RP222

Improving Passing Lane Safety and Efficiency

By

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National Institute for Advanced Transportation Technology

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Prepared for

Idaho Transportation Department

Research Program, Contracting Services

Division of Engineering Services

http://itd.idaho.gov/highways/research/

September 2015

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1. Report No. FHWA-ID-15-222	2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Improving Passing Lane Safety and Efficiency			5. Report Date September 2015	
			6. Performing Organization Code KLK566	
7. Author(s) Ahmed Abdel-Rahim and Brian Dyre			8. Performing Organization Report NIATT-N17-09	
9. Performing Organization Name and Address National Institute for Advanced Transportation Technology (NIATT) P.O. Box 440901 University of Idaho Moscow, Idaho 83844-0901			10. Work Unit No. (TRAIS)	
			11. Contract or Grant No. RP222	
12. Sponsoring Agency Name and Address Research Program, Contracting Services, Division of Engineering Services Idaho Transportation Department 3311 West State Street Boise, ID 83707-5881			13. Type of Report and Period 05/15/12-09/30/14	
			14. Sponsoring Agency Code RP 222	
15. Supplementary Notes				

16. Abstract
Field data collected in the passing lane sites shows several important characteristics. The speed in the right lane are consistently higher than the operating speed just upstream from the passing lane. Most importantly, and for both sites, the difference in average speed between vehicles in the right lane and left lane was lower than 3 mph at both locations along the passing zone. Such operations characteristics clearly show a need for intervention measure to slow traffic in the right lane to allow for a safer passing maneuvers.

The crash analysis for 67 passing lanes segments identified a total of 137 crashes occurred either at the passing lane segments or at the merging areas downstream of the passing lane. The analysis covered a 10-year period from 2005 to 2015. Of these crashes, 46.15 percent were property damage crashes, 15.38 percent were possible injury crashes, 23.08 percent were visible injury crashes, 13.94 percent were serious injury crashes, and 1.45 percent were fatal crashes. Only 9 of the 137 crashes (6.57 percent) involved alcohol use. The majority of passing lane crashes occurred during clear weather conditions (62.04 percent) and during daylight (76.64 percent). Only 8.03 percent of the crashes occurred during ice/snow conditions. Speeding, improper lane-use, and improper overtaking were the major contribution factors in 84.67 of the crashes. The average crash rates (crash/million vehicle-mile/year) for merging segments, non-merging segments, and passing lane segments are 2.316, 2.228, and 2.271, respectively. While the merging segments, downstream of the passing lanes, have slightly higher crash rates than non-merging roadway segments (3.8 percent higher), the difference is not statistically significant at the 95% confidence level.

| 17. Key Word:
Highway Safety Improvement Program,
Weather Traffic Management, Responsive Traffic Signal Systems | | 18. Distribution Statement Unrestricted.
http://itd.idaho.gov/highways/research/
and
http://www.uidaho.edu/engr/research/niatt/research/itd-projects/klk566/full-description | | |
| 19. Security Classif. (of this report)
Unrestricted | 20. Security Classif. (of this page)
Unrestricted | | 21. No. of Pages
56 | 22. Price |

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)

Acknowledgements

The authors would like to acknowledge the Idaho Transportation Department's Office of Highway Safety staff for their continuing support and guidance throughout this study and for providing the data used in the analysis.

Technical Advisory Committee

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Executive Summary

Passing lanes in two-lane two-way rural highways provide motorists with the opportunity to pass slow moving vehicles, improving the level of service of the operations in these highways. Such passing maneuvers, however, can lead to a hazardous situation for the passing vehicle as well as for the opposing traffic. Several head-on fatal and severe injury crashes have occurred in passing lanes in either at merge points (where passing maneuvers have continued too far) or just downstream of passing lanes where demand to pass is high. Field observations have shown that once entering the wider roads and high design quality of passing lanes, some vehicles- including large trucks and recreational vehicles - tend to increase speeds. Many motorists are observed to speed in the fast lane and pass at excessive speeds that could carry into the merge area increasing the risk of a fatal or a severe injury crash. Passing lane safety and efficiency can be significantly improved if the lead vehicles with varying speeds were induced to maintain a relatively slower speed allowing more vehicles to pass without excessive speeds or reckless weaving maneuvers.

A driver simulator study conducted by researchers from the University of Idaho's National Institute for Advanced Transportation Technology (NIATT) concluded that that regulatory speed reduction signs early in a passing zone that limit the speed of right-lane drivers relative to left-lane drivers offer the greatest opportunity for increasing the efficiency—and perhaps also the safety—of rural passing zones. The study found that regulatory signs imposing split speed limits between the lanes (65 mph-left, 55 mph-right) or limiting RVs and trucks to 55 mph along with advisories to allow others to pass, reliably increased the difference in speed between left- and right-lane drivers, which should allow more passes to occur within each passing zone. This increase in passing efficiency has the potential to reduce driver frustration and passing urgency, and may therefore significantly enhance the safety of rural highways.

The driver simulator study also analyzed the effect of several passive speed reduction measures using alternative pavement striping (Chevrons, transverse lines, parallax, lane narrowing). The passive speed reduction measures were all less effective in reducing speed of drivers in the right-hand lane than regulatory and advisory speed reduction signs. However, among these alternatives lane narrowing and traverse lines showed the highest potential in reducing driver speed. The primary objective of this research project was to field test the effectiveness of these measures in two passing lane sites in Idaho. Due to some regulation limitations, the proposed speed reduction signs and improved striping measures were never implemented in the field. Accordingly, the project tasks were limited to collecting field data to document the speed operational characteristics upstream from, at, and downstream of the passing lanes and analyzing crash data to investigate the characteristics of passing lane crashes in Idaho.

The speed data collected in the passing lane sites shows several important characteristics. The speeds in the right lane are consistently higher than the operating speed just upstream from the passing lane. Most importantly, and for both sites, the difference in average speed between vehicles in the right lane and left lane was lower than 3 mph at both locations along the passing zone. Such operational

characteristics clearly show a need for intervention measure to slow traffic in the right lane to allow for safer passing maneuvers.

The crash analysis for 67 passing lanes segments identified a total of 137 crashes occurred either at the passing lane segments or at the merging areas downstream of the passing lane. The analysis covered a 10-year period from 2005 to 2015. Of these crashes, 46.15 percent were property damage crashes, 15.38 percent were possible injury crashes, 23.08 percent were visible injury crashes, 13.94 percent were serious injury crashes, and 1.45 percent were fatal crashes. Only 9 of the 137 crashes (6.57 percent) involved alcohol use. The majority of passing lane crashes occurred during clear weather conditions (62.04 percent) and during daylight (76.64 percent). Only 8.03 percent of the crashes occurred during ice/snow conditions. Speeding, improper lane-use, and improper overtaking were the major contribution factors in 84.67 of the crashes. The average crash rates (crash/million vehicle-mile/year) for merging segments, non-merging segments, and passing lane segments are 2.316, 2.228, and 2.271, respectively. While the merging segments downstream of the passing lanes have slightly higher crash rates than non-merging roadway segments (3.8 percent higher), the difference is not statistically significant at the 95% confidence level.

Chapter 1
Introduction

Overview

Passing lanes in two-lane two-way rural highways provide motorists with the opportunity to pass slow moving vehicles, improving the level of service of the operations in these highways. Such passing maneuvers however, can lead to hazardous situations for the passing vehicle as well as for the opposing traffic. Several head-on fatal and severe injury crashes occur in passing lanes in Idaho either at merge points (where passing maneuvers have continued too far) or just downstream of passing lanes where demand to pass is high. Field observations have shown that some vehicles, including large trucks and recreational vehicles, tend to increase speeds once in the passing lanes. This leads motorists to pass at excessive speeds that may carry into the merge area increasing the risk of a fatal or a severe injury crash. Passing lane safety and efficiency can be significantly improved if the lead vehicles with varying speeds were encouraged to be courteous and maintain a relatively slower speed allowing more vehicles to pass without excessive speeds or reckless weaving maneuvers. This project examines the effectiveness of two low-cost measures that have the potential of influencing the behavior of drivers while on the passing lanes. The two alternatives are: 1) improved signage upstream from and at the passing lanes and 2) alternative striping and lane marking.

Benefits to ITD and to the public from this project include: 1) low-cost alternatives that have the potential of improving the safety and efficiency of the traffic operations on passing lanes in Idaho's two-lane rural highways, 2) reduced head-on collision on passing lanes, and 3) increase public awareness of safe and efficient passing maneuvers through the project's outreach activities. This research project aligns with Idaho's Strategic Highway Safety Plan and supports the top performance measure of eliminating fatalities and serious injuries.

Research Objectives

The project has the following three objectives: 1) examine the effectiveness of improved signage on the safety and efficiency of the passing lane operations, 2) examine the effectiveness of alternative striping and pavement marking on reducing the speed at the passing lane locations, and 3) document the characteristics of passing lane crashes in Idaho's two-lane rural state highways.

Report Organization

This report includes four chapters. After the introduction, Chapter 2 provides an extensive summary of the results of the driver simulation study that assessed the potential safety benefits of using improved signage and striping in passing lane locations considered for this project. Chapter 3 presents the study's field data collection and the results of the crash analysis. Chapter 4 documents the study conclusions.

Chapter 2
Driver Simulator Study Summary Results

Overview

A series of experiments using the University of Idaho's National Advanced Driving Simulator (NADS) Minisim fixed-base driving simulator were conducted to examine the potential safety and operational benefits of several highway safety interventions for reducing collision risk. These safety interventions were aimed at inducing safer driver behaviors such as slowing in the right-hand lane while being passed to reduce incidences of last-second, high-speed passes. The study approach goes beyond typical mitigations of collision risk that use explicit behavioral interventions such as enforcing lower speed limits (regulation) and public education (safety warnings). These explicit enforcement interventions can be costly to implement and have limited impact on a sometimes uncooperative public who are in a hurry and whose decision making might be impaired by alcohol or fatigue.

The study aim is to examine whether semi-permanent alterations to the visual appearance of the unsafe zones might implicitly reduce risky driver behaviors by slowing traffic and inducing better passing decisions without drivers being consciously aware that their behavior is being affected. Such implicit changes in behavior may be more efficient and long-lasting since they do not require conscious compliance from drivers nor engagement from law enforcement. Rather, these safety interventions will be designed to passively engage drivers in safer passing behaviors by sub-consciously altering their perceptions of speed and distance. An overview of the study methodology, results, and conclusions is presented in this chapter. The full details of this study is documented in the study's final report[1].

Simulation Study Aims

In this study, two experiments aimed at evaluating the efficacy of various passing zone scenarios on driving behavior were conducted. In each experiment, a sample of participants was tested driving a simulation of a two-lane rural highway through the Alaskan countryside with passing zones occurring intermittently. The simulation method had two broad aims. First, the study authors endeavored to immerse drivers in a simulation so as to produce natural driving behaviors. To this end, they developed a virtual environment describing a 50 mile driving loop through typical rural terrain (farms, forests, mountains) and instructed the participants to imagine they would be driving through a rural highway segment after a long recreational weekend and to drive with their "normal style and etiquette" (instructions are detailed in the procedure sections of each experiment).

The second broad aim was to examine effects of the passing zone scenarios on the behavior of two types of drivers: those towing a recreational vehicle (RV) and those driving a sedan not towing a RV. Experiment 1 examined drivers towing a RV, while Experiment 2 examined sedan (non-towing) drivers. Different traffic scenarios were developed for these two categories of drivers and slightly different

instructions were provided to implicitly induce the RV-towing drivers to use the right lane of passing zones to let vehicles pass and the non-towing drivers to use the left hand lane and attempt to pass slower traffic.

Simulation Study Stimuli

Both experiments used almost identical stimuli. Participants drove a 50-mile track simulating a two-lane rural Alaskan highway with 10 three-lane passing zones interspersed every three to four miles. The inter-passing-zone stretches of the two-lane highway consisted of three to four miles of a variety of terrain, including both horizontal and vertical curves (hilly terrain) and straight and level sections. The speed limit for inter-passing-zone stretches of highway was marked as 65 mph and advisory signs for curves were included. Passing zones consisted of a two-mile length of straight and level (0% grade) roadway with standard advisory and regulatory signs preceding each zone in their typical locations (see Figure 1). For each passing zone, the full two lanes separated by white dashed lane markings was one mile long, with a 1/8 mile lane-addition transition, and a 1/8 mile lane-reduction transition. Each passing zone simulated one of ten different set of signage or roadway markings, hereafter referred to as *scenarios* (see Figures 2-11)

Figure 1 Standard Passing Lane Advisory and Regulatory Signs

Table 1 The Ten Passing Zone Scenarios Examined in the Study

Baseline

0. Advisory
1. Regulatory
2. Regulatory plus advisory
3. Chevrons
4. Transverse lines
5. Lane narrowing
6. Parallax
7. Force right/Neutral zone
8. Transverse lines with middle segment

Descriptions of Testing Scenarios

- **Scenario 0:** *Baseline.* This scenario simulated the conditions presently implemented in passing zones on Alaska rural highways. All other passing zone scenarios were variations on this baseline scenario and shared all elements except for the differences described below.

- **Scenario 1**: *Advisory.* This scenario replaced the "Keep Right Except to Pass" sign with a "Slower Traffic Keep Right" sign and added the advisory sign "Allow Others to Pass" next to the "Slower Traffic Keep Right" sign.

- **Scenario 2**: *Regulatory with right lane reduced speed limit.* This scenario changed the 65 mph of the Baseline Scenario 0 to a split speed limit for the left and right lanes, with the right lane speed limit reduced to 55 mph.

- **Scenario 3**: *Regulatory with truck/RV speed limit plus advisory.* This scenario added the same advisory and "Slower Traffic Keep Right" signs included in Scenario 1 and combined it with a reduced speed limit of 55 mph for Trucks and RVs.

- **Scenario 4**: *Passive speed reduction using chevrons.* This scenario added partial chevrons painted on the road surface to the Baseline Scenario 0. The partial chevrons consisted of groups of ten 5.9" wide white lines extending from the lane edge markings into the lane at an angle of 30 degrees toward the direction of travel and spaced 2" apart. Each group thus extended 6' 7" longitudinally along the roadway. The lines extended 1.5' laterally toward the center of the lane from each edge line, then left a 3' lateral gap before starting again for the center 3'-wide "^" shape. This left two 3'-wide paint-free gaps for vehicles tires to contact the road. The chevron groups started at the point where the two full passing lanes divided by a dashed white line began, with the first five groups spaced longitudinally at a distance of 42' measured from the beginning of one group of chevrons to the beginning of the next group. After the fifth group of Chevrons, the spacing decreased by a factor of 0.988 for the next 33 groups, reaching a minimum of 26.8' between the 38th and 39th group, which was located ¼ mile into the passing zone. For the next ½ mile, 61 groups of chevrons occurred at a constant longitudinal spacing of 26.8'. For the last ¼ mile of the full two lane section of the passing zone, the spacing increased by a factor of 1/0.988 = 1.012 for the first 34 chevron groups and then remained at a constant 42' for the final 5 chevron groups.

