Research & Technology Transfer

Alaska Department of Transportation & Public Facilities

ANALYZING DRIVER BEHAVIOR IN PASSING ZONES WITH DIFFERENTIAL SPEED LIMITS ON TWO-LANE TWO-WAY UNDIVIDED HIGHWAYS IN ALASKA

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4		mm
ft	feet	0.3048		m
yd	yards	0.914		m
mi	Miles (statute)	1.61		km
		AREA		
in^2	square inches	645.2	millimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.4046	hectares	ha
		MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g
lb	Pounds (avdp)	0.454	kilograms	kg
T	Short tons (2000 lb)	0.907	megagrams	mg
		VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL
gal	Gallons (liq)	3.785	liters	liters
ft^3	cubic feet	0.0283	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

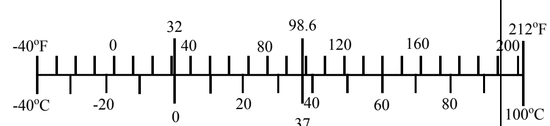
Note: Volumes greater than 1000 L shall be shown in m^3

Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
ºF	Fahrenheit temperature	5/9 (ºF-32)	Celsius temperature	ºC
		ILLUMINATION		
fc	Foot-candles	10.76	lux	lx
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2
		FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

These factors conform to the requirement of FHWA Order 5190.1A *SI is the symbol for the International System of Measurements

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 (statute)	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
km^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.471	acres	ac
		MASS (weight)		
g	grams	0.0353	Ounces (avdp)	oz
kg	kilograms	2.205	Pounds (avdp)	lb
mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	milliliters	0.034	fluid ounces (US)	fl oz
liters	liters	0.264	Gallons (liq)	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
ºC	Celsius temperature	9/5 ºC+32	Fahrenheit temperature	ºF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	pound-force	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi



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ABSTRACT

Due to the relatively high crash rates attributed to two lane highways in Alaska, solutions have been explored to improve safety by providing passing lanes to give drivers a better chance to pass the slow moving vehicles. Drivers of slow moving vehicles tend to drive at higher speed on the more level passing lanes reducing the chance of other to pass. In an earlier pilot study, a fixed-base driving simulator was used to assess the potential safety and operational benefits of multiple passing lane configurations before moving on to any field investments. One such suggestion is differential speed limits—the right lane would have a slower speed limit than the left, enabling easier and thus safer passing showed positive outcomes. DOT&PF proceeded with implementing a test of these results from the first study (Dyre and Abdel-Rahim, 2014) on the Seward Highway. Six level passing lane sections on the Seward Highway implemented differential speed limits for the two lanes in each 1-mile passing section during summer 2016 for approximately 1 month to investigate real-life effects. Traffic data were analyzed and driver surveys and video footage were collected to better understand driver behavior in these passing lanes. It was concluded that differential speed limits are not an effective means of mitigating problems associated with passing lanes in Alaska.

SUMMARY OF FINDINGS

A previous study, utilizing simulation technology, suggested that differential speed limits (DSLs) on level passing lane (PL) zones might be the most effective of nine scenarios considered towards mitigating crashes in these areas of highway. To determine the real-life effect of DSLs at PLs on rural highways in Alaska compared with the existing uniform speed limit (USL), this technique was implemented for a trial run at six PLs along the Seward Highway during the period June 24 to July 28, 2016. A before-and-after study was implemented by using temporary regulatory signs installed along these PLs that indicated a reduction in speed limit in the right lane to 55 mph, while the left lane speed limit remained the highway's normal speed limit of 65 mph. Three courses of examination were taken to determine the effectiveness of the new PL speed system: driver surveys taken at various points along the highway, traffic analysis using Numetric brand pads to collect individual vehicle data, and video analysis to observe and analyze driver behavior.

Driver surveys indicated general public disapproval for the DSL system. A major concern expressed in the surveys was the confusing nature of this implementation. Without comprehensive driver education, many drivers did not know how to use the new speed limits, resulting in a perceived increase in risky passing and driving behaviors. Though the purpose of DSLs is to improve safety and efficiency in PL zones, the surveys indicated that the new system had the opposite effect. Note that a prolonged application of the DSL system along with public awareness might change drivers' perception of the system.

The results from traffic analysis complement the conclusions drawn from the driver surveys, that the DSL system has an adverse effect on roadway safety. Differential speed limit conditions result in a decrease in the speed differential between the lanes, the mean speed in the right and left lane in PLs actually grows closer under DSL conditions than under USL conditions, making passing more difficult. This effect means that passing is less frequent and driver behavior becomes more aggressive, with an increase in risky maneuvers since drivers are not as easily able to pass when they feel they need to. These results demonstrate that when vehicles are able to pass, there is an increase in the likelihood that they will pass unsafely, that is, at very high speeds or by passing on the right. Similar to driver surveys, the traffic analysis from the trial study indicates that DSL conditions result in riskier, rather than safer, PLs.

Video analysis demonstrated that, due to the increased difficulty in passing found under DSL conditions, more platoons formed among vehicles in these PLs. Platoons greatly increase driver frustration and the likelihood of riskier driving, and are an undesired highway attribute. The likelihood of changing lanes was reduced under the DSL condition. Thus, the DSL condition was shown through video analysis to be adverse to a desired outcome.

Overall, all methods of analysis and performance criteria considered in this project, including the trials, showed that the DSL technique does not demonstrate benefits supporting a permanent installation, as it decreases safety and mobility along PLs. Please note that this conclusion is based on a short implementation period of the DSL system. A prolonged period of testing might have a different outcome.

CHAPTER 1 – INTRODUCTION AND RESEARCH APPROACH

Problem Statement and Research Objective

Two lane highways in Alaska have been shown to need improvement. One of the measures taken by DOT&PF is to introduce a passing lane (PL) along the two lane highways to give drivers the chance to pass slow moving vehicles. On level ground, slow moving vehicles tend to speed as they reach the PL as the road widens, reducing the effectiveness of the PL and leading to concerns over speed differential and risky driving. Crashes happen in these PLs because of frustrated drivers' risky attempts to pass slower vehicles. Because, historically, fatal crashes occur on these stretches of road, it is imperative that improvements are made to increase safety in these areas.

The geometrical and traffic features of these PL zones in Alaska might contribute to risky maneuvers. Some PLs are built on relatively flat ground giving the drivers an incentive to drive at higher speeds. In addition, peak traffic occurs during summer months as outdoor recreation activities are at its peak with lots of motorhomes, trailers, tourists, fishing boats, etc. going between anchorage and Seward/Kenai/Homer. The state is looking for cost effective measures to maximize the use of existing facilities to accommodate the short period summer peak travel. With Alaska having "let others pass" type law that if you're holding up 5 or more vehicles you need to let others pass you, it becomes difficult to enforce such a law during the peak summer travel and provide enough opportunities for others to pass.

A recent study conducted by the University of Idaho (Dyre and Abdel-Rahim, 2014) showed that a possible solution to PL problems is differential speed limits (DSLs), where the right lane has a slower speed limit than the left lane, allowing for a greater speed differential between lanes and facilitation of more passing vehicles. To determine if this idea is a feasible solution to Alaska's PL problems, a trial study was conducted during summer 2016 at Milepost (MP) 59–66 on the Seward Highway. The six PLs are almost identical making it ideal for trial. A 55 mile per hour (mph) regulatory speed limit was implemented for the right lane of the PL zone on this stretch of the highway, and a 65 mph speed limit was implemented for the left lane. Each PL is approximately 1 mile in length. There are three PLs in each direction approximately equidistant from each other. The effectiveness of DSL conditions was analyzed through driver surveys, traffic analysis, and video analysis.

Research Approach

This project was divided into four tasks:

1. A literature review to analyze studies that were similar to this project or had any relevance to the subject matter.
2. Driver surveys to gather information on public perception of using the DSL system versus the uniform speed limit (USL) system.
3. Traffic analysis using Numetric pads to analyze driver behavior before and after using the DSL system.
4. Video analysis to observe driver behavior before and after changes under DSL conditions.

The following paragraphs describe the four tasks.

Literature Review

Before the trial began, we performed a literature review to understand what has and has not made similar speed limit systems successful. Past articles and similar projects from different states were read to determine any difficulties that might arise in the course of the project. In general, the literature review provided a better idea of how to approach the project to have as successful an analysis as possible. Details of the literature review are given in Appendix A.

Driver Surveys

To better understand passing behaviors during field tests on the Seward Highway, we conducted a survey of drivers to learn their perceptions of DSLs on MP 60–65 of the highway. We distributed the paper survey at two locations: The Tesoro gas station in Girdwood and the Hope Junction rest area located on Seward Highway at MP 90 and 56.5 respectively. The survey was distributed online also. The survey questions were largely multiple choice, fill-in-the-blank. The survey was engineered in this manner in an attempt to regulate answers to simplify analysis. In addition, survey participants were given the opportunity to leave additional comments if they chose. Any missing values were supplemented using mean value calculations and interpretation where reasonable. Care was taken in this supplementation to represent the survey takers' sentiments accurately and avoid skewing results. The survey was taken by 895 participants, 465 of whom were chosen for analysis based on certain criteria which, when met, demonstrated reasonable familiarity with the Seward Highway. We selected participants from various backgrounds in an attempt to make the sample population reasonably representative of Alaska drivers as a whole.

Traffic Analysis

We conducted a before-and-after study to determine the effect of DSLs on two-way two-lane PL. Speed and traffic volume data, among other criteria, from three of the six PLs located between MP 59–66 on the Seward Highway in Alaska were collected using Numetric pads and analyzed. Lane utilization and speed differentials between lanes were examined to determine how DSL conditions affect both driver behavior (which lane is chosen to drive in) and overall efficiency of the PL (the larger the speed differential between lanes, the better the zone works to facilitate passing).

Video Analysis

We set up video cameras in various locations throughout the three PLs in the trial to enable visual observation of driving behaviors under DSL conditions. Figure 1 shows an example of the setup of these cameras as well as the Numetric pads on one of the PL. Details of the setup for the other locations are shown in appendix B.

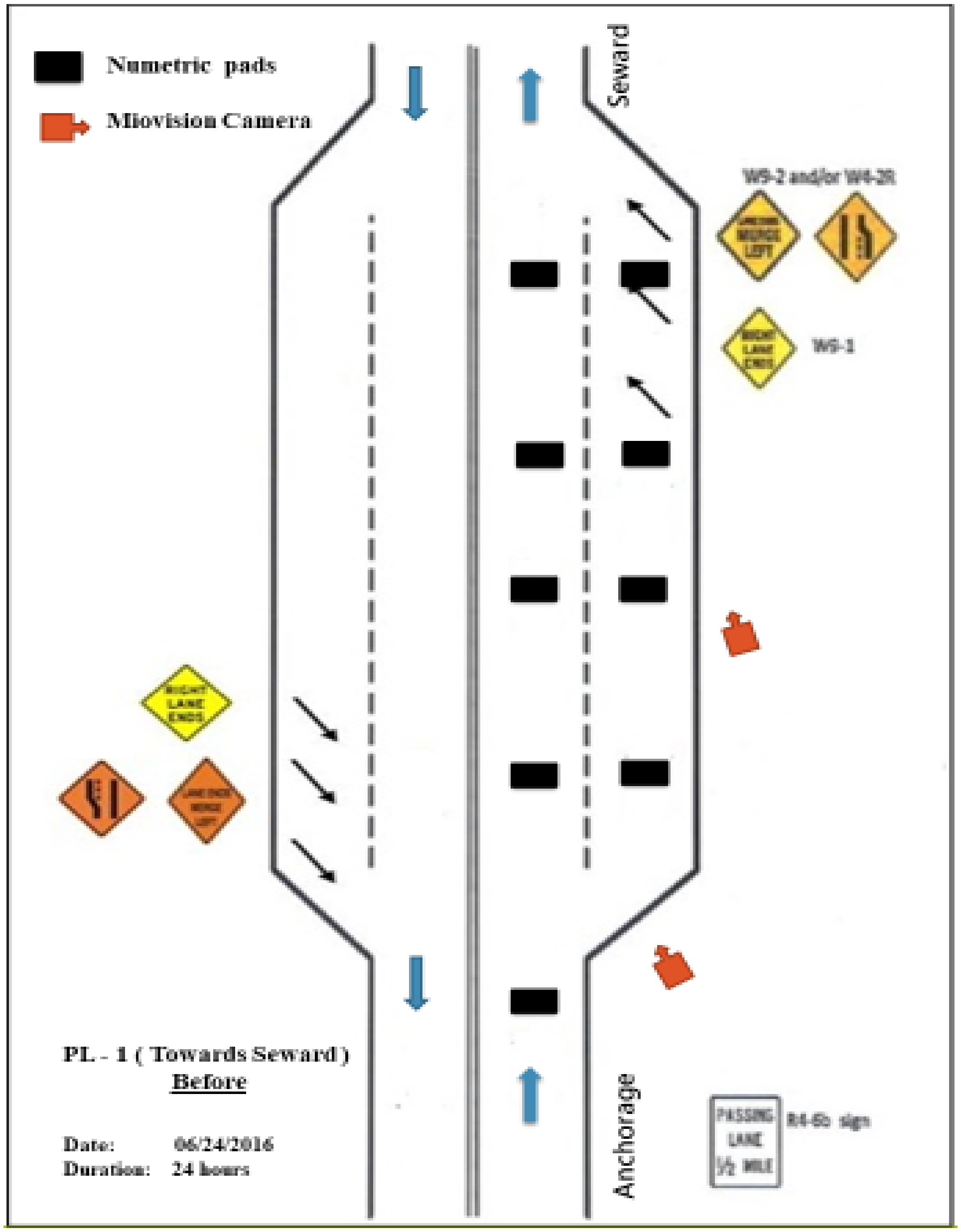

Figure 1. Example of video camera and Numetric pads setups along passing zones.

To perform this analysis, videos were collected and compared to determine passing and platooning behaviors. Passing behaviors were divided into four categories, and one of these—Type 1—was examined. Type 1 passing is the ideal form, where the left-lane vehicle passes the right-lane vehicle. At diverge locations (beginning of the PL), the slower vehicle moves into the right lane to allow the vehicle(s) behind to proceed in the left lane. If vehicles are allowed to pass in the left lane, platooning behavior should decrease. By comparing different rates of Type 1 passing under USL and DSL conditions, as well as looking at lane usage, passing maneuvers, rates of right and wrong passing maneuvers, diverge lane changes, and platooning behaviors, we were able to analyze how DSL conditions differ from USL conditions.

