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FHWA-WY-16/03F

SAFETY EFFECTIVENESS OF REGULATORY HEADLIGHT SIGNS IN WYOMING—PHASE 1

Interim Report—Phase 2

JANUARY, 2016

REPORT BY:

Department of Civil and Architectural Engineering

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16. Abstract

Although Daytime Running Lights (DRLs) may have a significant impact on increasing vehicle conspicuity during different times of the day, their effect on overall safety is still up for debate. A recent study by the U.S. Department of Transportation (USDOT) National Highway Traffic Safety Administration (NHTSA) showed that DRLs offer no statistically significant reduction in the frequency or severity of crashes analyzed. There are functional issues with using automatic DRLs only: drivers with automatic DRLs often do not turn on their low-beam headlights in adverse weather conditions and at dusk or dawn. This is especially dangerous because the taillights do not come on until the low-beam headlights are turned on manually. This becomes more important at hazardous roadway sections that require both headlights and taillights.

This project investigated the impact of the compliance rate, and the density of the DRL technology on the safety benefits of regulatory headlight signs on mountainous and non-mountainous rural two-lane highways. The safety effectiveness of headlight signs was examined based on DRLs-equipped and non-DRL- equipped vehicles. Simple odds and ratio of odds ratios were utilized to adjust for a variety of exogenous factors. Four different scenarios were considered in analyzing crash data. A case-control method was used to compare crashes for a set of passenger vehicles equipped with DRLs and vehicles without DRLs on roadway sections with and without headlight signs. The low compliance rate to the mandatory headlight sign may result in misleading conclusions about the safety benefits of the regulatory headlight signs. A careful analysis should be carried out to quantify the actual benefits. Development of social media campaigns might be necessary to raise public awareness about the importance of complying with the mandatory headlight use signs.

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

EXECUTIVE SUMMARY

The use of Daytime Running Lights (DRLs) may have a demonstrable impact on increasing vehicle conspicuity during daytime, dusk, and dawn; however, their effect on overall safety for different road users is still up for debate. Inclement weather events such as fog, snow, ground blizzard, slush, rain, and strong wind, etc., affect roadways by impacting pavement conditions, vehicle performance, visibility, and driver behavior. Road-user characteristics are among the most important elements influencing the driving task—the ability to see objects that are in motion relative to the eye "dynamic visual acuity" and the reaction process are of utmost importance for safe driving. DRLs are a low-cost safety feature that increase visual contrast between vehicles and their background, which, in turn, enhance their conspicuity and detectability. Drivers with DRLs often do not turn on their low-beam headlights in adverse weather conditions and at dusk or dawn. This is especially dangerous because the taillights do not come on until the low-beam headlights are turned on. This becomes more important in hazardous roadway conditions that require both headlights and taillights.

The main goal of this project was to investigate the safety benefits of using regulatory headlight signs in Wyoming and to provide guidelines of the best implementation strategy of control devices (e.g., signs with orange flags, yellow strip, or flashing beacons) to increase the compliance rate and reduce fatalities and injuries. With the increase of automatic Daytime Running Lights (DRLs) and automatic low-beam headlights, many drivers forget to manually override the automatic headlights' setting and manually turn on the headlamps. WYDOT recommended to drop the flashing beacon option to reserve it for messages of high priority, leaving flashing beacons on, most of the time might also dilute their impacts on road users.

The study has two phases. Phase 1, which is completed, was directed at tackling key issues regarding the safety benefit of using headlight signs. Phase 2, which is ongoing, is focused on testing various signs in a driving simulation-controlled environment, and in real-life field testing. Driving simulators have been used in many prior studies as they are a very economical and safer option compared to field studies. Driving simulators have also proven to be a very cost-effective

tool to examine a broad variety of driver behavior as such experiments in real-life highway conditions would put drivers at risk.

Seven locations in Wyoming have the “TURN HEADLIGHTS ON FOR SAFETY NEXT XX MILES” sign. These locations are classified as principal or minor arterial roads. Three data sets were used to accomplish Phase 1 tasks. The first data set—Vehicle Identification Number (VIN)—was obtained from WYDOT. The second data set was extracted from the Critical Analysis Reporting Environment (CARE) software. In addition, Annual Average Daily Traffic (AADT) was obtained for the study roadways. The final data set was compiled using the three mentioned data sets.

Crash data are the foundation of traffic safety analyses. Evaluating the data using analytical methods helps to identify hidden associations between its various factors. Moreover, crash data are utilized to better understand where, when, and how the crashes occurred, the type of crash that occurred, and the characteristics of the people involved, whether behind the steering wheels or part of the crash surroundings. This enables transportation agencies to identify the most cost-effective strategies and treatments to reduce the frequency and severity of crashes. Based on crash history and future crash prediction, identifying and ranking “hotspots” (sections of highways with increased risk of head-on, opposite-direction sideswipe, and lane-departure crashes) were performed. Evaluating the safety effectiveness of DRL-equipped and non-DRL vehicles on roadway sections with and without regulatory headlight signs was also accomplished.

Field-data collection was a major part of the study; it took place to investigate driver compliance to headlight signs. The purpose of the data collection is to quantify the existing condition of compliance rate at the locations with headlight signs and to examine if there is any difference in compliance rate among locations. The compliance rate analysis was conducted for non-DRL-equipped vehicles. The total average compliance rates were twenty five percent and thirteen percent, respectively, for headlight-sign sections and non-headlight sections. Some drivers tend to turn on their headlights while driving on highways regardless of the roadway and weather conditions. Though both percentages are low, the percentage of vehicles complying with the headlight signs is higher than those in non-headlight sections. If an assumption that thirteen percent of all roadway users who always turn on their headlights on sections with or without headlight signs could be made, then it could be assumed that only twelve percent of road users are complying with headlight signs. According to the results from Phase 1, it is recommended to increase the frequency of the headlight signs to two signs per each 10-mile segment. It is also recommended to use the proposed design with a yellow strip across the top reading “Turn Headlights On,” in combination with a large headlight symbol in the lower portion of the sign, to improve the visibility of these signs. As will be explained in this report, the use of all-white signs with black lettering do not show up as well during conditions with white backgrounds, such as snow, fog, ground blizzard, etc.

Phase 2 is focused on testing various signs in a driving simulation-controlled environment. Multiple scenarios were developed simulating actual roadway conditions. The driving simulator experiment is being used to assess the visibility and recognition of various designs of headlight signs. The goal of this task is to examine the judgment and recognition of these signs as well as other vehicles with and without DRLs under inclement weather for different age groups and driving experience. Subjects volunteering for the driving simulator experiments were invited by e-mail or personal conversation; additionally, flyers were distributed in Laramie, and Cheyenne.

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LIST OF ACRONYMS/ABBREVIATIONS

AADT	Annual Average Daily Traffic
AADTT	Annual Average Daily Truck Traffic
AASHTO	American Association of State Highway and Transportation Officials
CARE	Critical Analysis Reporting Environment
CCR	Curvature Change Rate
CV	Coefficient of Variation
DALY	Disability-Adjusted Life Year
DRL	Daytime Running Lights
DMS	Dynamic Message Signs
DS	Driving Simulator
EB	Empirical Bayes
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
FMVSS	Federal Motor Vehicle Safety Standards
GES	General Estimates System
GIS	Geographic Information Systems
GM	General Motors
HAZMAT	Hazardous Materials
HD	High Definition
HSM	Highway Safety Manual
IRB	Institutional Review Board
ISA	Internet Scene Assembler
KDE	Kernel Density Estimation
LED	Light-Emitting Diode
MP	Milepost
MUTCD	Manual on Uniform Traffic Control Devices
NHTSA	National Highway Traffic Safety Administration
OR	Odds Ratio

PDO	Property Damage Only
PI	Potential of Improvement
RTM	Regression To The Mean
SHSP	Strategic Highway Safety Plan
SPF	Safety Performance Function
VIN	Vehicle Identification Number
WYDOT	Wyoming Department of Transportation
WYOSIM	University of Wyoming Driving Simulator Lab

CHAPTER 1- BACKGROUND

Road crashes have a devastating impact on society, causing loss of life, bodily injuries, and damage to property. In 1990, road traffic injuries ranked 9th for the 10 leading causes of death in the world based on a disability-adjusted life year (DALY). It is estimated that road traffic injuries will be ranked as the third leading cause of death in the world by 2020 [1]. Traffic safety research has a big role in mitigating the increased risk on our roadways via various countermeasures. One of the roadway safety treatments is the regulatory headlight signs. The purpose of these signs is to require roadway users to turn on headlights during daytime to increase vehicle conspicuity. It is mandatory - by law - for drivers to turn on headlights whenever they enter regulatory headlight-sign sections.

The use of Daytime Running Lights (DRLs) may have a demonstrable impact on increasing the vehicle conspicuity during daytime, dusk, and dawn; however, their effect on overall safety for different road users is still up for debate [2]. There are contradicting findings regarding whether the use of DRLs has significant safety benefits to reduce certain types of crashes. Elvik, 1996, [3] utilized the log-odds meta-analysis method to evaluate safety effectiveness of DRL using data collected from 17 studies. The use of DRLs was estimated to result in a ten to fifteen percentage reduction in the number of multi-vehicle daytime crashes. A 2004 report by the National Highway Traffic Safety Administration (NHTSA) revealed some safety benefits of DRLs [4]. The generalized simple odds, a conventional statistical technique, was used to analyze 1995–2001 data from the NHTSA Fatality Analysis Reporting System (FARS) and the General Estimates System (GES). The data revealed that DLRs were proven to reduce opposite-direction daytime fatal crashes and opposite direction/angle daytime non-fatal crashes by five percent each. The study also found a twelve percent reduction in crashes involving non-motorists, i.e., pedestrians and cyclists, and a twenty three percent reduction in opposite fatal crashes of a passenger vehicle with a motorcycle. It is worth mentioning that none of these results were found to be statistically significant using odds ratio when controlling for a variety of factors other than the presence or absence of DRLs. In a recent—contradicting—large-scale study by NHTSA (2008), DRLs were found to be statistically insignificant in reducing the types of crashes studied, except for a nearly fifty six percent reduction in the involvement of light trucks/vans in two-vehicle crashes [5].

Inclement weather such as fog, snow, ground blizzard, slush, rain, and strong wind, etc., affect roadways by impacting pavement conditions, vehicle performance, visibility, and driver behavior. Road-user characteristics are among the most important elements influencing the driving task—the ability to see objects that are in motion relative to the eyes' "dynamic visual acuity" and the reaction process are of utmost importance for safe driving. DRLs are a low-cost safety feature that increase visual contrast between vehicles and their background, thus enhancing their conspicuity and detectability. There are two main ways to implement DRLs: (1) requiring drivers to manually turn on their low-beam headlamps; or (2) the use of DRLs that automatically switch on when a vehicle's ignition is started. Automatic DRLs can be categorized according to the type of lamp used:

1. Low-beam headlamps or fog lamps operated at full or reduced intensity.
2. High-beam headlamps operated at reduced intensity.
3. Steady-burning operation of the front-turn signals.
4. Low-wattage light-emitting diode (LED).

It should be mentioned that there are functional issues with using automatic DRLs only: drivers often do not turn on their low-beam headlights in adverse weather conditions and at dusk or dawn. This is especially dangerous during such conditions because taillights do not come on unless the low-beam headlights are turned on.

While DRLs may be beneficial for certain scenarios, previous studies have been unable to document overall safety of using DRLs due to inadequacy of superior statistical techniques used [5]. NHTSA suggested re-examining the safety effectiveness of DRLs using alternative approaches. Moreover, the issue of mandating a law requiring use of low-beam headlights on certain rural two-way, two-lane roadway sections at certain times of the year and weather conditions needs further investigation. Current laws for headlight signs use are considered to be behavior-based, unlike the newly devised technology-based DRL standards, compliance to the headlight sign play an important role on the safety effectiveness of the sign.

The main goals of this project are to investigate the safety benefits of using regulatory headlight signs in Wyoming and to provide guidelines on how best to implement control devices (e.g., signs with orange flags, flashing beacons, or a bright yellow strip) to increase the use of DRLs and reduce fatalities and injuries.

The use of DRLs has become a mandatory road-safety measure in several countries. In 1990, Canada, Denmark, Finland, Hungary, Norway, and Sweden required drivers to turn on vehicle headlights at all times. This was based on studies showing that DRLs are a statistically significant countermeasure to reduce daytime, dawn, and dusk multiple-vehicle crashes (NHTSA studies in later years could not confirm this finding). The use of low-beam headlights is encouraged during winter in Ireland due to daytime low ambient light levels. Italy, Hungary, and Romania require the use of DRLs in rural areas at all times. In the past, many European countries—Germany, Spain, and France, among others—required daytime use of low-beam headlamps on certain roads at certain times of the year [6] [7] [8] [9] [10].

DRLs that automatically turn on when a vehicle is started have become standard safety features in many countries. Canada Motor Vehicle Safety Standards required all new vehicles made or imported after January 1990 to come equipped with automatic DRLs. Automakers battled this regulation because of the increased cost of adding a new front lighting device (and associated warranty) to run the low-beam headlights. The standard was updated to allow the use of reduced-wattage high-beam headlamps and permit any light color from white to amber or yellow [11]. In 2011, a European Union directive required all passenger cars and vans to come equipped with DRLs (in 2012, the mandate was extended to include trucks).

The National Highway Traffic Safety Administration (NHTSA) in 1993 permitted the use of automatic DLRs in the United States [12]. NHTSA objected to the use of high-intensity DRLs on the grounds of potential glare issues and problems with turn-signal masking. General Motors (GM) started equipping some of its vehicles with DRLs in 1995. In order to reduce the automotive manufacturing variation in the North American market, by 1997, all GM vehicles come equipped standard with DRLs. GM complied with Federal Motor Vehicle Safety Standards (FMVSS) No. 108, which limits the maximum light intensity output of DRLs to 7,000 candela (ten percent of the standard high-beam headlamp intensity). The DRL intensity output was further reduced in 1998 to 1,500 candela because of numerous complaints regarding DRL glare. In addition to glare, there are concerns that DRLs might make motorcycles, pedestrians, and bicyclists less conspicuous [13].

Many researchers studied the effect of the DRL on the traffic safety. There are contradicts among the results of these studies. Some studies show that using DRL would reduce certain crashes types by increasing the vehicle conspicuity, which would lead to improve the roadway safety. Other studies shows that using DRL has no effect or increases rear end crashes.

Gordon et al. (1993) found a twenty eight percent reduction in DRL-relevant daytime two-vehicle crashes and fifteen percent reduction in crash types [14]. Farmer and Williams (2002) analyzed multiple-vehicle daylight crashes in nine states over four years and found a three percent reduction in crashes when DRLs were used [15]. Also Michael et al. (2011) shows that eight percent crash reduction in daylight and twenty eight percent for dawn and dusk for fatal, two-vehicle, head-on crashes was obtained using DRL [16].

However, Theeuwes et al. (1995) concluded that the data used in the study failed to show a clear effect of DRL [17]. Elvik (1993) showed that the total number of multiple-vehicle, pedestrian, and twilight crashes were not reduced by the use of DRLs. Also, the rear end crashes increased by twenty percent. It was also stated that daytime multi-vehicle crashes were reduced only during summer by about one and half percent [18]. Additionally, a 2011 report prepared for NHTSA indicated that DRLs might have a negative impact on the environment by increasing fuel consumption [13].According to the Synthesis of Non-MUTCD Traffic Signing study conducted by FHWA [19], a wide variation in the legend and wording of signs that require road users to turn on vehicle headlights under certain conditions was found. These sign regulations depend on laws that vary from state to state. In Wyoming, State law requires headlights to be on one-half hour after sunset to one-half hour before sunrise, and when persons or vehicles on the highway are not clearly discernible at a distance of 1,000 feet because of insufficient light or unfavorable weather conditions (Wyoming State Legislature, 2015). Therefore, the FHWA added a new section titled “Headlight Use Signs” in the 2009 edition of the Manual on Uniform Traffic Control Devices for Streets and Highways [20] to provide increased uniformity of the signs for road users. The FHWA did not adopt the “TURN OFF HEADLIGHTS” sign because it believed that might communicate an inappropriate message to road users during nighttime conditions.

The Federal Highway Administration (FHWA) [21] showed that fifty six percent of the traffic fatalities in 2013are attributed to lane and road departures. A roadway-departure crash includes those where a vehicle leaves its lane and runs off the road, opposite-direction sideswipe crashes, and head-on crashes. The 2012 Wyoming Strategic Highway Safety Plan (SHSP) [22] indicated that lane-departure crashes comprised seventy two percent of all severe crashes in Wyoming from 2008 to 2010, as shown in Figure 1. These types of crashes were targeted in Wyoming SHSP as a first priority to reduce fatal and serious-injury crashes. These most severe crashes are often dominated by distracted driving, failure of a driver to notice another vehicle, and poor visibility during inclement-weather conditions.