- **Scenario 5**: *Passive speed reduction using transverse lines.* This scenario added transverse lines painted on the road surface to the Baseline Scenario 0. The transverse lines consisted of 2'-wide lines extending orthogonally from the lane edge markings into the lane 1.5'. Longitudinal spacing of the transverse lines was identical to the chevrons described in Scenario 4.

- **Scenario 6**: *Passive speed reduction with lane narrowing.* This scenario was identical to the Baseline Scenario 0 except for a linear narrowing of the right lane edge line such that the lane width reduced from 12' to 10' over the first ¼ mile, remained a constant 10' width for the next ½ mile, then linearly expanded to the original 12' lane width over the last ¼ mile.

- **Scenario 7**: *Passive speed reduction with poles creating optical parallax along the side of the road.* This scenario added groups of yellow poles extending 10' above the ground along the side of the road to the Baseline Scenario 0. The poles were 6" in diameter and painted with the same yellow color as the center dividing line of the highway. The longitudinal spacing of the pole

groups decreased logarithmically during the first ¼ mile, was constant for ½ mile, and increased logarithmically over the last ¼ mile in a manner identical to Scenario 4: Chevrons. The number and lateral spacing of the poles within each pole group also changed over these segments of the passing zone. The initial four pole groups and last four pole groups—corresponding to the initial and final four constant longitudinal gaps—contained only one pole, located 60' laterally from the right-hand edge line of the roadway. All other pole groups contained 3 poles, whose inter-pole lateral spacing increased linearly from 1' for the 5th pole group to 10' for the 16th pole group. For pole groups 1-16, the farthest pole was always located 60' from the roadway right-hand edge line, therefore for the 16th pole group the near and middle poles were located 40' and 50' from the edge line, respectively. Pole groups 17-38 continued with 10' lateral spacing but the distance of the poles from the roadway right-hand edge line decreased linearly from 40, 50, and 60' to 15, 25, and 35' (respectively) at ¼ mile into the full 2-lane segment of the passing zone. For the next ½ mile of the passing zone 61 pole groups had constant lateral and longitudinal spacing. Over the last ¼ mile of the full 2-lane passing zone pole groups 62-83 had 10' lateral spacing but linearly increased in distance from the right edge-line of the roadway until the distance again reached 40, 50, and 60' for the nearest, middle, and furthest pole, respectively. For the next 12 pole groups, 84-96, inter-pole lateral spacing linearly decreased from 10' to 1' with the furthest pole located 60' laterally from the right roadway edge line, followed by the last 4 single pole groups.

- **Scenario 8**: *Force right at lane addition and neutral zone with arrows at lane reduction.* This scenario added two elements to the Baseline Scenario 0: 1) a "force right" center line at the beginning of the passing zone; and 2) an early return with arrows, rumble strip, and a neutral zone at the end of the passing zone. A rumble strip was simulated under this line to create a loud rumble sound when driven upon, which shortened the passing zone by 200 feet leaving Standard arrows from the MUTCD pointing diagonally toward the left-lane preceded the early return neutral zone .

- **Scenario 9**: *Passive speed reduction using transverse lines with a middle segment.* This scenario added a middle segment to the transverse lines painted on the road surface for the Transverse Lines Scenario 5. The middle line segment was 2' wide and 3' long placed exactly in the lane center, providing 3' wide unpainted pavement between the center and outer transverse line segments.

As part of the study, 10 unique counter-balanced orders were developed for the 10 passing scenarios such that each scenario occurred equally often in each place of the order and preceded and followed every other scenario an equal number of times. These orders are listed in Table 2. Each passing zone also included a pseudo-random headwind-tailwind disturbance profile to induce participants to make accelerator pedal movements to maintain constant speed. The wind disturbances profiles were defined by 5 velocities: strong head-wind (defined as -100 mph in the MiniSim software), head-wind (-50 mph), zero, tail-wind (50 mph), and strong tail-wind (100 mph), each presented twice in a pseudo-random order for 1/10 mile segments of the passing zone. While the magnitude of these disturbances as defined in the Minisim software seem extreme, their effect in accelerating the vehicle was actually very modest: In the absence of accelerator or brake inputs, these disturbances changed the vehicle speed by

a maximum of 3-4 mph. Further, because the wind disturbances always summed to zero within a passing zone, the cumulative effect of each disturbance on the mean vehicle speed in a passing zone was negligible. The order of the wind disturbances were balanced across the 10 passing zones such that each wind velocity profile was paired with each passing lane scenario an equal number of times.

The simulation also included traffic, with cars and trucks in front of and behind the participant's vehicle and in the oncoming lane. Traffic density in the oncoming lane was moderate, with oncoming vehicles passing every 10-20 seconds. Traffic density in the driver's lane was manipulated differently for the two experiments (see below), but for both experiments each passing zone was "reset" during the inter-zone highway stretch by scripting the vehicles from the previous passing zone to pull off onto the shoulder, while simultaneously scripting a new set of 9 vehicles to be created out of sight around corners ahead of and behind the driver. This procedure ensured that each passing zone had nearly identical traffic conditions, with the same number of cars in front and behind the driver.

Apparatus and Testing Procedures

Identical apparatus was used for both Experiments 1 and 2. A seven video channel National Advanced Driving Simulator (NADS) MiniSim rendered the simulations and collected behavioral data. Participants "drove" the simulations from an instrumented cab based on a 2001 Chevrolet S10 pick-up truck (see Figure 12). Participants were treated in accordance with a university-approved protocol governing the use of human subjects in research. Prior to starting the experiments, all participants were read a general description of the study, warned of the risks involved (primarily motion sickness), and asked to sign a consent form. Next, the instructions were read to participants. Importantly, these instructions emphasized that participants should imagine themselves driving on a rural highway and that they should act normally in obeying traffic laws and driving etiquette.

Figure 2. Overhead View of Chevy S-10 Cab with the Three Main Forward Displays and Right-Side Mirror Display

Driver Simulator Experiment 1 Results

Experiment 1 was designed to test the efficacy of the different passing zone scenarios on the speed and lane choice of RV-towing drivers. Though it was assumed that these drivers would choose to use the right hand lane, it was also expected that the different passing zone scenarios might affect lane choice, so the researchers chose to not explicitly instruct the participants to use the right lanes of the passing zones. Such instructions could have potentially altered participants' normal driving behavior. To induce a right lane choice, the researchers therefore relied upon subtle instructions for participants to imagine themselves pulling a RV trailer, explicit inclusion of a simulated trailer behind the vehicle filling much of the center rearview mirror, and following traffic pressure.

Experiment Participants

Thirty-three participants with valid driver's licenses were tested for this experiment. Three participants failed to complete the experiment due to motion sickness; their data were excluded from the analysis. Participants included twenty students from the University of Idaho, who received class extra credit for their participation. The study team recruited the remaining 10 participants using an online advertisement, and compensated them $30 for their participation. All participants wore corrective lenses if they were required to wear them while driving. Participants had an average age of 29.7, ranging from age 18 to 62, with an average of 14.4 years of driving experience. Additionally, 57% of participants had previous experience pulling a trailer.

Experiment Stimuli

 Traffic in the participants' direction of travel was specifically designed to induce a feeling of following traffic pressure. In each inter-passing zone stretch of highway a new set of 9 vehicles was created out of sight both ahead and behind the participant's vehicle. Two leading vehicles were scripted to maintain a speed of 45 mph until the participant's vehicle caught up to them, at which time they increased speed to maintain 600 and 1000 feet gaps in front of the participant's vehicle.   These gaps were close enough to induce a feeling of driving in traffic, but also far enough ahead that the RV-towing drivers would not feel pressured to try to pass. The seven following vehicles were scripted to induce pressure on the RV-towing drivers to allow them to pass. These vehicles were scripted to drive at moderately high speeds to catch up to the participant's vehicle, at which time they maintained gaps of 100 feet between vehicles. Hence the seventh vehicle followed the participant's vehicle at a distance of 700 feet. Once the participant reached a passing zone and pulled into the right-hand lane, this gap maintenance terminated and the vehicles accelerated to 74 mph to pass. The RV-towing drivers were thus induced to stay in the right lane throughout the length of the passing zone. To discourage participants from driving too fast, a simulated police siren sounded whenever their speed exceeded 75 mph.

Experiment Procedure

Each participant was instructed to imagine they were driving home from a recreational out of town weekend in Alaska where they had been boating or camping, and that they were pulling a trailer behind them. They were explicitly instructed to follow all rules and etiquette they would normally use while driving a vehicle pulling a trailer. The entire experimental session lasted 90 minutes.

Experiment-1 Results: RV Drivers

To increase passing efficiency, the passing lane scenarios needed to affect two driver behaviors: lane-control and speed-control. Efficient passing lane designs encourage slower drivers to move quickly to the right hand lane and slow down so that more vehicles may pass within the length of the passing zone. Safe passing zones also require a smooth merging of traffic before the passing lane has been eliminated.

Lane Control

The study team did not explicitly instruct participants to use the right lane and allow others to pass, but rather implicitly encouraged participants to use the right-hand lane through the simulation of pulling a RV trailer, combined with pressure from overtaking traffic and instructions to "observe normal driving etiquette." Because a primary aim of Experiment 1 was to compare how the scenarios differentially-affected right-lane drivers, the study team hoped these experimental operations would implicitly induce the drivers to choose to use the right-hand lane. It appears these operations worked: as can be seen in Figure 13. The Figure shows Vehicle lane deviation in feet from the center of the right lane as functions of distance for each scenario. The center of the left lane corresponds to 12 feet on the y-axis. The distance axis extends from the beginning of 1-to-2 lane-addition transition through the end of the 2-to-1 lane-reduction transition. The 1-mile full-two-lane segment extends from 660 to 5940 ft. For each panel, the blue traces represent data from individual participants. The bright red trace represents the ensemble average. The red fills represents 95% confidence intervals on the ensemble averages. Participants moved to the right lane within the first ¼ mile (1320 ft.) over 99% of the time, and averaging across all the scenarios, participants occupied the right-hand lane of the one-mile long two-lane segment of the passing zone 90.55% of the time.
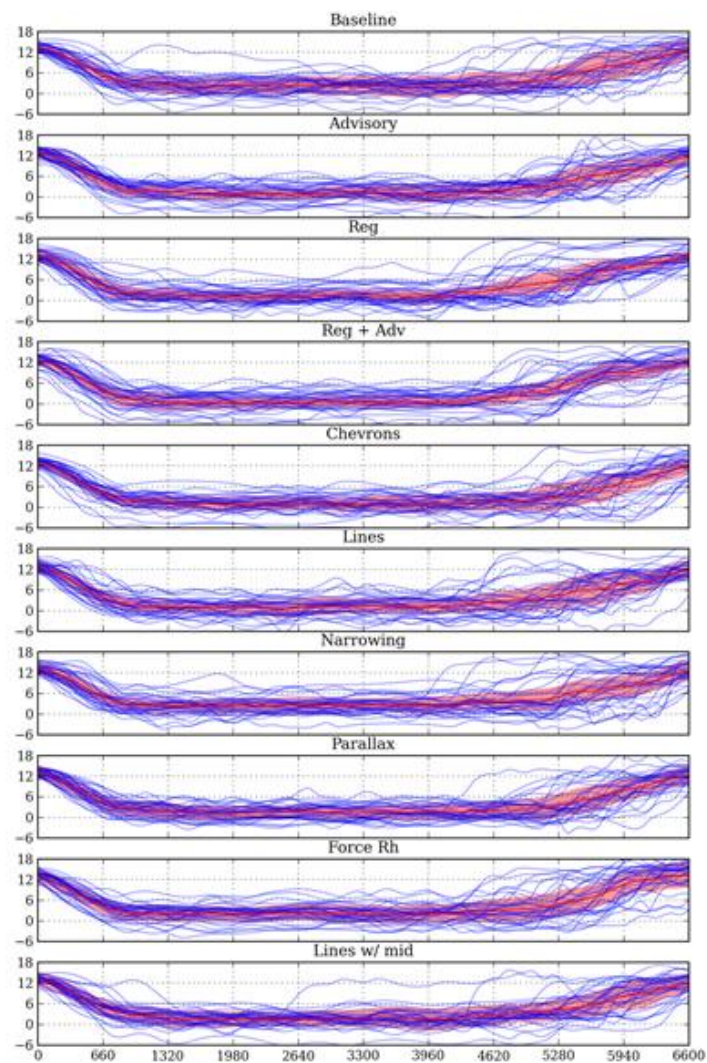
Figure 3. Distance Traveled from Beginning of Passing Zone (ft.)

Lane Choice and Control for the Full Two-lane Segment

The study team assessed the effects of the 10 passing lane scenarios on lane control by examining the percentage of time spent in each lane and lane deviations within a lane during the one-mile full-two-lane segment of the passing zone—for the moment ignoring the 1/8 mile long diverging and merging transition zones. For each participant, and for each of the passing zones scenarios, the study team computed the arithmetic mean and standard deviation for each of these measures. The study team used Welch's test to determine whether the means and standard deviations across the ten scenario conditions were statistically equivalent[1]. If Welch's test indicated statistically reliable differences among the 10 means or standard deviations, the study team determined which pairs of means or standard deviations differed reliably from one another using the Games-Howell procedure, which forms a pooled variance estimate for each individual pairwise comparison. The study team used a Type I error probability of $\alpha = .05$ as the decision criterion for statistical reliability (the probability of any differences being due to chance was less than .05).

These analyses found a borderline effect of scenario on the proportion of time spent in the right hand lane [$W'(9, 117.902) = 2.104, p < 0.05$] with the only reliable pairwise differences occurring between the chevron scenario 4 (m = 94.3%) and the regulatory scenario 2 (m = 87.2%) and the regulatory + advisory scenario 3 (m = 87.9%). All other pairwise comparisons were non-significant. Examination of Figure 13 suggests that the greater time spent in the right lane for the chevron scenario may have been carried primarily by the latter stages of the passing zone—the merge left appears to be somewhat delayed compared to scenarios 2 and 3.

No statistically reliable differences between the scenarios for the mean position within a lane was found [$W'(9, 117.897) = 1.211, p > 0.05$], the standard deviation of position within a lane [$W'(9, 118.065) = 1.574, p > 0.05$], the mean steering angle . [$W'(9, 118.001) = 1.284, p > 0.05$], or the standard deviation of steering angle [$W'(9, 117.794) = 1.071, p > 0.05$]. These results suggest that precise control of steering through the one-mile two-lane segment of the passing zone was not reliably affected by the different scenarios. The lack of effects can be easily seen in Figure 13 between distances of 660 and 5940 ft.: participants overwhelmingly chose to drive in the right-hand lane, and maintained lane position throughout the one mile long section of full multiple lanes with statistically equivalent precision regardless of the passing lane scenario.