CHAPTER 2 – FINDINGS

Driver surveys showed that feedback was generally negative, with the new conditions increasing perceived risk driving and, in some cases, confusing drivers. Traffic data analysis showed that DSL conditions decreased, rather than increased, the speed differential between lanes, effectively doing the opposite of its intent. Video analysis proved that riskier passing behaviors/maneuvers increased under DSL conditions. Overall, analysis showed that DSLs have an adverse effect on PL zones on highways in Alaska.

Summary

Each type of analysis gave results of a fashion. These results present a full picture of the effects that DSL conditions have on driver behavior and safety.

Literature Review

Much research has been done on PL, safety impacts of DSLs, and driver behavior in areas of DSL implementation. Several studies suggest that traffic operation, traffic safety and drivers' comfort are enhanced by providing PL in two-lane two-way highways. Regulatory signs with speed limits play a vital role in increasing the efficiency and safety of a highway. Diverse examinations demonstrate that a higher difference in speed limit tends to cause more collisions than a smaller difference in speed limit. Many studies report a relationship between DSL and safety impacts on highways. Truck-related collisions are less likely to occur with a DSL policy and truck lane restriction. Both real-time and simulated environments in many studies show that driver behavior is influenced by the geometry of a highway and by traffic conditions.

While studies have examined the speeding behavior of drivers, little is known about drivers' perception of the presence of PL zones and their preferred speed while traveling through PL. Thus, a gap exists in the previous research. To fill this gap in the literature, we examined the effects of PL on drivers' preferred speed with a difference in posted speeds in the left and right lanes of the PL. We analysed suggested speed limits at PL and the impact of DSLs on drivers' operating speed at PL. Without a proper understanding of drivers' preferred speed in PL and the influencing factors such as speed control measures (e.g., speed limit signage, changeable message signs, photo and video speed camera, and law enforcement) to improve traffic safety, the benefits of DSLs at PL may not be effective. For example, a reduction in speed limit for the right lane only of the PL might result in low-level compliance or resistance to change, as examined in another study. Appendix A contains a detailed literature review for this subject matter.

Driver Surveys

The survey respondents were 30–70 years of age, with a majority having at least one year of college education. Four percent of participants reported having been in at least one crash along the Seward Highway. Most of these participants drove passenger cars. However, drivers of motorcycles, buses, recreational vehicles, and other vehicle types were also represented. Figure 2 gives an example of the graphs used for demographic analysis. Further details are found in Appendix B.

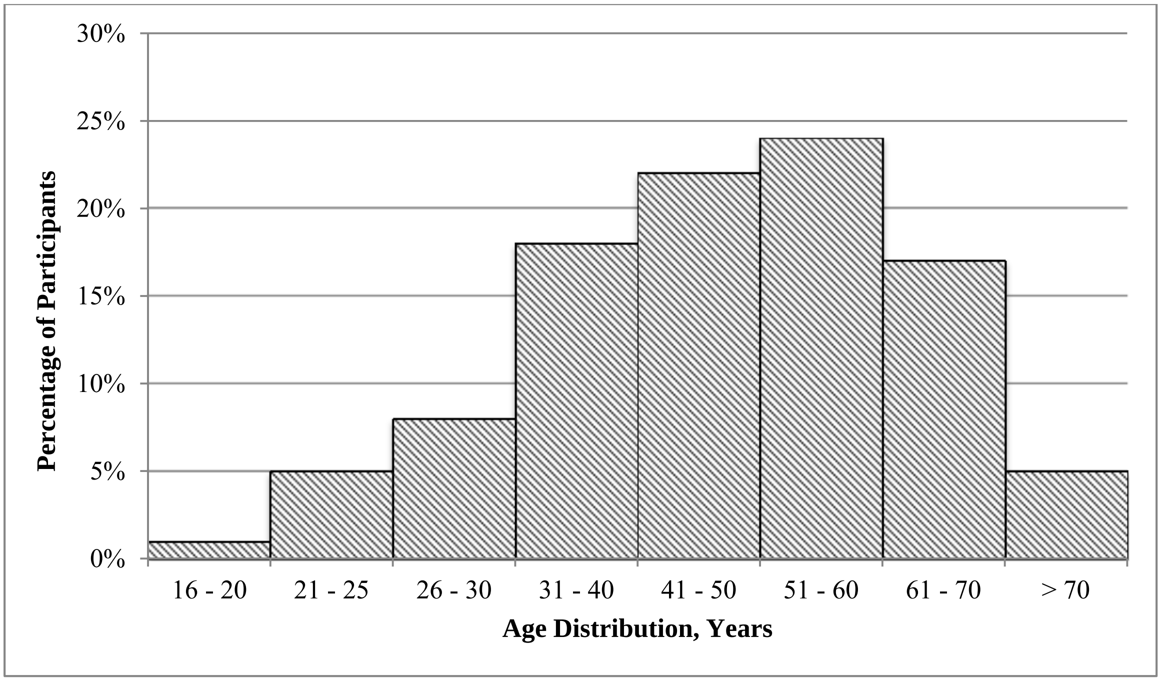

Figure 2. Age distribution of survey participants.

The survey addressed multiple categories of questions with the aim of better understanding driver behaviors, driver perception of how to use the new DSLs, safety concerns, and the demographics of the drivers. We asked a number of questions about driver behavior, both perceived in other drivers by survey participants and the behaviors of the participants themselves. The first of these questions asked the survey participants how much notice was preferable before the beginning and end of PL. Participants generally responded that more notice rather than less was ideal, and more was needed to alert drivers to the beginning of a PL rather than the end of one. The survey asked which lane drivers most frequently travel on the Seward Highway in PL zones. A majority of the drivers responded that they preferred the right lane to the left lane. Additionally, most of the participants move to the right lane as soon as a passing area begins.

We analyzed some questions in this survey using a Likert scale. Using this scale, we determined that there is a significant increase in driver stress while driving behind a slower vehicle. The survey asked about six risky conditions and their ranking according to how risky the participants perceived them. Using the Likert scale, we determined that drivers consider poor road markings to be one of their highest concerns. This concern was followed by long vehicles, weather conditions, overtaking slow vehicles on the right, merging at the end of a PL, and aggressive drivers, in this order. Figure 3 shows the results from this question.

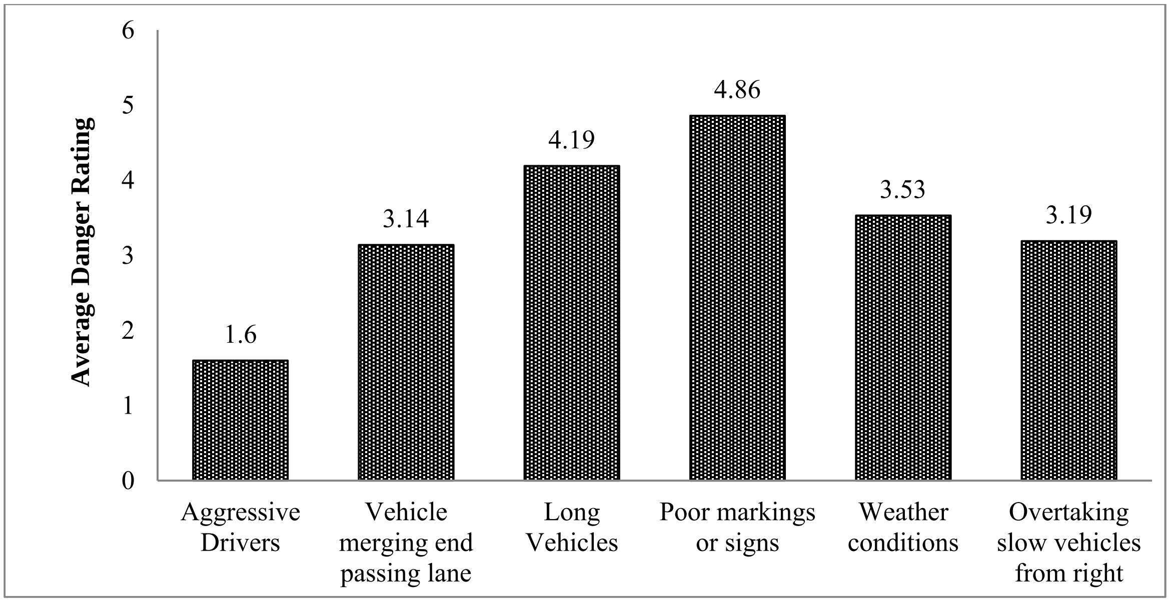

Figure 3. Driver ratings of risky conditions.

Asked what they thought about the length of PL, survey participants responded that the lanes were a little short, but generally acceptable. A large number of the respondents noted that more lanes needed to be built, indicating general passing frustration. The survey asked how the slower right lane speed limit impacted different road conditions. The consensus was that the lower right lane speed limit did not overall increase driving speed on the left lane nor did it reduce travel time, but it did succeed in improving traffic flow and making passing slower vehicles easier. The participants were evenly split regarding whether the speed limit improved safety, merging, lane changing, and reducing the risk of accidents.

The survey also asked about speed limits on the Seward Highway. The responses indicate that most survey participants drive between 61 and 70 mph. When asked about the speeds with which they travel in the right and left lanes on PL specifically, the participants gave speeds close to the current 65 mph speed limit for the right lane and slightly higher for the left lane. When asked about recommended speeds for the right and left lanes, survey participants gave speeds slightly slower than the actual speeds that drivers travel in the right and left lanes. The participants were asked whether a slower right lane speed limit was plausible. Answers were in slight agreement, with half of the participants remaining neutral or negative regarding the question.

The online survey featured several questions that were not in the paper survey. These questions were answered by 176 participants. The first question, which described three different scenarios in a zone with a Slower Traffic Keep Right sign, asked participants which lane they would most likely travel. In the first scenario with no other drivers around, the vast majority of survey participants responded that they would travel in the right lane. In the second scenario with a slower car in front of them, almost all of the drivers chose the left lane to travel. In the third scenario in which they are followed by a faster vehicle, all but a few respondents replied that they would move to the right lane. The participants were then presented with the differential speed limit signs that were posted for the duration of this project, and given four different choices to provide the correct interpretation of the signs. The respondents agreed that these signs indicate different speed limits depending on the lane being used.

The survey participants were also given the opportunity to leave comments regarding the project and any of their additional safety concerns. Generally, the participants gave helpful feedback regarding the pros and cons of the differential speed limit. Those who approved of the differential speed limit mentioned that they believed that the project had the potential to improve safety and decrease aggressive behaviors. Those who did not approve of the differential speed limit mentioned that the project was impractical to implement due to a lack of law enforcement and drivers who ignore the speed limits altogether. Many individuals mentioned the presence of extremely aggressive drivers and the need for increased law enforcement presence on the Seward Highway. Concern was voiced regarding ticketing if the new limits were implemented, and about general confusion. As a result, there was a request for further clarification and attempts to raise awareness if the differential speed limit are implemented. The overall survey results of the surveys and analysis are given in Appendix B.

Traffic Analysis

Three PL zones considered in this study as shown in Figure 4. Passing lane one (PL-I) is located at the start of the three PLs for southbound (SB) traffic, that is, from Anchorage towards Seward. Only SB data was collected on PL-I. This PL is 7300 feet long, the longest of the three PLs. The grade at this location was determined to be flat enough so as not to affect driver ability and performance. Twenty-four hours of peak day data were collected for uniform speed limit (USL) conditions, and 96 hours of data were collected for DSL conditions. Passing lane two (PL-II) is located downstream of PL-I for SB traffic and upstream of Passing lane three (PL-III). Data were collected for only northbound (NB) traffic on PL-II (traveling towards Anchorage). This PL is around 5000 feet. The gradient at this location was also determined to be flat enough so as not to affect driver ability and performance.

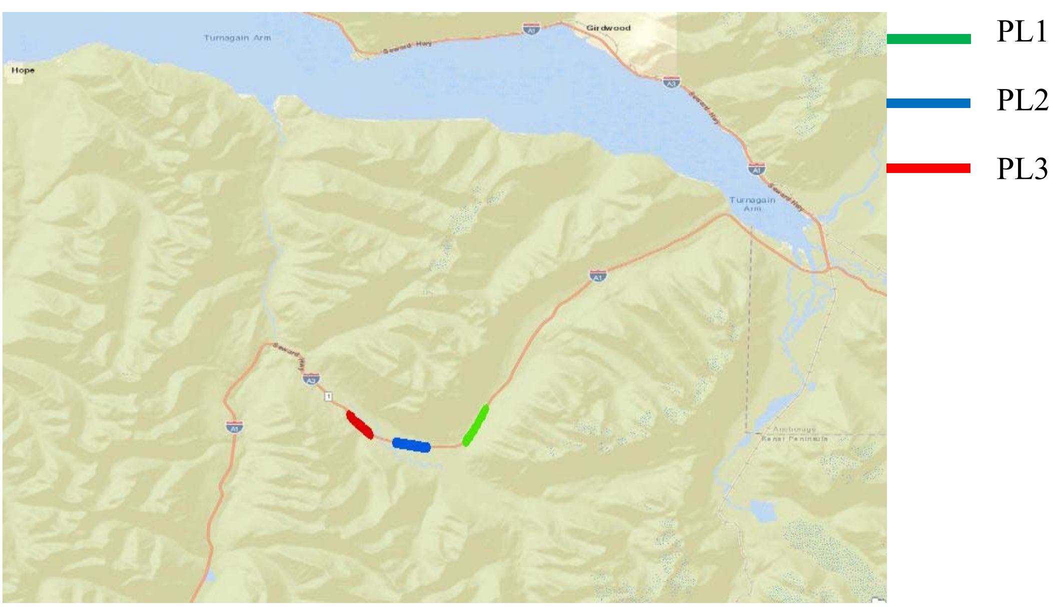

Figure 4. Passing lanes zones considered

Twenty-four hours of peak day data were collected for USL conditions, and 96 hours of data for DSL conditions were collected. Passing lane three (PL-III) is located downstream of PL-II for SB traffic. Data were collected for only NB traffic on PL-III. The length of this PL is around 5000 feet. The gradient at this location was determined level enough not to affect driver behavior. Twenty-four hours of peak day data were collected for USL and DSL conditions.

In PL–I, with DSL deployment, right lane utilization decreased due to the lower speed limit in that lane. Figures 5 and 6 show lane utilization under USL and DSL conditions. To view graphs for other PLs, see Appendix C.