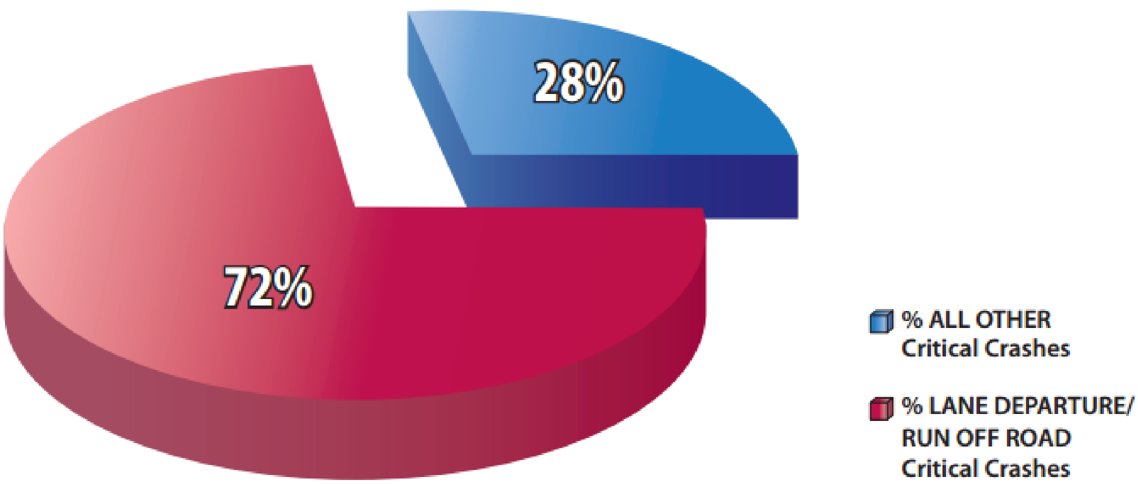

Figure 1. Chart. Percentage of lane departure/run off road in critical crashes (2008–2010) (Source: Wyoming Strategic Highway Safety Plan, 2012)

Team members of Wyoming SHSP analyzed Wyoming crash data and determined that the following six "safety emphasis areas" represented the greatest opportunity to reduce critical crashes: (1) lane- and road-departure crashes; (2) use of safety restraints; (3) impaired driving; (4) speeding; (5) curve crashes; and (6) young drivers (25 and under).. Of these six, lane departure consistently produced the highest number of crashes from 2002 to 2010 as illustrated in Figure 2.

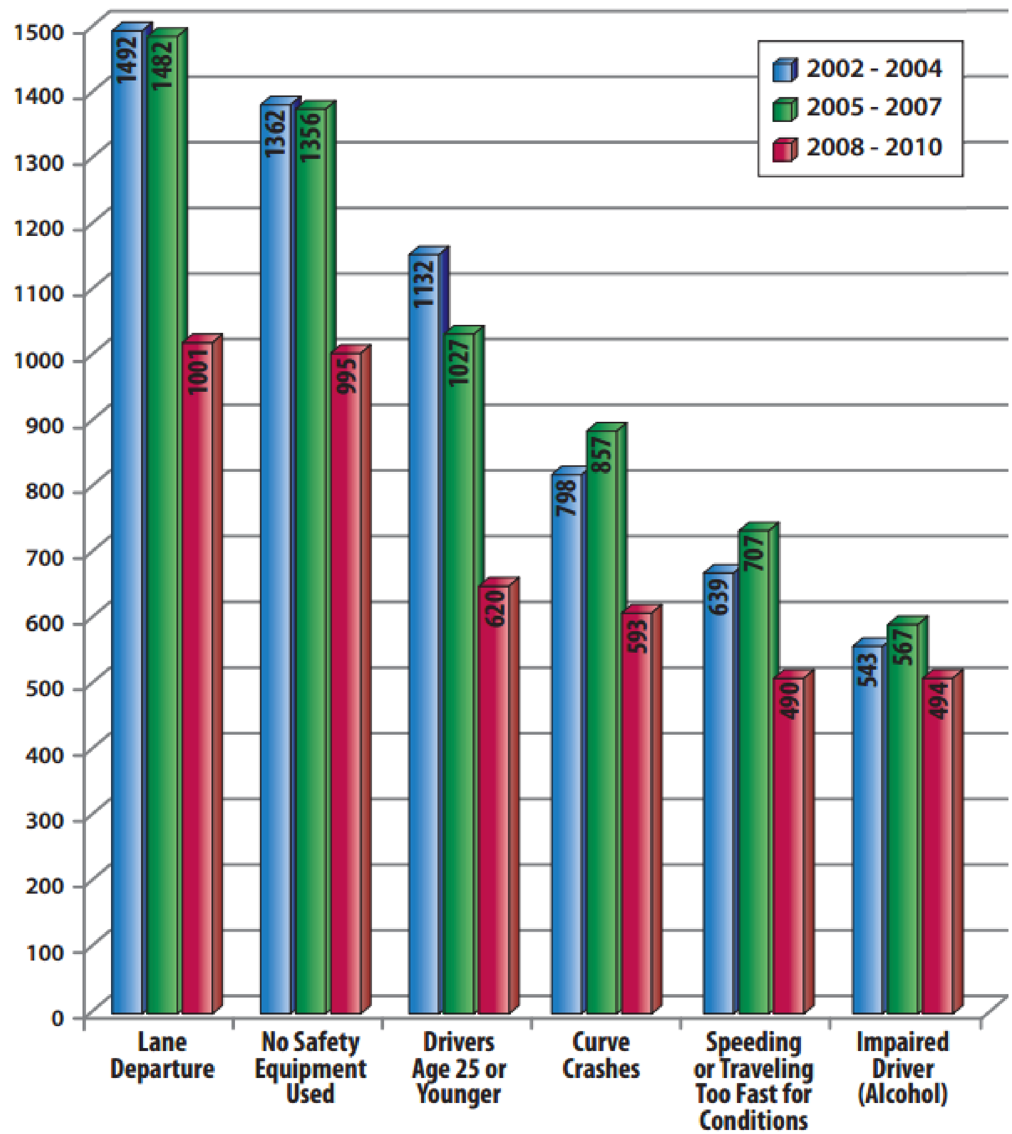

Figure 2. Chart. Wyoming's critical crashes (incapacitating injury and fatal) (2002–2010).

(Source: Wyoming Strategic Highway Safety Plan, 2012)

Crashes associated with lane departures/run-off-the-road typically result from driver fatigue, impaired driving, speeding, and distracted driving. These crashes were determined to have contributed to seventy two percent of all critical crashes, while the other five areas combined contributed to twenty eight percent of the critical crashes.

STUDY OBJECTIVES AND GOALS

As mentioned earlier, the main goal of this research proposal was to examine the safety effectiveness of using regulatory headlight use signs on certain sections in Wyoming. With the increase of automatic Daytime Running Lights (DRL) and automatic low-beam headlights, many drivers forget to manually override the automatic headlights setting and manually turn on their headlights.

The study has two phases: Phase 1 was directed at tackling key issues regarding the safety benefit of using headlight signs; Phase 2 is focused on testing various signs in driving simulation-controlled environment, and in real-life field testing.

In Phase 1, six main objectives were accomplished:

1. Synthesize existing studies of the safety benefits of DRLs.
2. Identify and rank hotspot locations of lane-departure, head-on, and opposite-direction sideswipe crashes on Wyoming roadways.
3. Evaluate the safety effectiveness of DRLs using Wyoming crash data for DRL-equipped and non-DRL vehicles and motorcycles.
4. Conduct a field study on current headlight-signed locations to collect data regarding the compliance of headlight signs use and DRLs.
5. Develop a preliminary plan for statewide sign implementation and conduct a cost/benefit analysis.
6. Implement and transfer technology.

. Driving simulators have been used in many prior studies as they are a very economical and safer option compared to field studies. The driving simulator has been proven as a very cost-effective tool to examine a broad variety of driver behaviors that would not be safe to test in real-life driving experiences on the highway. The following eight tasks will be accomplished in Phase 2:

1. Purchase, install, and calibrate the driving simulator (DS).
2. Train D.S. operators.
3. Acquire UW approvals to use human subjects.
4. Carry out comprehensive driving simulation experiments.
5. Conduct Field Testing.
6. Finalize of statewide sign implementation and cost/benefit analysis.

7. Conduct Before-After Analysis.
8. Implement and transfer technology.

The University of Wyoming Institutional Review Board (IRB) approved the use of human subjects in this research. The lead principal investigator developed the driving simulator lab at the University of Wyoming. UW and the university's Major Equipment Program funded the lab. Four graduate students received training to operate the simulator and to develop driving scenarios. The scenarios were developed to examine the best design and frequency of regulatory headlight use signs.

CHAPTER 2- DESCRIPTION OF THE STUDY AREAS

This section provides a detailed description about the locations where headlight signs are located in Wyoming. Since 1994, headlight signs were implemented in seven sections of two-lane highways in Wyoming. These signs were mainly used to help increase vehicle conspicuity during the daytime via the use of headlights and taillights. Motorists driving through sections with a headlight sign should turn on their headlights as it is mandatory by law. The locations and the different characteristics of the locations where the signs are posted are discussed below.

HEADLIGHT SIGN LOCATIONS

Seven locations in Wyoming have "Turn Headlights On for Safety Next XX Miles" signs. Table 1 and **Figure 3** show the locations, district, milepost, and implementation year of the headlight signs. The roadways having headlight signs are classified as "principal" or "minor arterial" roads. The signs located on US 287/WY 789 were the first signs implemented in Wyoming; they were placed in 1994. The last signs were implemented in 2012 on WY 220 and WY 59.

Table 1. Locations of headlight signs in Wyoming.

Number	District	Road Number	Milepost/Location	Implementation Year
1	1	US 287	402.59N, 414.83N, 414.92S, and 424.81S	2001
2	2	US 287/WY 789	2.4, 13.37*, and 13.59	1994
3	2	US 287	23 and 33	2001
4	2	WY 220	88 and 102	2012
5	4	WY 59	76 and 101	2012
6	5	US 20/26	Shoshoni to Waltman	2002
7	5	WY 28	South Pass – 24.4 and 68	2010

* The sign located at MP 13.37 was removed

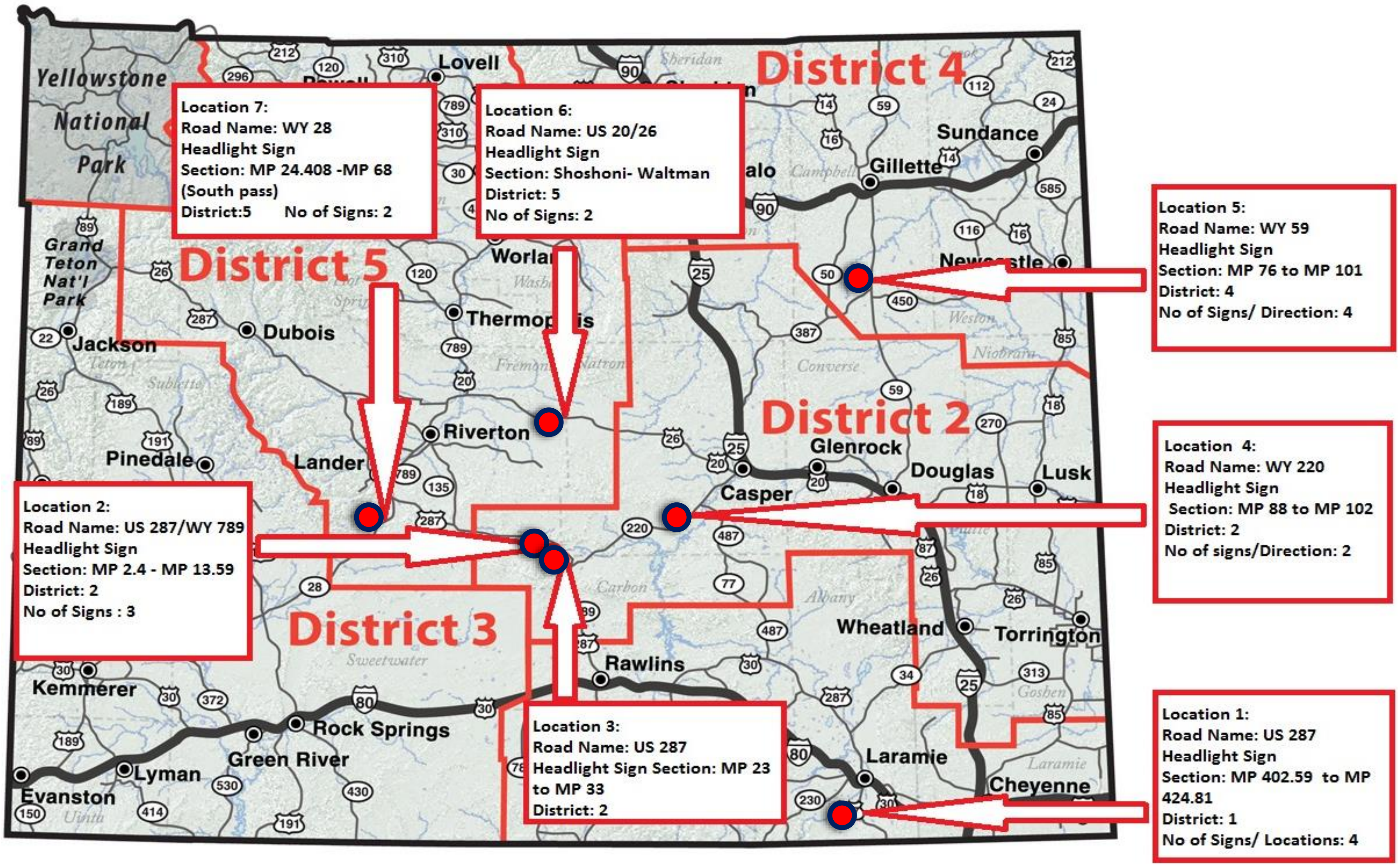

Figure 3. Graph. Map of headlight-sign locations in Wyoming.

GEOMETRIC CHARACTERISTICS OF STUDY LOCATIONS

The geometric characteristics of the regulatory headlight-sign sections are different among locations. Horizontal, vertical, and cross-section characteristics of the headlight sections were investigated and summarized.

Horizontal-Alignment and Cross-Sectional Properties

Although some of the cross-sectional characteristics such as the width of the travel way and shoulders are identical among the study sections, the characteristics of horizontal and vertical alignments are noticeably different. The curvature change rate (CCR) was used to describe the overall horizontal alignment of the roadway section. CCR is defined as the sum of the absolute values of the angular changes in the horizontal alignment of the roadway section divided by the total length of the road section. For instance, the headlight section on WY 28 over South Pass (Location 7) features the highest CCR (30.40), whereas the number of horizontal curves per mile was found to be the highest in Location 1—the headlight-sign section south of Laramie on US 287 in District 1—with 1.17 curves/miles.

Table 2 provides detailed information about the geometric characteristics of all headlight-sign locations in Wyoming.

Table 2. Horizontal-alignment properties for headlight-sign sections.

Location No.	Road Number	Begin MP	End MP	Section Length (Miles)	No. of Curves	Total No. Curves /Mile	Average Deflection Angle	CCR	Avg. Curve Length (Feet)	Avg. Radius
1	US 287	402.6	424.8	22.2	26	1.17	21.35	24.03	1,720	5,943
2	US 287/WY 789	2.4	13.6	11.2	12	1.07	10.58	11.35	626	4,119
3	US 287	23	33	10	3	0.30	7.40	2.21	865	7,583
4	WY 220	88	102	14	13	0.93	16.98	15.78	1,388	6,502
5	WY 59	76	101	25	7	0.28	9.60	2.69	800	4,911
6	US 20/26	50.7	100	49.3	24	0.48	17.11	8.33	2,240	7,400
7	WY 28	24.4	68.2	43.8	51	1.16	26.09	30.40	1,168	4,417

Vertical Alignment Properties

The geometric characteristics of vertical alignment of the sections were also investigated. It can be observed from Table 3 that US287/789 has the highest number of vertical curves per mile (1.96 crest and 1.98 sag for a total of 3.94). Section 4 on WY 220 southwest of Casper, meanwhile, has the lowest number of vertical curves/mile among all headlight-sign sections (1.21 crest and 1.36 sag for a total of 2.57).

Table 3. Vertical alignment properties for headlight-sign sections.

Location No.	Road Name	Section Length (Miles)	Crest Vertical Curve			Sag Vertical Curve		
			No.	Avg. Curve Length	Total No. Curves/Mile	No.	Avg. Curve Length	Total No. Curves/mile
1	US 287	22.2	29	940	1.30	31	657	1.40
2	US 287/ WY 789	11.2	22	1,136	1.96	23	778	1.98
3	US 287	10	14	1,051	1.40	18	456	1.80
4	WY 220	14	17	1,024	1.21	19	884	1.36
5	WY 59	25	33	900	1.32	45	493	1.80
6	US 20/26	49.3	79	466	1.60	72	432	1.46
7	WY 28	43.8	57	996	1.30	66	706	1.51

TRAFFIC CHARACTERISTICS

Table 4 shows the Annual Average Daily Traffic (AADT) and the Annual Average Daily Truck Traffic (AADTT) on the headlight sections. AADT was extracted from the 2013 automatic traffic recorder report [23]. The traffic volume on WY 59 (Location 5 between Gillette and Douglas) was found to be the highest among the study sections with a total average daily vehicle and semitrailer traffic count of 5,124. This section of highway is characterized by a high percentage (eighteen percent) of semitrailer traffic in both directions. Trucks carrying hazardous materials (HAZMAT) were observed uniquely on this roadway section compared to other headlight locations. Though

WY 220 southwest of Casper had a fewer number of semitrailers, the percentage of semitrailer passing through WY 220 was actually higher (twenty percent). Traffic on this section of highway was predominantly from Wyoming with occasional out-of-state vehicles. Traffic on Location 1—US 287 south of Laramie—was found to be diverse in composition with a similar proportion of in-state (Wyoming) and out-of-state (vast majority Colorado) vehicles. Though the percentage (eighteen percent) of semitrailers on this section of roadway equaled the percentage on WY 59 between Gillette and Douglas, there were nearly 200 less semis per day. In all seven study locations, passenger vehicles dominate roadway traffic with fairly low percentage of truck traffic. The traffic on WY 220 was predominantly found to be from Wyoming with occasionally out-of-state vehicles.

Table 4. Traffic counts in Wyoming's headlight-sign sections.