Speed and Passing Efficiency

To assess the effects of the 10 scenarios on control of speed the study team computed the mean and standard deviations of the time-series measures of accelerator and brake pedal positions, and vehicle speed. The passing efficiency of the automated traffic was largely determined by two factors: 1) how quickly the participant moved into the right lane, and 2) how fast they drove once in the right lane. The analysis of lane control above found that participants moved into the right hand lane in an equivalent amount of time across scenarios; therefore, differences in passing efficiency are influenced most by the

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[1] The Welch procedure is a non-pooled test statistic in that it does not pool variability from heterogeneous sources, therefore type I errors are not subject to inflation from potential violations of homogeneity of variance.

speed of the participants vehicle: the slower the speed, the greater the efficiency. Vehicle speed was measured directly from the simulation, but the study team also examined differences in how participants used the controls like the accelerator and brake pedal to regulate speed. However, because the participants only very rarely used the brake during the passing zones, this analysis focused only on vehicle speed and accelerator position measures.
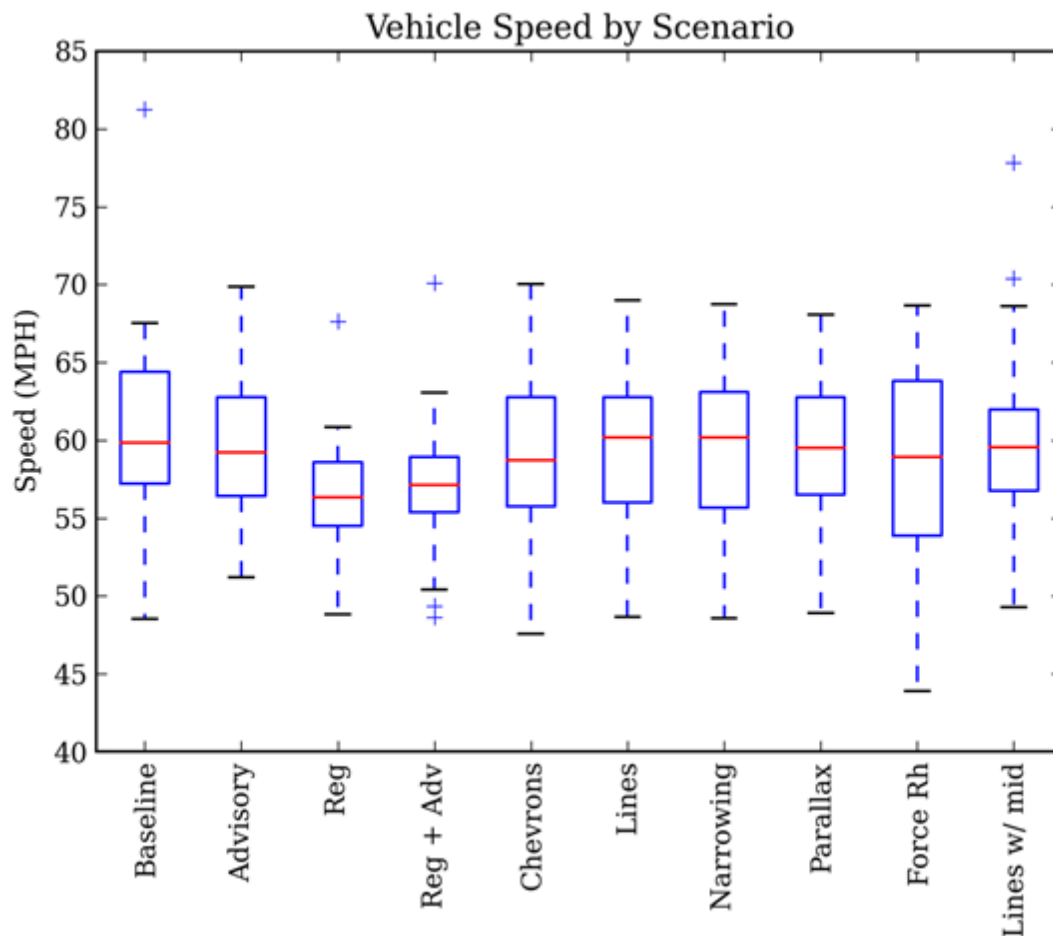
Note: Box divisions represent 25, 50, and 75th percentiles. This figure represents the variability you would expect to see on the road across a sample of participants.

Figure 4. Mean Vehicle Speed by Scenario Averaged Over the 1-mile Passing Section
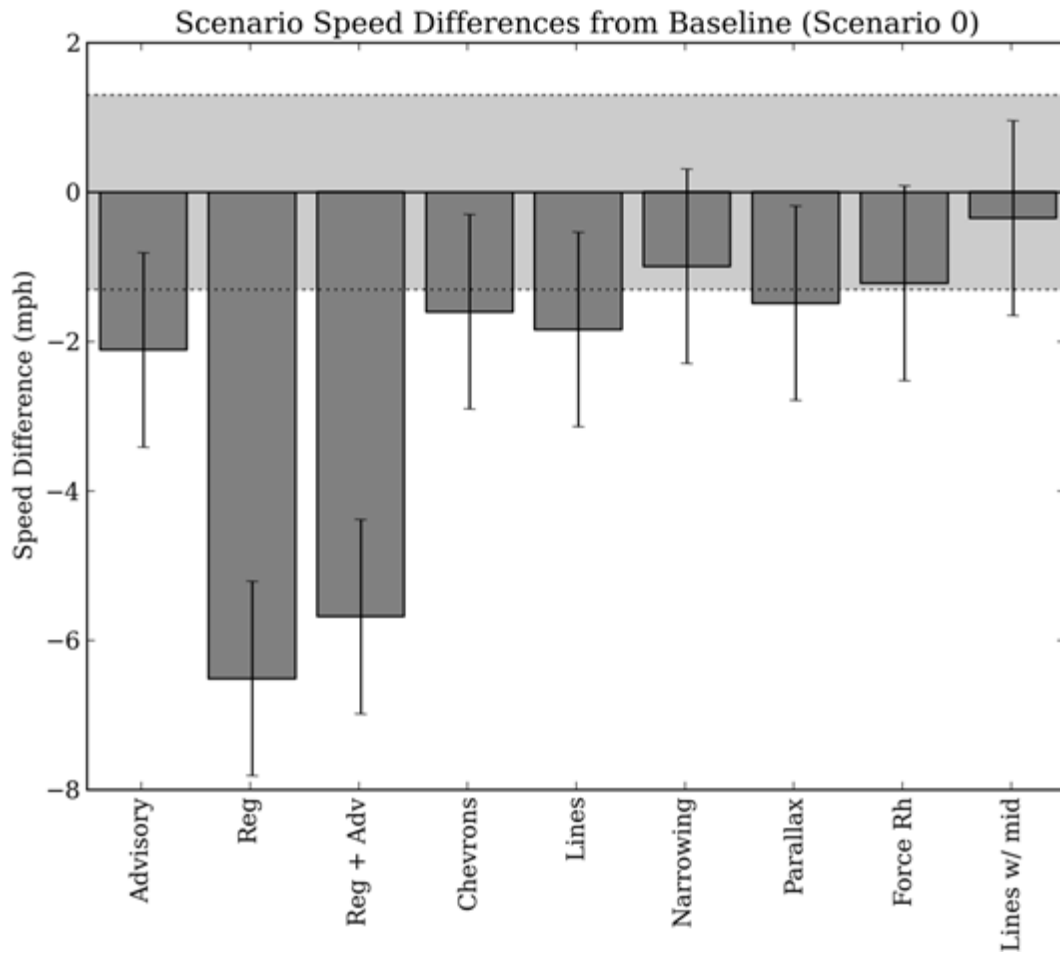
Note: Error bars reflecting 95% confidence intervals after removing the between-subjects variability.

Figure 5. Speed Differences Normalized from Baseline Speed

Figure 15 presents mean vehicle speeds for scenarios 1-9 normalized to each Figure 16 represents the participant's mean vehicle speed in the baseline scenario with 95% confidence intervals indicated on the plot as error bars. Means with error bars that fall outside of the light gray band are considered reliably different from baseline, and means whose error bars do not overlap are considered reliably different from one another.
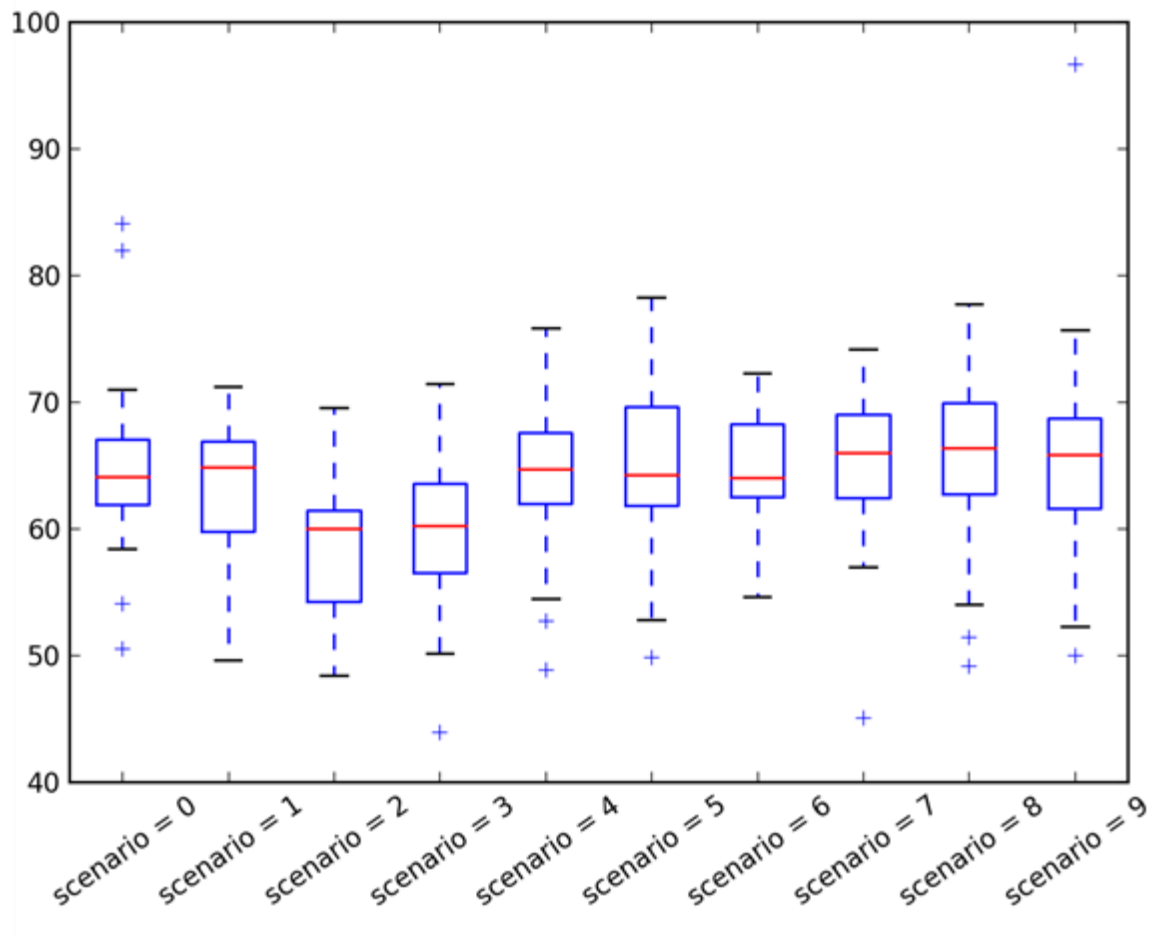
Figure 6. Boxplots Representing the Distributions of Speed Intercept Estimates Across the Scenarios

The box divisions in Figure 16 represent 25, 50, and 75th percentiles. The intercept for scenario 2–regulatory is reliably lower than all the intercepts except scenario 3 – regulatory + advisory (p < .05). All other intercepts are statistically equivalent (p > .05). According to this analysis, six of the 9 test scenarios (non-baseline) reliably reduced the average vehicle speed over the one-mile full two-lane segment of the passing zone: scenario 1—advisory reduced speed by 2.2 mph; scenario 2—regulatory by 6.6 mph; scenario 3—regulatory + advisory by 5.5 mph; scenario 4—Chevrons by 1.6mph; scenario 5—transverse line by 1.8 mph; and scenario 7—parallax by 1.5 mph.

In effect, the data presented in Figure 15 depict the variability one would expect to see on the road across a sample of drivers, whereas the data presented in Figure 16 depict the reliability of the scenarios in effecting the speed control of each individual participant controlling for individual differences. Both approaches converge on a similar conclusion: scenarios including regulatory elements have the largest effect on reducing the speed of the participants, but the use of chevrons, transverse lines, or parallax should also be expected to have a reliable, though smaller effect on speed control.
To more precisely examine how participants controlled vehicle speed over the 1-mile passing zone, vehicle speed was linearly regressed on distance and the effect of scenario on the intercept and slope

parameters was assessed using the Welch and Games-Howell procedures. (Regressing on distance, rather than time, prevents slow speed segments of data from carrying more weight in the model fitting.) Pairwise multiple comparisons showed that the speed intercept for the regulatory scenario 2 was reliably lower than for all other scenarios except the regulatory + advisory scenario 3 (see Figure 17). This result is consistent with participants reducing speed for the regulatory scenario 2 either before entering or very early in the passing zone. Further, the estimated slope parameters were not reliably different across the scenarios ($p > .05$), suggesting that the rate of deceleration was statistically equivalent across the conditions. When taken together, these results suggest an important conclusion: regulatory signage has its greatest impact in reducing speed when placed before or early in the passing zone.

The analysis of mean vehicle speed found a segment main effect, with participants driving more slowly in the lane-reduction transition segment (5940-6600 ft. on the abscissa of Figure 18, $\mu = 55.59$ mph) as compared to the full 2-lane segment (660-5940 ft. on the abscissa of Figure 18, $\mu = 57.7$ mph), and the fastest speeds occurring in the lane-addition transition segment (0-660 ft. on the abscissa of Figure 18, $\mu = 63.89$ mph), $F(2, 58) = 102.679$, $p < 0.001$, $\eta^2_G = 0.321$, $\varepsilon_{GG} = 0.550$, observed-power = 1.000. The study team also found a significant interaction of segment and scenario on mean vehicle speed [$F(18, 522) = 1.991$, $p = 0.043$, $\eta^2_G = 0.016$, $\varepsilon_{GG} = .481$, observed-power = 0.083]. This interaction reflects two deviations from the segment main effect across the 10 scenarios:

> a) a greater reduction in vehicle speed during the full 2-lane segment of the passing zone as compared to the transition segments for the regulatory Scenario 2 and the regulatory+advisory Scenario 3, and
> b) reliably slower speeds in the lane-reduction segment as compared to the full 2-lane segment, for scenarios 6, 8 and 9 (lane narrowing, force-right, and transverse lines with middle segment, respectively).

The analysis of the standard deviation (SD) of vehicle speed shows greatest variability in the full 2-lane segment ($\sigma = 4.97$ mph), moderate variability in to the lane-reduction transition segment ($\sigma = 2.28$ mph) and least variability in the lane-addition transition segment ($\sigma = 0.88$ mph), $F(2, 58) = 288.673$, $p < 0.001$, $\eta^2_G = 0.963$, $\varepsilon_{GG} = 0.525$, observed-power = 1.000. As with accelerator position SD, vehicle speed SD is confounded by the fact that the wind disturbance was only present throughout the full 2-lane segment. Even so, speed is significantly more variable the lane addition transition segment than in the lane reduction transition segment.