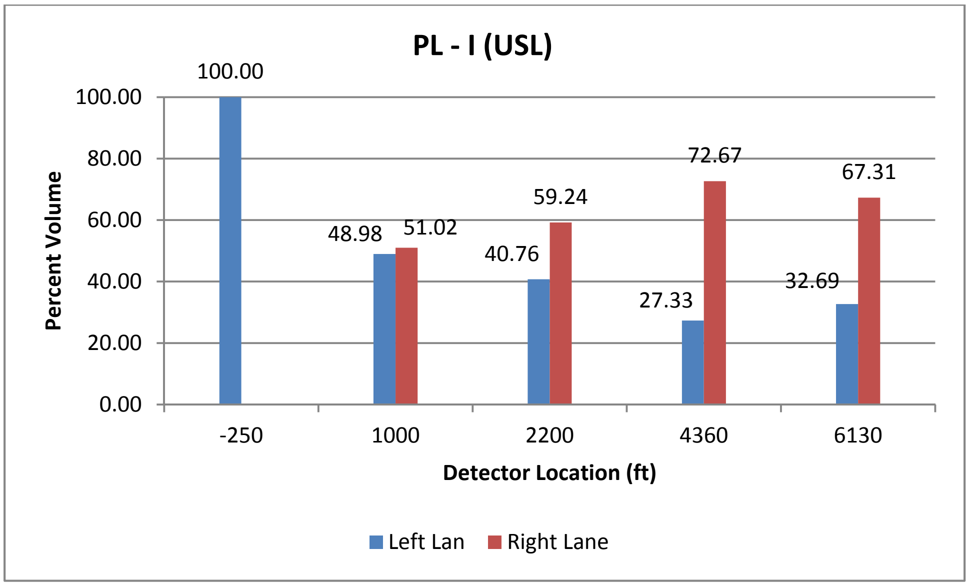

Figure 5. Percent passenger vehicles on each lane (USL).

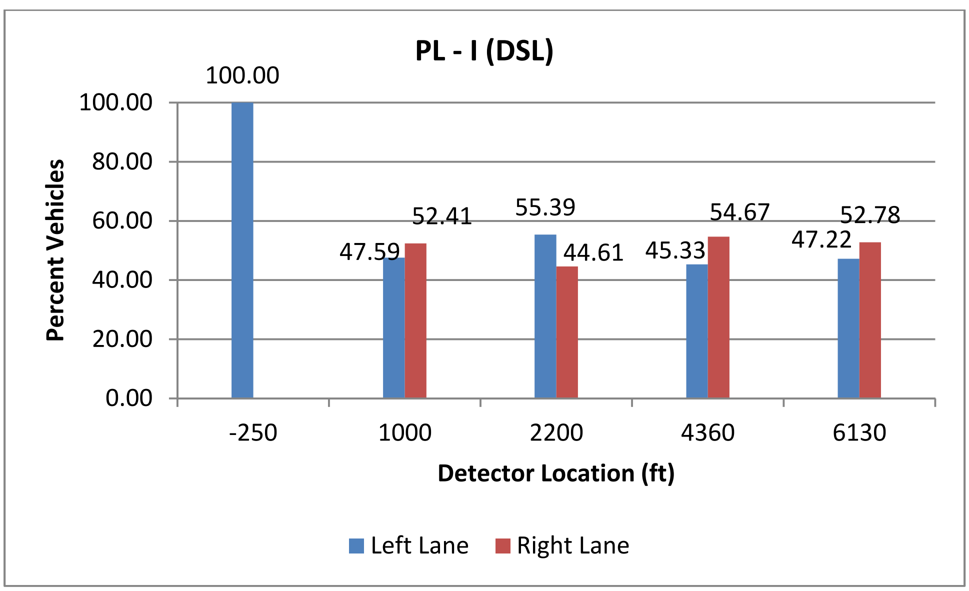

Figure 6. Percent passenger vehicles on each lane (DSL).

This indicates drivers' preference to continue at the same speed but also follow posted speed limits, resulting in increased driving in the left lane and fewer legal and easy passing opportunities. The speed difference between the two lanes within the PL zone was drastically reduced due to the deployment of DSLs compared with the USL. Figures 7 and 8 demonstrate this change in speed differential between the lanes. For further details on this analysis on other PLs and specific vehicle types, see Appendix C.

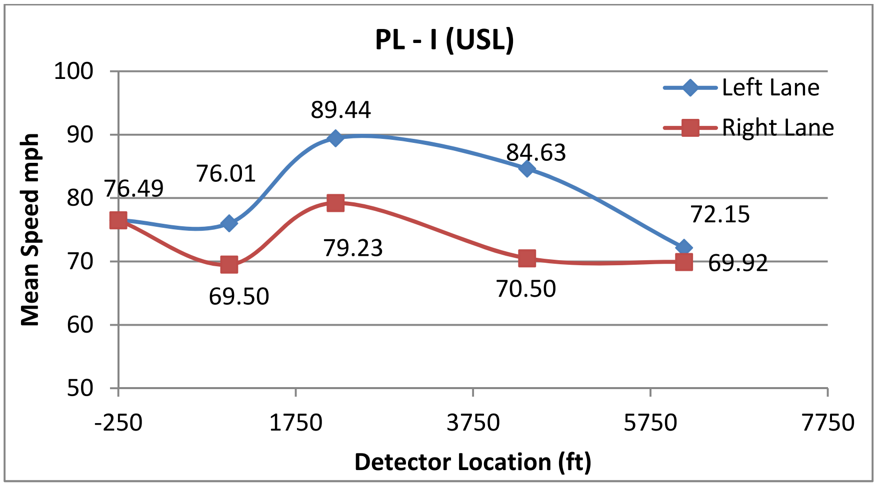

Figure 7. Mean speed of overall vehicles under USL conditions.

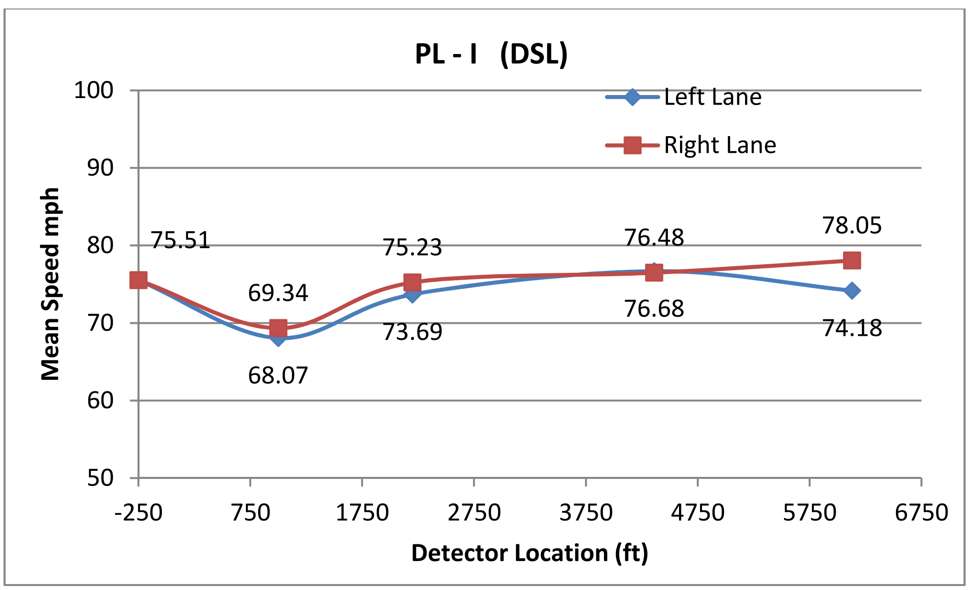

Figure 8. Mean speed of overall vehicles under DSL conditions.

The results for PL-II are different from the results for PL-I and PL-III, as this PL is located between PL-I and PL-III. The PL located in the same direction with less than 8 miles of separation can be considered a single system (Harwood et al., 2010). Therefore, PL-III has an impact on the operation of PL-II, as it is located downstream of PL-III (for northbound traffic). The results of PL-II demonstrate that the speed difference between the two lanes within the PL zone was increased due to the deployment of DSL conditions compared to

USL conditions. The average speed in both lanes was reduced due to DSL conditions. In terms of lane utilization with DSL deployment, right lane usage decreased due to the lower speed limit on that lane. This indicates drivers' avoidance of driving at a lower speed limit (55 mph) given an adjacent lane with a higher posted speed limit, similar to PL–I.

The findings of PL–III indicate that the speed difference between the two lanes within the PL was reduced due to the deployment of DSL conditions compared with USL conditions, similar to PL-I. The reduction of the speed difference between the left and the right lanes may result in a decrease of passing frequency within the PL. In terms of lane utilization, right lane utilization decreased due to the lower speed limit on the right lane under DSL conditions. This indicates drivers' avoidance of a lower driving speed given an adjacent lane with a higher posted speed limit. The speed of vehicles on the left lane was lowered significantly under DSL conditions when compared with USL conditions.

In all PLs passenger vehicle speeds followed the same trend as that of overall vehicles for both USL and DSL conditions. Further, the mean speed of passenger vehicles is similar to the mean speed of all the vehicles. This indicates that heavy vehicles also drive at speeds similar to passenger vehicles, reflecting a limited choice of speed in the PL.

A comparison of the results of DSL conditions with USL conditions in all PLs indicates that the percentage of passenger vehicles in the left lane at each location under DSL conditions was higher than that under USL conditions and stabilized at about 45% for all passenger vehicles. This implies that drivers do not want to travel at the 55 mph speed limit in the right lane and use the left lane as the driving lane. In addition, the trend in the right lane is to slightly decrease as traffic approaches the merge lane. The comparison also shows that compliance with "KEEP RIGHT EXCEPT TO PASS" decreases with the implementation of DSLs.

Ultimately, these findings present evidence that DSL conditions have an adverse effect on traffic operation and safety if implemented on the PL. The analysis was based on four hours of evening peak time and dry weather conditions speed data were analyzed for each USL and DSL conditions. Speed data of four hours having equal traffic volume for each USL and DSL condition were compared. The drivers' speed behavior in morning (relatively low volumes) hours was similar to that in the peak hours. Therefore, only peak hours data were analyzed. The entirety of this analysis is in Appendix C.

Video Analysis

The video data from this project yielded analysis in several areas: traffic flow, driving behavior, and platooning behavior. These are detailed below.

Traffic Flow: A reliable measure of traffic flow is the percent of Type 1 passed and passing vehicles in each lane. A Type 1 pass occurs when a vehicle starts in the left lane at the beginning of the PL and continues in the left lane while passing slower vehicles in the right lane. If traffic flow improves, there should be an increase in the percentage of Type 1 passed and passing vehicles. For PL-I, there was an increase in the percentage of Type 1 passing vehicles under the differential condition and no change in percentage of Type 1 passed vehicles. Figures 9 and 10 show this change. To view graphs for other PLs, see Appendix D.

In PL-II, there was a decrease in the percentage of Type 1 passing vehicles, and a decrease in the percentage of Type 1 passed vehicles. Due to a technological malfunction, PL-III only had one camera recording, so the one camera cannot be used to analyze passing behavior from beginning to end of the PL. Because of this technological malfunction, there is no Type 1 pass data for PL-III.

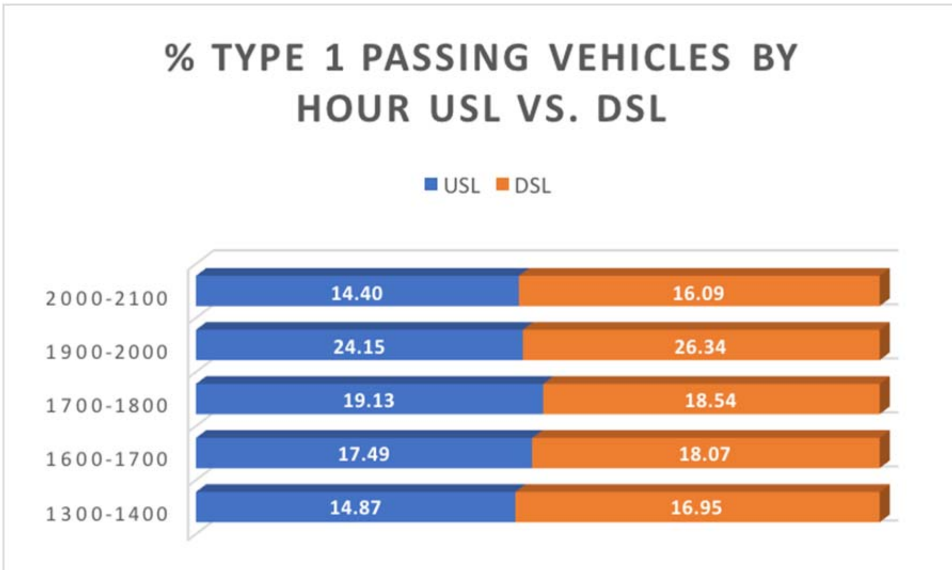

Figure 9. Percentage of Type 1 passing vehicles by hour for USL vs. DSL, PL-I.

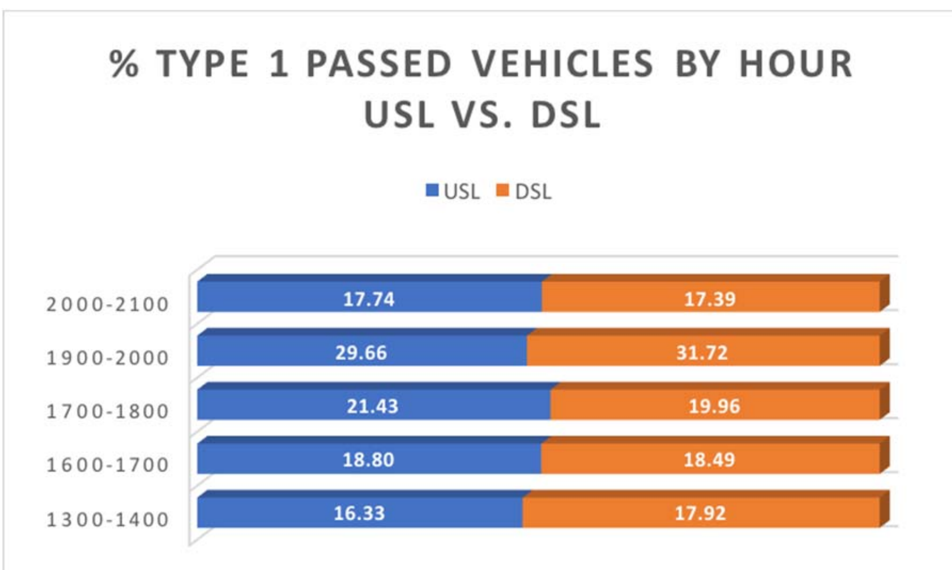

Figure 10. Percentage of Type 1 Passed Vehicles by Hour for USL vs. DSL, Passing Lane I

Another method used to evaluate traffic flow is the percent of vehicles in each lane. With the imposition of DSLs, we expected that more vehicles would move to the right lane to allow faster vehicles to pass using the left lane. Thus, we expected to see an increase in the percentage of vehicles in the right lane due to the DSL. In all three PLs, there was a decrease in the percentage of vehicles in the right lane due to the DSL, which is opposite of the effect the DSL should have.