Road ID	Section		Section Length (Miles)	Average 2013 AADT	Average 2013 AADTT
	Begin MP	End MP			
US 287	402.6	424.8	22.22	3,329	603(18%)
US 287/WY 789	2.4	13.6	11.19	748	96(13%)
US 287	23	33	10	967	129(13%)
WY 220	88	102	14	3,143	642(20%)
WY 59	76	101	25	4,332	792(18%)
US 20/26	50.7	100	49.31	2,480	413(17%)
WY 28	24.4	68.2	43.791	1,347	216(16%)

SIGN CHARACTERISTICS

Seven different templates are presented in the Manual on Uniform Traffic Control Devices for Streets and Highways (U.S. Department of Transportation, 2009) [20] for the headlight use signs; however, the headlight signs currently used in Wyoming do not comply to any of the MUTCD standards. A bigger sign and font sizes were utilized in Wyoming. Figure 4 shows the headlight sign posted on US 287 at MP 402.59 just south of Laramie. The board size is nearly 118 inches by 60 inches with bigger text font than the standard sign in MUTCD, the latter of which is displayed in Figure 5. MUTCD states that the dimension of signboard along highways should be 96 by 30 inches. It was also observed that the number of words on Wyoming's signs is longer than the standard message outlined in MUTCD. Wyoming's message reads "TURN HEADLIGHTS ON FOR SAFETY NEXT XX MILES," while the standard MUTCD text is shorter with "TURN ON HEADLIGHTS NEXT XX MILES."

Figure 4. Photo. Headlights sign on US 287 south of Laramie at MP 402.59.

Figure 5. Graph. Standard headlights sign, "R16-7", in MUTCD.

CHAPTER 3- DATA DESCRIPTION AND PREPARATION

To examine the safety effectiveness of headlight signs, three data sets were used. Crash data were extracted from Critical Analysis Reporting Environment (CARE) software developed by the University of Alabama's Center for Advanced Public Safety. It should be noted that crash data in the CARE package do not include Vehicle Identification Numbers (VINs). VINs were needed to identify vehicles with automatic Daytime Running Lights (DRLs) in the crash reports. Full list of VINs for vehicles involved in crashes were obtained from WYDOT and matched to crashes in the CARE package. Ten years traffic data (2004–2013) were also acquired from WYDOT. A Total number of 106,622 crashes for the years 2004–2013 were collected with complete VINs. Filters were applied on the data sets in order to obtain the suitable data to accomplish the required objectives. Description of each data set and data preparation process are discussed below.

Only crashes with the following criteria were considered in this study: head-on and opposite-direction sideswipe crashes occurring on two-lane rural highways; crashes where the posted speed limit was equal to or greater than 55 mph; daytime-only crashes; crashes without alcohol or drug involvement; and crashes not involving animals. The data set was further split into: crashes for locations with headlight signs, and crashes for locations without headlight signs.

It is worth mentioning that head-on and opposite-direction sideswipe crashes are considered the main types of crashes targeted by headlight countermeasures. Crashes only occurring during daytime were considered in this study since headlight-sign countermeasures have no safety benefits during nighttime. Crashes because of driver impairment and animals were not a target for the headlight-sign countermeasure as well.

DATA PREPARATION

VIN data sets were used to evaluate the safety effectiveness of vehicles equipped with DRLs on sections with headlight signs. Data from a total of 106,622 crashes with their respective VIN information for 10 years (2004 to 2013) were collected in this study. Head-on and opposite-direction sideswipe crashes occurred on roadway sections with headlight signs were filtered out and analyzed separately.

Data extracted from CARE software were used to identify and rank the seven locations with headlight signs. Eleven years data, from 2003 to 2013, was extracted. The same filters utilized with the VIN data were also applied on the extracted data. The crash data set for the seventh location (South Pass) was divided into two groups by the year of placing the headlight sign. The sign was implemented on 2010, crashes occurred in the implementation year was eliminated from the data. Three to five years of crash data are required to perform EB before/after analysis [24]. Due to the recent implementation of the headlight sign on WY 28 over South Pass, only three years of crash data were collected.

Another data set was prepared for all two-way, two-lane highways in Wyoming to identify and rank the hotspot locations. Table 5 shows two-lane, two-way highways with identified target crashes.

Table 5. Wyoming two-lane highways with head-on and opposite-direction sideswipe target crashes.

Serial	Road Name	MP From	MP To	Route	# Target Crashes
1	WY 22	0	17	ML2000B	35
2	US 191	0	163	ML13B	32
3	US 278	325	425	ML23B	28
4	WY 59	0	75	ML43B	27
5	WY 220	0	117	ML21B	27
6	US 85	16	256	ML85B	23
7	US 30	0	100	ML12B	16
8	US 189	15	122	ML11B	12
9	US 26II	0	41	ML20B	12
10	WY 789	0	53	ML18B	8
11	WY 414	93	140	ML16B	6
12	WY 387	93	151	ML42B	6
13	US 14	0	100	ML31B	5
14	US 16	153	259	ML44B	5
15	US 191	500	551	ML17B	5
16	WY 120II	0	81	ML33B	4
17	US 26	0	38	ML27B	3
18	US 212	0	35	ML38B	3

Crash data were normalized using AADT as an exposure. Eleven years of traffic data were acquired from 2003 to 2013 and linked to the above-mentioned data sets.

CHAPTER 4- NETWORK SCREENING AND SPATIAL ANALYSIS

This chapter presents the network screening analysis used in this study to identify and rank the seven headlight locations as well as to identify crash hotspots on all two-way two-lane highways in Wyoming. Also, data were used to evaluate the safety effectiveness of DRL-equipped and non-DRL vehicles. Different techniques in the 2010 Highway Safety Manual (HSM) were utilized in this study. The different performance measures used in the network screening to identify hotspots are discussed below. Additionally, target crashes were mapped using Geographic Information Systems (GIS) maps for the headlight- and non-headlight-sign locations. Investigating the safety effectiveness of DRL-equipped and non-DRL vehicles in locations with and without headlight signs was also examined.

GIS CRASH MAPS FOR HEADLIGHT AND NON-HEADLIGHT LOCATIONS

The ArcGIS software was linked with the CARE software to provide an easy method to visualize crashes. The generated maps for the seven locations having headlight signs show the different crash-severity levels for head-on and opposite-direction sideswipe crashes. Different severity levels are separated using different colors (red = fatal crash; orange = injury crash; and yellow = PDO [property damage only] crash). All the mapped target crashes are for the years from 2003 to 2013.

Figure 6 shows a general map for the seven locations. The seven locations could be easily identified using the general layout map. Black boxes shown on the map represent the location of the magnified figures for each of the seven locations that will be presented below. The map shows that the 1st and 5th locations have higher crash frequencies compared to the other five locations.

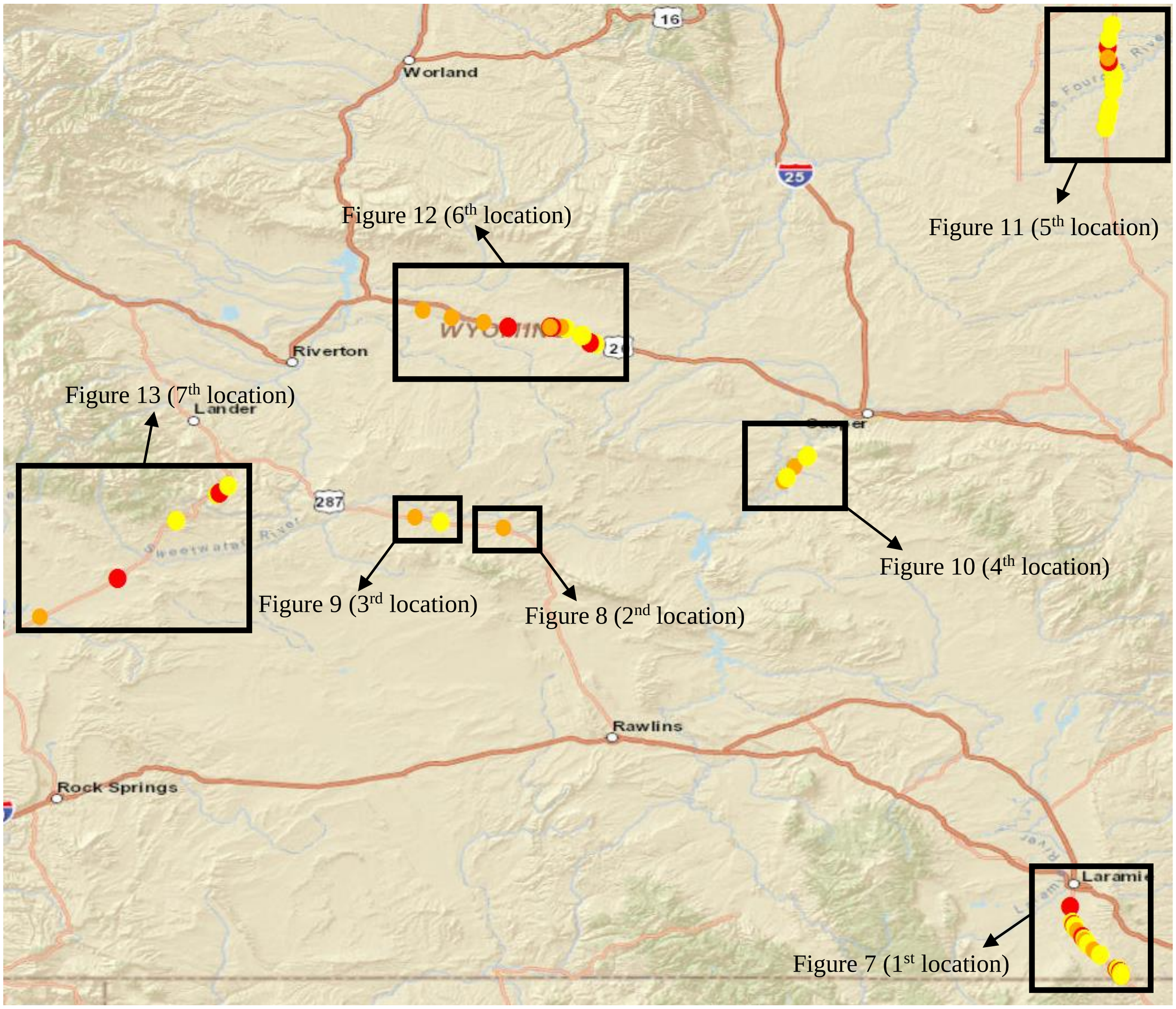

Figure 6. Graph. General map for target crashes at the seven locations with headlight signs (2003–2013).

Figure 7 shows the target crashes classified by the different severity levels (fatal, injury, and PDO) for the Location 1 south of Laramie (US 287/WY 789 MP 2.4 to MP 13.59). It shows six fatal, four injury, and nine PDO crashes occurred on the headlight-roadway section.

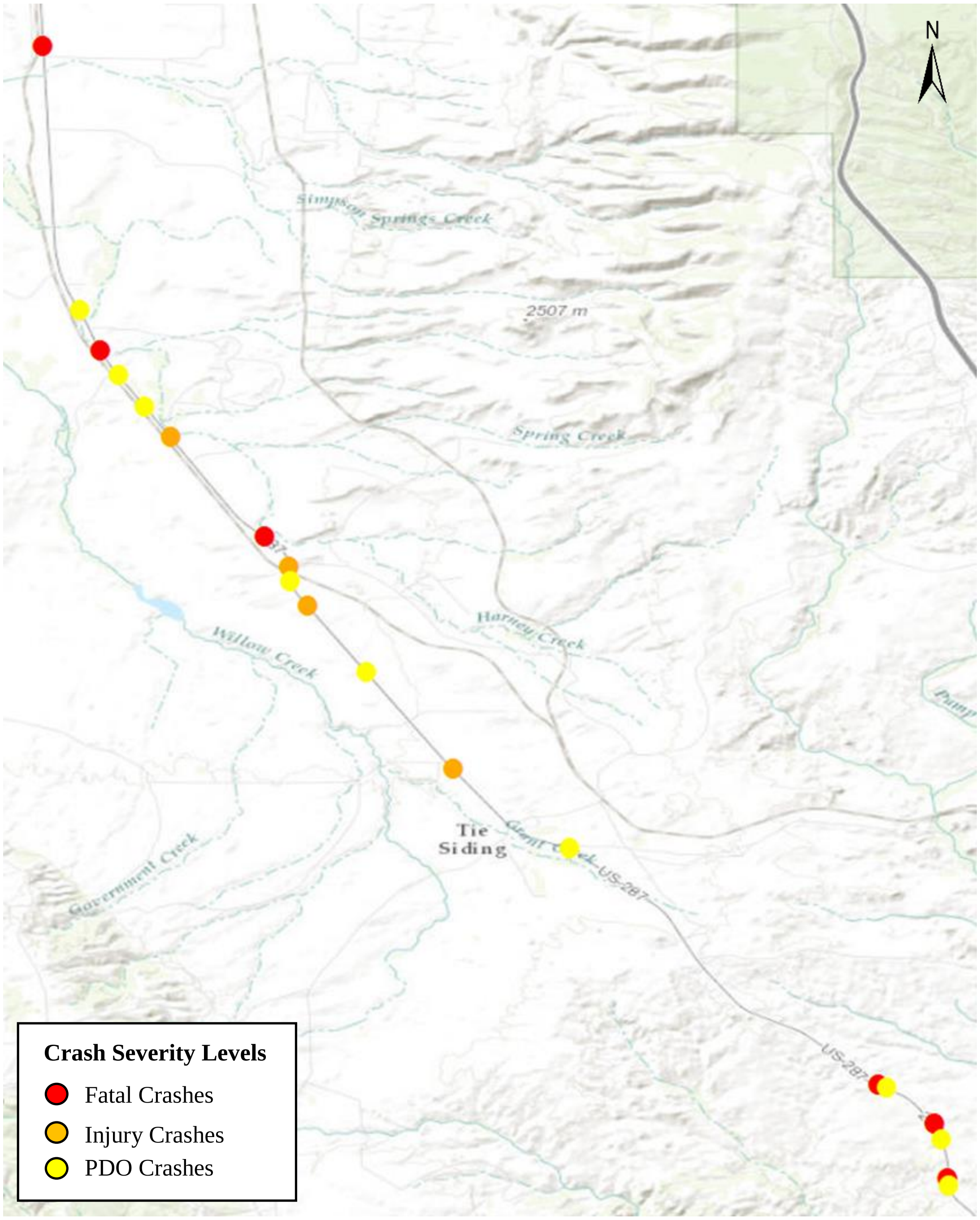

Figure 7. Graph. Target crashes for 1st location, us 287 MP 402.59–424.81 (2003–2013).

Figure 8 shows that only one injury target crash occurred at the second location, which is between Muddy Gap Junction and Jeffrey City (US 287/WY 789 MP 2.4 to MP 13.59) from 2003 to 2013.

Figure 8. Graph. Target Crashes for 2nd Location, US 287/WY 789 MP 2.4–13.59 (2003–2013).

Figure 9 shows the target crashes classified by different severity levels (fatal, injury, and PDO) for the third location, which is between Jeffrey City and Sweetwater Station (US 287 MP 23 to MP 33). It shows that only two target crashes occurred on that roadway segment from year 2003 to 2013.

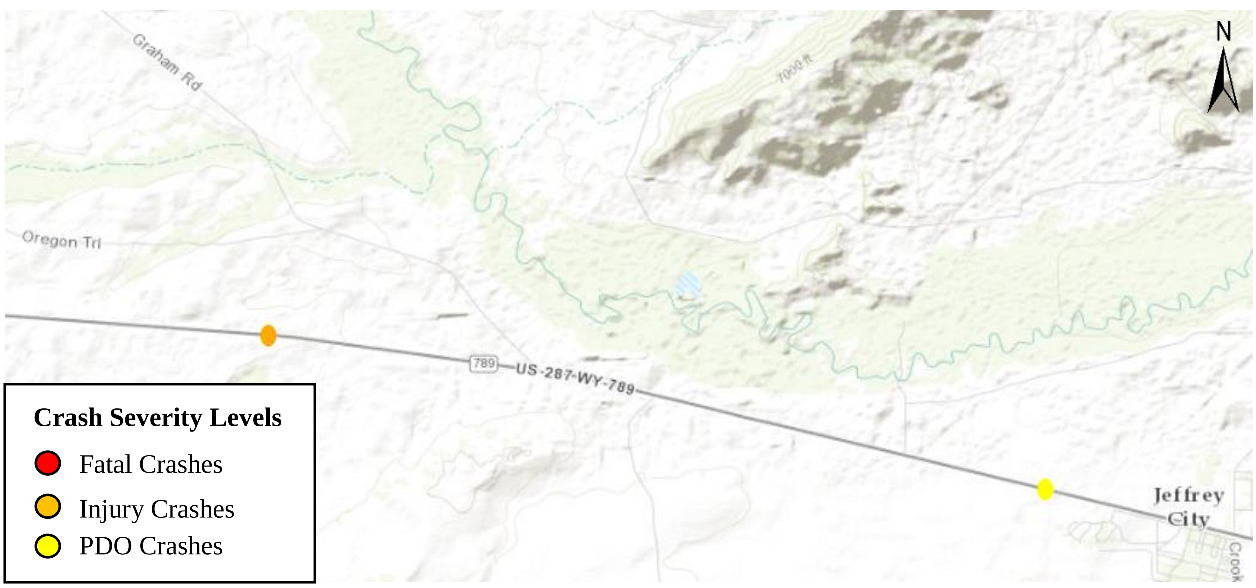

Figure 9: Graph target crashes for 3rd location, US 287 MP 23–33 (2003–2013).

Figure 10 shows the target crashes classified by different severity levels (fatal, injury, and PDO) for the fourth location, which is between Casper and Muddy Gap Junction (WY 220 MP 88 to MP 102). It shows that no fatal crashes occurred on that roadway segment, two injury crashes, and three PDO crashes from 2003 to 2013.