Passing Efficiency and Safety of AI Controlled Vehicles.
The analyses of vehicle speeds suggest that the regulatory conditions resulted in slower speeds. Here the study team examine whether the speed reductions enabled simulated vehicles to more efficiently and safely pass the driver.

For each passing lane, the participant was accompanied by a platoon of nine or ten other vehicles dynamically controlled by the NADS MiniSim. For the majority of the scenarios, two vehicles would lead

the participant into the passing lane. Passing performance was quantified by counting the number of cars that passed the vehicle during the 1-mile 2-full lane segment. Based on this metric, Welch's test found that passing efficiency was not equivalent across the 10 scenarios [W' (9, 117.995) = 5.128, p < .001]: significantly more vehicles were able to pass during the regulatory scenario 2 as compared to baseline and visual cue conditions. Indeed, passing performance reached the optimal ceiling-- all 7 trailing vehicles were allowed to pass—with the regulatory scenario 2 for 22 of the 30 participants.

The study team used *average time margin* at the start of the lane-reduction segment as the measure of safety in passing. For each scenario and participant, the study team determined average time margin by computing the mean of times at which each vehicle in the platoon of passing vehicles entered the lane-reduction segment and subtracted this mean time from the time when the participant's vehicle entered the lane-reduction segment. Positive average time margins occurred when a participant entered the lane-reduction at a later time than the average, negative values indicate the participant entered at a time ahead of the average. The Welch test indicated a reliable effect of scenario on average time margin [W' (9, 118.076) = 4.085, p < .001]. Post-hoc tests indicated that the regulatory scenario differed significantly from the baseline scenario 0 and scenarios 4, 6, 7, 8, and 9.
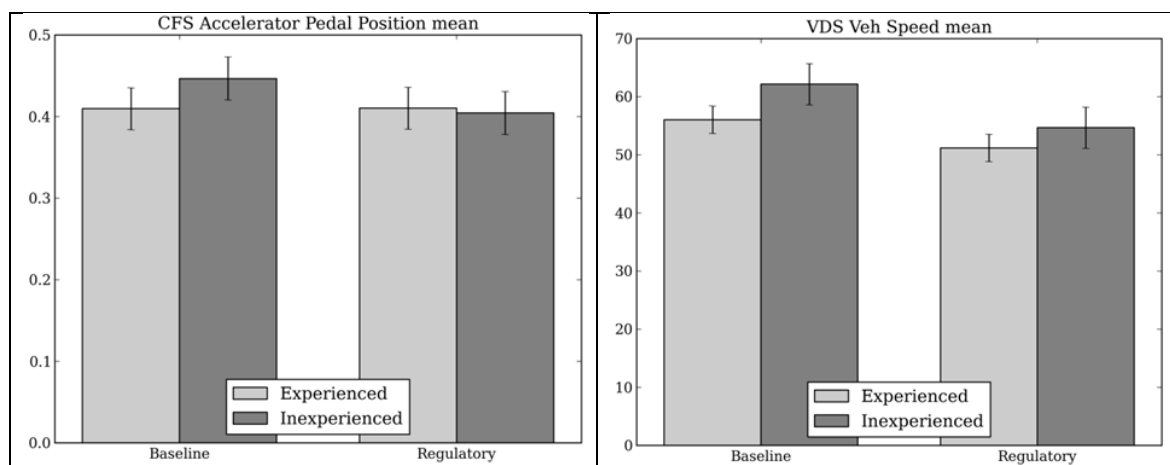
Note: Error bars reflect 95% confidence intervals calculated according to Moray (2008).

Figure 7. Accelerator Position and Mean Vehicle Speed as Functions of Driving Experience for the Baseline and Regulatory Scenarios

The analysis found a reliable effect of scenario on mean vehicle speed [Q(1.08) = 7.389, p = 0.009, obs. power = 0.889, already discussed above] and a marginally reliable effect of experience [Q(1.08) = 4.011, p = 0.051, obs. power = 0.780].   According to this effect, inexperienced drivers demonstrated greater changes in driving behavior. Interpreted with the vehicle speed trend it suggests that experienced drivers are slower regardless of the scenario (see Figure 17).

Summary and Conclusions of Experiment 1

The lane choice and deviation data showed that the instructions and following traffic pressure were successful in inducing the RV-towing drivers to reliably move into the right lane of the passing zone during the lane-addition transition (99% of the time).   This result was critical, since the regulations, advisories, and passive interventions for speed were specifically designed to affect drivers in the right lane only. Because the drivers moved to the right lane so reliably the study team are able to interpret the effects of the different scenarios on speed control. The primary result was an approximately 5-6 mph average reduction in speed for the regulatory scenario 2 and regulatory + advisory scenario 3 as compared to the baseline scenario. Importantly, these scenarios had their greatest effect in reducing speed during the initial entry into the passing zone, which suggests that locating regulatory and advisory signs early in the passing zone or before it may optimize their impact. Some of the passive speed interventions (e.g., Chevrons, lane narrowing) also reliably reduced speed, but only by 1-2 mph.

Because drivers were so consistent in moving to the right lane during the lane addition, the study team found that passing efficiency mirrored the speed results. The regulatory and regulatory + advisory scenarios induced drivers in the right lane to drive more slowly, so more vehicles were able to pass in these conditions. There was also a greater time gap between the passing vehicles and the participant's vehicle at the beginning of the lane reduction segment, suggesting a safer passing environment for these scenarios.

In addition, it does appear that experience mitigates the speed reduction effects of the regulatory and regulatory + advisory scenarios. More experienced drivers (> 15 years since licensing) drive more slowly overall and have less reduction in speed than less experienced drivers, who drive more quickly overall and show greater reductions in speed for these scenarios. This result suggests that the regulatory and regulatory + advisory scenarios may be particularly effective in reducing speed for less experienced drivers.

In sum, the regulatory and regulatory + advisory scenarios appear create the greatest right-lane speed reductions, particularly for less-experienced RV-towing drivers. Passing efficiency should therefore increase for these scenarios, but only if the speed reduction occurs only for right-lane drivers. The next experiment sought to measure the influence of these different scenarios on non-RV-towing drivers in the left lane to assess whether the speed reduction is specific to only the right lane as intended.

Results of Experiment 2: Non-Towing Drivers

Experiment 2 was designed to assess the effects of the 10 passing lane scenarios on the behavior of drivers using the left lane. This experiment had two aims: 1) to examine whether the regulations, advisories, and lane markings designed to affect right-lane drivers lane also affected drivers in the left lane—an undesirable result, since it would reduce the efficiency of the passing lanes—and 2) to examine the influence of right-lane vehicle size on passing behavior.

Experiment 2 Participants

Twenty-three participants with valid driver's licenses were tested for this experiment. Three participants failed to complete the experiment due to motion sickness and were excluded from the analysis. Fourteen students from the University of Idaho participated and were given class credit for their participation. The study team recruited the remaining six participants using an online advertisement and compensated each of them $30 for their participation. All participants wore corrective lenses if they were required to wear them while driving. Participants had an average age of 25.1 years, ranging from age 19 to 47, with an average of 9.2 years of driving experience.

Experiment 2 Stimuli

Traffic in Experiment 2 was designed to induce pressure for participants to pass other vehicles. In each inter-passing zone stretch of highway a new set of 9 vehicles was created out of sight both ahead and behind the participant's vehicle. Seven leading vehicles were scripted to appear ahead of the participant's vehicle and drive 45 mph until the participant caught up to them, at which point the vehicles maintained a specific gap in front of the driver with the closest car being 200 feet ahead, and all other cars increasing in 100 foot increments, with the furthest car being 800 feet ahead.
At the start of each passing zone, these vehicles turned on their right-turn signals and pulled into the right-hand lane maintaining a constant speed of 65 mph, except for the regulatory scenarios where the vehicles maintained a speed of 55 mph. Two following cars were scripted to maintain distances of 600 and 1000 feet behind the participant's vehicle until it exited the passing zone, at which point these vehicles pulled to the side of the highway.   To discourage participants from driving extremely fast, simulated police sirens sounded whenever their speed exceeded 85 mph.

To examine whether vehicle size influences passing behavior, the third vehicle ahead of the driver, or fifth in the platoon of seven vehicles counting from the front, was either a small sedan or a large semi-truck while the other six vehicles were always small sedans. The study team chose to manipulate the third vehicle ahead of the driver based on these assumptions: a) the platoon of vehicles in the right-lane would be driving 65 mph, b) most participants would maintain a speed of 72-73 mph while passing. This differential of 7-8 mph at 72-73 mph results in the passing vehicle gaining about 300 feet on the platoon of right-lane vehicles over the first half- mile stretch of the passing zone, making the third vehicle ahead (fifth in the platoon of seven)—located approximately 400 ft. ahead of the driver at the entrance to the passing zone—the likeliest object of a passing decision at the mid-point of the passing zone.

The location of the semi-truck relative to the platoon of vehicles was adjusted backwards such that its front end was the same distance ahead of the driver as the front end of the sedan at the time the driver entered the passing zone. Because the semi-truck was 45 ft. longer than the sedan, this reduced the gap between the second and third vehicles by approximately 45 feet.

Experiment 2 Procedure

The study team instructed participants to imagine they were heading home from a recreational weekend in the Alaskan countryside and—importantly—that they were in a hurry to get home. In addition, the study team instructed them to obey traffic regulations, advisories, and etiquette in a manner they normally would while driving in a hurry. The full instructions are listed in Appendix C. The entire experimental session lasted 90 minutes.

Experiment 2 Results

The instructions was designed, tasked, and simulated traffic in this experiment to induce participants to use the left lane of the passing zones to pass some or all of the platoon of seven leading vehicles. The first section of the results presents evidence that this design succeeded in inducing these behaviors in the sample of participants. The second part of this section presents results that address whether the different passing zone scenarios affected the speed of drivers passing in the left hand lane. For maximum passing efficiency, the scenarios that reduced speed in the right lane should not affect drivers in the left lane, thereby maximizing the speed differential between the two lanes of traffic. The last section of the results addresses the manipulation of vehicle size (passenger car vs. semi-truck) on driver behavior while passing.

Lane Choice

The study team did not explicitly instruct participants to use the left lane and pass the leading vehicles, but rather implicitly encouraged participants to use the left lane by placing slower moving vehicles ahead of them and providing the instructions that they were "in a hurry to get home" and driving a sedan (rather than an RV). Because the study team aimed to examine whether the different scenarios affected left-lane drivers, the study team hoped these experimental operations would induce the drivers to choose to use the left hand lane and pass at least some of the vehicles ahead of them. It appears these operations worked: Figure 18 shows that participants overwhelmingly preferred the left lane. Across all the scenarios, drivers occupied the left lane approximately 82% and there were no reliable differences in this percentage across scenarios ($p > .05$). Further, no reliable differences on mean lane deviation or steering wheel angle was found ($p > .05$), suggesting that the scenarios did not differentially affect lane choice or steering control.
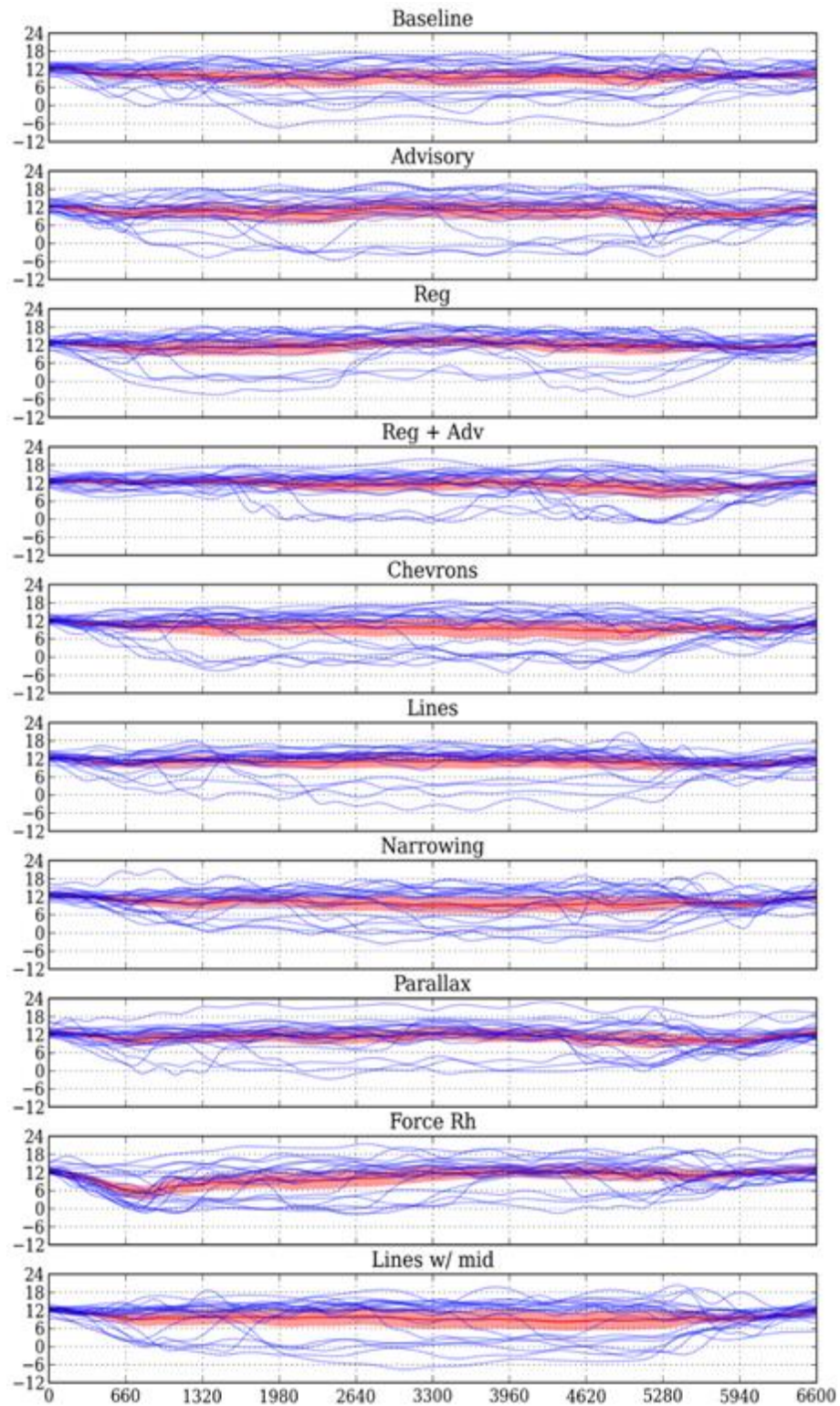
Figure 8. Vehicle Lane Deviation in Feet from the Center of the Right Lane as Functions of Distance for Each Scenario

In figure 23, the center of the left lane corresponds to 12 feet on the y-axis. The distance axis extends from the beginning of 1-to-2 lane-addition transition through the end of the 2-to-1 lane-reduction transition. The 1-mile full-two-lane segment extends from 660 to 5940 ft. For each panel, the blue traces represent data from individual participants. The bright red trace represents the ensemble average. The red fills represents 95% confidence intervals on the ensemble averages.