<u>Driver Behavior:</u> Passing maneuvers occur when a vehicle traveling behind a slower vehicle travels into another lane to pass that slower vehicle. When the passing vehicle is in the left lane, this is known as a right-side maneuver. When the passing vehicle is in the right lane, this is a wrong-side maneuver. The DSL should cause a decrease in the percentage of total passing maneuvers. In both PL-I and PL-II, the total percentage of passing maneuvers decreased, but in both cases, the number of wrong-side maneuvers increased, which is a significate safety concern. Recall that wrong-side maneuvers require a faster vehicle traveling behind a slower vehicle in the left lane. When the slower driver does not move to the right as a courtesy, the faster driver uses the right lane to pass the slower driver that is in the left lane. Again, PL-III has no Type 1 pass data due to the technological malfunction.

The percentage of mandatory diverge lane changes was also analyzed to evaluate driver behavior. In all three PLs, the percent of mandatory diverge lane changes decreased because of the DSL. Figure 11 shows this change on PL-I. To view other graphs about driver behavior video analysis, see Appendix D.

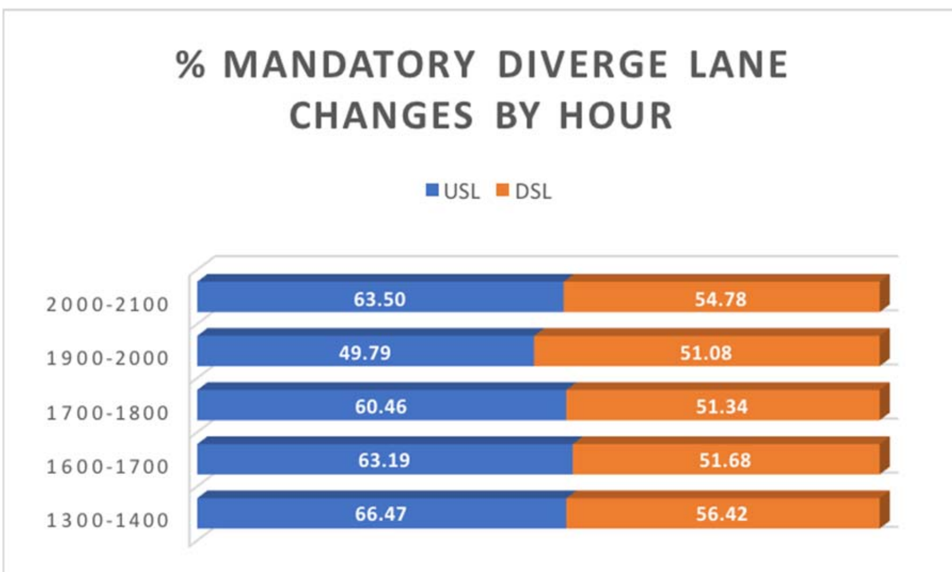

Figure 11. Percent mandatory diverge lane changes by hour for USL vs. DSL, PL-I.

This is opposite the effect the DSL should have on driver behavior compared to the outcome of the simulator study, meaning drivers probably prefer to travel at the faster limit, 65 mph.

<u>Platooning Behavior:</u> Platooning behavior is important to keep track of between the two conditions because another safety concern on the Seward Highway is backups in traffic due to platooning. Four different measures were analyzed for platooning behavior. The first

is the percentage of platoons with more than one vehicle; the second is the mean size of platoons with more than one vehicle; the third is the percentage of vehicles in the largest platoon; and the fourth is the total percentage of platoons, which is defined as the number of platoons divided by the total number of vehicles per hour.

The percentage of platoons with more than one vehicle should decrease because of the DSL, as we expect to see more vehicles traveling alone due to increased traffic flow. In PL-I, the percentage of platoons with more than one vehicle decreased due to the DSL. In PL-II, the results for the percentage of platoons with than one vehicle are inconclusive. In PL-III, there was no change in the percentage of platoons with more than one vehicle. Although there *is* a decrease in percentage of platoons of more than one vehicle in PL-I, no conclusion can be drawn about platooning behavior from this measure because the results from PL-II are inconclusive and there was no change from before to after conditions.

The mean size of platoons of more than one vehicle will also tell whether there is an increase or decrease in platooning behavior from the USL to the DSL condition. Upon imposition of the DSL, there should be a decrease in mean platoon size because of improved traffic flow. In PS-I and PL-II, the mean size of platoons of more than one vehicle increased due to the DSL. The results for the mean size of platoons of more than one vehicle for PL-III was inconclusive.

Another measure that will help to identify an increase or decrease in platooning behavior from the USL to the DSL is the percent of vehicles in the largest platoon of each hour. Because the DSL is supposed to reduce the number of vehicles in each platoon, there should be a decrease in the percentage of vehicles in the largest platoon. In PL-I, the percentage of vehicles in the largest platoon did decrease due to the DSL, but it is clear from the measure of the mean size of platoons greater than 1 vehicle in PL-I that the mean size of each platoon actually increased from the USL to the DSL, so mean size of platoons is a more reliable measure and supersedes the measure of the percent of vehicles in the largest platoon of each hour. In both PL-II and PL-III, the percentage of vehicles in the largest platoon increased due to the DSL, which means DSLs have the opposite effect on traffic flow than is intended.

The last measure analyzed for platooning behavior is the total percent of platoons, which is the total number of platoons divided by the number of vehicles in each hour. In this measure, individual vehicles are also counted as platoons. There should actually be an increase in the total percent of platoons, because as traffic flow improves, more vehicles will travel alone. In both PL-I and PL-III, the total percentage of platoons decreased as a result of the DSL. The data for PL-II's total percentage of platoons is inconclusive. To summarize, the DSL was not effective in decreasing platooning behavior, improving traffic flow, or reducing passing maneuvers. The entirety of this analysis is given in Appendix D.

CHAPTER 3 – INTERPRETATION, APPRAISAL, AND APPLICATIONS

Each type of analysis gave different results that may all be interpreted separately to better understand the scope of the results of the differential speed limit (DSL) trial.

Interpretation

Driver surveys raised a concern as to how realistic the project was—many drivers believed the DSL conditions would have no effect. Many drivers also mentioned that, for the differential speed limit to be successful, further clarification and education would be needed. As the project stands, the driver surveys point to an unsuccessful trial with regard to both public perception and public use.

Traffic analysis showed that, under DSL conditions, a larger portion of drivers chose the left lane as a travel lane than under USL conditions. More vehicles driving in the PL means less effective passing, greater driver frustration due to this, and thus riskier attempted passing maneuvers. This interpretation is further shown through the reduction of the speed differential between lanes under DSLs versus USLs, which makes passing more difficult, increasing frustration even more. Overall, this type of analysis showed that DSL conditions ultimately increased driver frustration by making passing harder, thus increasing willingness to drive riskier to relieve these situations. This analysis shows that DSLs had an adverse effect on drivers' proper use of PL.

Video analysis showed a decrease in safe passing maneuvers under DSL conditions, and it indicated that drivers are more likely to stay in the left lane over the course of the PL under DSL conditions than they are under USL conditions. Video analysis also showed that the mean size of platoons increased under DSL conditions. As mitigation of all these problems was attempted with DSLs, these findings prove that implementation of DSLs would be antithetical to the goals of improving safety and decreasing frustration in PL zones.

Appraisal

Since the results of the trial are starkly contrasted with the simulation that began the project, it shows that simulation results are not always equal to field results. Simulation with willing participants may be more intent upon compliance with testing and inherently less representative than a driver in the field with many other demands on their time, especially traditional driver nature in Alaska (Osama and Hussein, 2009). Simulations may be simpler and more cost-effective to run than field trials, but do not guarantee driver behaviors and reactions in field trials. In this case, simulation was used to identify options before investing in field trials or significant field changes. In any event, real-life trials are more effective at revealing the implications and consequences of a change to roadway systems. It is a balancing act to pursue field trials when results are uncertain, and while simulator results did not work out in this case, they still can winnow the field of options towards developing field trial options.

Applications

We find that DSLs do not work as intended when applied to roadways in Alaska. If a similar concept is implemented in the future, the system should be left in place for a period of at least a month to allow drivers more time to adapt to and understand it. Other effective countermeasures to the PL problem should be explored, as the current conditions on two-way two-lane highway PL zones in Alaska tend to cause severe crashes.

CHAPTER 4 – CONCLUSIONS AND SUGGESTED RESEARCH

Through analysis done on the differential speed limit (DSL) trial implemented on the Seward Highway during summer 2016, we have determined that this speed limit system is not an effective countermeasure to the high rates of severe crashes observed in this area—rather, this method increases the problems already observed.

Survey Conclusions

The driver surveys indicate that implementation of the DSL system occurred in too short of a timeframe for it to be well understood. For this reason, overall, the system was confusing and ineffective. The trial may have been more effective had it been in place for a longer period. If the concept is revisited, another trial should be implemented for at least a month to allow drivers to adjust to and better understand the PL.

Traffic Analysis Conclusions

Traffic analysis showed that DSLs reduce desired characteristics, such as a wide speed differential between lanes and right lane utilization in PL zones. Traffic analysis also showed a reduction in passing frequency and, therefore, PL effectiveness. This analysis showed that DSL conditions worsen the problems seen with traffic characteristics in PL. Details of conclusions on this part are addressed at the end of Appendix C

Video Analysis Conclusions

Video analysis indicated a decrease in safe driving maneuvers and an increase in right-side passing, a risky and unwanted driver behavior. After the implementation of DSL conditions, there was a decrease in mandatory diverge lane changes (that is, a decrease in drivers moving to the right lane at the beginning of a PL), indicating that drivers do not want to slow down and thus the PL becomes ineffective, as drivers cannot safely be passed if they do not move to the right upon entering a PL.

The video analysis also showed that while the number of platoons decreased, the average size of each increased, so cars are in a platoon must pass more cars under DSL conditions than under USL conditions. PL become less effective under this speed limit system under the condition measured and studies as part of this project.

Suggested Research

If the other modifications of PL zones are undertaken in the future, a trial should be implemented for at least a month for drivers to adapt, so that they get a more realistic idea of what a permanent implementation of the condition would be like. However, different countermeasures that will be more effective should be researched to mitigate the passing zone problem. Further, a public awareness campaign on the problems facing motorists in PL zones on Alaska highways should be initiated to help drivers be more aware of the dangers they may face or cause. Such a campaign could influence drivers to practice safer passing techniques, resulting in safer PL zones. In addition, since the peak of traffic is during the summer time, a new striping technique might help divers understand and navigate through the PL as intended.

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APPENDICES

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Appendix A – Literature Review

Introduction

Drivers of two-lane, two-way undivided highways usually experience a higher frequency of crashes due to greater interaction between vehicles. Several head-on fatal and severe injury crashes have occurred in PLs in Alaska, either at merge points (where passing maneuvers continued too far) or just downstream of PL zones, where passing demand is high (Dyre and Abdel-Rahim, 2014) Consequently, direct improvements are needed to reduce the frequency of vehicle crashes. According to a survey by the Kansas DOT, wider shoulders and adding PL are highly recommended as safety improvement methods for two-lane highways (Schrock, Parsons and Zeng, 2011). Highway speed limits are another major concern depending on the prevailing road and traffic conditions. Differential speed limits (DSLs) in comparison with uniform speed limits (USLs) can reduce the possibility of crashes by decreasing traffic flow in congested areas. However, some studies have found that more crashes occur in areas with DSLs due to the higher speed variation of different traffic streams.

This literature review primarily discusses published research findings that are pertinent to this project. The relationship of safety and DSLs, and driver behavior during passing in both USL and DSL conditions are covered in this review. Also provided are the perceptions of topics related to drivers' speed choice and safety implications on rural highways. The databases used for this literature review include the *Journal of the Transportation Research Board*, *Journal of Applied Psychology, Journal of Transportation Engineering, the Federal Highway Administration (FHWA), Highway Capacity Manual 2010,* and research reports and conference articles.

Passing Lanes on Two-lane Highways

The Michigan DOT concluded from a study of historical volume, implementation dates, and crash history at 10 sites that PL decrease crash rates on a two-lane highway. Researchers perceived that all 10 PL sites performed at level of service "A." The researchers found at the time of the speed studies that drivers were not behaving recklessly and unsafely by exceeding the posted speed limits. Speed studies show that the highest speed at any PL site was 76 mph; the lowest speed was 40 mph. These speeds are much lower than that of drivers on Alaska highways, where high speed is around 90 mph on highways due to more aggressive drivers. Results indicate that PLs also help reduce traffic delays, improve the overall performance of traffic operations, reduce driver frustration, and improve safety by providing passing opportunities (Bagdade et al., 2012).

The Highway Capacity Manual (HCM 2010) defines percent-time-spent-following (PTSF) as one of the criteria for level of service (LOS) definition for two-lane highways. Percent-time-spent-following describes the freedom to maneuver as the percent of travel time in a platoon behind slow-moving vehicles due drivers' inability to pass. Figure A-1 exhibits the relation of PTSF and distance, illustrating the operational effect of a PL. The figure shows that the effective length of a PL is greater than its actual length, as it provides operational benefits, in reduction of PTSF for some distance after the end of the PL (HCM 2010).