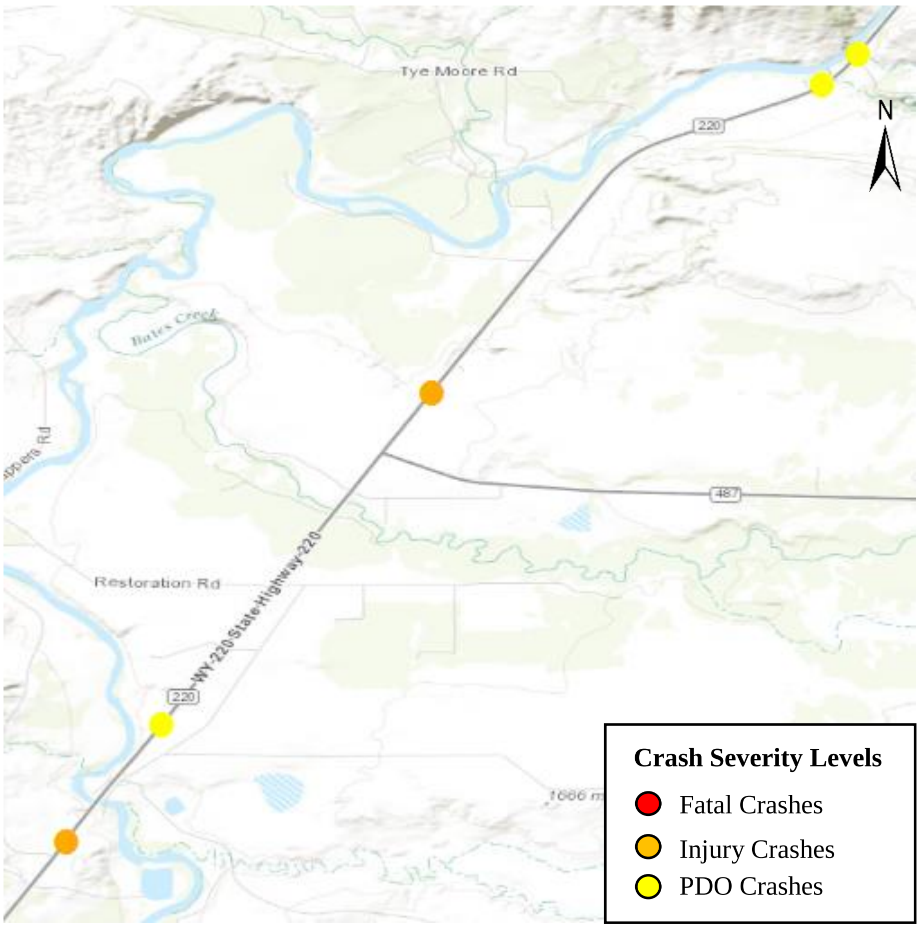

Figure 10. Graph. Target crashes for 4th location, WY 220 MP 88–102 (2003–2013).

Figure 11 shows the target crashes classified by different severity levels (fatal, injury, and PDO) for the fifth location, which is between Douglas and Gillette (WY 59 MP 76 to MP 101). Two fatal, two injury, and 12 PDO crashes occurred on that roadway segment.

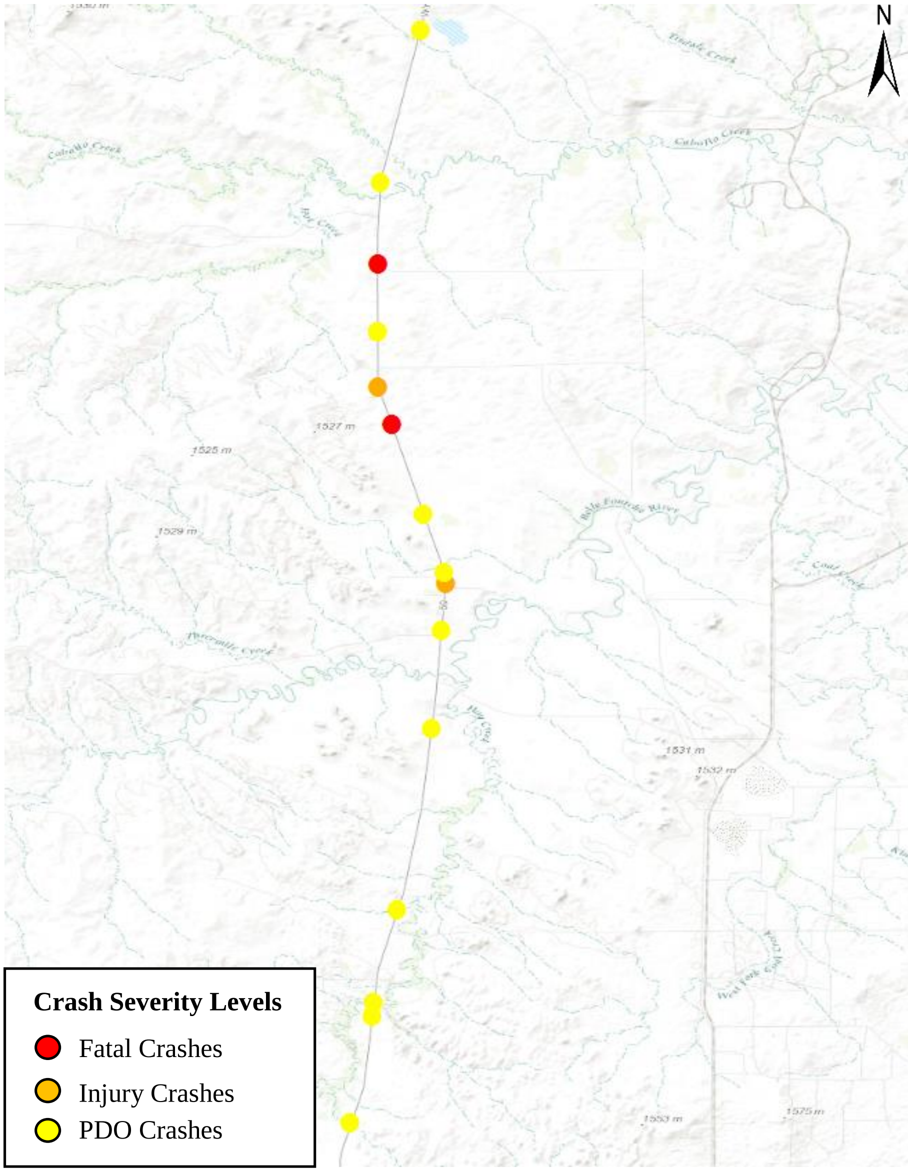

Figure 11. Graph. Target crashes for 5th location, WY 59 MP 76–101 (2003–2013).

Figure 12 shows the target crashes classified by the different severity levels (fatal, injury, and PDO) for the sixth location (US 20/26, Waltman to Shoshoni). The analysis indicated that three fatal crashes, five injury crashes, and four PDO crashes occurred on the headlight-roadway section from 2003 to 2013.

Figure 12. Graph. Target crashes for 6th location, US 20/26, Waltman to Shoshoni (2003–2013).

Figure 13 shows the target crashes classified by the different severity levels (fatal, injury, and PDO) for the seventh location (WY 28/South Pass). Two fatal crashes, one injury crash, and three PDO crashes took place on that roadway segment from 2003 to 2013.

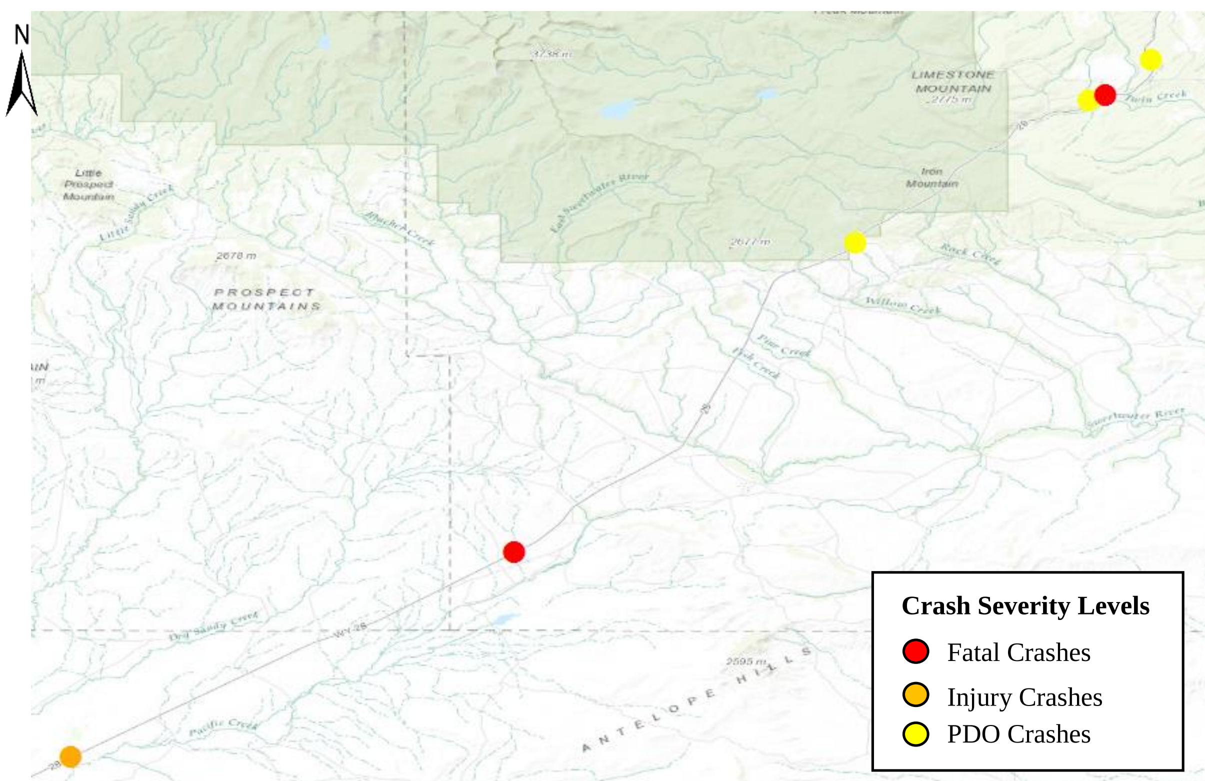

Figure 13. Graph. Target crashes for 7th location, WY 28, South Pass (2003–2013).

The first step of investigating the target crashes was to visualize the spatial distribution in ArcGIS. The spatial analysis will aid in identifying target crash hotspots. The Kernel Density Estimation (KDE) [25] (Chainey and Ratcliffe, 2005) was used to cluster target crashes (head-on and opposite-direction sideswipe crashes). KDE defines the spread of risk as an area around a defined cluster in which there is an increased likelihood of a crash to occur based on spatial dependency. It (1) places a symmetrical surface over each point; (2) it evaluates the distance from the point to a reference location based on a mathematical function; and (3) then it sums the value for all the surfaces for that reference location. This procedure is repeated for successive points, where a kernel is placed over each observation, and summing these individual kernels reveals the density estimate for the distribution of crash points [26].

The ArcGIS spatial analyst tool was used to perform the cluster analysis by density estimation methods. A heat map was created for the target crashes in all two-lane highways in Wyoming except for the seven locations with headlight signs from 2003 to 2013 as shown in **Figure 14.** Graph. Heat map for target crashes on Wyoming's two-lane highways (2003–2013). The analysis aimed at identifying locations with promise for improvement using headlight signs as a countermeasure.

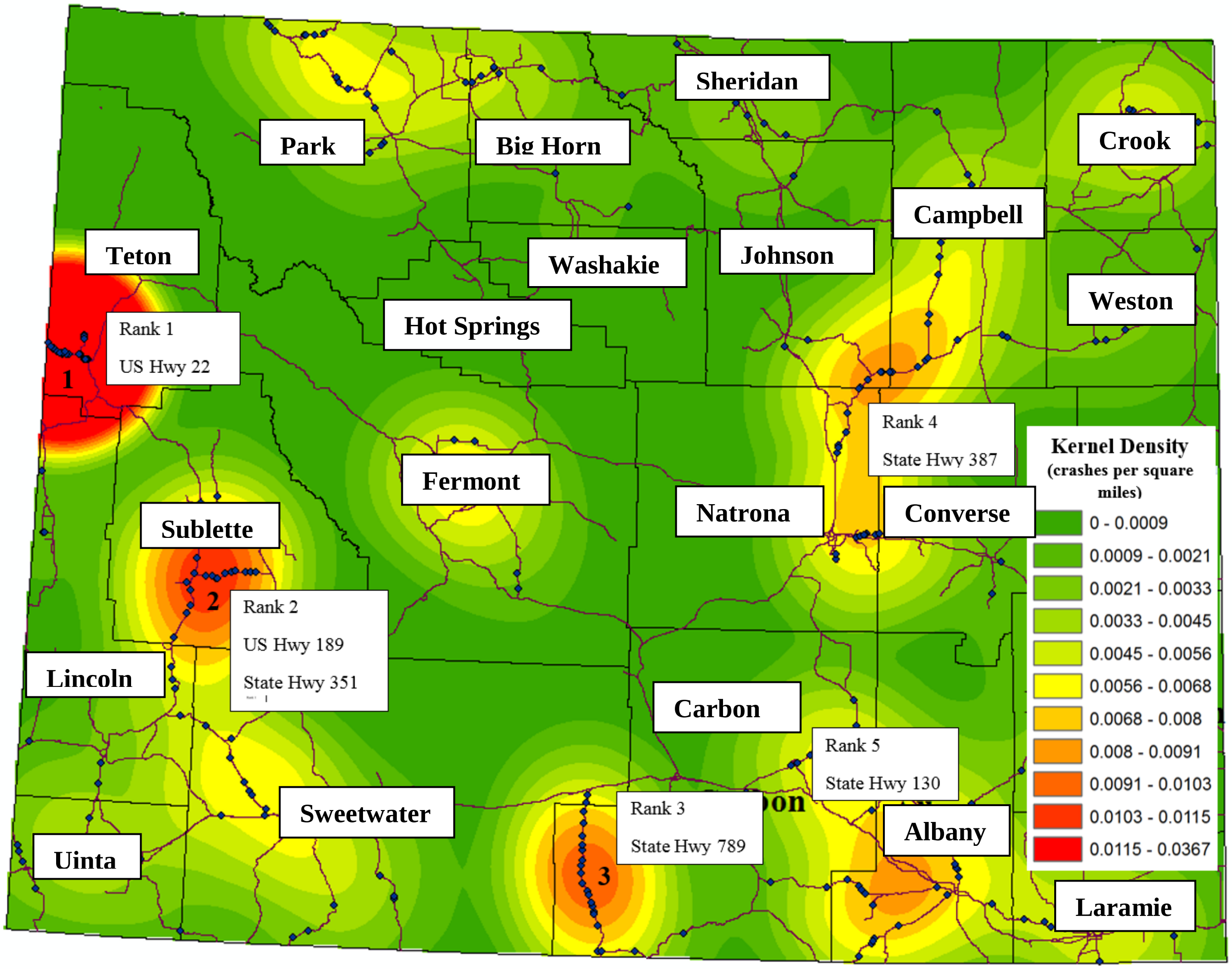

Figure 14. Graph. Heat map for target crashes on Wyoming's two-lane highways (2003–2013).

The Geographic Information Systems (GIS) analysis showed that the first ranked hotspot with a high number of target crashes per square mile is located in Teton County, the second in Sublette County, and the third in Carbon County (Figure 14).

Mapped crashes provide a general knowledge for the crash locations with high frequency and severity; however, they are not a reliable method to identify and rank hotspot locations. Different performance measures and screening techniques following the AASHTO (American Association of State Highway and Transportation Officials) Highway Safety Manual were utilized to identify and rank crash hotspots. The following sections discuss the different hotspot identification and ranking methods used in the study.

SCREENING SITES WITH PROMISE

To improve safety on two-way two-lane highways in Wyoming, a systematic process was provided in the AASHTO Highway Safety Manual. Network screening is considered the first step in the safety improvement process. As mentioned earlier, the main goal of the network screening is to identify and rank sites with the greatest promise for safety improvement. Four performance measures (Table 6) were used to identify and rank hotspots. The network screening step was performed one time on the seven headlight-sign locations and another time on the entire two-way two-lane highway network excluding the headlight sections. The reason for ranking the seven headlight locations was for the implementation of new headlight-sign designs on two sets of locations and having a third set as a control group. The following four methods were used for hotspot identification:

1. C*ritical rate*. This performance measure is based on the average crash rate at similar segments and the average annual daily traffic (AADT)[24]. It reduces the exaggeration effect on low AADT road segments, considers variance in crash data, and establishes thresholds for segment comparison. It should be noted that the critical rate method does not account for regression to the mean (RTM) bias.
2. *Excess predicted average crash frequency using method of moments*. The potential of improvement for the different segments is determined using the adjusted observed average crash frequency. Although it establishes a threshold for predicted performance for the different roadway segments and considers variance in crashes, it does not account for traffic volumes. The effect of RTM bias using this method may still be presented in the results.
3. *Excess predicted average crash frequency using safety performance functions*. Segments are ranked according to excess predicted crash frequencies. RTM bias may still be presented in the results. This method accounts for the AADT and provides a threshold for comparison.
4. *Expected average crash frequency using Empirical Bayes (EB) adjustments*. This method requires more data to be performed. It requires crash data, AADT, and calibrated safety performance functions for the roadway segments. This method accounts for RTM bias.

Table 6 summarizes the strengths and limitations for the four performance measures used for hotspot identification.

Table 6. Strengths and limitations for performance measures used for hotspot identification.