Scenario 8 incorporated a knurled force right pavement marking at the beginning of the passing lane. To examine whether this force right marking affected behavior the study team examined lane deviation at 664 ft. from the beginning of the passing zone and found a reliable effect of scenario [$W'(9, 77.084)$ =3.161, p = .003]. The effect of the force right marking is apparent the 9th pane of Figure 23. Perhaps because of the novelty of the stimuli roughly 25% (5 of 20) participants did not abide by the pavement marking and drove directly into the left lane of the passing zone.

Speed and Passing Efficiency
Similar to Experiment 1, to assess the effects of the 10 scenarios on control of speed, the study team computed the mean and standard deviations of the time-series measures of accelerator pedal position and vehicle speed. As with Experiment 1, brake pedal force data was recorded but was used so infrequently analyzing the variance about the means was not possible. Passing efficiency was determined by counting the number of cars passed for each condition. Figure 24 shows the vehicle speeds over the entire length of the passing zone as a function of scenario.   It is clear that all the scenarios have qualitatively similar speed profiles. Initially, the participants slow as the platoon of leading vehicles moves into the right lane, then the participants accelerated, reaching their peak speed at approximately half-way through the passing zone before decelerating.
In Figure 19, distance axes are in feet and extend from the beginning of 1-to-2 lane-addition transition through the end of the 2-to-1 lane-reduction transition. The 1-mile segment extends from 660 to 5940 feet. For each panel the blue traces represent individual participants. The red trace represents the ensemble average over distance. The red fills represents 95% confidence intervals on the ensemble averages. Box plots representing the distributions of speed across the 10 scenarios can be seen in Figure 20.

To examine whether the passing lane scenarios affected speed and accelerator position during the one-mile full two-lane segment of the passing zones, the study team calculated the arithmetic mean and standard deviation of accelerator position and vehicle speed for each participant and for each scenario. Similar to Experiment 1, Welch's test was used to control type I errors from violations of homogeneity of variance and to compare the equality of the means across the ten scenario conditions and the Games-Howell procedure for assessing pairwise comparisons.

None of these four analyses found any reliable effect of scenario. Though it would be logically unsound to conclude that no differences existed, the study team concluded that any scenario differences in accelerator position or speed were insignificant in comparison to the overall variability in the data. Coefficients of determination for a single-factor repeated-measures ANOVA on vehicle speed were calculated, and these metrics show that individual differences between participants account for 60% of

the variability compared to the 2.4% accounted for by scenario type (see Figure 21). When the speeds are normalized relative to baseline, a more accurate visualization of the scenario differences can be obtained. Figure 22 shows that drivers were within ± 4.5 mph of their baseline speed across all of the scenarios.
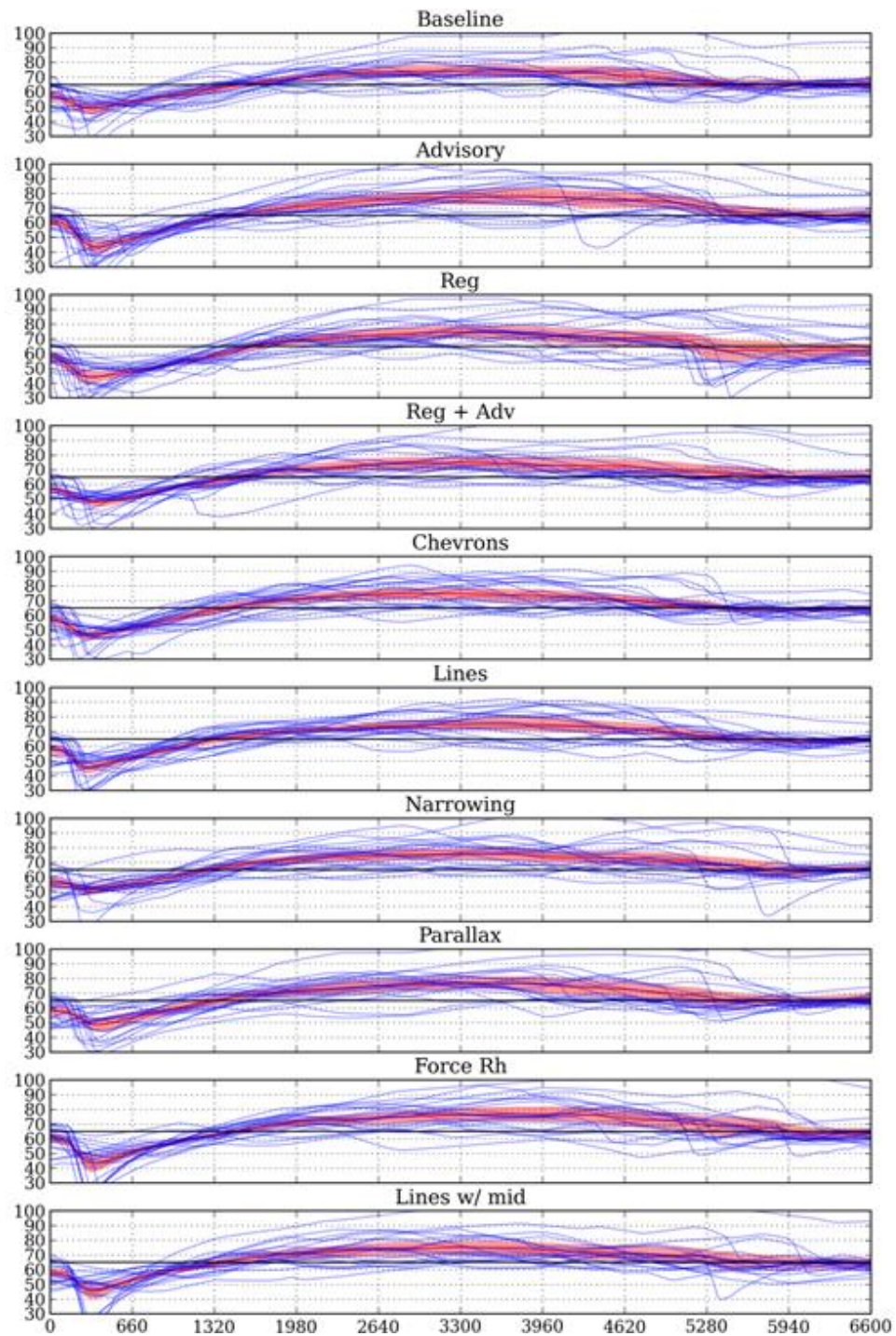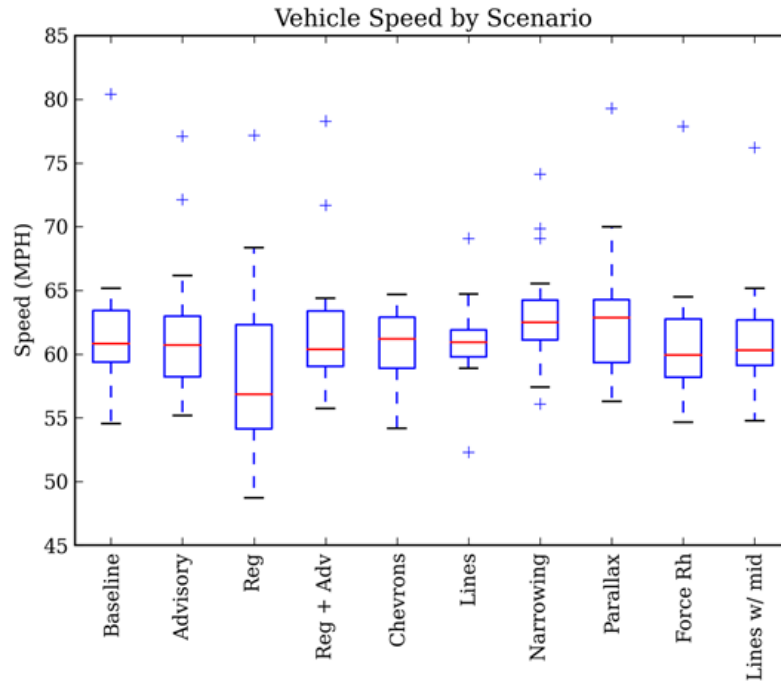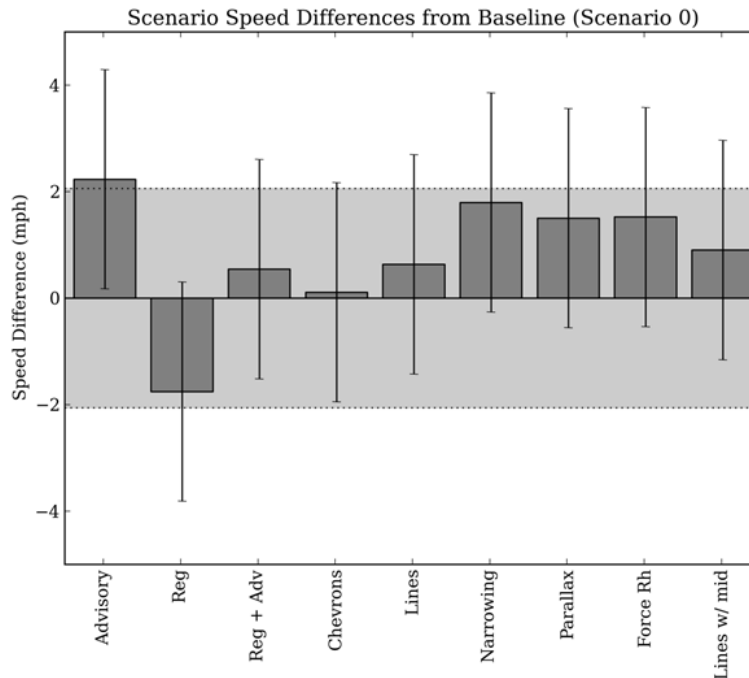

**Figure 9. Vehicle Speeds as Functions of Distance Segregated by Scenario**

Note: Box divisions represent 25, 50, and 75th percentiles.

Figure 10. Mean Vehicle Speed by Scenario Averaged Over the 1-mile Passing Section

Note: Error bars reflect 95% confidence intervals after removing the between-subjects variability.

Figure 11. Speed Differences Normalized from Baseline Speed
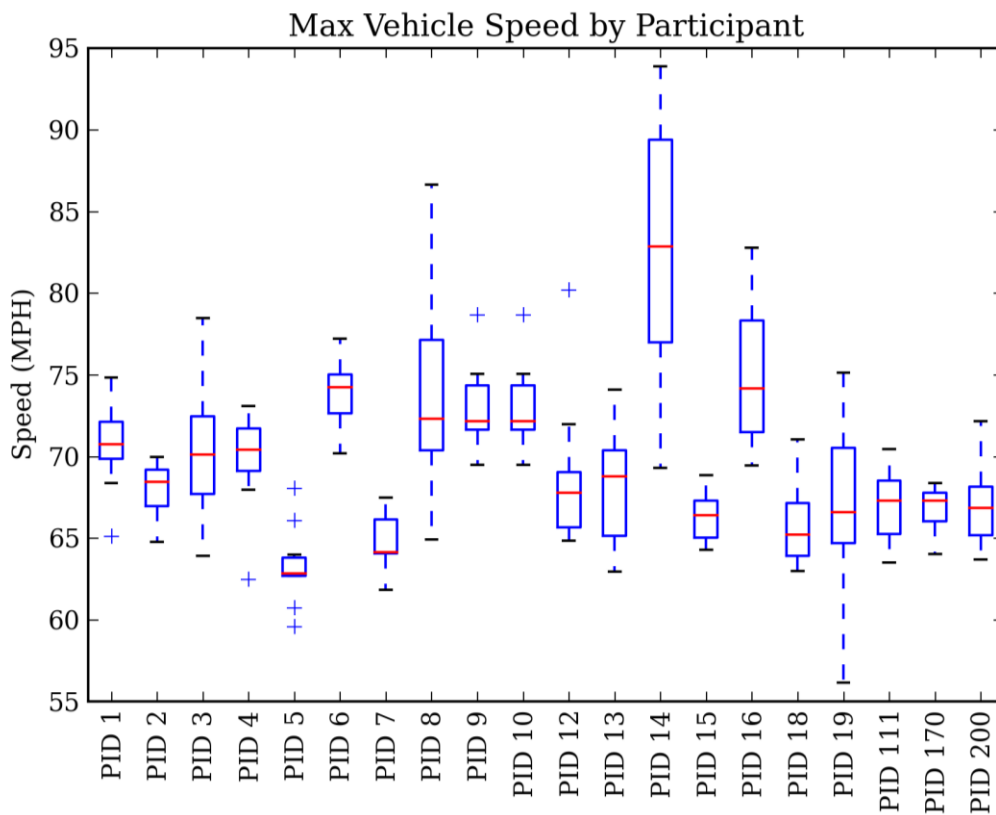
Note: Error bars reflect 95% confidence intervals after removing the between-subjects variability.

Figure 12. Speed Differences Normalized from Baseline Speed

In each passing zone the driver was accompanied by a platoon of 7 to 9 vehicles heading the same direction. To examine passing efficiency, the study team calculated the mean number of vehicles passed for each scenario. Welch's test reveals a reliable effect of scenario on the number of vehicles passed [$W'(9, 77.345) = 2.060$, $p = .044$]. The effect was carried primarily by the regulatory scenario 2 and the regulatory + advisory scenario 3. The reduction in speed of the simulated vehicles in the right lane of these scenarios allowed participants to pass 2.5 more vehicles on average compared to the baseline (as well as significantly more compared to the scenarios 4, 5, 7, and 9). Figure 24 depicts ensemble vehicle speeds by distance. In these plots, the full two-lane passing zones begin at the 660 foot marks. At first it may seem counterintuitive, but participants often slow down before reaching the two-lane section of the passing zone. This information, however, can be reconciled when taken together with the relative headway plots in Figure 28. When drivers approach the passing zone, they decrease their headway to the car in front of them (*tailgating maneuver*). Once the passing lane is available, they transition to the left lane and leap frog over the vehicles they wish to pass.

Summary and Conclusions of Experiment 2

The lane choice and deviation results indicate that the combination of instructions and slow leading traffic were successful in inducing drivers to reliably use the left lane of the passing zone and attempt to

pass vehicles in the right lane. This result was critical for achieving the two aims of this experiment, which were to evaluate the effect of the speed interventions on left lane drivers and the effect of larger vehicles on passing behavior.

In contrast to Experiment 1, which found that a majority of the scenarios significantly reduced speed of right-lane drivers relative to baseline, Experiment 2 found no reliable evidence that any of the speed mitigations implemented in the nine scenarios affected the speed of drivers in the left hand lane. This non-effect is important since it suggests that the scenarios could slow down traffic in the right lane without similarly slowing traffic in the left lane, creating higher differential speeds between lanes and increasing passing efficiency.

Indeed, Experiment 2 found no effects of scenario on any of the driving performance measures, with one important exception: the Force-right/Neutral Zone Scenario resulted in reliable deviations into the right-hand lane at the beginning of the passing zone. This result suggests that drivers were generally sensitive to the change in center line markings.