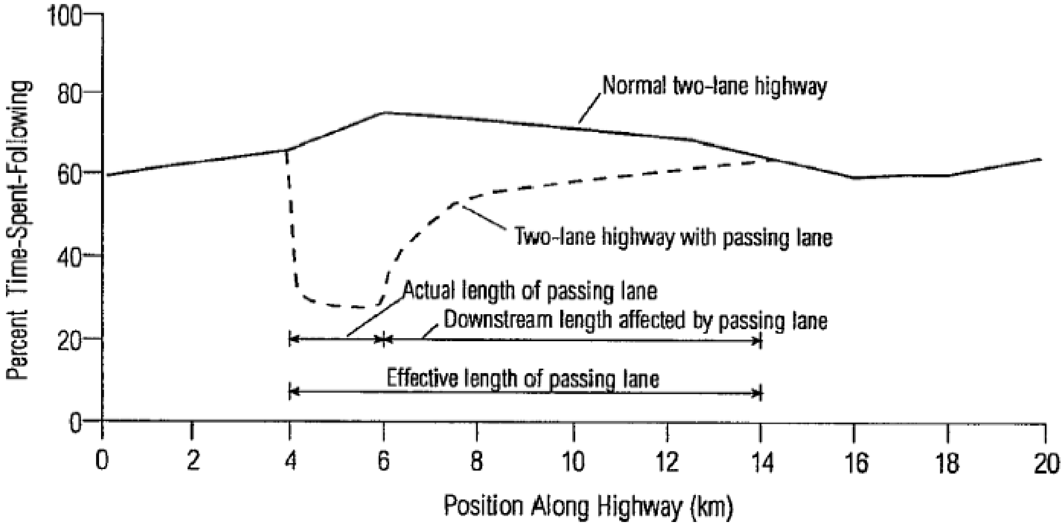


Figure A-1. Operational Effect of a Passing Lane (Highway Capacity Manual, 2010)

Al-Kaisy and Freedman (2010) studied the effect of PLs in Montana, and proposed a new performance measure: percent impeded (PI), which is similar in theory to PTSF. Percent impeded expresses the percentage of drivers traveling at speeds lower than their desired speed, because they are impeded by slower vehicles in the traffic stream due to platooning. Other major performance measures were investigated for use as a reference: percent followers, follower density, and ratio of average travel speed to free-flow speed. Percent followers represent the percentage of vehicles with short headways in the traffic stream. Follower density is the number of followers in a directional traffic stream over a lane per unit length. Ratio of average travel speed to free-flow speed is an indicator of the amount of speed reduction due to traffic. The findings suggest that PI has a more logical and consistent sensitivity to platooning variables, demonstrating a relatively high correlation with other performance measures and platooning variables with the exception of traffic volume. Percent impeded showed significant improvements in performance compared with percent follower and follower density in the before-and-after passing-lane analysis (Al-Kaisy and Freedman (2010).

Dyre and Abdel-Rahim (2014) examined the safety and efficiency of passing zones by maintaining slower speed, permitting more vehicles to pass and tempting better passing decisions on reckless drivers unconsciously using split speed limits. A fixed-base driving simulator was used to assess the potential safety and operational benefits of several highways for decreasing crash hazard. From a series of experiments, it was established that prior regulatory signs in a passing zone with different speed limits for different lanes aid noteworthy efficiency as well as safety. It was also found from the study that additional passes are possible in each passing zone by using 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. Extra passing functions to reduce the reckless behavior of the driver and thus improve the potential safety of rural highways. Other passive speed reduction setups such as chevrons, transverse lines, parallax, and lane narrowing were also tested, though these applications did not show a significant decrease in speed in passing zones, especially in the right-hand lane. This dissimilarity in results may be due to either confused right-lane drivers in the study or unfocused passive speed measures.

Speed and Speed Variation

Speed is an important characteristic that has serious implications for traffic operations and safety; it is one of the fundamental performance measures of traffic operations on any roadway facility. Speed is a critical factor in design of roadway facilities; the speed of individual vehicles may have serious implications for a traffic stream. A study found that a decrease in crash rates at all injury severity levels was attributed to reduced speeds and speed variance (Burritt, Moghrabi, and Matthias, 1976). Subsequent studies found that lower speed limits resulted in safety benefits (Dart, 1977; Weckesser et al., 1977; Tofany, 1981; Deen and Godwin, 1985). Research examining the effects of speed limit reductions in Finland (Salusjarvi, 1981), Denmark (Egsmose and Egsmose, 1985), Sweden (Nilsson, 1990; Johansson, 1996), the Netherlands (Borsje, 1994), and Australia (Sliogeris,1992) all reported that lower speed limits resulted in lower average speeds, with the reductions typically being less than the associated reduction in the speed limit. Lower speed limits were also reported to result in reduced traffic crashes and crash severity.

From the perspective of traffic safety, speed variation among vehicles in the same lane is critical, specifically on two-lane highways. An increase in the percentage of rear-end collisions may be a concern because of an increase in speed variation among the vehicles in the same lane. A study evaluated the impact of speed limit, and found that variability in travel speed (standard deviation) was higher under DSL than USL conditions, and increased with the increase in difference of DSLs; i.e., variability in speed was higher for DSLs of 70/60 mph than DSLs of 70/65 and USL of 55 mph (Savolainen et al., 2014). Research in the United States examined data more closely at the road segment level. The study focused on three types of roadways with 55 mph speed limits: interstates, arterials, and major collectors. Results showed that roadways with larger speed variation (i.e., larger speed differentials between vehicles) exhibited higher crash rates than roadways with lower speed variation (Garber and Gadiraju, 1989). Further research has shown that fatality rates increase with the increase in average speed and speed variance (Forester, McNown, and Singell, 1984; Fowles, and Loeb, 1989; Levy, and Asch, 1989 and Solomon, 1961; Zlatoper, 1991; Garber and Ehrhart, 2000). Analytical results suggest that a 5% increase in mean speed will subsequently produce a 10% increase in the total number of injury crashes, along with a 20% increase in the number of fatal crashes (Transport Research Centre, 2006). The literature clearly suggests that traffic crashes increase with the increase in mean speed and speed variation.

A study was conducted by Lee et al. (2004) on safety benefits assessment of variable speed limits. In this research, a PARAMICS microscopic traffic simulation model integrated with a real-time crash prediction model was used to identify the connection between dynamic speed control and reduction in crash potential in a quantitative manner, thus estimating the changes in crash potential as an effect of variable speed limits. The result from the study showed that crash potential was lower for reduced speed limits, which is an indication of safety benefits although a reduced speed limit was accountable for increasing travel time. The research recapitulated that significant safety benefits may be obtained by using variable speed limits.

Differential Speed Limit (DSL)

While there has been some research on DSLs on two-lane highways and multilane highways, DSLs on two-lane highways, especially on PLs, has received limited attention, despite the fact that speed is a major determinant of traffic operations and safety on two-lane highways. Many studies have examined the use of DSLs based on different vehicle types.

Dixon et al. (2012) conducted a study on impacts of DSLs on interstate highways in Idaho, a research project sponsored by the Idaho Transportation Department (ITD). The impacts of DSL data and crash data of passenger cars and trucks before and after enactment of the DSL policy in Idaho were analyzed statistically. Passenger car and truck speeds were found to be steadied after implementation of the DSL policy. Regarding the effects on crashes, it was found that drivers experienced lower crash rates after the DSL policy, though other factors such as more urbane braking systems and developed highway design may have influenced the crash rate reduction. Based on the statistical analysis of speeds and different crash types, and the Empirical Bayes method of analysis, the study concluded that as the average truck speed decreased and the percentage of trucks in compliance with the posted speed limit increased, the truck-related crash rate decreased, which indicates a conspicuous safety benefit of the state's DSL policy.

Sun et al. (2009) estimated the expected number of crashes on a four-lane freeway in Louisiana, using the methodology proposed by Hauer (1997), which takes regression-to-the-mean into account. The researchers support the success of DSLs with a truck lane restriction, as vehicles operating in the same lane with different speed limits can create a gap in operating speed, thus increasing crash risk as this gap increases. The researchers suggested that the number of interchanges could affect the success of DSLs. The study included only three interchanges.

A study investigated the impact of DSLs with a truck lane restriction on safety, estimated on a four-lane freeway in Louisiana. The researchers found a significant reduction of 13% for total crashes and 77% for truck crashes and supported the success of DSLs with a truck lane restriction (Sun et al., 2009).

Garber and Gadiraju (1991) conducted a study to examine the effect of DSLs on vehicle speeds. Two different types of sites were selected for the study: one type with the DSL (i.e., speed raised to 65 mph for passenger cars, while 55 mph for remaining vehicles), the other type with a USL of 55 mph for all vehicles, located parallel or close to the DSL sites. Speed data for before/after conditions were collected from these locations and analyzed. The study found that passenger car speeds increased by 1 to 4 mph to a range of 62 to 67 mph on those sites where the speed limit was raised to 65 mph for passenger vehicles. The speed difference between before-and-after conditions for trucks was statistically not significant at those sites where the DSL was implemented.

Ghods et al. (2012) assessed the safety implication of three speed control strategies applied to two-lane highway operations: USLs, DSLs, and differential speed controls with truck speed limiters (MSLs). A calibrated microscopic traffic simulation model was applied to a 6 km (3.75 miles) straight stretch of two-lane highway to estimate safety performance of USLs, DSLs, and MSLs, considering three overtaking indicators: number of vehicles overtaking, percentage time spent in “desire to overtake mode,” and time-to-collision to the opposing vehicle prior to return. According to the study, reduction in car-car passing in differential speed strategies (DSLs and MSLs) indicated increasing safety. However, increasing number and rate of car-truck overtakes resulting from differential speed strategy led to the opposite.

Garber et al., (2005) covered research on the safety impacts of DSLs on rural interstate highways. The research focused on how speed and crashes are affected by USLs and DSLs on rural highways. The speed and crash data were collected from nine states of four different groups. Empirical Bayes procedure and conventional statistical methods including Tukey’s and Dunnett’s tests were applied to analyze the data. From the analysis, it was found that speed characteristics were similar for both USL and DSL policy. The safety effects of DSLs as opposed to USLs were inconsistent within the scope of the study. According to the Empirical Bayes methodology, crash risk during the study period was increased for all four policy groups.

Another microscopic simulation was carried out by Ghods and Saccomanno (2016) to assess the safety and traffic implications of differential car/truck speed limits for two-lane highway operations, with emphasis on the passing maneuver. Like the previous study by Ghods et al. (2012), this study considered three speed control approaches: USLs, DSLs, and MSLs. The simulation test in DSL and MSL strategies projected that average travel speed (ATS) would decrease, while head-on time-to-collision (TTC) and percentage time spent following (PTSF) would increase a bit. From DSL and MSL strategies, the study found that the number of car-car overtakes and car-truck overtakes decreased and increased, respectively, though total overtakes increased slightly. Finally, the study concluded that safety was affected by three measures of ATS, TTC, and car-car overtaking positively and negatively by PTSF, car-truck, and total number of overtakes.

Platooning

The distance or time headway between two consecutive vehicles is an important measurement of vehicle interaction. Vehicle interaction is explained in terms of platooning. Different studies have used distinct values of time headway to define a platoon, summarized in the following paragraphs.

Mutabazi et al. (1999) conducted a study in Kansas that used automatic traffic counters to measure volume and speed, extract vehicle classification, and compute time headways. Five seconds were used as the time headway in defining a vehicle as part of a platoon. Based on the traffic count and vehicle speeds, sufficient difference was not detected in the proportion of vehicles traveling in platoons between the upstream and downstream ends of a passing lane. When time headway of less than 2 seconds was used, however, the percentage of vehicles in a platoon decreased from the upstream to downstream location of the PL. This indicates the ability of PL to break up groups of vehicles traveling together.

Gattis et al. (2006) examined passing lane operations in Arkansas. The study analyzed continuous three-lane cross sections with alternating PL. Five sets of field data at four rural sites, and five years of crash data from 19 passing lane sites were collected. The initial field collection station was positioned just before the number of lanes began to expand from two to three. Subsequent stations were spaced at 0.9-mile intervals adding to three or four stations. Classifiers, lidar and radar guns, and video cameras were used to collect speed, platooning, and passing attribute data in the field. The researchers considered a platoon according to the Highway Capacity Manual (HCM, 2010); i.e., vehicles were considered in a platoon if the headway between two successive vehicles was less than 3 seconds. The study found a modest increase in average speed immediately after a vehicle entered a passing lane segment due to the freedom acquired by constrained drivers to select their own speed. Passing activity was greatest at the beginning of the segments as a result of the higher volume. These facts contributed to platooning at the end of the passing lane, compared with the beginning of the passing lane. The study identified greater benefits of three-lane alternate passing segments in the form of decreased platooning and increased safety.

Al-Kaisy and Karjala (2008) used field data collected from four study sites in the State of Montana to examine performance indicators on two-lane rural highways. Automatic traffic recorders were used to collect data for each direction of travel at each study site. All sites were located in rural areas on straight segments, generally on level terrain, and far from the influence of traffic signals and driveways. Directional data sets from sites next to PLs and four-lane segments were excluded from the analysis. The six investigated performance indicators were average travel speed, average travel speed of passenger cars, average travel speed as a percent of free-flow speed, average travel speed of passenger cars as a percent of free-flow speed of passenger cars, percent followers, and follower density. Graphical screening, correlation, and regression analyses were used to inspect relations between performance indicators and major platooning variables (traffic flow in the direction of travel, opposing traffic flow, percent heavy vehicles, standard deviation of free-flow speeds, and percent no-passing zones). The researchers found that follower density exhibits the highest correlation with platooning variables, accounted for traffic flow, and were easier to estimate in the field compared with the PTSF. Consequently, follower density was the most promising measure on two-lane two-way highways.

Driver Behavior

Driver behavior was also found to be of interest to researchers on two-way two-lane highways. Farah et al. (2009) studied drivers' passing decisions on two-lane rural highways using a driving simulator. Gap acceptance during lane changes and the implications on traffic flow and safety were analyzed. For high traffic volumes, this gap was found to be shorter, and as the speed of the vehicle increased, the gap was found to increase as well. Traffic related variables had the most important effect on the measure of risk chosen, while factors related to geometric design and driver characteristics also contributed significantly to passing behavior. Highways with a design speed of 62 mph, lane width of 12.3 feet, shoulder width of 7.4 feet, curve radius of 4920–8200 feet, and side-slope of 3% were considered to have good geometry, while highways with a design speed of 50 mph, lane width of 10.8 feet, shoulder width of 5 feet, curve radius of 980–1310 feet, and side-slope of 30% were considered to have poor geometry. For a highway with poor geometry, gaps at the end of the passing process were found to be shorter than a highway with good geometry.

Bar-Gera and Shinar (2005) used a driving simulator to study the speed differential threshold at which drivers decide to pass a lead vehicle. The results were interpreted in terms of driver aggression, association of car-following with added effort, attention overload, and risk. The results showed that there is a strong tendency for drivers to pass slower vehicles in front of them. This fact suggested that drivers seem to have a range of preferred speeds, and they perceive vehicles traveling at any speed within that range as an interference, which can result in additional mental load. Drivers reduce this attention overload by passing such vehicles. Having to follow other vehicles forces drivers to constantly adjust their speeds, thus increasing mental load as well as increasing the risk of accidents.

Lee and Abdel-Aty (2008) conducted research on the effect of warning messages and variable speed limits on driver behavior using a driving simulator. The behavior of 86 participants in a 5-mile section of a freeway was observed, displaying three types of warning messages with variable speed limits. This study developed a set of binary logit models to investigate two aspects of a participant behavior called "degree of speed change" and "compliance with speed limit" at various signs. The study revealed that drivers' speed variation followed the warning messages and variable speed limits, which in turn was considered as potential safety benefits of differential speed limits as well as reduction of congestion. Both the presence of the message and the content of the warning message were important for improving drivers' compliance with the speed limit.