Method	Strengths	Limitations
(1) Critical Rate	• Reduces the exaggerated effect of segments with low AADT • Considers variance in crash data • Establishes a threshold for comparison	• Does not account for RTM bias
(2) Excess Predicted Average Crash Frequency Using Method of Moments	• Considers variance in crash data • Allow all segments to be ranked in one list • It is similar to Empirical Bayes methods • Establishes a threshold of predicted performance for the segments	• Effects of RTM bias may still be presented in the results • Does not account for AADT
(3) Excess Predicted Average Crash Frequency Using Safety Performance Functions (SPF)	• Accounts for AADT • Estimates threshold for segment comparison	• Effects of RTM bias may still be presented in the results
(4) Expected Average Crash Frequency Using EB Adjustments	• Accounts for RTM bias	• Requires calibrated SPF

SEGMENT SCREENING METHODS

According to the Highway Safety Manual (American Association of State Highway and Transportation Officials, 2010) [24], screening roadway segments requires identifying the locations within the segments that are most likely to benefit from the countermeasure. Safety improvement on these roadway segments is expected in a form of reductions in crash frequency and severity. Simple ranking, sliding window, and peak searching can be used to identify the location on a roadway segment that is likely to benefit from the intended countermeasure. Simple ranking is not a reliable ranking method for roadway segments [24]. Unlike the other two methods, it is calculated for the entire length of the roadway segment, and thus was not utilized in the study. However, it is a fast and simple procedure to rank hotspot locations after identifying them using the four performance measures. In the peak searching method, the roadway segment is divided into one-mile segments. The different performance measures are calculated for every subdivision of the roadway segment and then ranked. This segment screening method could only be applied with one of the chosen performance measures—expected average crash frequency using EB adjustments performance measures. The precision of the performance measure is assessed by its coefficient of variation (CV). The calculated CV is compared with a specific CV limit (0.5). If the calculated CV is higher than the limits, that subdivision is not considered in the ranking. According to the 2010 Highway Safety Manual, the sliding window method could be utilized with all performance measures for roadway segments. In the ranking of the segments with and without headlight signs, a window of two miles and a sliding value of one-half mile were used. For each sliding step, the different performance measures are calculated and ranked.

RANKING OF SEVEN LOCATIONS WITH HEADLIGHT SIGNS

The previously mentioned network screening methods were applied on locations with headlight signs. Head-on and opposite-direction sideswipe crashes were the target crashes used in the ranking. The two manners of collisions are considered as crashes related to difficulty in recognizing roadway cues because of challenging roadway geometry and/or reduction of visibility during daytime. As mentioned earlier, road users would more easily see vehicles with headlights turned on. Having a headlight sign placed at specific challenging roadway segments should lead to a decrease in head-on and opposite-direction sideswipe crashes.

The objective for ranking the seven headlight locations was for the implementation and field testing of new headlight-sign designs on two sets of locations and having a third set as a control group. As this report was being finalized, the updated sign design was under testing in a controlled environment using the University of Wyoming driving simulator lab (WYOSIM). The alternative designs are discussed in Chapter Seven.

Table 7 shows the obtained summary results of the different network screening methods used in ranking seven headlight-sign locations.

Table 7. Summary of obtained results from different network screening methods.

Serial	Location	Critical Rate	Excess Predicted Average Crash Frequency Using Method of Moments	Excess Predicted Average Crash Frequency Using SPF	Expected Average Crash Frequency Using EB Adjustments		Final Ranking
					(Sliding Window)	CV Value (Peak Searching)	
1	US 287 (402.59–424.81)	(Flagged)[1]	2.18[2]	-0.66[3]	2.25[1]	0.69[3]	1
2	US 287/WY 789 (2.4–13.59)	(No Flag) [5]	0.89[4]	-0.34[2]	1.35[3]	- *[6]	4
3	US 287 (23–33)	(No Flag) [2]	0.89[4]	-0.35[4]	0.53[7]	0.85[5]	5
4	WY 220 (88–102)	(No Flag) [6]	0.86[5]	-0.94[6]	1.23[5]	0.79[4]	7
5	WY 59 (76–101)	(No Flag) [6]	0[6]	-1.44[7]	1.39[2]	0.64[2]	6
6	US 20/26 (Waltman–Shoshoni)	(No Flag) [4]	2.16[3]	-0.63[5]	1.28[4]	0.69[3]	3
7	WY 28 (South Pass)	(No Flag) [3]	2.86[1]	-0.32[1]	0.91[6]	0.61[1]	2

* Could not be calculated as the total number of target crashes for the whole section was only one crash
[#] the number between the parentheses indicates the ranking number

Critical rate ranking shows that US 287 from MP 402.59 to MP 424.81 was the only flagged section. Method of moments shows that the first, sixth and seventh locations have the highest potential of improvement (PI) with values ranging from 2.16 to 2.86, with Section 7 on South Pass have the highest PI value. All seven locations have a negative value of excess predicted average crash frequency, which means that the expected target crashes on these location is higher than the occurred ones.

Sliding window results for the expected average crash frequency using EB adjustments shows that Section 1—the US 287 headlight section from MP 402.59 to MP 424.81—has the highest value. The fifth, sixth, second, and fourth, locations also have an expected average crash frequency higher than one. Using the peak searching method, the locations show a higher coefficient of variation value than the CV limit (0.5); however, the seventh, fifth, first, and sixth locations have the lowest CV values.

It is concluded from the results of the different network screening methods that US 287 section south of Laramie (MP 402.59–424.81) has the highest rank among the seven locations, while WY 220 southwest of Casper (MP 88–102) has the lowest rank.

HOTSPOT IDENTIFICATION EXCLUDING HEADLIGHT-SIGN SEGMENTS

Table 8 through Table 12 show the rank and hotspot locations on the two-lane highways in Wyoming. The same procedures used to rank the seven headlight-sign locations were also applied on the 18 Wyoming two-way highways depicted in CHAPTER 3-, Table 5.

Table 8 shows that only two highways - US 220 and WY 22 - among the two-lane road network should be flagged using the critical rate method. The two hotspot locations are MP 6–8 on WY 220 and MP 8–11.5 on WY 22.

Table 8. Wyoming two-lane highway ranking using critical rate performance measure with sliding window screening method.

Serial	Road Name	Milepost		Status	Rank
		From	To		
1	WY 22	8	14	Flagged	2
2	US 191	82.5	86	No Flag	10
3	US 278	258	260	No Flag	18
4	WY 59	90.5	93	No Flag	11
5	WY 220	6	8	Flagged	1
6	US 85	193.5	195	No Flag	4
7	US 30	46	48	No Flag	15
8	US 189	14.5	17	No Flag	6
9	US 26II	0.5	4	No Flag	12
10	WY 789	35	38	No Flag	7
11	WY 414	96.5	99	No Flag	16
12	WY 387	118	120.5	No Flag	17
13	US 14	58.5	60.5	No Flag	5
14	US 16	250	253	No Flag	8
15	US 191	500	502	No Flag	9
16	WY 120II	60.5	64	No Flag	13
17	US 26	1	3	No Flag	14
18	US 212	16.5	20	No Flag	3

Table 9 represents the two-lane highways ranking using the method of moments performance measure with the sliding window screening method. It shows that US 85, US 26, WY 220, US 30, and US 191 are the top five ranked roadway segments, respectively.

Table 9. Wyoming two-lane highway ranking using method of moments performance measure with sliding window screening method.

Serial	Road Name	Milepost		PI	Rank
		From	To		
1	WY 22	9	12	1.17	14
2	US 191	3	5	2.63	5
3	US 278	258	260	1.91	7
4	WY 59	91.5	95	2.13	6
5	WY 220	6	8	3.06	3
6	US 85	193	195.5	7	1
7	US 30	57.5	59.5	2.88	4
8	US 189	14.5	17	1.89	8
9	US 26II	0.5	4	0.91	16
10	WY 789	35	38	1.49	12
11	WY 414	96.5	99	1.08	15
12	WY 387	114	117.5	1.72	9
		118	120.5		
13	US 14	58.5	61	1.69	10
14	US 16	251	252	0.18	18
15	US 191	500	502	1.52	11
16	WY 120II	60.5	64	1.37	13
17	US 26	1	5	5.33	2
18	US 212	1.5	8	0.91	16
		16.5	20		

Table 10 shows the Wyoming two-lane highways ranking using the excess predicted average crash frequency measure with the sliding window screening method. US 278, US 191, WY 22, WY 387, and US 26 are the top five ranked roadway segments, respectively.

Table 10. wyoming two-lane highway ranking using excess predicted average crash performance measure with sliding window screening method.

Serial	Road Name	Milepost		Excess Predicted Average Crash Frequency	Rank
		From	To		
1	WY 22	11.5	13.5	-0.79	3
2	US 191	15	17.5	-0.97	2
3	US 278	314	325	-1.1	1
4	WY 59	43	46.5	-0.49	8
5	WY 220	57.5	65.5	-0.6	6
6	US 85	252	255.5	-0.23	16
7	US 30	34	37.5	-0.58	7
8	US 189	69	72.5	-0.35	11
9	US 26II	0.5	4	-0.33	14
10	WY 789	33.5	37	-0.35	11
11	WY 414	113	116	-0.22	17
12	WY 387	114	117.5	-0.7	4
		118	120.5		
13	US 14	58.5	60.5	-0.35	11
14	US 16	251	252	-0.46	9
15	US 191	547	550	-0.3	15
16	WY 120II	31.5	35.5	-0.42	10
17	US 26	1	3	-0.64	5
18	US 212	16.5	20	-0.08	18

Table 11 shows the Wyoming two-lane highways ranking using the expected average crash frequency with the EB performance measure following a sliding window network screening method. WY 22, US 414, US 191, WY 59, and WY 220 are the top five ranked roadway segments, respectively.

Table 11. Wyoming two-lane highway ranking using expected average crash frequency with eb performance measure with sliding window screening method.

Serial	Road Name	Milepost		Expected Average Crash Frequency	Rank
		From	To		
1	WY 22	9	11	3.33	1
2	US 191	3	5	2.59	3
3	US 278	314	325	1.15	8
4	WY 59	91.5	93.5	2.57	4
5	WY 220	6	8	1.83	5
6	US 85	82	85	1.1	10
7	US 30	21	25	1.15	8
8	US 189	30.5	34	1.05	12
9	US 26II	7.5	11	0.49	17
10	WY 789	41	45	0.83	15
11	WY 414	96.5	99	2.85	2
12	WY 387	114	117.5	1.06	11
		118	120.5		
13	US 14	37	40.5	0.86	14
14	US 16	154	156.5	1.21	7
15	US 191	500	502	1.69	6
16	WY 120II	60	67	0.65	16
17	US 26	3	5	1.01	13
18	US 212	1.5	5	0.34	18

Table 12 shows the Wyoming two-lane highways ranking using the expected average crash frequency with the EB performance measure following peak searching network screening method. The method indicates that US 26, US 191_{ML17B}, WY 414, US 191_{ML13B}, and US 212 are the top five ranked roadway segments.

Table 12. Wyoming two-lane highway ranking using expected average crash frequency with eb performance measure with peak searching screening method.

Serial	Road Name	Milepost		Excess Predicted Average Crash Frequency	Rank
		From	To		
1	WY 22	9	10	0.14	11
2	US 191	3	4	0.22	4
3	US 278	36	37	0.19	7
4	WY 59	68	70	0.19	7
5	WY 220	6	7	0.14	11
6	US 85	83	84	0.17	9
7	US 30	22	24	0.15	10
8	US 189	32	33	0.13	14
9	US 26II	2	3	0.1	17
10	WY 789	42	43	0.12	16
11	WY 414	98	99	0.49	3
12	WY 387	115	116	0.06	18
13	US 14	38	39	0.13	14
14	US 16	154	156.5	0.22	4
15	US 191	500	501	0.59	2
16	WY 120II	62	63	0.14	11
17	US 26	2	5	0.98	1
18	US 212	3	4	0.22	4

To determine the final ranking of the 18 roadway segments, the rankings of the five methods were averaged. Excluding the excess average crash frequency. The excess average crash frequency method results in negative values for all the segments. The final ranking and hotspot locations are shown in Table 13. The top six ranked segments were WY 220, US 191_{ML13B}, US 85, WY 22, US 191_{ML17B}, and WY 59.

Table 13. Final ranking and hotspot locations for wyoming two-lane highway target crashes.

Serial	Road Name	Hotspot Segment		Route	# Crashes	Ranking
		From	To			
1	WY 22	8	13.5	ML2000B	35	4
2	US 191	3	5	ML13B	32	2
3	US 278	258 314	260 325	ML23B	28	11
4	WY 59	90.5	95	ML43B	27	4
5	WY 220	6	8	ML21B	27	1
6	US 85	193 82	195.5 85	ML85B	23	3
7	US 30	21 34 46 57.5	25 37.5 48 59.5	ML12B	16	9
8	US 189	14.5 30.5 69	17 34 72.5	ML11B	12	11
9	US 26II	0.5 7.5	4 11	ML20B	12	18
10	WY 789	33.5	45	ML18B	8	15
11	WY 414	96.5 113	99 116	ML16B	6	8
12	WY 387	114	120.5	ML42B	6	17
13	US 14	37 58.5	40.5 61	ML31B	5	14
14	US 16	154 250	156.5 252	ML44B	5	9
15	US 191	500 547	502 550	ML17B	5	4
16	WY 120II	31.5 60.5	35.5 67	ML33B	4	16
17	US 26	1	5	ML27B	3	7
18	US 212	1.5 16.5	8 20	ML38B	3	13

EVALUATING THE SAFETY EFFECTIVENESS OF DRL-EQUIPPED AND NON-DRL-EQUIPPED VEHICLES IN WYOMING.

The safety effectiveness of DRL use for certain types of crashes was examined using Wyoming crash data. To thoroughly understand the safety benefit of headlight signs with the presence and absence of automatic DRLs, simple odds and ratio of odds ratios were utilized to adjust for a variety of exogenous factors. As discussed earlier that there is a difference between the newly DRL-equipped vehicles and requiring drivers to turn on their headlights manually. Four different scenarios that should be considered in analyzing Wyoming crash data as illustrated in the two-way contingency in Table 14. Only specific make-models for each year are equipped with DRLs. A case-control method was used to compare crashes for a set of passenger vehicles equipped with DRLs and vehicles manufactured in the same years without DRLs. Vehicle Identification Numbers (VIN) were used for identification on roadway sections with and without headlight signs.

Table 14. Two-way contingency table for possible crash scenario.

	Non-DRL Vehicles	DRL-Equipped Vehicles
Roadway Sections with Headlight Signs	Π_{11}	Π_{12}
Roadway Section without Headlight Signs	Π_{21}	Π_{22}

Three data sets were used to achieve the objectives of this study. Crash data were extracted from Critical Analysis Reporting Environment (CARE) software. VINs are needed to identify vehicles with automatic DRLs in the crash reports, but it should be noted that crash date in the CARE package do not include VINs. A full list of VINs for vehicles involved in crashes was obtained from WYDOT, and each number was matched to crashes in the CARE package. Ten years of traffic data (2004–2013) were also acquired from WYDOT. A total of 106,622 crashes for those years were collected with complete VINs.

Only crashes with the following criteria were considered in the study: (1) head-on and opposite-direction sideswipe crashes occurring on two-lane rural highways; (2) crashes where the posted speed is equal to or greater than 55 mph; (3) daytime-only crashes since headlight-sign countermeasures have no safety benefits during nighttime; (4) crashes not involving alcohol or drug use; and (5) crashes not involving animals. The data set was further split into: crashes for locations with headlight signs and crashes for locations without headlight signs.

As mentioned earlier, the VIN data set was used to evaluate the safety effectiveness of headlight signs based on vehicles equipped or not equipped with automatic DRLs. To identify what headlight technology a vehicle might have, VINs were typed into the "DECODE!" box in the Decode This! website at www.decodethis.com. This website classifies DRL into three groups: "Standard DRL", "No DRL", and "Optional DRL". A total of 6,713 VINs (6,230 randomly sampled crashes for locations without headlight signs and 483 crashes for locations with headlight signs) were checked to determine headlight technology. Only crash data belonging to the "No DRL" and "Standard DRL" were used in the analysis. The bar charts located in the left side of **Figure 15** and **Figure 16** show the rates of crashes for all crashes and target crashes in blue and orange colors, respectively. The bar charts shown at the right side of the previously mentioned figures show the crash counts and percentages of different groups of DRL. **Figure 15** shows the statistics for Wyoming two lane highway that does not have headlight signs and **Figure 16** shows the statistics for the seven headlight sign locations. The data showed that seventy percent and seventy seven percent of vehicles involved in crashes in locations with and without headlight signs are non-DRL-equipped vehicles, respectively.

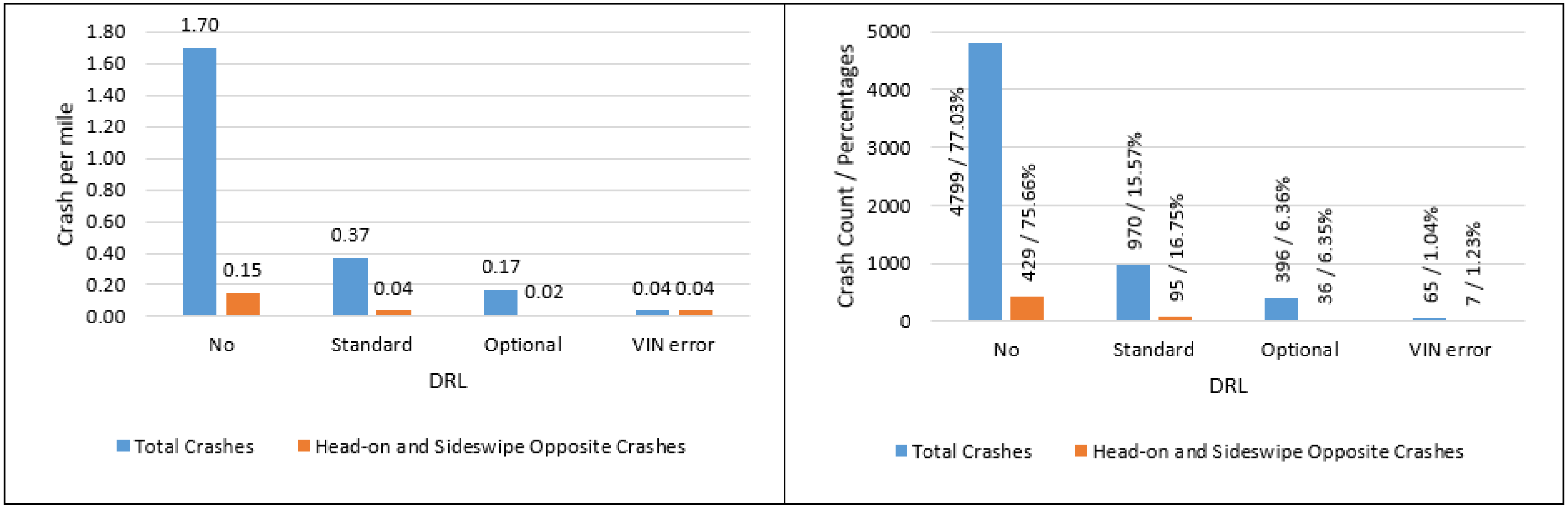

Figure 15: Chart. Percentages and rates of total and target crashes for DRL/non-DRL vehicles (non-headlight-sign locations).