The most interesting result of Experiment 2 pertains to the effects of vehicle size on accelerator position and speed. While the frequency of passing the third vehicle ahead in the platoon of slow moving vehicles was essentially the same for both the large and small vehicles, the study team found that passing large vehicles significantly increased the power spectrum of accelerator position between 0.30 and 1.00 Hz and also resulted in maximum speeds about 3 mph higher than when passing small vehicles. This is the first objective data indicating that the size of the vehicle being passed has an effect on passing behavior consistent with an increased urgency to pass. These results clearly indicate that the relationship between vehicle size and urgency is an important topic for further research on passing safety.

Driver Simulator Study Conclusions and Recommendations

Taken together, the results of the two experiments clearly show that regulatory signs early in a passing zone that limit the speed of right-lane drivers relative to left-lane drivers offer the greatest opportunity for increasing the efficiency—and perhaps also the safety—of rural passing zones. The study found that regulatory signs imposing split speed limits between the lanes (65 mph-left, 55 mph-right) or limiting RVs and trucks to 55 mph along with advisories to allow others to pass, reliably increased the difference in speed between left- and right-lane drivers, which should allow more passes to occur within each passing zone. This increase in passing efficiency has the potential to reduce driver frustration and passing urgency, and may therefore significantly enhance the safety of rural highways.
In contrast, the passive speed reduction scenarios tested (Chevrons, transverse lines, parallax, lane narrowing) were all far less effective in reducing speed of drivers in the right-hand lane. This result was surprising given that previous research on passive speed mitigations found significant reductions in speeds approaching roundabouts and freeway off-ramps. The difference in results could be due to any number of factors, but two hypotheses seem particularly important to test: a) right-lane drivers in the

study may have been distracted by the need to monitor vehicles passing them and finding a gap to merge and may not have paid attention to the passive highway markings, and b) passive speed measures may only affect speed control in situations where a driver is already slowing down, rather than maintaining constant speed. Future research will be needed to determine why passive speed reduction appears to work for some highway applications but not for passing zones.

Finally, the results indicate that passing urgency may indeed be higher when passing large sized vehicles such as tractor-trailer trucks. This increased urgency could lead drivers to engage in riskier passing decisions. This conclusion requires further research to validate the effect and explore its complexities.

Chapter 3
Field Data Collection and Crash Analysis

Overview

Two passing lane sites are identified as test sites for the project. The two passing sites are along US 30 in ITD District 5. Site 1 is in the eastbound direction from milepost 408.4 to milepost 409.7 with a length of 1.3 miles. Site 2 is in the westbound direction from milepost 411.531 to milepost 409.911 with length of approximately 1.6 miles. Both sites are relatively flat with relatively high heavy truck representation.

The initial data collection plan included collecting speed data at different locations along the two passing lanes for two periods: 1) a before period (without any speed reduction measures) and 2) an after period (with improved signage and striping speed reduction measures implemented). Due to some regulation limitations, the proposed speed reduction signs and improved striping measures were never implemented in the field. Accordingly, no data was collected for the after period.

Field Data Collection

The project team collected the before data in the two test sites during the month of July. Six Nu-Metrics counters were used in the data collection (See Figure 13). Data was collected for two full days at each of the two sites. Summary of the speed data collected are presented in Table 2.

Table 2. Average Speed Data at the Two Test Sites (Before Period)

Site	Data Collection Location	Daytime		Night time	
		Passenger vehicles	Trucks and RVs	Passenger vehicles	Trucks and RVs
Site 1 EB	Location 1: Upstream from the passing lane	64.1	63.3	63.2	61.4
	Location 2: Beginning of the passing lane - right lane	66.4	65.2	65.9	64.6
	Location 2: Beginning of the passing lane - left lane	69.8	67.4	68.3	67.2
	Location 3: End of the passing lane – right lane	67.9	66.7	67.4	66.1
	Location 3: End of the passing lane – left lane	69.4	68.2	68.9	67.5
	Location 4: Downstream of the passing lane	66.7	65.8	65.7	63.9
Site 2 WB	Location 1: Upstream from the passing lane	65.7	62.5	65.1	61.0
	Location 2: Beginning of the passing lane - right lane	66.9	64.8	65.3	64.9
	Location 2: Beginning of the passing lane – left lane	69.6	67.4	67.9	67.5
	Location 3: End of the passing lane – right lane	68.4	66.3	66.8	66.4
	Location 3: End of the passing lane – left lane	69.9	67.7	68.3	67.9
	Location 4: Downstream of the passing lane	68.3	65.0	67.7	63.4

The speed data collected in the passing lane sites shows several important characteristics. The speed in the right lane are consistently higher than the operating speed just upstream from the passing lane. Most importantly, and for both sites, the difference in average speed between vehicles in the right lane and left lane was lower than 3 mph at both locations along the passing zone. Such operations

characteristics clearly show a need for intervention measure to slow traffic in the right lane to allow for safer passing maneuvers.
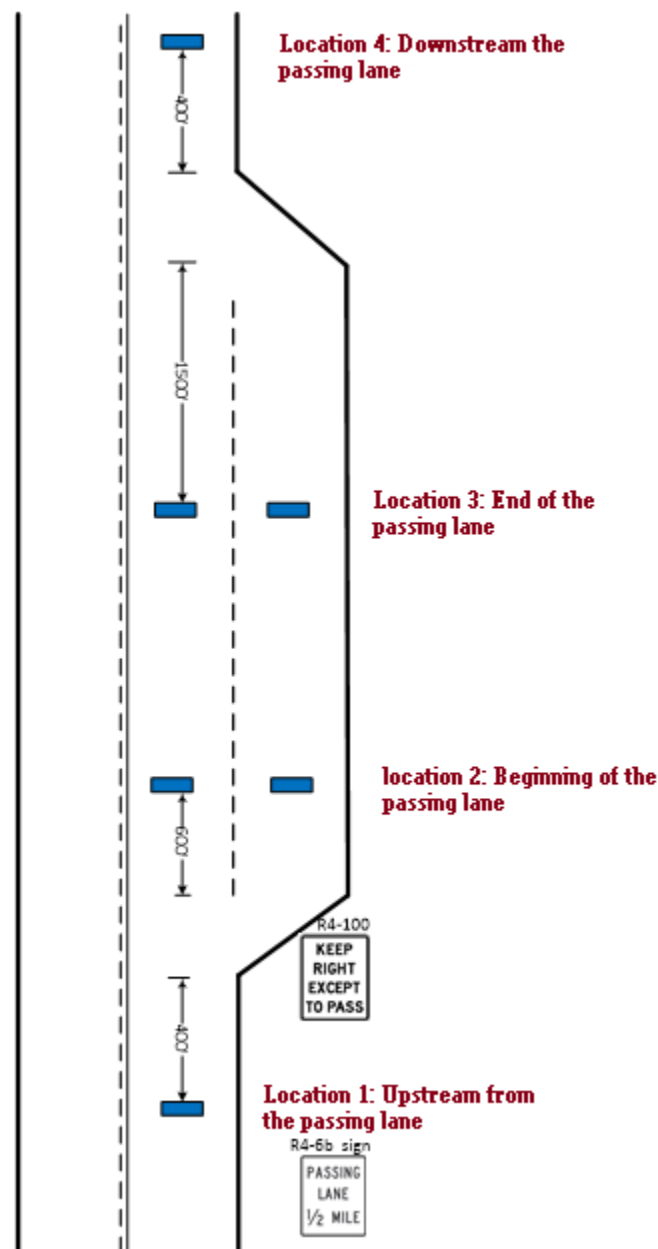

Figure 13. Passing Lane Area Speed Data Collection Locations

Characteristics of Crashes at Passing Lane Locations

ITD crash data for ten years (2005-2014) was used to document the characteristics of passing lane crashes in Idaho's highways. The crash data was obtained using ITD WebCars web-based interface [2]. A total of 67 passing lanes were included in this part of the analysis. These passing lanes were identified

through ITD highway geometry data and all locations were validated through site visits. The length of each of the passing lanes included in this part of the study was more than 0.5 mile and the grade at the passing lane location was 3 percent of lower. The analysis focused only on two-vehicle passing-related crashes (head-on and side-swipe crashes - same direction or opposite direction). A total of 137 crashes occurred at these passing lane segments or near the passing lane merging areas. Of these 137 crashes, 46.15 percent were property damage crashes, 15.38 percent were possible injury crashes, 23.08 percent were visible injury crashes, 13.94 percent were serious injury crashes, and 1.45 percent were fatal crashes. Only 9 of the 137 crashes (6.57 percent) involved alcohol use. The majority of passing lane crashes occurred during clear weather conditions (62.04 percent) and during daylight (76.64 percent). Only 8.03 percent of the crashes occurred during ice/snow conditions. Speeding, improper lane-use, and improper overtaking were the major contribution factors in 84.67 of the crashes.

To document the characteristics of merging related crashes at passing lane locations, crash rates on 0.5-mile segments of the roadways immediately downstream of the passing lanes were analyzed. Crash rates at these merging segments were compared with the crash rates on non-merging segments for the same roadways (segments immediately downstream of the merging segments used in the analysis). The average crash rates (crash/million vehicle-mile/year) for merging segments, non-merging segments, and passing lane segments are 2.316, 2.228, and 2.271, respectively. While the merging segments, downstream of the passing lanes, have slightly higher crash rates than non-merging roadway segments (3.8 percent higher), the difference is not statistically significant at the 95% confidence level.   The results are summarized in Table 3 and Table 4.

Table 3 Differences in Crash Rates between Merging, Non-Merging, and Passing Lane Segments

Difference in Crash Rate (crash/million vehicle-mile/year)	Average Difference	Standard Deviation	Standard Deviation of Mean
(Merging segments) - (Non-merging Segments)	0.088	0.827	0.073
(Merging segments) - (Passing Lane Segments)	0.045	0.919	0.081
(Passing Lane Segments) - (Non-Merging Segments)	0.043	0.842	0.074

Table 4 T-Statistics for Differences in Crash Rates

Difference in Crash Rate (crash/million vehicle-mile/year)	T-Statistics	Significance	Interval of the Mean	
			lower	upper
(Merging segments) - (Non-merging Segments)	1.200	0.232	-0.057	0.234
(Merging segments) - (Passing Lane Segments)	0.533	0.581	-0.116	0.207
(Passing Lane Segments) - (Non-Merging Segments)	-0.576	0.566	-0.191	0.105

Chapter 4 Study Summary and Conclusions

A driver simulator study conducted by researchers from the University of Idaho's National Institute for Advanced Transportation Technology (NIATT) concluded that that regulatory speed reduction signs early in a passing zone that limit the speed of right-lane drivers relative to left-lane drivers offer the greatest opportunity for increasing the efficiency—and perhaps also the safety—of rural passing zones. The study found that regulatory signs imposing split speed limits between the lanes (65 mph-left, 55 mph-right) or limiting RVs and trucks to 55 mph along with advisories to allow others to pass, reliably increased the difference in speed between left- and right-lane drivers which should allow more passes to occur within each passing zone. This increase in passing efficiency has the potential to reduce driver frustration and passing urgency, and may therefore significantly enhance the safety of rural highways.

The driver simulator study also analyzed the effect of several passive speed reduction measures using alternative pavement striping (Chevrons, transverse lines, parallax, lane narrowing). The passive speed reduction measures were all less effective in reducing speed of drivers in the right-hand lane than regulatory and advisory speed reduction signs. However, among these alternatives lane narrowing and traverse lines showed the highest potential in reducing driver speed. The primary objective of this research project was to field test the effectiveness of these measures in two passing lane sites in Idaho. Due to some regulation limitations, the proposed speed reduction signs and improved striping measures were never implemented in the field. Accordingly, the project tasks were limited to collecting field data to document the speed operational characteristics upstream from, at, and downstream of the passing lanes and analyzing crash data to investigate the characteristics of passing lane crashes in Idaho.

The speed data collected in the passing lane sites shows several important characteristics. The speed in the right lane are consistently higher than the operating speed just upstream from the passing lane. Most importantly, and for both sites, the difference in average speed between vehicles in the right lane and left lane was lower than 3 mph at both locations along the passing zone. Such operations characteristics clearly show a need for intervention measure to slow traffic in the right lane to allow for a safer passing maneuvers.

The crash analysis for 67 passing lanes segments identified a total of 137 crashes occurred either at the passing lane segments or at the merging areas downstream of the passing lane. The analysis covered a 10-year period from 2005 to 2015. Of these crashes, 46.15 percent were property damage crashes, 15.38 percent were possible injury crashes, 23.08 percent were visible injury crashes, 13.94 percent were serious injury crashes, and 1.45 percent were fatal crashes. Only 9 of the 137 crashes (6.57 percent) involved alcohol use. The majority of passing lane crashes occurred during clear weather conditions (62.04 percent) and during daylight (76.64 percent). Only 8.03 percent of the crashes occurred during ice/snow conditions. Speeding, improper lane-use, and improper overtaking were the major contribution factors in 84.67 of the crashes. The average crash rates (crash/million vehicle-mile/year) for merging segments, non-merging segments, and passing lane segments are 2.316, 2.228, and 2.271, respectively. While the merging segments, downstream of the passing lanes, have slightly

higher crash rates than non-merging roadway segments (3.8 percent higher), the difference is not statistically significant at the 95 percent confidence level.

References

1) Dyre, Brian P., and Ahmed Abdel-Rahim. Improving Passing Lane Safety and Efficiency for Alaska's Rural Non-divided Highways. No. INE/AUTC 14.08. 2014.

2) Idaho Transportation Department, Office of Highway Safety (ITD- OHS). "WebCARS." http://apps.itd.idaho.gov/apps/webcars/ (Accessed March 2015).