Llorca and Farah (2016) studied driver passing behavior on two-lane roads in real environments and compared it with driver behavior in simulated environments using data on passing performance and passing gap acceptance decisions. The study obtained variables related to passing behavior such as starting from the following process (gap acceptance) to the completion of passing maneuvers (passing time and distance, and time-to-collision) and compared them with the data from the simulation. It was found from the research that passing time, passing distance of completed maneuvers, and gap acceptance decisions were similar in both environments. Passing speed and clearance were found, however, to be greater in the driving simulation.

Elliott et al (2003) applied the theory of planned behavior (TPB) to determine drivers' compliance with speed limits. The main purpose of the study was to examine TPB variables, demographic information, and self-reported prior behavior initially, and self-reported subsequent behavior was measured after the duration of 3 months. Attitude, subjective norm, and perceived control were positively connected with behavioral intention in accordance with the TPB, and intention and perceived control were positively related to subsequent behavior. The study suggested that road safety interventions might be best in the event they concentrate on the perceived control segment of the model. The study suggested that interventions concentrating on the perceived control part of the model will probably have success in changing the behavior of drivers who do not regularly follow speed limits.

Bella (2011) used an interactive fixed-base driving simulator to analyze the behavior of drivers in passing maneuvers on two-lane rural roads of more than 8 km (5 miles) length. The simulation was carried out by 32 drivers for four different traffic situations. Time to collision, distance of passing and following gap between passing vehicle and impeding vehicle were determined to assess driver behavior. The study concluded that the driver behavior is significantly influenced by traffic conditions for three different phases of passing.

Drivers' Choice of Speed

Considerable research has been conducted to improve comprehension of the factors that influence drivers' speeding behavior and to devise effective road safety strategies. Moreover, change in posted speed limit (PSL) is related to changes in the likelihood of traffic crashes and associated injury severity. A 3% decrease in crash rate in response to a 1 km/h (0.75 mph) reduction in speed has been reported (Finch et al., 1994). Another study conducted on the effects of an increase in posted speed limit from 55 to 65 mph concluded that the crash rate increased by 3% and the probability of a fatality by 24% (Kockelman et al., 2006). Higher variation in speed among vehicles on a roadway section was associated with higher crash frequency, possibly because this variation influenced the rate of overtaking in a traffic stream (Hauer, 1971). Aarts and Van Schagen (2006) found that the risk of being involved in a crash increases when a vehicle is faster than the surrounding vehicles, while Horberry et al. (2004) concluded that driving slower than surrounding vehicles could be a safety problem that possibly causes accidents. Limited research has been conducted on the effects of PSL on drivers' choice of speed and perception of safety. Anastasopoulos and Mannering (2016) conducted a study on freeways in Indiana to evaluate the influence of three different PSLs (55 mph, 65 mph, and 75 mph) on drivers' choice of speed. The study surveyed 211 drivers, asking them for their normal operating speeds under the PSLs. The research concluded that a wide variety of factors affects a driver's choice of speed in the presence of PSLs, including driver's demography, marital status, number of children, household income, and driving experience.

Gates et al., (2016) evaluated the safety and operational impacts of DSLs on two-lane two-way rural highways in Montana, especially in comparison with the uniform 65 mph speed limit. After a series of field studies, the Montana DOT found that travel speed and shorter platoon lengths show less variability, and there was low-risk passing behavior and fewer crashes for the uniform 65 mph speed limit. Motorists' and trucking industry members' speed limit preferences were also surveyed in the study. The members of the trucking industry supported a uniform 65 mph speed limit, while motorists' preferences were diverse.

Bester and Marais (2012) studied the efficiency of different speed limits for different vehicle classes on the same road. Approximately, 9000 vehicles on 12 sections of road of general speed limit (120 km/h or 75 mph) were used to determine the speed. The researchers found that 85% of the drivers of light vehicles and buses kept their respective limits, but that drivers of heavy vehicles and minibus taxis exceeded their limits to a large extent.

Russo et al. (2017) carried out research on drivers' speed selection in two-lane highways in Montana by comparing speed summaries of uniform and variable speed limit. Ordinary least squares regression models were used to analyze different mean speeds, 85^{th} percentile speeds, and standard deviation in speeds for free-flowing vehicles. Data were collected from approximately 59,000 vehicles within 320 sites from Montana and four neighboring states. Analyses showed that speed parameters on two-lane highways are generally lower at locations with USLs, compared with locations with DSLs. The study concluded that other characteristics such as shoulder width, frequency of horizontal curves, percentage of the segment that included no passing zones, and hourly volumes have significant influence on drivers' speed selection. Local factors, such as driver population. enforcement, or differences in vehicle speed characteristics in different states may also affect the speed choice.

Review of past research (Lancaster and Ward, 2002; Stradling, 2003) shows that driver speeding behavior varies with demography such as gender (Brook, 1987; Waterton, 1992; French et al., 1993; Buchanan, 1996; Meadows, 1994; Shinar et al., 2001), age (Parker et al., 1992; Quimby et al., 1999; Stradling et al., 2000; Ingram et al., 2000; Shinar et al., 2001; Boyce et al., 2002), and vehicle type. In general, it was found that male drivers are more persistent in speeding than female drivers (Lawton et al., 1997). Different types of vehicles have different acceleration, deceleration, and braking capabilities, all of which have a certain degree of influence on driver speeding behavior.

Appendix B – Analysis of Survey Data

Introduction

As part of the study design, a stakeholder survey was conducted to gauge reaction to the differential speed limits on PLs of the Seward Highway. The objectives of the survey were to examine the impacts of the differential speed limits (DSLs) and challenges of driving in PLs on the Seward Highway, and to identify ways to improve safety. Stakeholders are defined for this research project as the general public. Both paper and online surveys were developed. Data regarding perceptions of the effectiveness of DSLs were collected a week after their deployment to frame the operational and safety benefits from the perspective of customer satisfaction.

The paper survey was distributed at the Tesoro gas station in Girdwood (MP 90) and the Hope Junction rest area (MP56.5), both along the Seward Highway. The survey was conducted at Hope Junction twice and at the Tesoro gas station three times during July 2016. The Tesoro gas station attracts many customers because shops and restaurants are located within walking distance of the station. This gas station is the only rest area that provides these facilities on the Seward Highway; it also serves visitors to the Alyeska Resort. The surveys are attached as an appendix.

Driving Behavior and Perceptions

On the Seward Highway, PLs are clearly marked with regulatory signs before the start and end. Figure B-1 presents the survey participants preferences regarding the location of these signs. To determine preferences regarding PLs on the Seward Highway, respondents were asked in which lane they most frequently travel (Figure B-2).

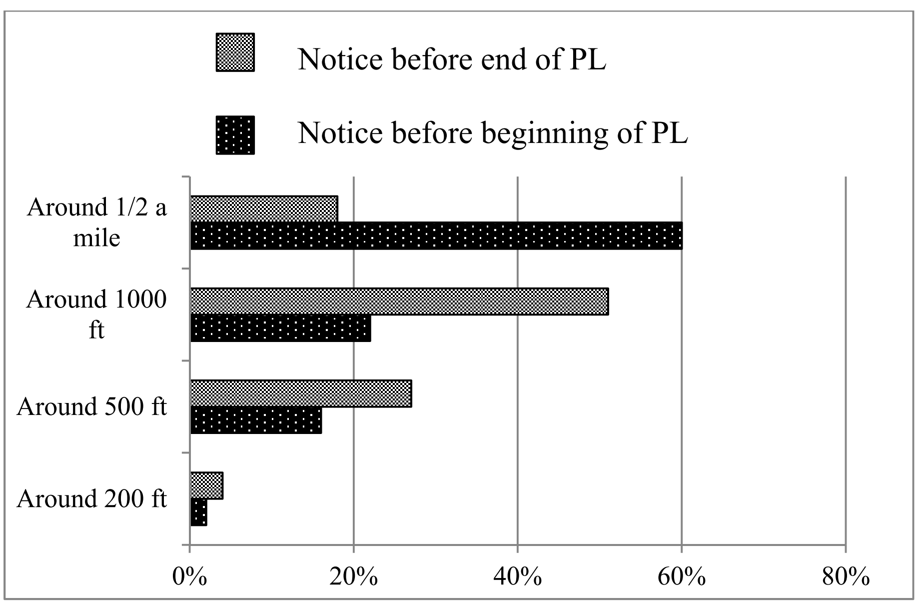


Figure B-1. Passing Lane Sign Preference

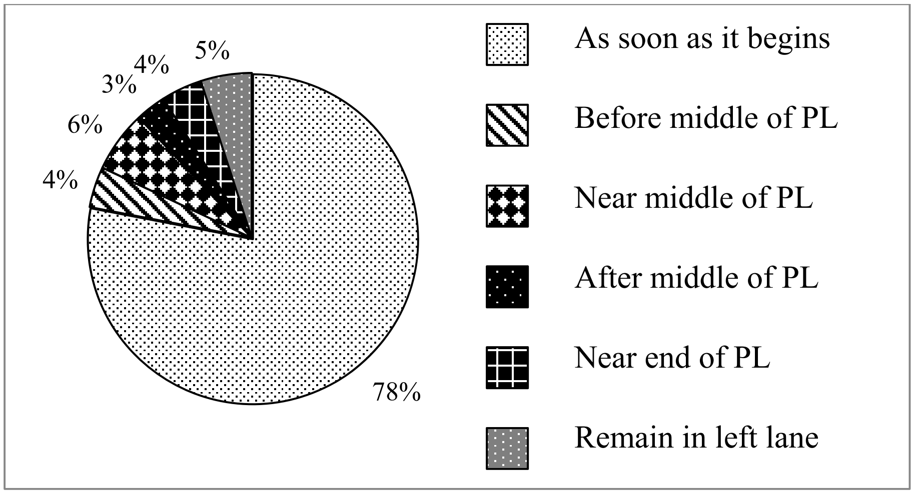


Figure B-2. Location of Lane Change into the Right Lane

Drivers were surveyed on their level of stress driving behind a slower vehicle in the PL. The drivers reported a mean level of stress of 4.12 (out of 5), indicating a definite increase in stress when driving behind a slower vehicle. To identify the riskiest behaviors that lead to crashes that drivers encounter at PL, the participants were presented with six conditions and asked to rate them on a scale of 1 to 6. The middle value was 3.5. On the scale, 1 indicated a mildly risky condition and 6 indicated an extremely risky condition. The six conditions were aggressive drivers, vehicles merging at the end of a PL, long vehicles, poor markings and signs, weather conditions, and overtaking slower vehicles from the right lane. Poor markings were considered the riskiest of the six conditions, with a weighted mean score of 4.86. This condition was followed by long vehicles, with a mean score of 4.19; weather conditions, with a score of 3.53; overtaking slower vehicles from the right, with a score of 3.19; and vehicles merging at the end of a PL, with a score of 3.14. Interestingly, aggressive drivers were considered the least risky road condition, with a mean score of 1.62, the lowest score of the six. When asked about the length of PL on the Seward Highway, a slight majority (55%) of drivers indicated that they thought the lengths were just right. However, 45% of the participants thought the lanes were too short. Seventy-five percent of the survey participants agreed at different levels that more PL should be built.

Drivers were surveyed with eight questions to assess the impact of lower speed limits in the right lane of the PL on driving conditions. First, drivers were asked whether a lower speed limit (in the right lane) improves safety, no obvious tendency to agreement or disagreement regarding this question was apparent. Second, drivers were asked whether a lower speed limit increases driving speed, in general, the survey participants did not agree with this statement. Third, the surveyed drivers were asked whether a slower speed limit improves merging, again, there was no definite tendency to agreement or disagreement regarding this question. Fourth, drivers were asked if a slower speed limit would ensure safer lane changing, 60 % of the participants were either agreed or totally agreed, while 40% replied that they either disagreed or totally disagreed. Fifth, the participants were asked whether a slower speed limit would reduce the risk of accidents, the participants were equally divided, with 37% either agreeing or totally agreeing and 37% either disagreeing or totally disagreeing. Sixth, drivers were asked if a slower speed limit would ease the passing of slower vehicles, for this question, 55% of the survey participants either agreed or totally agreed with the statement. Seventh, the participants were asked if a lower speed limit would reduce travel time. In general, drivers did not agree with this statement. Last, the surveyed drivers were asked whether a slower speed limit would improve traffic flow. In general, drivers agreed with this statement.

Speed Related Questions

The survey included three questions related to speeds. First, the participants were asked at what speed they usually drive on the Seward Highway. Thirty-seven percent of the drivers replied that they drive at 61–65 mph. This range contains the posted speed limit. Thirty-seven percent replied that they drive at 66–70 mph. Eighteen percent of the drivers replied that they drive at 56–60 mph. The rest of the surveyed participants reported speeds lower or higher than these speeds. Only 3% of the drivers reported driving at more than 70 mph. Second, the surveyed drivers were asked about the speeds at which they drive in the different lanes of the PL, for the most part, drivers reported that they kept to the speed limit in the right lane and drove slightly faster in the left lane. Third, the survey participants were asked the speeds they would recommend for both left and right lanes in a PL on the Seward Highway, for the left lane, 62% of the surveyed drivers replied that they would recommend a speed limit of 65 mph and thirty-two percent recommended a speed of 70 mph. For the right lane, drivers indicated that the speed limit should be lower. Forty-five percent of drivers suggested a speed limit of 65 mph, 23% recommended a speed of 60 mph, and 26% recommended a speed limit of 55 mph. Drivers were also asked about their support of a lower speed limit in the right lane. When asked if they were supportive of a lower speed limit in the right lane during the summer, there was a slight tendency to agree. When asked if a lower speed limit in the right lane of the PL was a good idea all year, there was general agreement, with 51% agreeing and 14% remaining neutral.

Sign Comprehension

The questions covered survey participants' reactions to different signs, specifically a "slower traffic keep right" sign and paired signs noting different speed limits in the right and left lanes. The participants were asked which lane they would choose to drive if they were presented with a "slower traffic keep right" sign under the three different conditions. The first of these conditions was if there were no nearby vehicles, of the participants asked this question, majority agreed that they would keep to the right. The second of these conditions was if the surveyed driver was following a slower vehicle, in answer to this scenario majority chose the left lane. The last of these conditions was if they were being followed by a faster vehicle, of the participants, 98% replied that they would move to the right lane. Overall, a notable majority of these surveyed drivers answered these questions in a manner consistent with the rules of the road and common courtesy.