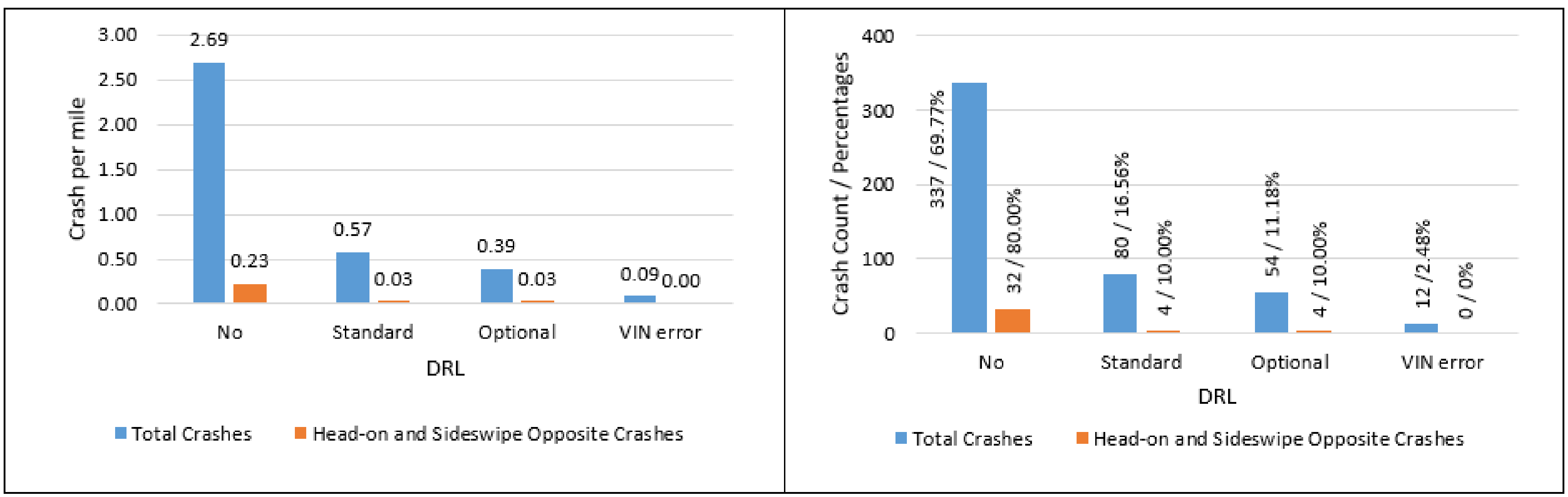

Figure 16: Chart. Percentages and rates of total and target crashes for DRL/non-DRL vehicles (headlight-sign locations).

SAFETY EFFECTIVENESS OF HEADLIGHT SIGNS

Four scenarios were considered in analyzing the crash data forming a 2 by 2 contingency table. A case-control method was used to compare crashes for a set of passenger vehicles equipped with DRLs and vehicles without DRLs on roadway sections with and without headlight signs. To quantify how strongly the presence of DRL is associated with the existence of headlight signs for crashes in two-way, two-lane highways, simple odds and odds ratios were utilized.

Sheskin (2000) notes that equation 1 can be used to calculate the odds ratio. To evaluate the null hypothesis of the odds ratio, confidence intervals should be calculated. To obtain the confidence intervals for ninety five percent confidence level, equation 2 and 3 were utilized. The Z-score for ninety five percent confidence level multiplied by the square root of the standard error was added to and subtracted from the exponential transformation of the log transformation of odds ratio. To get the upper and lower confidence levels, the result from the above calculation was retransformed using the exponential according to Sheskin's handbook of parametric and nonparametric statistical procedures [27].

$$OR = \frac{\pi_{11}/\pi_{12}}{\pi_{21}/\pi_{22}} \qquad \text{(Equation 1)}$$

$$CI_{upper} = e^{[\ln(OR)+Z_{0.05}*\sqrt{SE}]} \qquad \text{(Equation 2)}$$

$$CI_{lower} = e^{[\ln(OR)-Z_{0.05}*\sqrt{SE}]} \qquad \text{(Equation 2)}$$

Figure 17: Equation. Odds ratio, upper and lower confidence intervals equations.

Where:

OR : The odds ratio

π : The odds for each group category

$Z_{0.05}$: The Z-score for ninety five percent confidence level = 1.96

SE : Standard Error and is obtained be the equation $\frac{1}{\pi_{11}} + \frac{1}{\pi_{12}} + \frac{1}{\pi_{21}} + \frac{1}{\pi_{22}}$

Table 15 represents the 2 by 2 contingency table for all crash types. It shows the number of crashes that occurred on locations with/without headlight signs for vehicles equipped/not equipped with DRLs. The odds for locations with a headlight sign were twenty four percent vs. twenty percent for locations without headlight signs, resulting in an odds ratio of 1.17. The confidence intervals were calculated to range from 0.91 to 1.51, indicating no significant effect of having DRLs in crash reduction for two-way highways with the presence of headlight signs.

Table 15. Two-way contingency table with odds and odds ratio for all crash types.

	DRL-Equipped Vehicles	Non-DRL-Equipped Vehicles	Odds	Odds Ratio
Roadway Sections with Headlight Signs	80	337	23.74%	1.17%
Roadway Sections without Headlight Signs	970	4,799	20.21%	

The same procedure was applied on specific crash types related to vehicles conspicuity. Head-on and opposite-direction sideswipe crashes was investigated for the same locations to examine the effect of DRL with the presence of headlight signs for certain crash types in two- lane two-way highways.

Table 16 provides the two-way contingency table for head-on and opposite-direction sideswipe crashes. It shows the crash counts for the vehicles equipped and non-equipped with DRL occurred on locations with/without headlight signs. The odds for locations with headlight signs was thirteen percent vs. twenty two percent for locations without such signs. An odds ratio of 0.56 was obtained. The confidence intervals was calculated to range from 0.19 to 1.63. Confidence intervals indicate that there are no significant effects of having DRL in head-on and opposite-direction sideswipe crashes for two-lane two-way highways with the presence of headlight signs.

Table 16. Two-way contingency table with odds and odds ratio for head-on and opposite-direction sideswipe crashes.

	DRL-Equipped Vehicles	Non-DRL-Equipped Vehicles	Odds	Odds Ratio
Roadway Sections with Headlight Signs	4	32	12.50%	0.56%
Roadway Sections without Headlight Signs	95	429	22.14%	

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CHAPTER 5- FIELD STUDY ON CURRENT COMPLIANCE RATES

A field-data collection was one major part of this study. The purpose of the data collection was to quantify the existing condition of compliance rates at the locations with headlight signs and to examine if there is any change in compliance rate among locations. Field data were also collected from locations without headlight signs to determine the actual effect of having headlight signs posted in nearby sections of roadway. Field data were collected from three locations with headlight signs and two locations without signs. All locations are classified as rural principal arterial roadways.

As previously mentioned, it is mandatory—by law—for drivers to turn on headlights whenever they enter regulatory headlight-sign sections. Failure to observe this regulation by drivers was noticed frequently on these sections. Two video cameras were used for each direction to capture the front and rear of vehicles. Vehicles with only headlights on were considered DRL-equipped; vehicles with both headlights and taillights on were considered compliant non-DRL; and vehicles with no headlights or taillights on were considered non-compliant non-DRL.

LOCATIONS WITH HEADLIGHT SIGNS

Headlight signs located on US 287 at MP 402.59, WY 220 at MP 88, and WY 59 at MP 76 were the three locations with headlight signs chosen to collect field data. The first headlight-sign section is located between Laramie and Fort Collins, Colorado. The first point where drivers encounter a headlight sign while traveling toward Fort Collins is MP 402.59 south of Laramie. The other headlight sign is at MP 424.81 north of the Wyoming-Colorado border and is encountered by drivers while traveling toward Laramie. The chosen data collection point was at MP 405 on a straight segment as shown in Figure 18.

Figure 18. Photo. First compliance data collection location at MP 405, US 287.

The second headlight-sign section where data were collected is located between Casper and Muddy Gap Junction on WY 220. One headlight sign is located at MP 102 southwest of Casper and is encountered by drivers traveling toward Muddy Gap Junction. The other headlight sign is at MP 88 and is encountered by drivers traveling toward Casper. The chosen data collection point was at MP 96 on a straight roadway segment as shown in Figure 19.

Figure 19. Photo. Second compliance data collection location at MP 96, WY 220.

The third headlight-sign section was on WY 59 between Wright and Gillette. One headlight sign is placed at MP 76 north of Wright and is encountered by drivers traveling toward Gillette. The other headlight sign is at MP 101 in the opposite direction. The chosen data collection point was near MP 82 as shown in Figure 20.

Figure 20. Photo. Third compliance data collection location near MP 82, WY 59.

To obtain a representative sample for the compliance rate at a specific site, two hours of data were collected at each of the three locations in the morning (between 7 a.m.–10 a.m.), and two hours of data were obtained in the afternoon (4 p.m.–7 p.m.)

Table 17 shows the data collection timetable for locations with headlight signs. A straight segment with no major access road and no variation in vertical elevation was identified first. All instruments that were used in the data collection were prepared on the day that data were collected at earlier time of the data collection day. The preparation included: fully charging batteries, emptying memory cards of the video and digital cameras, and charging batteries of the radar recorders. On the day of data collection, equipment was set up 40 minutes in advance before the scheduled time of video recording. In this time, a radar recorder was set up on a roadside signpost and calibrated for recording of both directional speed and volume data. Following this task, tripods and video cameras were set up and leveled properly to capture both the headlights and taillights of traffic in both directions. Following each recording period, video files were downloaded and reduced in the office. Speed and volume data were collected from the radar recorder and matched to the video data.

Heavy trucks, semi-trailers, school buses, and motorcycles were not considered in the study.

Table 17. Data collection time periods for locations with headlight signs.

Road Name	Section (MP)	Day/Date	Time Period
US 287	402.59 to 424.81	Saturday, June 6, 2015	7 a.m.–9 a.m. and 4:40 p.m.–6:40 p.m.
WY 220	88 to 102	Tuesday, June 16, 2015	7 a.m.–9 a.m.
		Wednesday, June 17, 2015	7:20 a.m.–9:20 a.m. and 5:30 p.m.–7 p.m.
WY 59	76 to 101	Thursday, June 18, 2015	11 a.m.–1:30 p.m. and 5 p.m.–7 p.m.
		Friday, June 19, 2015	7:30 a.m.–9:30 a.m. and 5 p.m.–7 p.m.

As mentioned earlier, the main purpose of the field-data collection was to quantify the compliance rate at these locations and to examine if there was any change in compliance rate among locations. Percentage of DRL-equipped and non-DRL-equipped vehicles was determined. Also, the compliance rates for non-DRL-equipped vehicles were obtained. Percentage of non-DRL-equipped vehicles was greater than the DRL-equipped vehicles. The average percentage of vehicles equipped with automatic DRLs in sections with headlight signs was forty four percent, while the percentage was 56 for non-DRL-equipped vehicles. Figure 21 shows the different percentages of DRL-equipped vehicles vs. non-DRL vehicles. Table 18 shows the compliance rates for non-DRL vehicles in the three headlight-sign sections. It shows that US 287 had the highest compliance rate of thirty seven percent, while WY 220 had the lowest compliance percentage of 16. The total average compliance rate for the three investigated locations was twenty five percent, which indicates a low compliance rate.

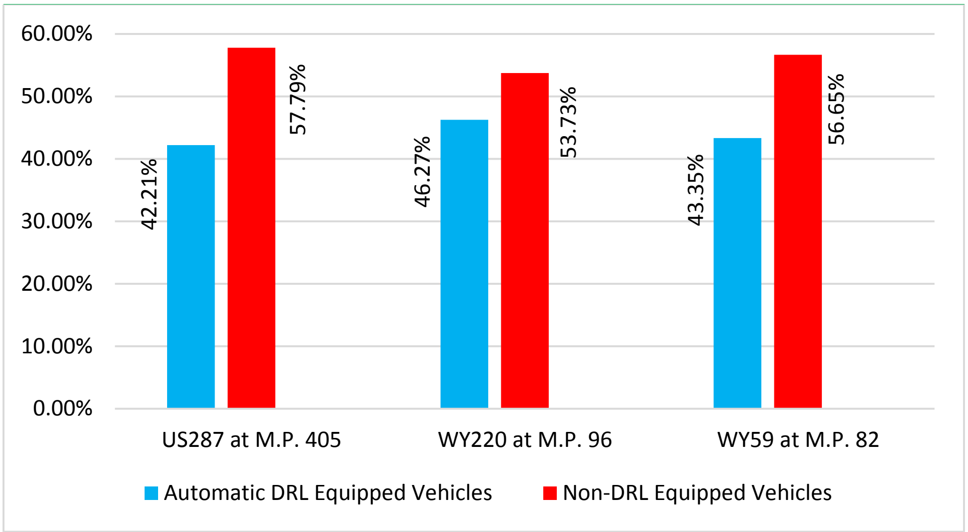

Figure 21. Chart. Percentage of vehicles equipped with DRL vs. non-DRL.

Table 18. Compliance rates for non-DRL vehicles.

Locations/MP	Dates	Time Period	% of Manually Complied	% of Non-complied
US 287 at MP 405	June 6, 2015	7 a.m.–9 a.m.	38.09%	61.91%
		4:40 p.m.–6:40 p.m.	40.82%	59.18%
	April 21, 2015	7:30 a.m.–8:44 a.m.	33.62%	66.38%
	Feb. 24, 2015	3:14 p.m.–4:24 p.m.	33.58%	66.42%
	Average Percentages		37.22%	62.78%
WY 220 at MP 96	June 16, 2015	7 a.m.–9 a.m.	23.64%	76.36%
	June 17, 2015	7:20 a.m.–9:20 a.m.	14.04%	85.96%
	June 17, 2015	5:30 p.m.–7 p.m.	9.44%	90.56%
	Average Percentages		16.16%	83.84%
WY 59 at MP 82	June 18, 2015	11 a.m.–1:30 p.m.	13.86%	86.14%
		5 p.m.–7 p.m.	15.83%	84.17%
	June 19, 2015	7:30 a.m.–9:30 a.m.	37.64%	62.36%
		5 p.m.–7 p.m.	20.00%	80.00%
	Average Percentages		20.19%	79.81%
Total Average Percentages			25.46%	74.53%

LOCATIONS WITHOUT HEADLIGHT SIGNS

Field data were collected for two non-headlight sections to help determine whether turning on headlights is a driver behavioral habit or a result of headlight-sign compliance. The two sections were chosen to match the geometric and traffic characteristics of the headlight sections. Data for non-headlight sections were collected from US 26, MP 5–32 northwest of Torrington (Location 1) and US 20/18, MP 5–32 between Orin Junction and Lusk (Location 2) (Figure 21).

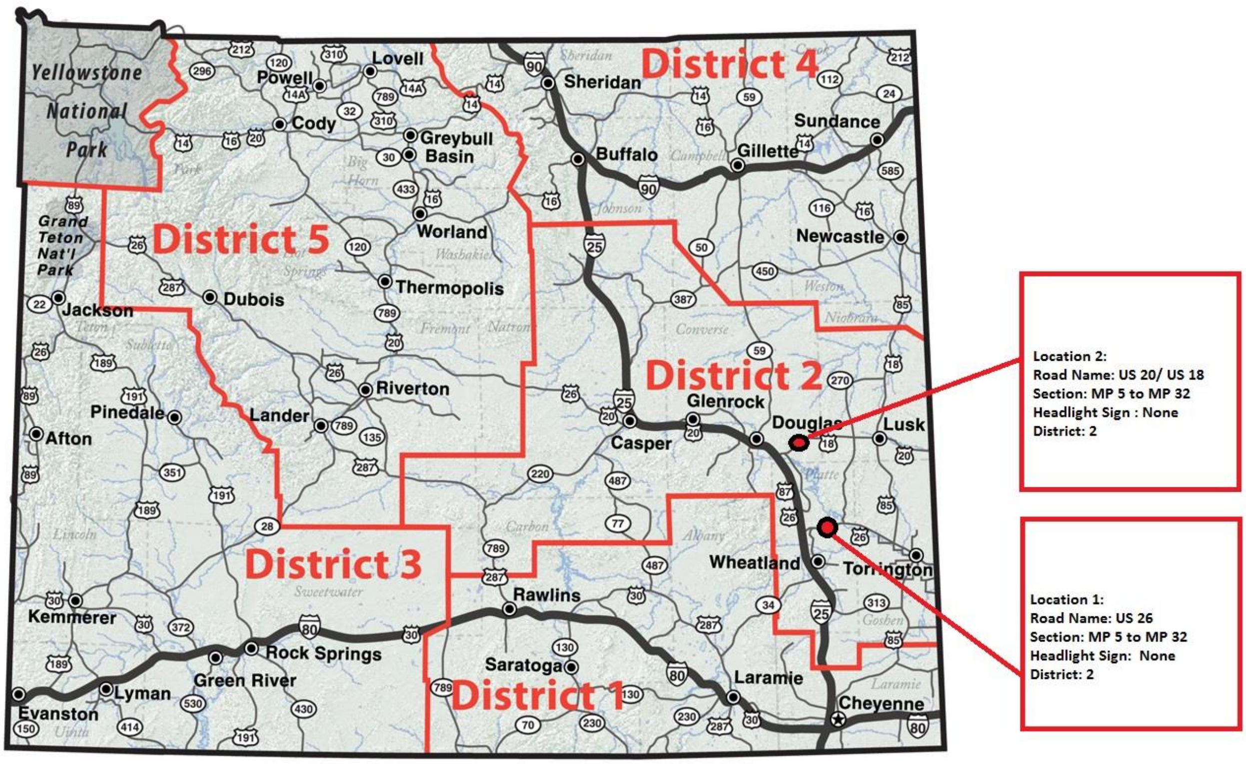

Figure 22. Graph. Data collection locations for non-headlight sections.