Appendix A
Passing Lane Testing Scenarios
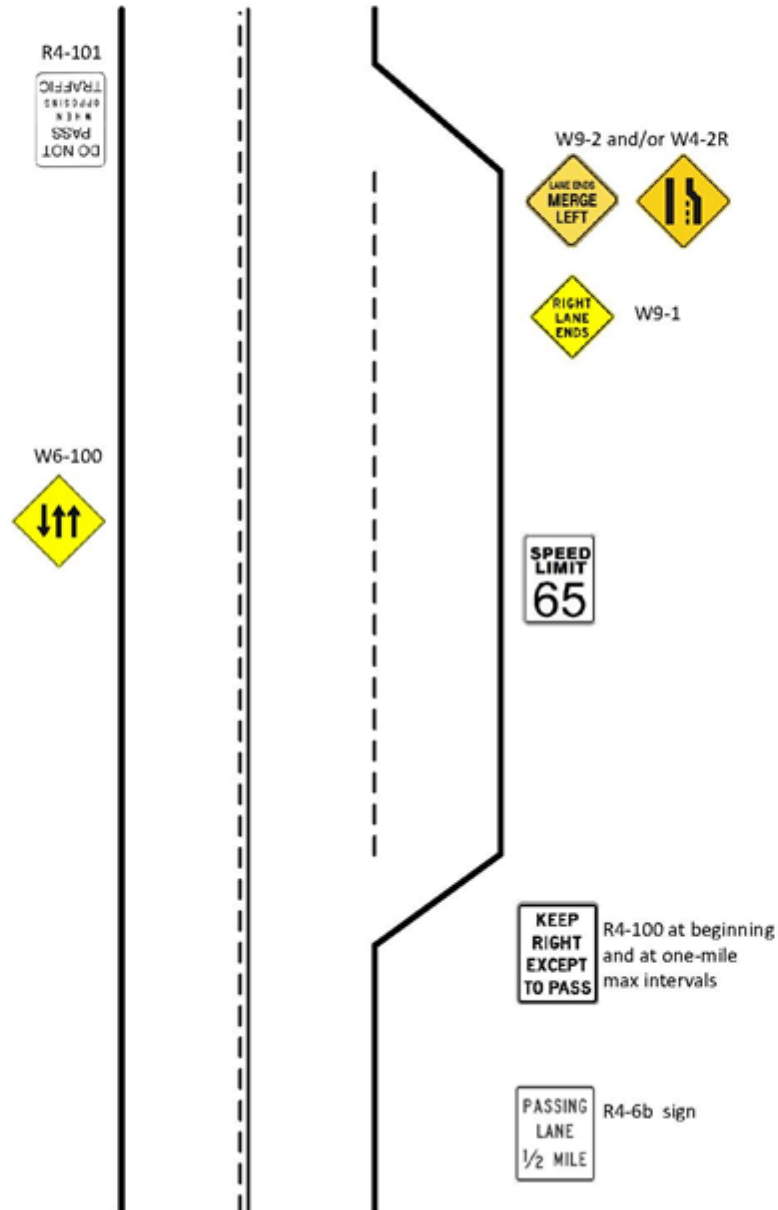
Figure 14. Schematic View of Scenario 0 – Baseline
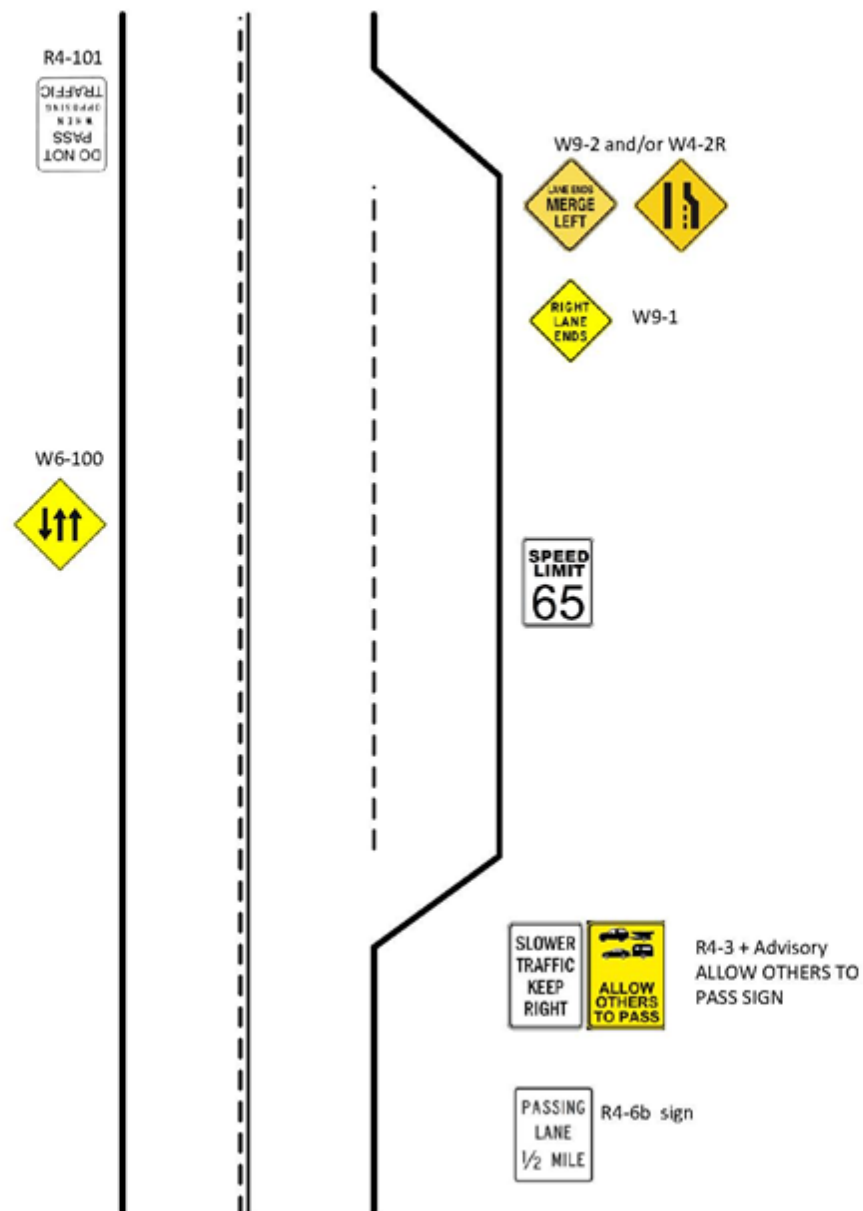
Figure 15. Schematic View of Scenario 1
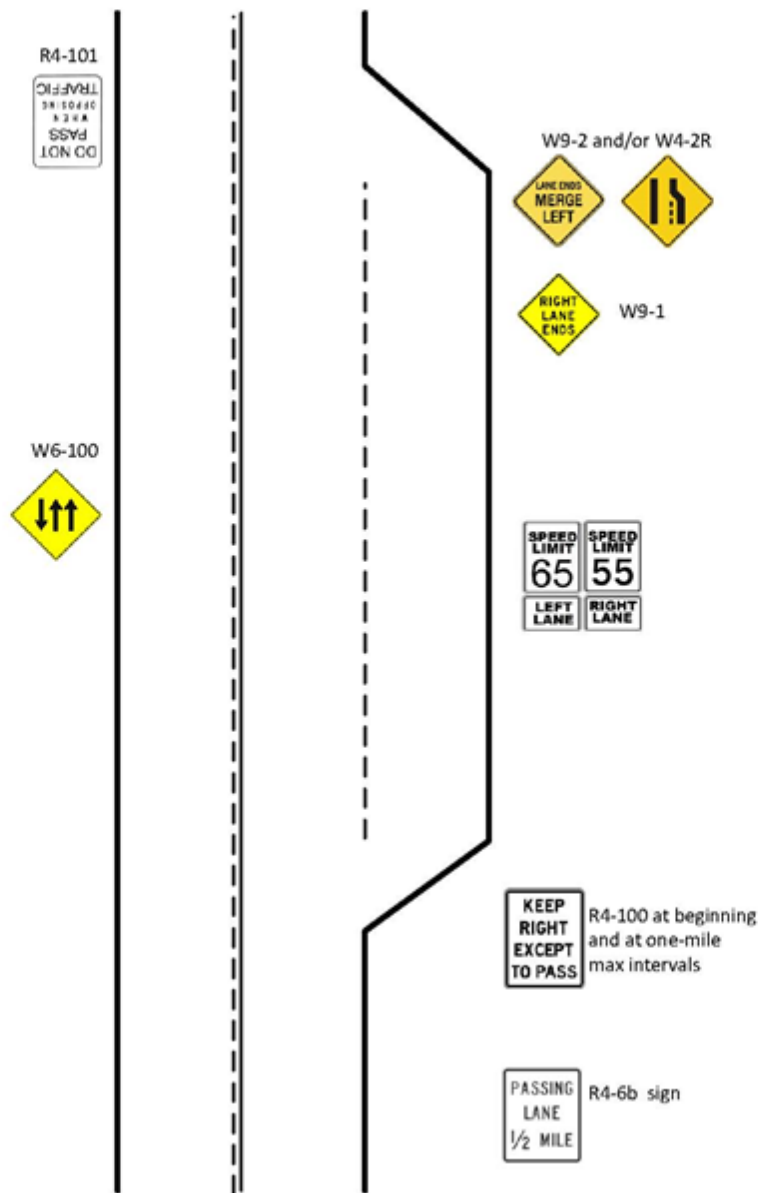
Figure 16. Schematic View of the Scenario 2 – Regulatory with Right Lane Reduced Speed Limit
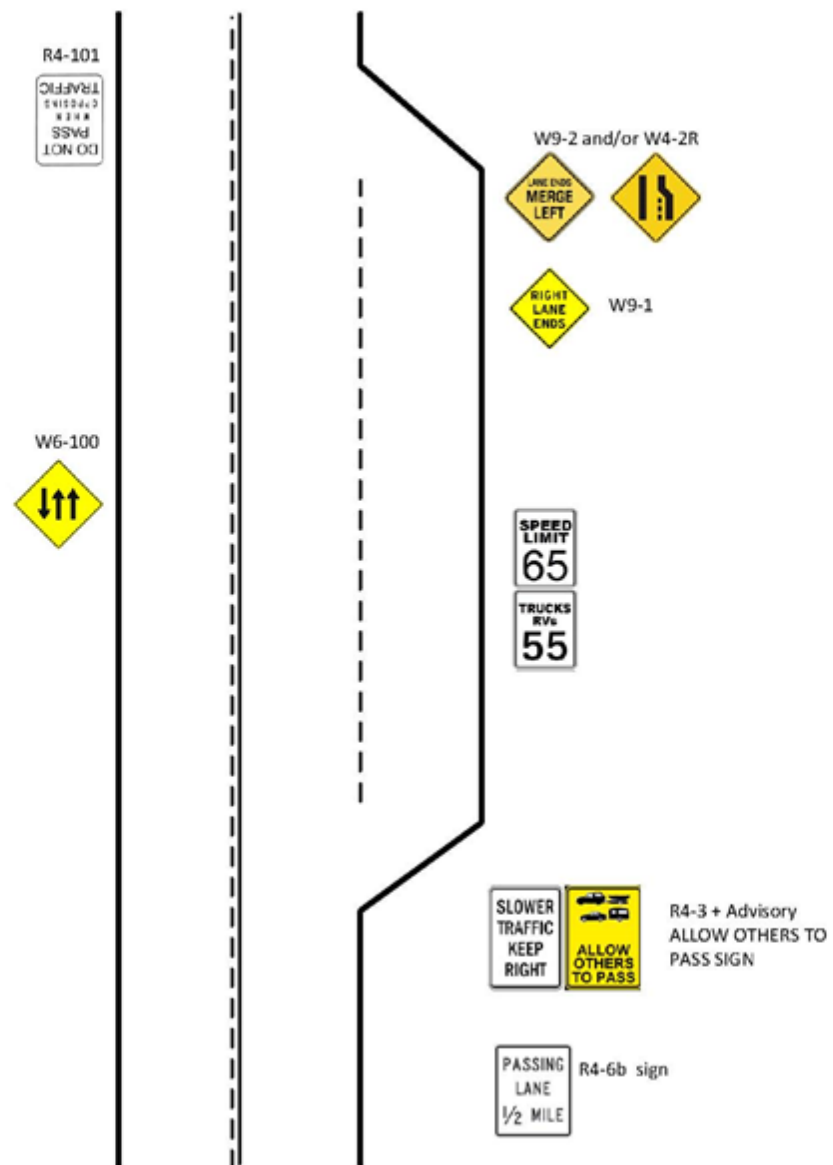
Figure 17. Schematic View of Scenario 3 - Regulatory with Truck/RV Speed Limit Plus Advisory
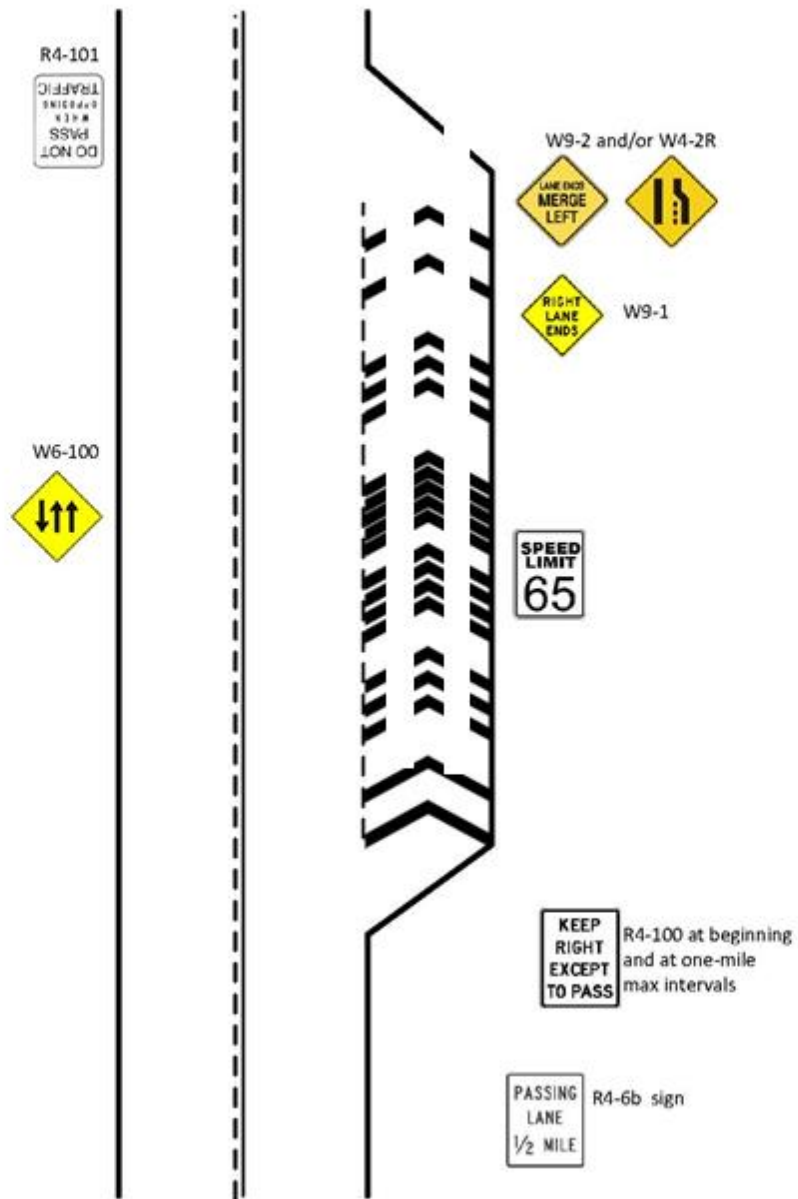
Figure 18. Schematic View of Scenario 4 – Passive Speed Reduction Using Chevrons
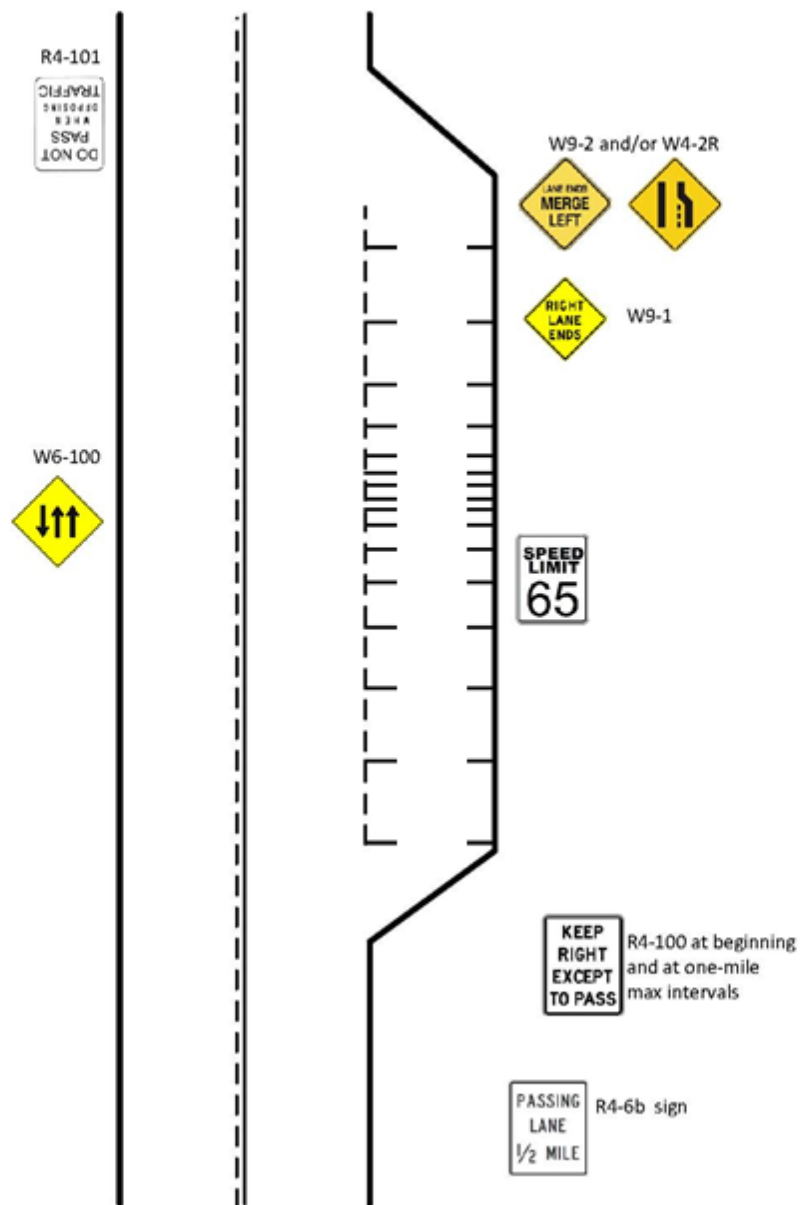
Figure 19. Schematic View of the Scenario 5 – Passive Speed Reduction Using Transverse Lines
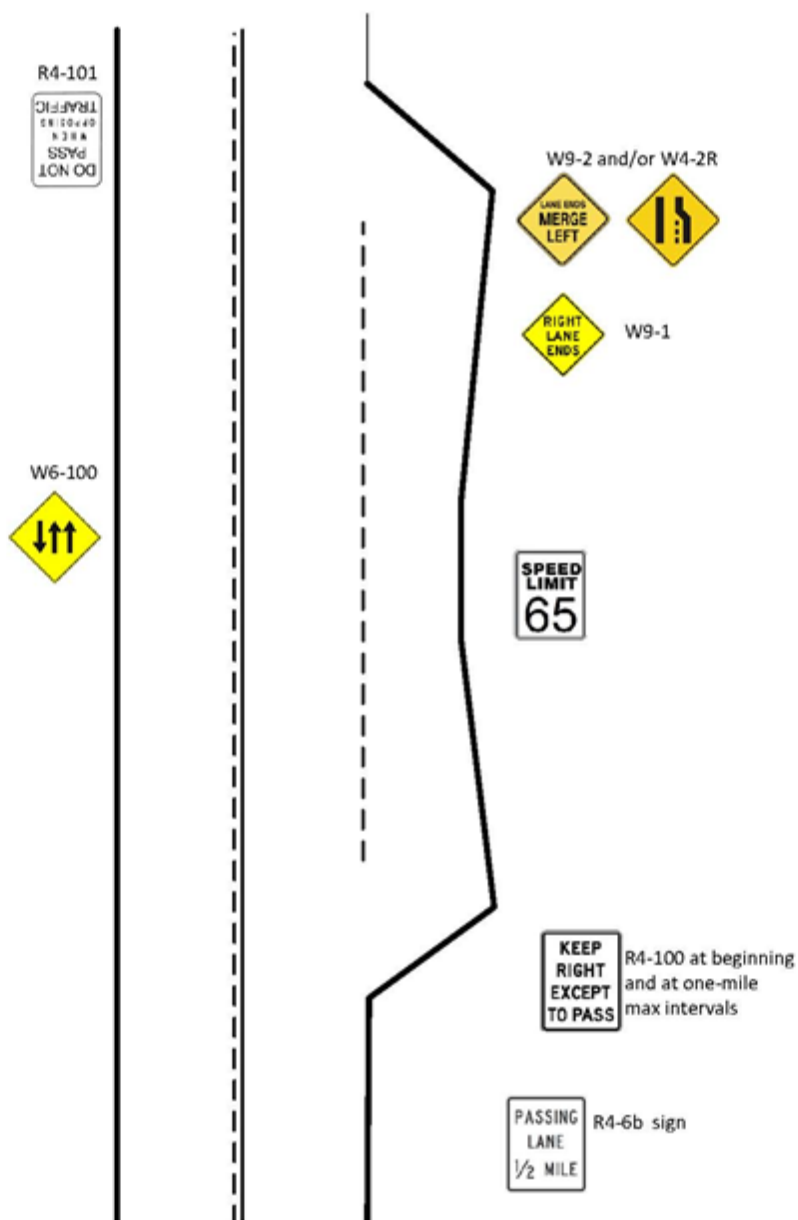
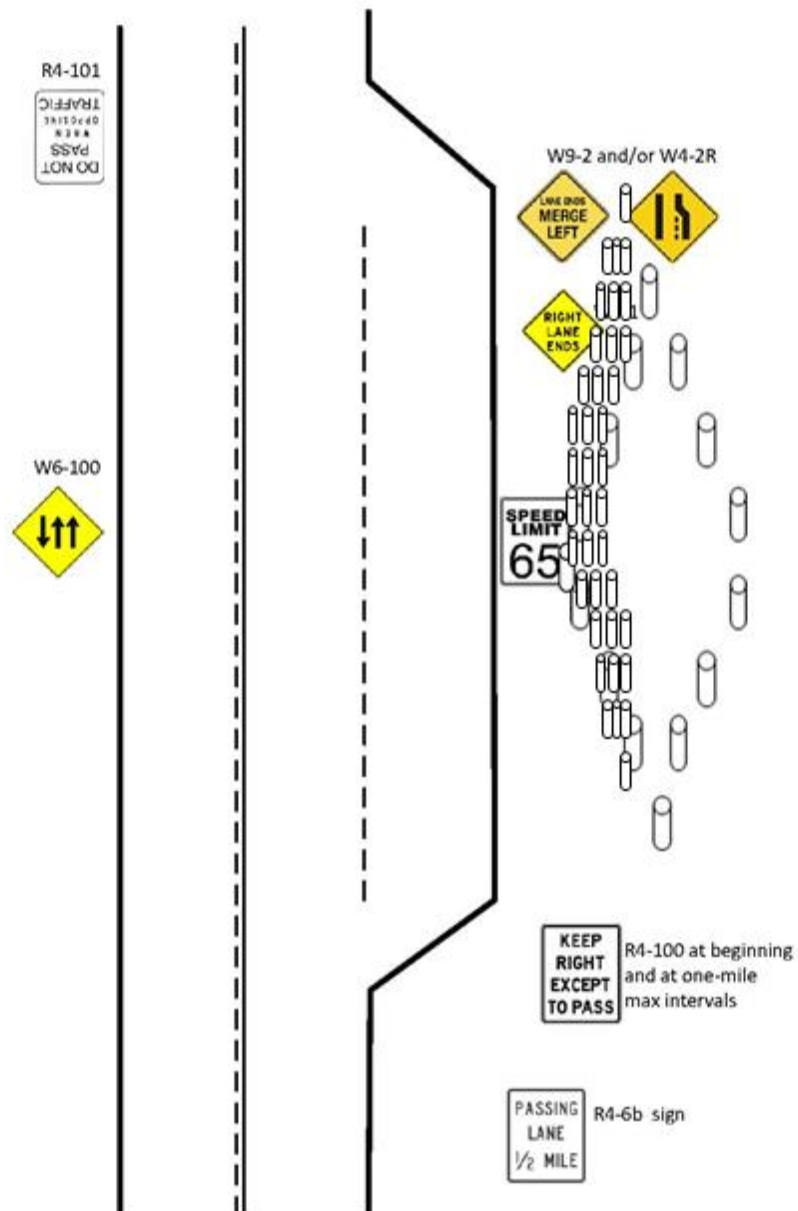**Figure 20. Schematic View of Scenario 6 – Passive Speed Reduction with Lane Narrowing**