A pair of speed limit signs was presented graphically in the online survey. The signs noted that the left lane speed limit was 65 mph and the right lane speed limit was 55 mph. A majority of the participants interpreted the signs to mean that there were different speed limits depending on the utilized lane

Conclusions

- A majority of drivers are aware that they need to drive on the right and pass on the left, even if they do not follow the practice.
- Weather and poor road markings are considered riskier than slow/aggressive drivers, which speaks to the condition of the roadway itself. Drivers want as much notice as possible before changes in PL
- Buffers between oncoming lanes are needed on the highway (more space/dividers between oncoming lanes, more PLs, etc.).
- In multiple choice survey responses, no strong opinion overall was expressed as to whether the slower speed limit would be beneficial. However, in the comment section, strong feelings against DSLs were expressed. Most of the participants who saw potential in the DSLs still stated that changes needed to be made for the project to work as intended.
- A lower right-hand lane speed limit causes problem, causing drivers to pass on the right-hand side of a PL. Slower drivers who drive slightly above 55 mph (e.g., 60 mph) think they belong in the PL rather than in the slow lane.
- Aggressive drivers are a major concern. A great deal of reckless behavior is witnessed. More law enforcement would be extremely beneficial.
- More clarification, public awareness, and time are necessary if DSLs are to be enacted

Appendix C – Traffic Data Collection And Analysis

Data Collection

A before-and-after study was conducted to determine the effect of DSLs in PLs on two-way two-lane highways. Figure C-1shows the location of three PL zones considered in this study. Three PLs located between Milepost (MP) 59 and 66 were selected for data collection. In USL conditions representing the before condition, the Seward Highway and the PLs had a speed limit of 65 mph. The after condition—use of DSLs—consisted of two different posted speed limits: 65 mph in the left lane and 55 mph in right lane. Traffic data were collected using Numetric detectors. The data includes speed of individual vehicle, vehicle length in feet (classification), time headway, and distance headway for each individual vehicle. Figure C-1 shows the typical setup for PL-1, similarly Figure C-2 a & b shows a detailed description of PL-2, 3, respectively for USL and DSL conditions.

Site I

Passing Lane I (PL-I) is located at the start of all three PLs from Anchorage toward Seward. Data were collected only for the southbound lane on PL-I. This PL is the longest of all three PLs with a length of 7300 feet. The gradient at this location was determined to be level enough to not affect driver behavior. Twenty-four hours of peak day data were collected for the USL condition, and 96 hours of data were collected for the DSL condition.

Site II

Passing Lane II (PL-II) is located downstream of PL-I for southbound traffic from Anchorage toward Seward and upstream of PL-III, i.e., between PL-I and PL-II. Data were collected only for the northbound lane on PL-II (toward Anchorage). The length of this PL is around 5000 feet. The gradient at this location was determined to be level enough to not affect driver behavior. Twenty-four hours of peak day data were collected for the USL condition, and 96 hours of data were collected for the DSL condition.

Site III

Passing Lane III (PL-III) is located downstream of PL-II for southbound traffic, i.e., from Anchorage toward Seward. Data were collected only for the northbound lane on PL-III. The length of this PL is around 5000 feet. The gradient at this location was determined to be level enough to not affect driver behavior. Twenty-four hours of peak day data were collected for each of the USL and DSL conditions.

Detector Locations

Data were collected by DOT&PF at different locations for each PL using Numetric pads. Data includes per lane volume count, classification count, speed and date and time. Details regarding the data collection location for each site are provided in the data analysis section for each site. A summary of the detector locations is presented in Table C-1.

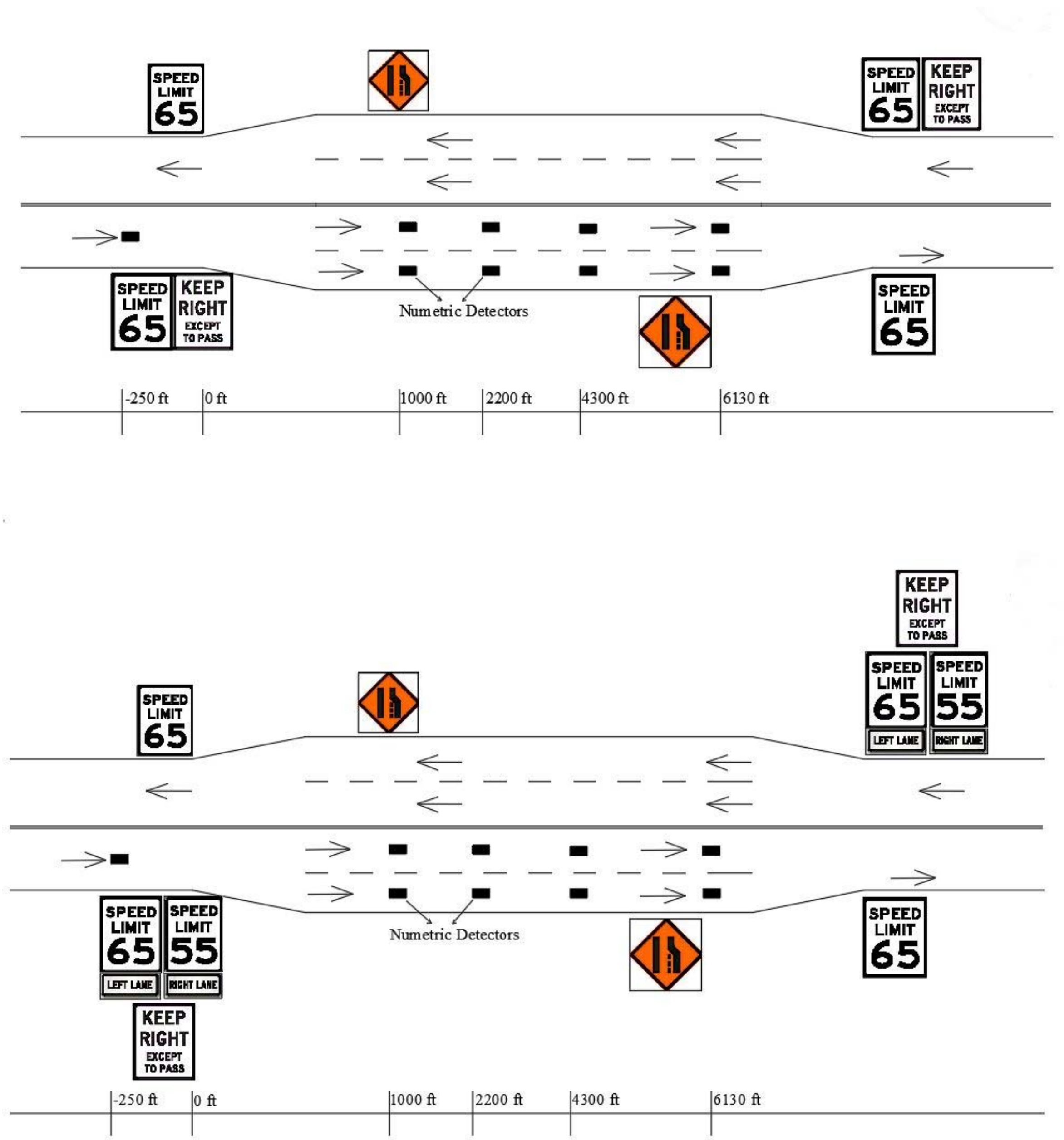
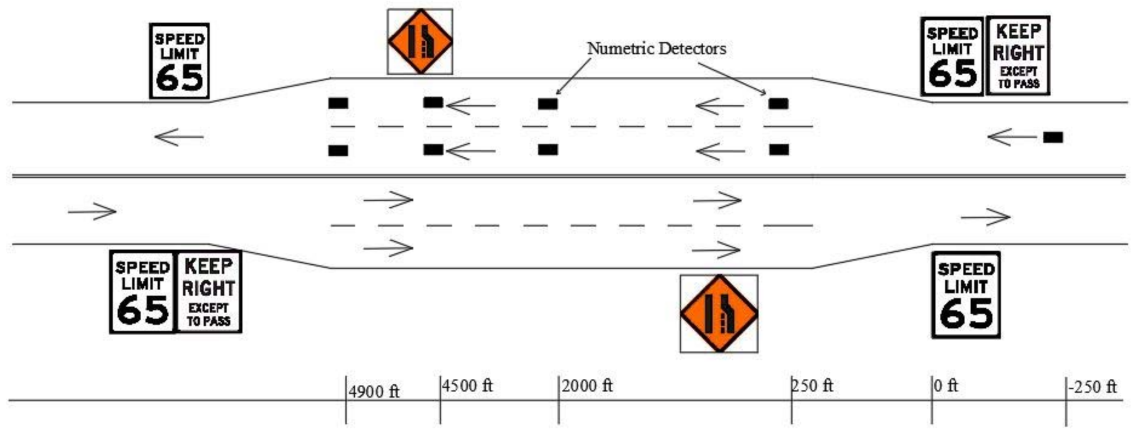


Figure C- 1. Description of PL-1 for USL and DSL conditions.



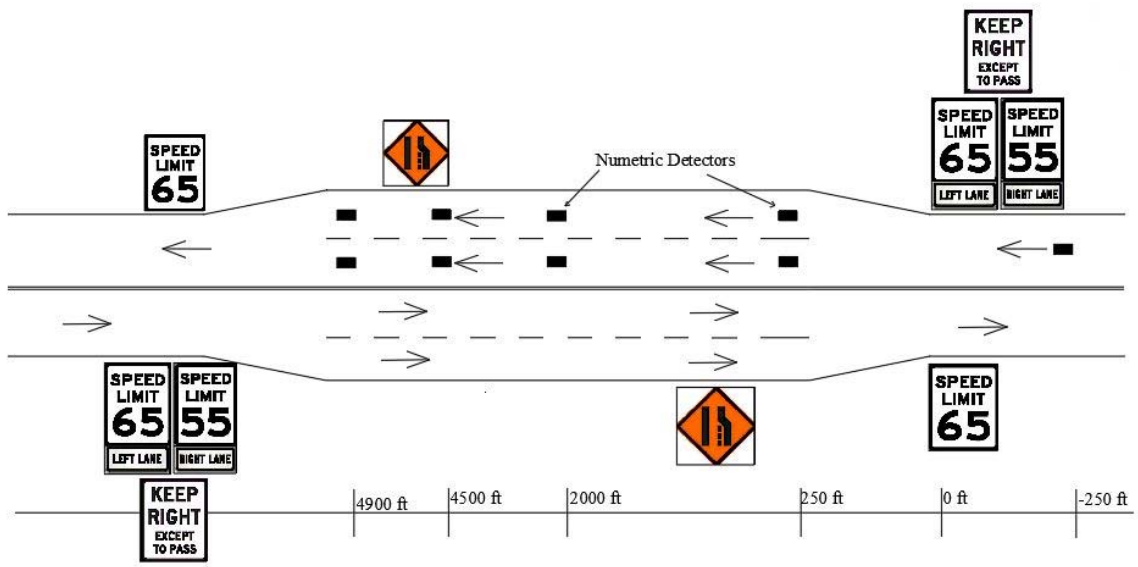


Figure C-2a. Description of PL-2 for USL and DSL conditions.

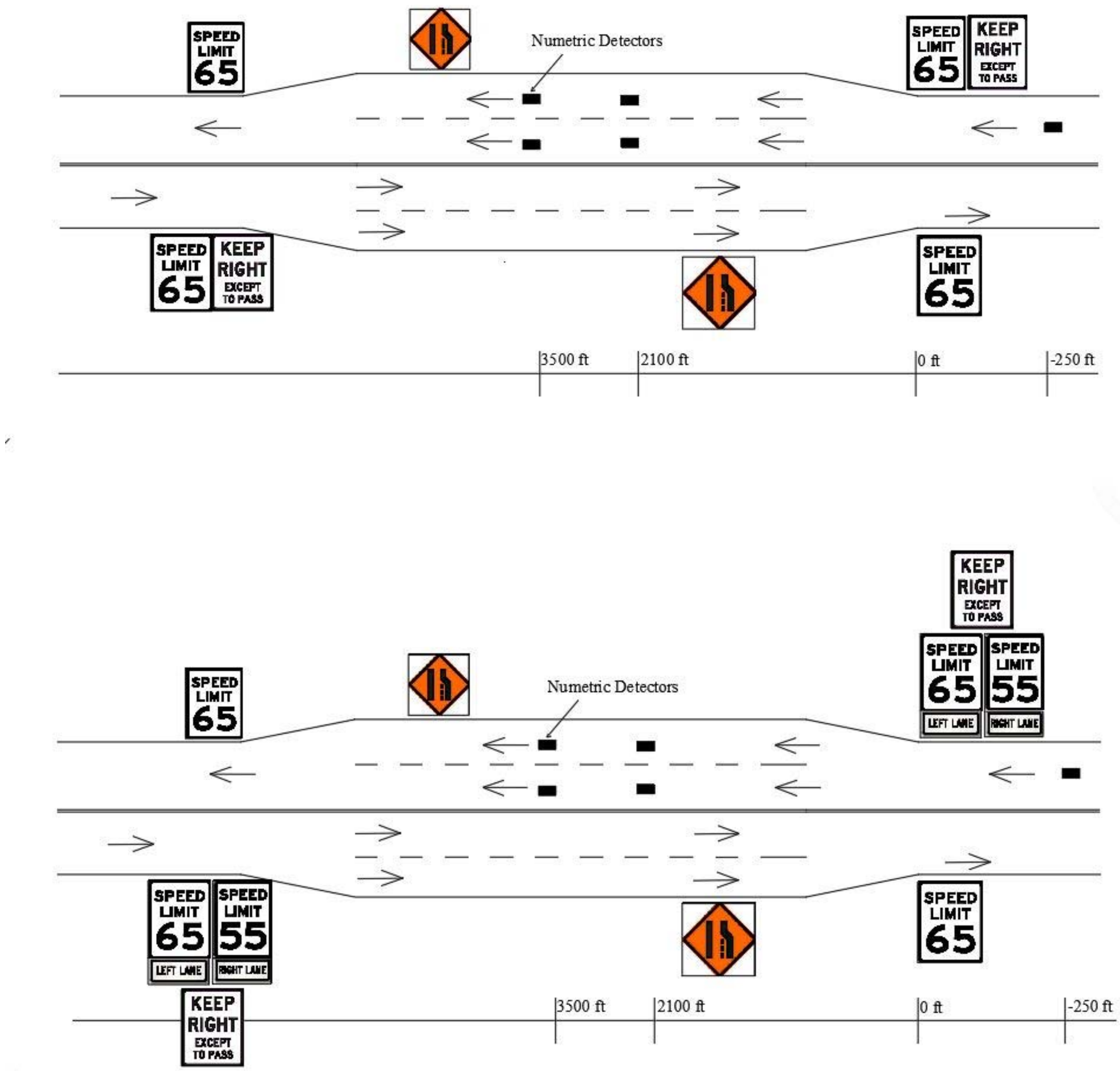


Figure C-2b. Description of PL-3 for USL and DSL conditions.