The AADT on US 26 and US 20/18 was 2,252 and 2,263 vehicles per day in 2013, respectively. The percentage of truck traffic was found to be thirteen percent and nineteen percent for US 26 and US 20/18, respectively.

The roadway section on US 26 between the Dwyer Junction rest area (adjacent to I-25) and Torrington is nearly flat with no major access points (Figure 23). The other non-headlight-sign section between the Orin Junction truck stop/rest area (near I-25) and Lusk on US 20/18 MP 5-32, (Figure 24). The speed limit is 65 mph for both sections. Similar to the headlight-sign sections' data collection, two hours of data were collected in the morning (between 7 a.m.–10 a.m.), and two hours in the afternoon (4 p.m.–7 p.m.) were conducted on both locations. Table 19 shows time periods for data collection in non-headlight sections.

Figure 23. Photo. Non-headlight-sign section at MP 27 on US 26.

Figure 24. Photo. Non-headlight-sign data collection section at MP 7 on US 20/18.

Table 19. Non-Headlight-sign section compliance data collection timetable.

Locations	Day/Date	Morning Period	Afternoon Period
MP 27 on US 26	Tuesday, July 14, 2015	10 a.m.–noon	4 p.m.–6 p.m.
MP 7 on US 20/18	Wednesday, July 15, 2015	10 a.m.–noon	4 p.m.–6 p.m.

The average percentage of non-DRL-equipped vehicles in locations without headlight signs was higher than the DRL-equipped vehicles. The percentages were 48 and 52, respectively. Figure 25 shows the different percentages of DRL-equipped vehicles vs. non-DRL vehicles. Table 20 shows the percentages of manual use of headlights on sections without headlight signs. It shows that nine percent of US 26 road users and seventeen percent of US 20/18 road users turned on headlights. Nearly thirteen percent of road users in sections without headlight signs turned on headlights.

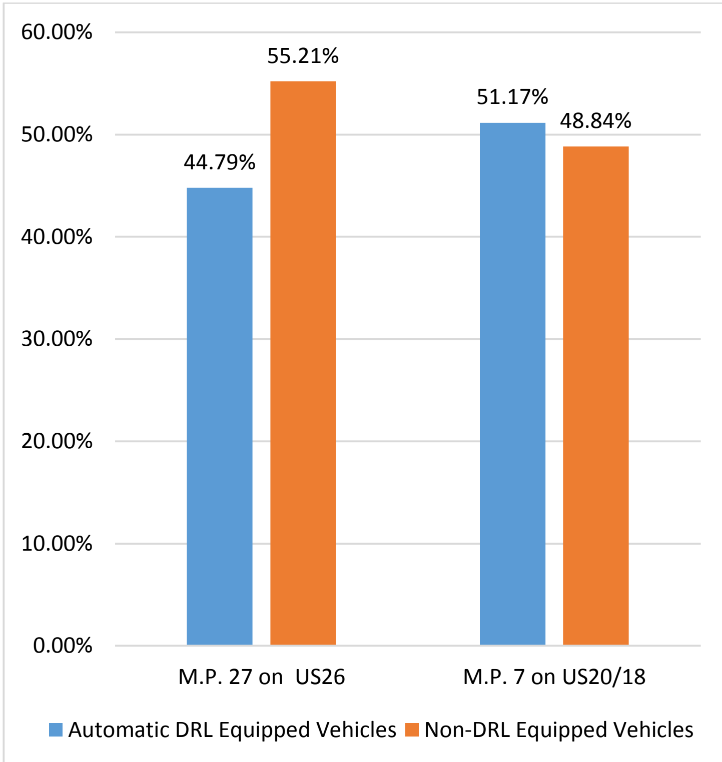

Figure 25. Chart. Percentage of vehicles equipped with DRL vs. non-DRL non-headlight sections.

Table 20. Percentages of vehicles using headlights at daytime for non-DRL vehicles.

Locations/MP	Day/Date	Time Period	Percentage of Manually Complied	Percentage of Non-Complied
MP 27 on US 26	Tuesday, July 14, 2015	10 a.m.–noon	8.51%	91.49%
		4 p.m.–6 p.m.	10.00%	90.00%
MP 7 on US 20/18	Wednesday, July 15, 2015	10 a.m.–noon	11.00%	89.00%
		4 p.m.–6 p.m.	22.39%	77.61%

COMPLIANCE RATES FOR HEADLIGHT SECTIONS VS. NON-HEADLIGHT SECTIONS

Compliance rate analysis was conducted for non-DRL-equipped vehicles. The total average compliance rates were twenty five percent and thirteen percent for headlight-sign sections and non-headlight sections, respectively. However, both percentages are low—the percentage of vehicles complying with the headlight signs is higher than those in non-headlight sections. If an assumption that thirteen percent of all roadway users who always turn on headlights on sections with or without headlight signs could be made, then it could be assumed that only twelve percent of road users are complying with the headlight signs. To determine if there is a significant difference between the compliance rates in both sections, a simple Z-test for proportions was conducted with "No difference in compliance rate between the two sections" hypothesis, $Z = 6.405$ was obtained. Comparing the obtained Z-score with the Z-critical for confidence level of ninety five percent, the null hypothesis is rejected. It should be noted that more data might be needed to confirm the results in this study.

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CHAPTER 6- DRIVING SIMULATOR EXPERIMENT

DRIVING SIMULATOR LAB

Phase 2 is focused on testing various headlight signs in a driving simulation-controlled environment. The lead principal investigator on this project has developed the first driving simulator lab in Wyoming-WYOSIM. The University of Wyoming (UW) and the Major Equipment Program at UW funded the driving simulator lab. The WYOSIM lab has a truck and a passenger car, both of which have open-cockpit cabs. The 2004 Ford Fusion motion-base driving simulator open-cockpit passenger vehicle cab was used for this study. The cab illustrated in Figure 26 is mounted on three degrees of freedom D-Box motion platform, comprising four electro-mechanical linear actuators. The driving simulator provides a 150-degree forward and side field of view using three 55-inch High Definition (HD) screens. Three main computers are used to operate the three visual displays with one host computer controlling all the visual channels.

Figure 26. Photo. 2004 Ford Fusion open-cockpit cab.

The simulator utilizes four Realtime Technologies Inc. SimObserver™ cameras to capture driver actions from different positions as shown in Figure 26. Six different sound channels are used to simulate ambient traffic and road noises. An additional speaker is used to provide instructions or commands to drivers during the test scenario.

Multiple scenarios were developed mimicking similar environments of two-lane highways in Wyoming. Internet Scene Assembler (ISA) software was used to develop the scenarios utilized in this study. ISA is a "virtual reality modeling language" that creates dynamic and interactive 3D scenes. Each scenario consisted of three main components: driving environment, static objects, and dynamic objects.

Figure 27 shows one of the developed scenarios that simulates one of the headlight-sign locations in snowy conditions. A headlight sign placed in the driving simulator environment has the same dimensions as the actual headlight sign now used on some Wyoming roadways. The sign was also placed in the same relative position to the road as shown in Figure 27.

Figure 27. Photo. Driving scenario simulating adverse weather conditions

The driving simulator has been used to assess various types of static and dynamic message signs (DMS). The goal of this task was to examine the judgment and recognition of signs under different weather conditions—clear and inclement—for different age groups and driving experience.

DRIVING SIMULATOR SCENARIOS

Multiple driving simulator scenarios were developed for different advisory scenarios using: (1) the headlight sign design now being used (a white sign that reads "TURN HEADLIGHTS ON FOR SAFETY NEXT XX MILES"), shown in **Figure 28** ; (2) the sign design now being used, but equipped with two orange flags on the top, as shown in **Figure 29** ; (3) the design now being used, but equipped with two flashing lights on top, as shown in **Figure 30**; and (4) a modified design having a yellow strip on top that reads "Turn Headlights On," a white block below the yellow strip that reads "For Safety Next XX Miles," and a large headlight symbol to the right, as shown in **Figure 31**.

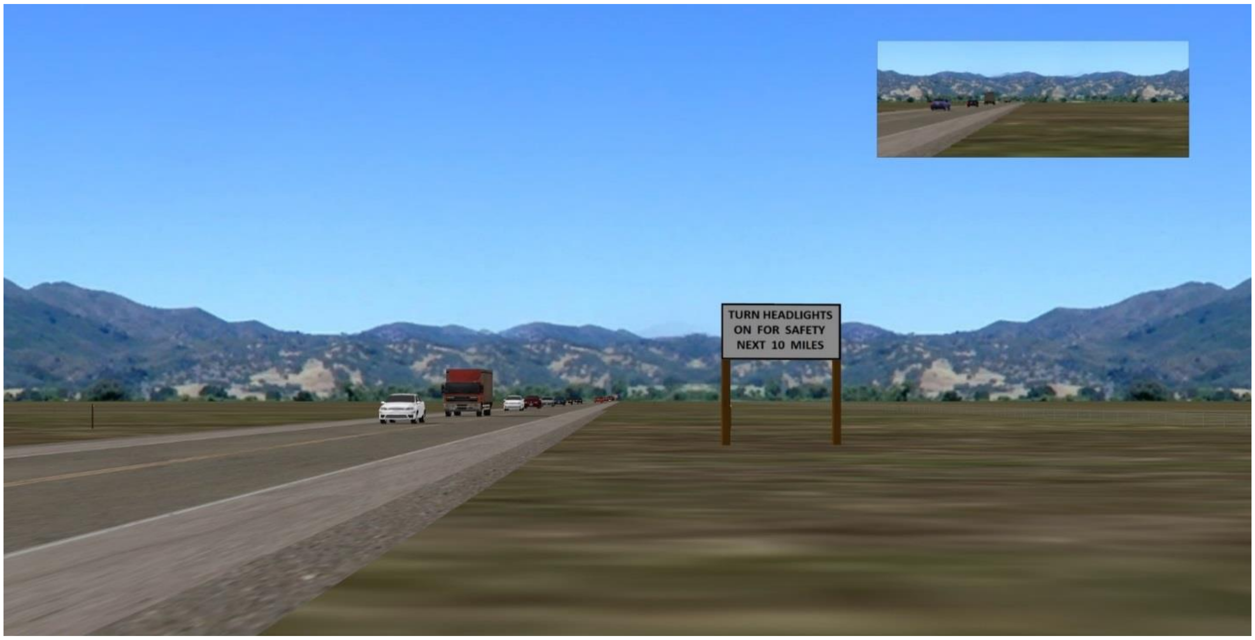


Figure 28: Photo. Existing design for headlights sign (Wyoming standard sign)

Figure 29: Photo. Option 1: Existing sign, but with orange flags

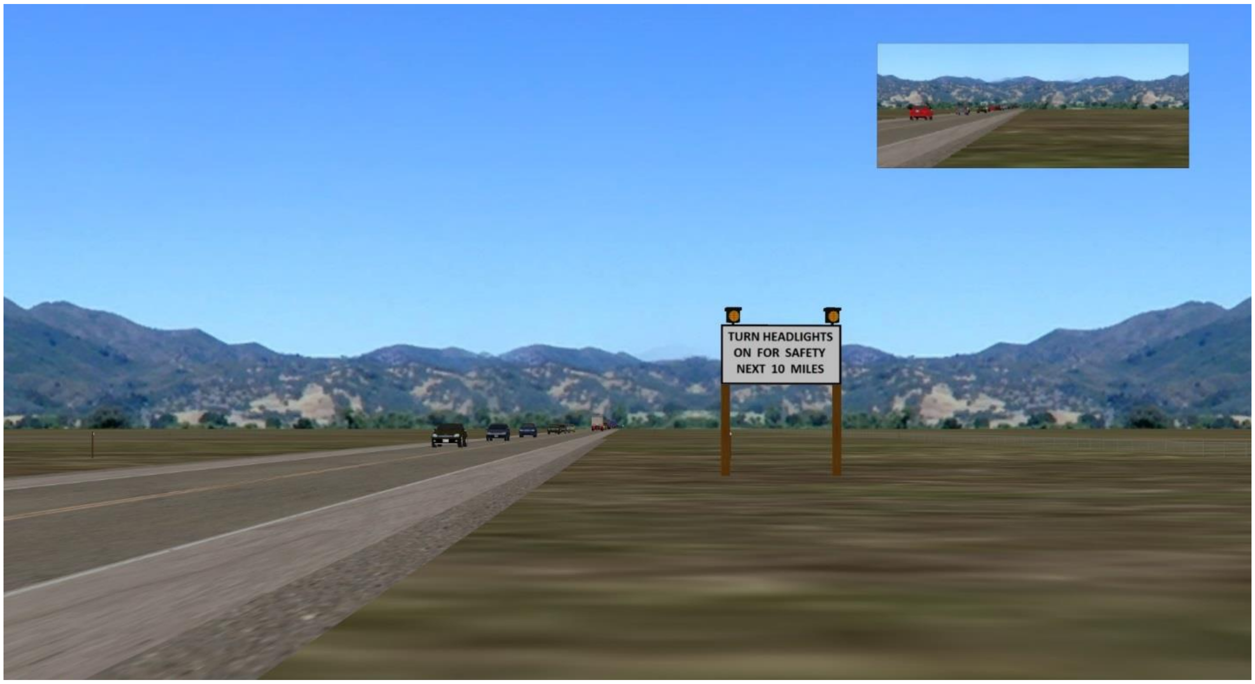


Figure 30: Photo. Option 2: Existing sign, with flashing beacons

(This option was dropped upon WYDOT request)

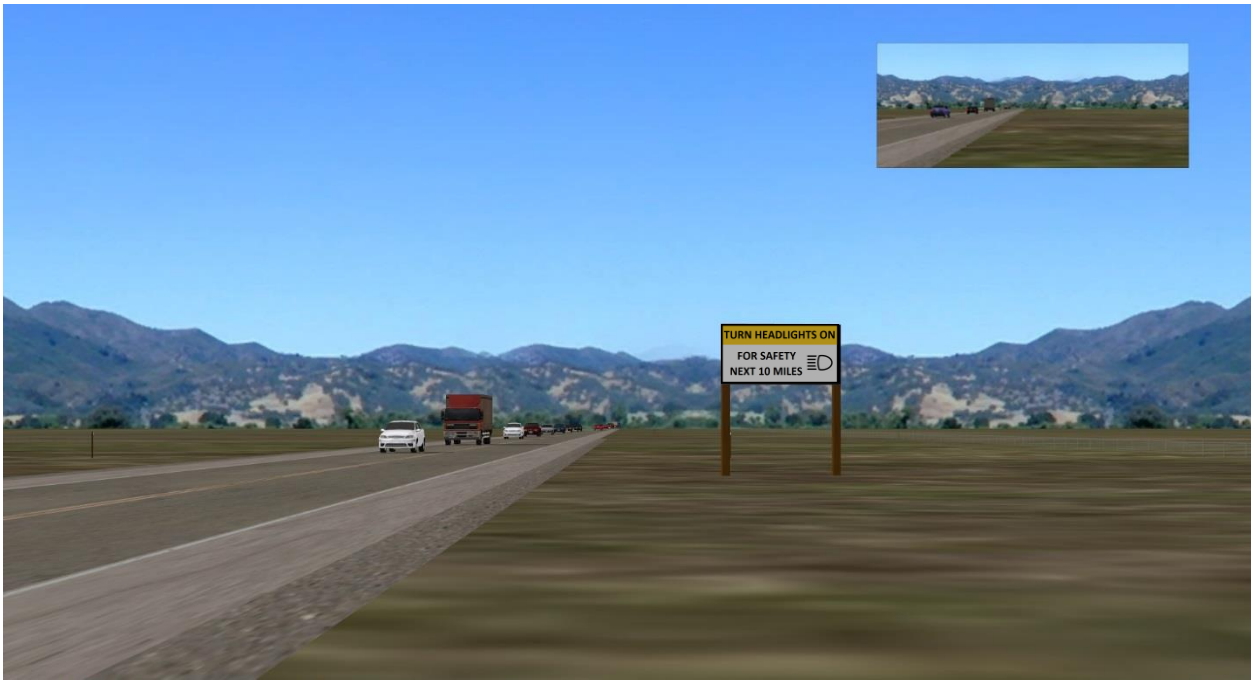
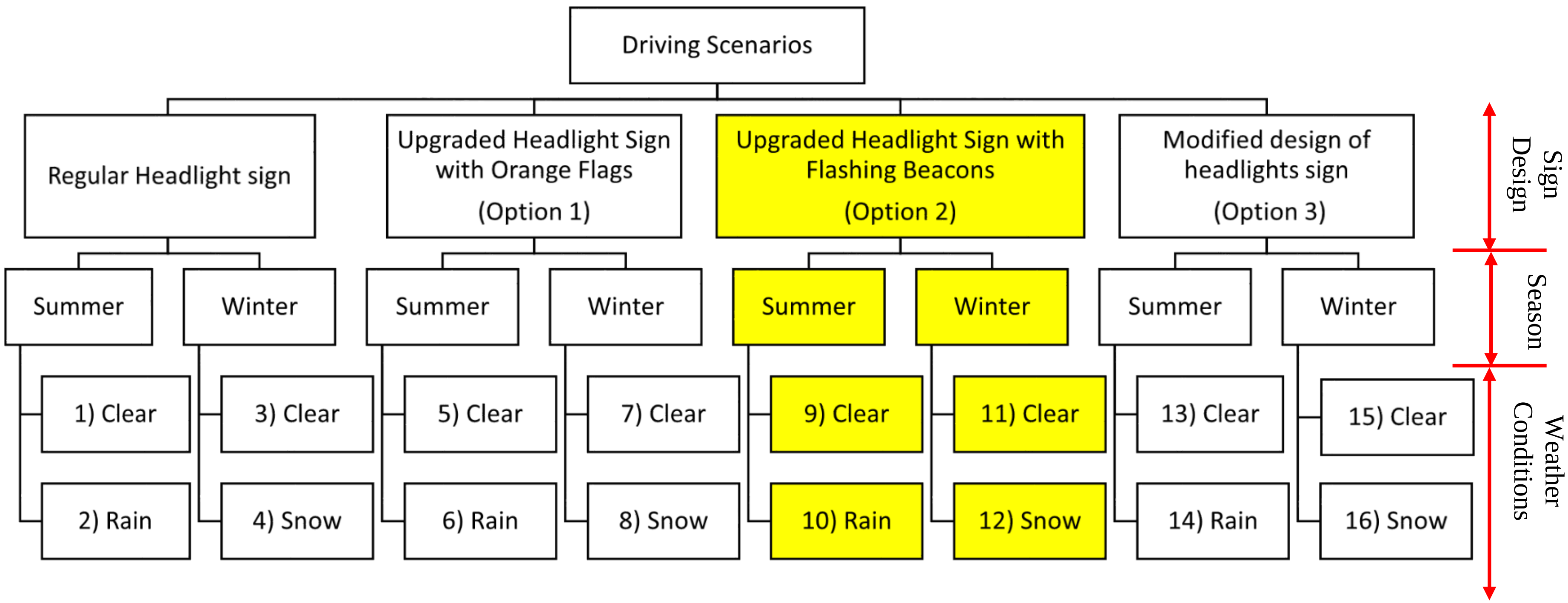


Figure 31: Photo. Option 3: Modified design of headlights sign

Option 2, which is the original sign with a flashing beacons, was dropped from the scenarios experiment as per WYDOT recommendations. Providing power source for the sign in order to operate the flashing beacon is quite costly. Moreover, flashing beacons is mainly used with traffic control signs and warning signs [20]. WYDOT recommended to drop the flashing beacon option to reserve it for messages of high priority. Moreover, leaving flashing beacons on, most of the time might also dilute their impacts on road users.