Figure 21. Schematic View of Scenario 7 – Passive Speed Reduction with Poles Creating Optical Parallax Along the Side of the Road
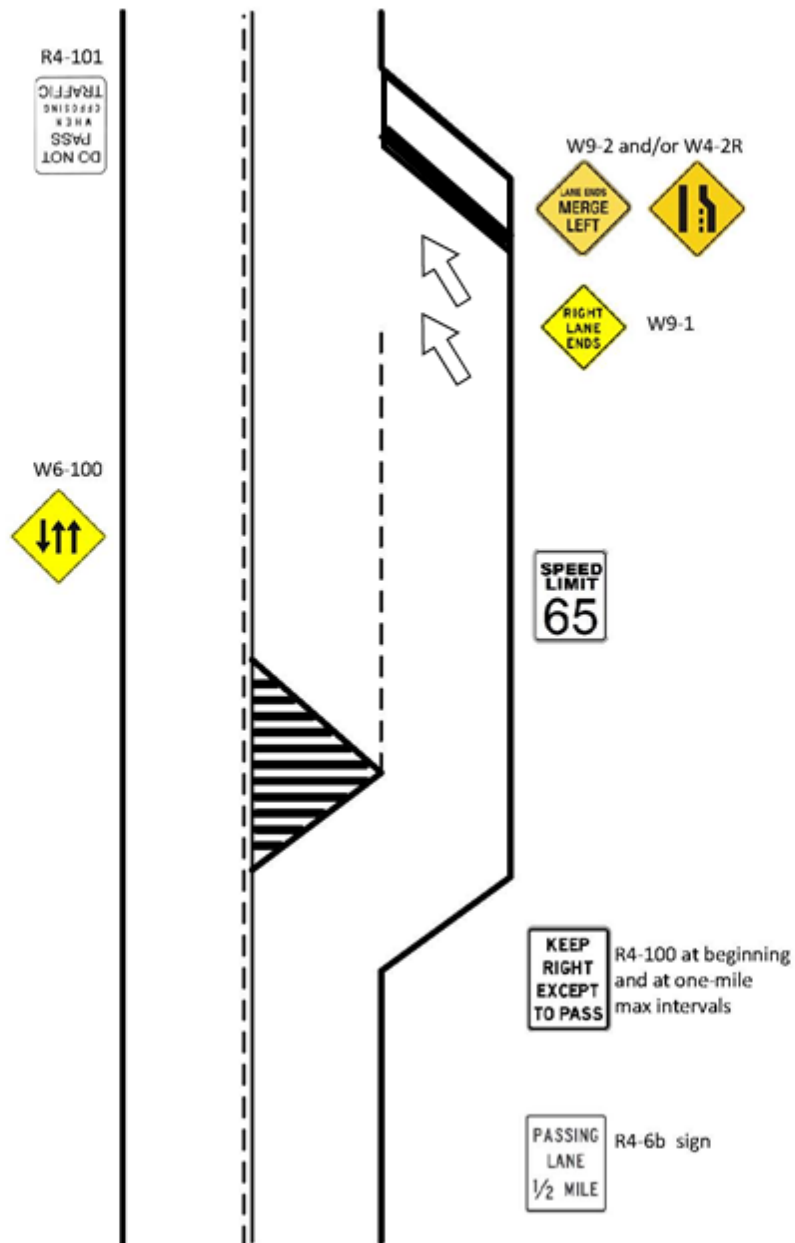
Figure 22. Schematic View of Scenario 8 - Force Right at Lane Addition and Neutral Zone with Arrows at Lane Reduction
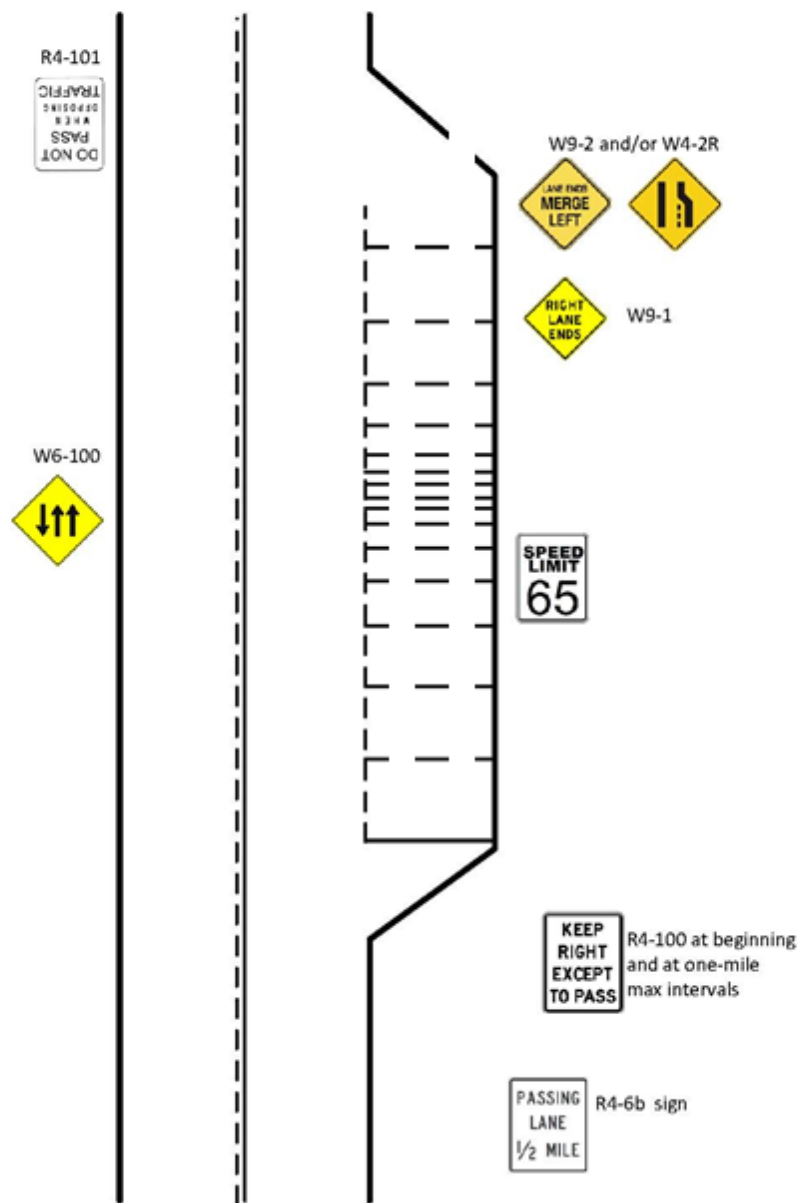
Figure 23. Schematic View of Scenario 9 - Passive Speed Reduction Using Transverse Lines with a Middle Segment