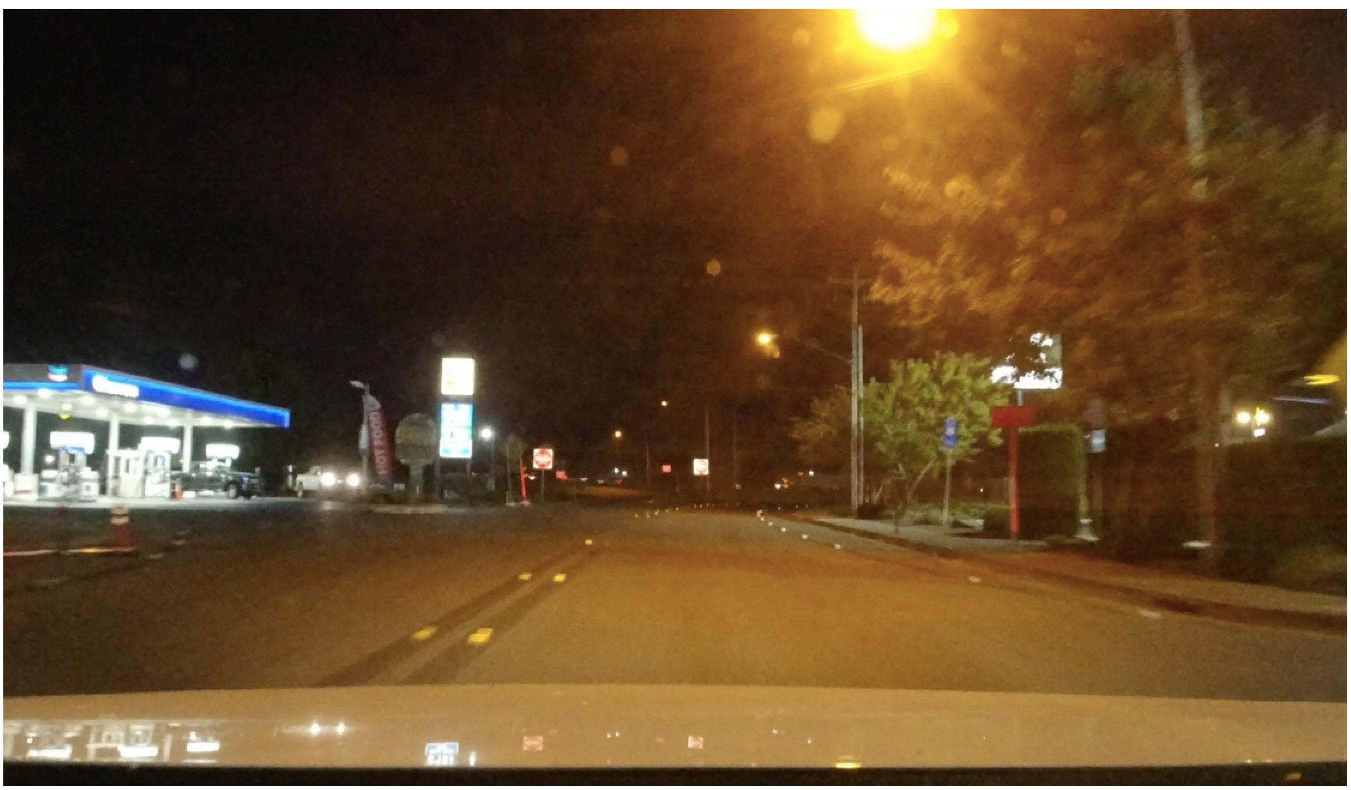
APPENDIX A: INDIVIDUAL SCENARIOS

Images for the scenarios provided to participants:

SCENARIO 1 –AIRPORT ROAD AND HIGHWAY 99 IN ALBANY DRY/DAY/HYDROBLASTING

SCENARIO 2 – SISKIYOU BOULEVARD IN ASHLAND DRY/DAY/GRINDING

SCENARIO 3 – SANTIAM HIGHWAY IN ALBANY DRY/DAY/HYDROBLASTING



SCENARIO 4 - AIRPORT ROAD AND HIGHWAY 99 IN ALBANY DRY/NIGHT/HYDROBLASTING

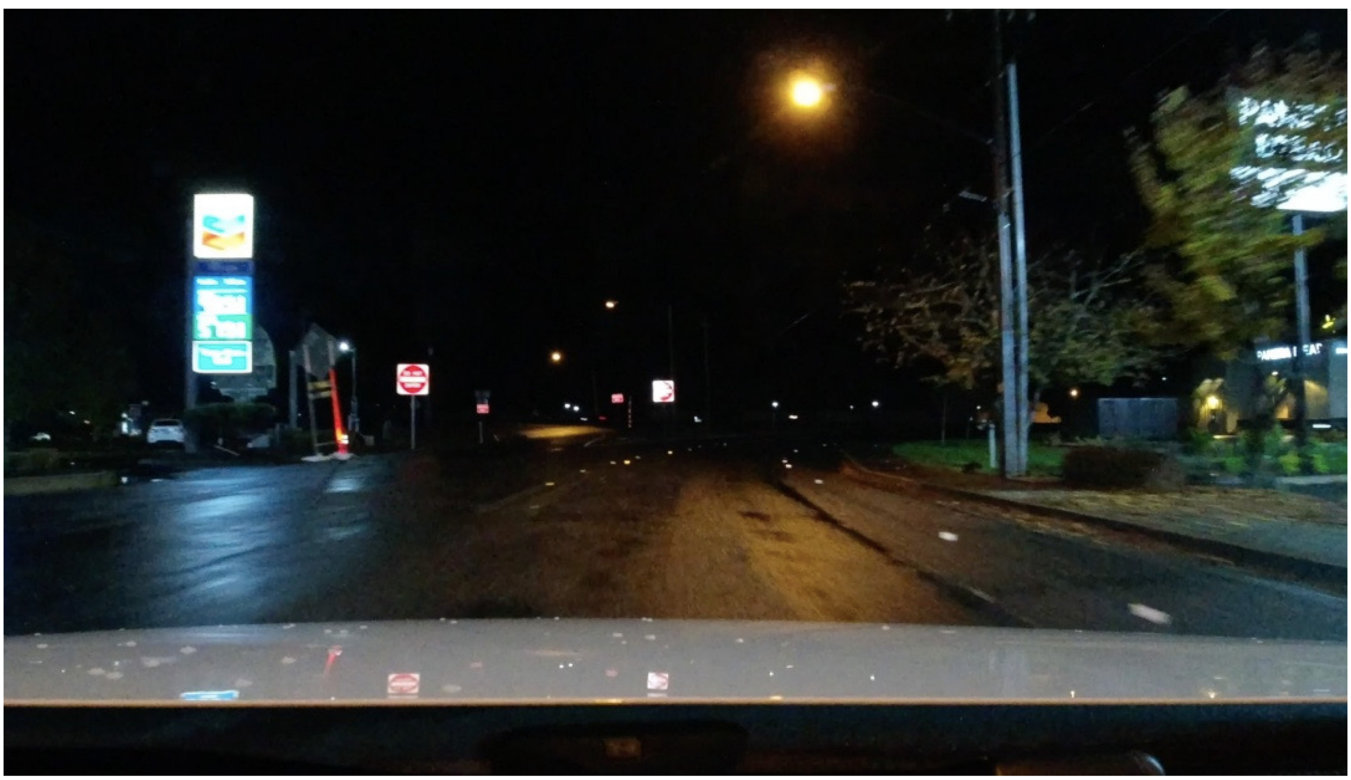
SCENARIO 5 - SISKIYOU BOULEVARD IN ASHLAND DRY/NIGHT/GRINDING

SCENARIO 6 - SANTIAM HIGHWAY IN ALBANY DRY/NIGHT/HYDROBLASTING

SCENARIO 7 - AIRPORT ROAD AND HIGHWAY 99 IN ALBANY WET/DAY/HYDROBLASTING

SCENARIO 8 - SISKIYOU BOULEVARD IN ASHLAND WET/DAY/GRINDING

Scenario 9 - Santiam Highway in Albany Wet/Day/Hydroblasting



Scenario 10 - Airport Road and Highway 99 in Albany Wet/Night/Hydroblasting

SCENARIO 11 - SISKIYOU BOULEVARD IN ASHLAND WET/NIGHT/GRINDING

SCENARIO 12 - SANTIAM HIGHWAY IN ALBANY WET/NIGHT/HYDROBLASTING