The developed scenarios each cover approximately three miles. Each scenario takes about 3minutes if an approximate speed of 65 mph is maintained. Sixteen scenarios were developed using ISA software, as shown in Figure 32. The figure shows four designs of headlight signs tested under different weather conditions. The visibility of the different sign designs might be significantly affected due to different adverse weather conditions. For example, the white background in snowy weather might cause the sign to be blended with the background. Various weather conditions were considered in this study to investigate the ability of drivers to recognize the different sign designs in clear, rain, and snow conditions.

The driving scenario with the existing headlight sign, the sign with orange flags placed on its top (option1) and the revised sign with the yellow strip (option 3), shown in **Figure 28**, **Figure 29**, and **Figure 31**, respectively, has a repeated sign with 1 mile separating distance. The field-data collection showed a low compliance rate to the regular headlight sign. Increasing the frequency of the headlight signs on each section of roadway may have a positive impact on increasing compliance rates. The two previously mentioned headlight-sign designs were chosen to be repeated as it is an easy and less expensive countermeasure to be tested in the field.



Note: According to WYDOT recommendations, the yellow shaded scenarios are not implemented in the expe

Figure 32: Chart. Hierarchy for the 16 developed scenarios.

EXPERIMENTAL DESIGN

The use of human subjects in this research project was approved by the University of Wyoming Institutional Review Board prior to beginning the driving simulator experiment.

Subjects volunteering for the experiments are invited via e-mails and through flyers distributed within southeast Wyoming. Appendix 2 contains the design of the flyer. Each subject is asked to drive three different scenarios. Each scenario contains a different headlight-sign design. Subjects are randomly assigned to drive a total of three scenarios out of the different seasonal and weather condition. The order of driving the three scenarios is assigned at random.

An introductory five-minute session is given to the subjects to familiarize them with the different components of the driving simulator cab. After filling out a pre-survey (described below), subjects go through a five-minute test driving scenario to become used to the driving-simulator vehicle dynamics.

PRE- AND POST-SURVEYS

Subjects fill out pre- and post-surveys. The main objective of the pre-survey was to collect subjects' basic knowledge about headlight signs in general. The post-survey was used to collect subject feedback concerning the different headlight-sign designs under various weather conditions. Appendix 3 has the final pre- and post-surveys.

PRELIMINARY RESULTS AND ANALYSIS

As this report was being finalized, the driving simulator experiments were continuing; the target is to achieve approximately 180 subjects. Complete results and analysis will be reported in the Phase 2 final report.

CHAPTER 7- CONCLUSIONS AND RECOMMENDATIONS

The main objective of the study was to evaluate the safety effectiveness of headlight signs on two-way two-lane highways in Wyoming. The seven locations having headlight signs were ranked according to peak searching and sliding window network performance measures. The results revealed the following rankings:

1. US 287 south of Laramie (MP 402.59–424.81).
2. WY 28 on South Pass (South Pass).
3. US 20/26 from Waltman to Shoshoni (MP 50.7–100).
4. US 287/WY789 (MP 2.4–13.59).
5. US 287 (23–33).
6. WY 59 between Wright and Gillette (76–101).
7. WY 220 southwest of Casper (88–102).

Identifying and ranking hotspots for the rest of Wyoming's two-way two-lane highways, non-headlight segments, were also performed using the same methods utilized for the seven headlight locations.

The results showed that the top five segments are: WY 220, US 191_{ML13B}, WY 85, US 22, and WY 59, respectively.

This study investigated the impact of the compliance rate, and the market penetration of the DRL technology on the safety benefits of regulatory headlight signs on mountainous, rural, two-lane highways. The safety effectiveness of headlight signs was examined based on DRL-equipped and non-DRL-equipped vehicles. Simple odds and ratio of odds ratios were utilized to adjust for a variety of exogenous factors. Four different scenarios were considered in analyzing crash data. A case-control method was used to compare crashes for a set of passenger vehicles equipped with DRLs and vehicles without DRLs on roadway sections with and without headlight signs. It is worth mentioning that conducting an observational before-after study was not possible because of the limited number of sites and the limited number of years of crash data in the before-after periods.

The analysis showed that seventy seven percent of vehicles involved in crashes were not equipped with DRLs. There was no significant difference between DRLs and non-DRL-equipped vehicles on sections with or without headlight signs on total and target crashes (head-on and opposite-direction sideswipe crashes). This could be mistakenly explained that there are no added safety benefits of headlight signs. The field study showed a very low compliance rate (only twelve percent) for headlight signs. Such signs are a behavior-based countermeasure, and compliance rates should be considered when evaluating the safety effectiveness of this countermeasure.

Transportation agencies might need to consider different strategies to increase compliance rates to such countermeasures. Different headlight-sign designs and frequency of use on challenging mountainous, rural highways should be considered to increase the compliance rate.

The driving simulator environment is used to assess various headlight-sign designs. The goal of this task is to examine the judgment and recognition of headlight signs under inclement weather for different age groups and driving experiences. Pre- and post-surveys are provided to subjects volunteering for the driving simulator experiment to briefly examine their driving history (pre-survey) and to assess their knowledge of headlights signs in the past and to also determine what sign designs worked best during different driving conditions (post-survey).

RECOMMENDATIONS

The field-testing phase should consider examining signs with higher frequency and with updated proposed designs. Increasing the number of signs in headlight-sign sections should increase driver compliance. The research team suggests testing the proposed sign with the yellow strip, revised wording, and headlight symbol for the following reasons: (1) the yellow strip should draw more attention to the sign; (2) using flashing beacons might imply a temporary use during specific conditions; (3) not all two-lane highways have access to power sources; and (4) using flags could be confused with signs used at construction zones. Hotspot analysis results for the seven headlight locations provided ranking for sites with promise as stated earlier. As mentioned earlier, two options are recommended for field testing based on rankings: (1) a greater number of signs will be installed in two locations; and (2) the newly designed sign with the yellow strip (option 3) will be implemented at another two locations. Three remaining locations will be kept without change as a control group. The recommended locations for the first implementation option are US 287 south of Laramie (MP 402.59–424.81) and WY 220 southwest of Casper (MP 88–102). The headlight-sign sections on WY 28 (South Pass) and WY 59 between Wright and Gillette (MP 76–101) are recommended for the second option. The three remaining locations—US 20/26 (Waltman–Shoshoni), US 287/WY 789 (2.4–13.59), and US 287 (23–33)—will be used as control group.

Data will be collected for three years. Following an evaluation of that data, recommendations will be offered on sign designs.

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APPENDIX 1—DRIVING SIMULATOR FLYER

Safety Effectiveness of Regulatory Headlights Signs in Wyoming

HELP US TO MAKE OUR ROADWAYS SAFER

You are invited to participate in a research study conducted by the University of Wyoming and the Wyoming Department of Transportation. Our goal is to enhance safety and reduce fatalities on our Wyoming two-way two-lane highways.

We invite you to visit the Driving Simulation Lab located in the Department of Civil and Architectural Engineering at the University of Wyoming and participate by driving the simulator. Your participation is entirely voluntary. To participate in the study, you must be at least 18 years old and hold a valid driver's license.

For more information about the study and how to participate, you may contact: Sherif M. Gaweesh, M.Sc., graduate student at the University of Wyoming, Department of Civil and Architectural Engineering,

Phone: 307-761-3039

E-mail:sgaweesh@uwyo.edu

Investigators: Mohamed Ahmed, Ph.D, P.E. and Khaled Ksaibati, , Ph.D, P.E.

APPENDIX 2—PRE- AND POST-DRIVING SIMULATOR SURVEYS

Pre-Driving Questionnaire Survey

Safety Study
University of Wyoming (UW) and Wyoming Department of Transportation (WYDOT)

SPONSOR: Wyoming Department of Transportation

INVESTIGATORS: Mohamed Ahmed, Ph.D., P.E., and Khaled Ksaibati, Ph.D., P.E.: University of Wyoming, Department of Civil and Architectural Engineering

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Objective of the Study

Researchers at **the University of Wyoming (UW)** are currently working on a **Wyoming Department of Transportation (WYDOT)** sponsored project intended to reduce crashes on Wyoming's Highways. To help us achieve this goal, we would like to invite you to complete this survey questionnaire before participating in the driving simulation experiment. All answers are anonymous. ***The only potential risks to subjects during testing could be slight motion sickness, fatigue, dizziness, eye strain, the potential of feeling anxious or stressed, or slight light headedness.*** There are no anticipated risks or direct benefits to you if you decide to participate. There is no penalty if you decide not to participate. You can end your participation at any time and you do not have to answer any questions that you do not want to answer. The survey will take only about five minutes of your time.

WOULD YOU LIKE TO PARTICIPATE IN THIS SURVEY? If yes, please begin to answer survey's questions.

Are you 18 years old or older? (Yes, No) **(if "NO" terminate survey)**
Please choose one answer only in each of the following survey's questions

1) What is your gender?
   a) Male   b) Female

2) Which of the following best describes your age (in years)?
   a) 18–25   b) 26–35   c) 36–50   d) 51–65
   e)over 65

3) What is the highest level of education that you have completed?
   a) Graduate school or higher   b) College degree   c) Some College
   d) High School   e) Did not graduate from high school

4) Do you have a valid driving license?
   a) Yes   b) No

5) For how long have you been driving?

a) Less than 1yr   b) Between 5–15 yrs

c) Between 1–5 yrs   d) More than 15 yrs

6) Did you drink alcohol during the last 24 hours?

a) Yes

b) No

7) Do you have a history of radial keratotomy, [laser] eye surgery, or any other ophthalmic surgeries?

a) Yes

b) No

If yes, which ones? ____

8) Do you need to wear glasses or contact lenses while driving?

a) Yes

b) No

9) Are you color or night blind?

a) Yes

b) No

10) Number of traffic citations (i.e., traffic rule violations) in the previous 3 years?.............

11) Do you drive frequently on two-way two-lane highways in Wyoming?

a) Yes

b) No

12) Have you ever been involved in any crash, while you were driving on two-way two-lane highways in Wyoming?

a) Yes

b) No

13) If yes, please state the number of crash(s) involved in and the type

____

____

14) Have you ever been involved in any crash, while you were driving in heavy rain, snow, whiteout, blizzards, or due to any reduction in visibility?

a) Yes

b) No

15) If yes, please state the number of crash(s) involved in and the type

____

____

Please provide your full name (last, first)

__________________________, ____________________________

End of Pre-Survey

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Subject Accepted for study _________________

Subject Rejected for study _________________

Participant ID: _________________

Date: _________________

Time: _________________

Design	Basic	Flags	Modified
Order			
Weather Conditions			

Post-Driving Questionnaire Survey

University of Wyoming (UW) and Wyoming Department of Transportation (WYDOT)

Safety Effectiveness of Regulatory Headlight Signs in Wyoming (Phases 1 and 2)

SPONSOR: Wyoming Department of Transportation

INVESTIGATORS: Mohamed Ahmed, Ph.D., P.E., and Khaled Ksaibati, Ph.D., P.E.: University of Wyoming, Department of Civil and Architectural Engineering

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1) Have you driven on any two-way, two-lane highway during the last few months (e.g., US 287, WY 789, WY 220, WY 59, US 20/26, WY 28)?
   - a) Yes
   - b) No

2) How often do you use two-way, two-lane highways? (One way trip is considered as one time)
   - a) More than four times a week
   - b) Two–four times a week
   - c) Once a week
   - d) Once in two weeks
   - e) Once a month
   - f) Rarely or never

A Headlight Sign is a regulatory traffic sign often used on two-way, two-lane roadways to require drivers to turn on their headlights for the coming few miles.

3) Have you ever encountered Headlight Signs on a two-way, two-lane roadway?
   - a) Yes
   - b) No

4) If you are provided with information on static sign that is designed to help avoid a potential crash in case of reduced visibility on a challenging two-way, two-road roadways section, would you agree to follow the advice provided?
   - a) Strongly Agree
   - b) Agree
   - c) Neither agree nor disagree
   - d) Disagree
   - e) Strongly Disagree

5) Did you encounter any reduction in visibility due to snow, blizzards, fog, smoke, or heavy rain while you were driving on a two-way, two-lane highway?
    a) Yes
    b) No

6) What did you do in that situation?
    a) Did nothing
    b) Followed other vehicles' speed. If they reduced their speed then you would also reduce your speed
    c) Drove below speed limit
    d) Drove below speed limit and put blinkers on
    e) Abandoned the journey and stopped the car immediately at the right shoulder of the road

7) It is useful to use two or more successive Headlight Signs prior to two-way, two-lane sections with challenging roadway characteristics. This could provide drivers another chance to see the message if they missed the first one. Do you agree or disagree with the previous statement?
    a) Strongly Agree
    b) Agree
    c) Neither agree nor disagree
    d) Disagree
    e) Strongly Disagree

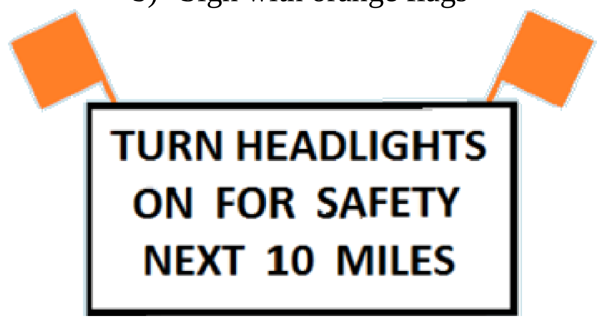
8) Do you agree or disagree that using headlights during daytime is useful in reducing the number of lane-departure crashes by informing drivers about locations where they should turn on their headlights?
    a) Strongly Agree
    b) Agree
    c) Neither agree nor disagree
    d) Disagree
    e) Strongly Disagree

Three different designs for the “Turn on your headlights” signs were used in the experiment scenarios.

a) Basic sign

Existing design used in Wyoming. It has a low compliance rates

b) Sign with orange flags



Adding orange flags on the top of the basic sign to increase sign visibility

c) Modified sign design

Using headlight symbol and a yellow panel to increase sign visibility

9) Which sign did you notice while driving the simulator? (Mark all noticed signs)

Sign	Mark
a) Basic sign	
b) Sign with orange flags	
c) Modified sign design	
d) None	

Sunny conditions

a) Basic sign

b) Sign with orange flags

c) Modified sign design

10) Please rank the different signs in the order of their visibility in the sunny condition? (“1”is poor and “3” is excellent)

Sign	Rank
a) Basic sign	
b) Sign with orange flags	
c) Modified sign design	

Snowy conditions

a) Basic sign

b) Sign with orange flags

c) Modified sign design

11) Please rank the different signs in the order of their visibility in the snowy condition?
(“1”is poor and “3” is excellent)

Sign	Rank
a) Basic sign	
b) Sign with orange flags	
c) Modified sign design	

Repeated signs were placed at the same driving scenario with a separation of one mile. The repeated strategy were used for the three designs, the Basic sign “design (a)”, Sign with orange flags “design (b)” and Modified sign “design (c)”.

12) Mark the sign that you noticed it was repeated in the scenarios.

Sign	Mark
a) Basic sign	
b) Sign with orange flags	
c) Modified sign design	

13) If you have any comments or suggestions, please mention below.

____

____

____

Please provide your full name (last, first)

__________________________, ____________________________

End of Survey

Thank you for participating in the survey!

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Participant ID: __________________

Date: __________________

Time: __________________

ACKNOWLEDGMENTS

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