Table C-1. Traffic data collection sites and detectors locations

Site	Condition	Upstream	Diverge	Passing – 1	Passing - 2	Merge

Site	Condition	Upstream	Diverge	Passing – 1	Passing - 2	Merge
PL-I (Northbound)	USL	*Yes*	*yes*	*Yes*	*Yes*	*yes*
	DSL	*Yes*	*yes*	*Yes*	*Yes*	*yes*
PL-II (Southbound)	USL	*Yes*	*yes*	*Yes*	*Yes*	*yes*
	DSL	*Yes*	*yes*	*Yes*	*Yes*	*no*
PL-III (Southbound)	USL	*Yes*	*no*	*Yes*	*Yes*	*no*
	DSL	*Yes*	*no*	*Yes*	*Yes*	*no*

Statistical Analysis and Results

To determine the effect of posted DSL on the speed difference between the two lanes of the passing area, the following test was performed:

Two sample independent *t*-tests were conducted to analyze if the mean speeds on left and right lanes were equal. The hypothesis for the test was:

H_0: $\mu_{SL} = \mu_{SR}$, reject H_0 when p-value < 0.05,
H_1: $\mu_{SL} \neq \mu_{SL}$, fail to reject H_0 when p-value > 0.05,

Negative *t*-values indicate that the speed in the left lane was lower than the mean speed in the right lane.

Speed and Lane Utilization for Three Passing Lanes

This section presents the results for the three PLs, with regard to direction, for the USL and DSL conditions. The mean speeds of free-flowing vehicles were analyzed. The vehicles traveling with time headways of greater than 5 seconds were considered free-flow vehicles. This analysis considered the mean free-flow speeds of the vehicles, traffic volume, and vehicle classification. Passenger vehicles, for the purpose of this research project, include vehicles having a length less than or equal to 25 feet. All other vehicles are categorized as heavy vehicles.

Passing Lane I

Nine detectors were placed on PL-I, as shown in Figure C-2. The first detector was placed 250 feet upstream of the PL and collected the data, which was gathered for one lane of the two-lane highway. Next, two detectors were placed about 400 feet downstream of the end of the taper to collect data regarding the diverging behavior of the drivers. Four detectors were installed in the middle area within the PL to collect weaving and passing behavior data. The last two detectors were placed downstream of the "Right Lane End" sign to collect data on merging behavior.

The results concerning PL-I for USL and DSL conditions are examined in detail below. All results are based on 4 hours of evening peak time and dry weather conditions. The peak traffic flow was observed on Friday toward Seward.

Overall (Passenger and Heavy) Vehicles

Mean Free-Flow Speed

This section discusses the mean free-flow speed of all observed vehicles. Figure C-3 outlines the mean free-flow speed of vehicles at each detector location for the USL condition. The plot indicates that the mean free-flow speed for all vehicles, in both lanes, was higher than the speed limit (65 mph) by 5 to 25 mph. Mean free-flow speed in the left lane is higher than in the right lane at each location within the PL. The speed difference between the two lanes is up to 14 mph and is statistically significant at each location within the PL, as presented in Table C-2. In the left lane, speed increased sharply in the first 0.5 mile (around 19% increase), then decreased gradually to a lower value at the merge location at the end of the PL. A slightly different trend is shown for the right lane upon entering into the PL zone. The vehicles first decelerated, probably due to moving into the right lane, and then accelerated to follow trends similar to those of the left lane. The mean speed in both lanes at the merge location exceeds the posted speed limit (PSL) by average of 6 mph.

Figure C-4 presents the mean free-flow speed of vehicles at each detector location for the DSL condition. The plot indicates that the mean free-flow speed for all vehicles, in both lanes, is higher than the PSL (65 and 55 mph for left and right lanes, respectively). The speed in the left lane exceeded the PSL by 3–11 mph; the speed in the right lane exceeded the PSL by 15–23 mph. Contrary to the USL condition, during the DSL condition, the mean free-flow speed in the left lane was equal or lower than that of the right lane at each location within the PL zone. The speed difference between the two lanes was relatively low, but still statistically significant at each location, with the exception of the 4500 feet location within the PL zone. Under the DSL condition, the mean free-flow speeds in both lanes decreased as vehicles entered the PL and then gradually increased throughout the length of 2500 feet within the PL. At the merge location, the mean speed difference between the two lanes was about 2 mph under the USL condition, while about 4 mph under the DSL condition.

Upon comparing the USL condition to the DSL condition, we found that the left lane speed in the DSL condition decreased by 15 mph compared with the USL condition, and the speed in the right lane increased by 6–8 mph after the middle section of the PL. This situation has the potential to cause a safety issue when maneuvering between lanes. Moreover, the speed difference between the two lanes was significantly reduced during the DSL condition, and the mean speed was higher in the right lane than in the left lane.

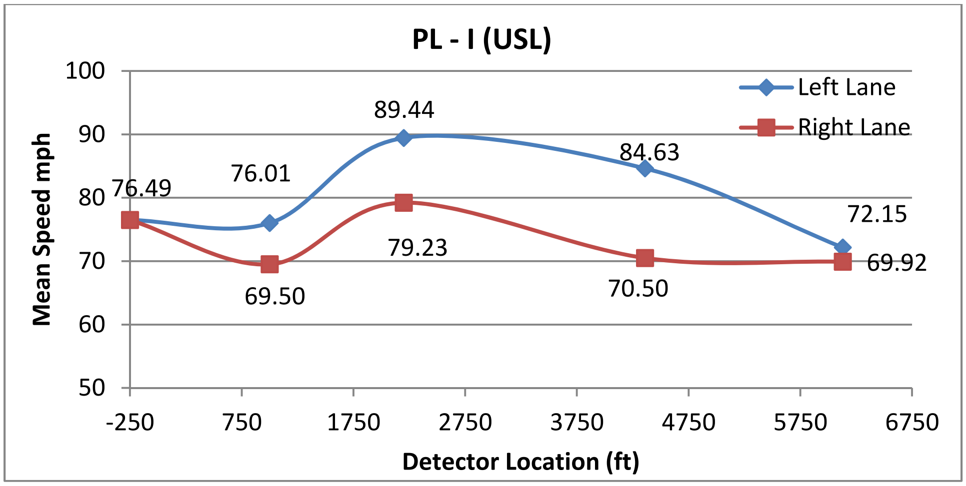


Figure C-3. Mean Speed of Overall Vehicles under USL Condition

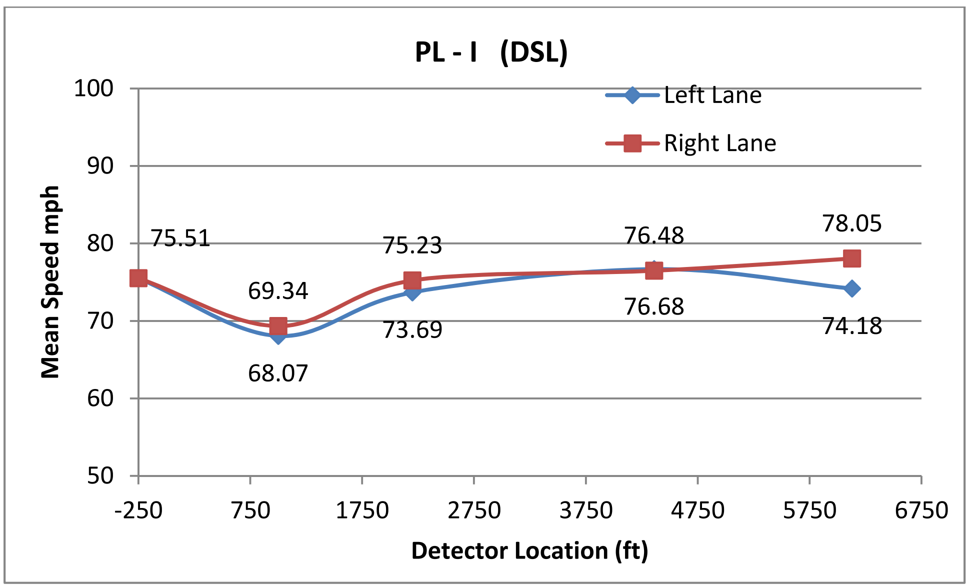


Figure C-4. Mean Speed of Overall Vehicles under DSL Condition

Table C-2. Comparison of Mean Speeds between Left and Right Lane (*t*-test)

Condition	Vehicle Type	Location 1	Location 2	Location 3	Location 4
USL	Overall	0.000 (14.03)	0.000 (15.51)	0.000 (22.01)	0.001 (3.32)
DSL	Overall	0.003 (-2.97)	0.003 (-2.99)	0.718 (0.36)	0.000 (-4.87)

Lane Utilization

This section compares traffic volumes under USL and DSL conditions. Three peak hours of the peak day data were analyzed. Figure C-5 summarizes the volume of vehicles in each lane for the USL condition. The figure presents the percentage of vehicles at different locations upstream and within the PL. The results of this analysis indicate that the total volume of vehicles increased in the right lane, and consequently, decreased in the left lane. This movement was more consistent at the detector located 4360 feet downstream within the PL. The percent volume of vehicles in the left lane decreased from 42% to 30%, which indicates that vehicles generally move to the right lane after passing slow-moving vehicles. In addition, this finding indicates that 30% of drivers use the left lane as their primary driving lane.

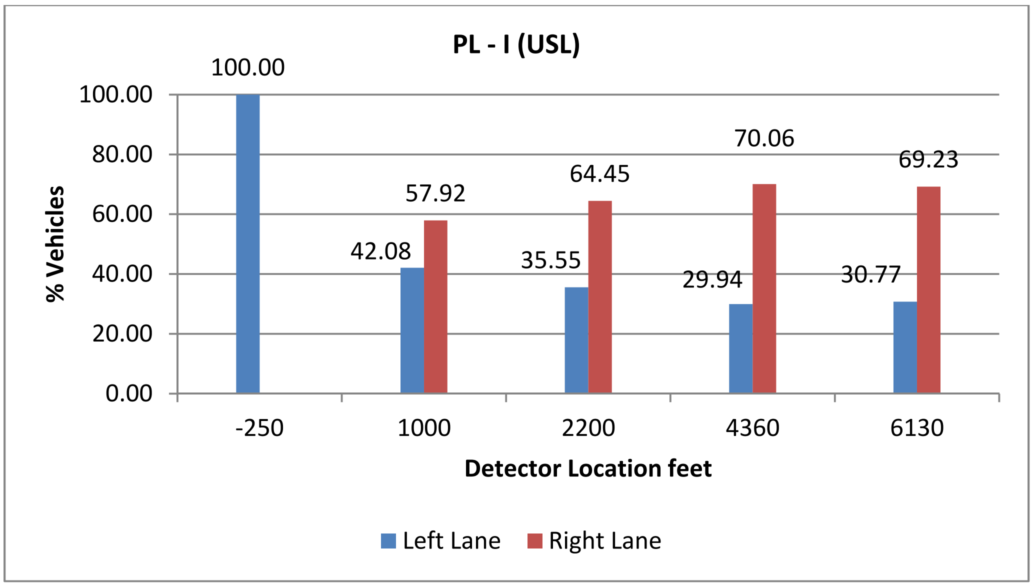


Figure C-5. Percent Overall Vehicles on Each Lane (USL)

Figure C-6 presents the percentage of vehicles in each lane under the DSL condition. The results indicate that the percent of vehicles in the left lane was 44% at the start of the PL and decreased to 41% at the end. Analysis of this trend demonstrates that drivers in the left lane avoid moving to the right lane. The probable reason for this behavior is the lower speed limit (55 mph) in the right lane.

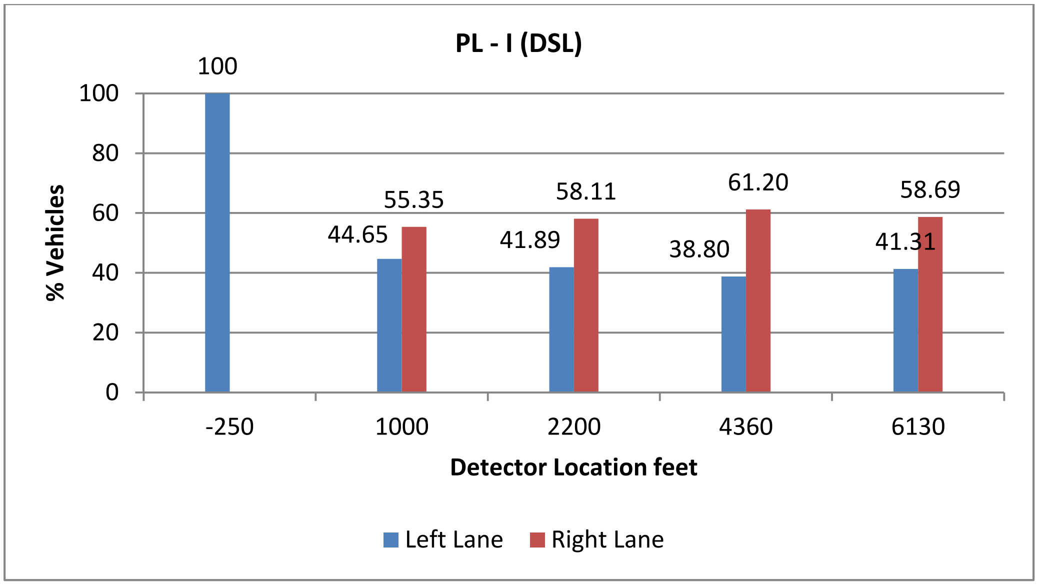


Figure C-6. Percent Overall Vehicles on Each Lane (DSL)

Upon comparing the results of the DSL condition with those of the USL condition, we found that the percent traffic volume in the left lane at each location under the DSL condition was higher than that of the USL condition, and stabilized at about 60% of the overall traffic. These results imply that drivers do not want to travel at 55 mph in the right lane and instead use the left lane as their primary driving lane. In addition, the trend in traffic volume in the right lane slightly decreased as traffic approached the merge lane.

Passenger Vehicle

Mean Free-Flow Speed

To further understand driver behavior in the PLs, we focused on passenger vehicles. Passenger vehicles for the purpose of this research include vehicles having a length less than or equal to 25 feet, with all other vehicles categorized as heavy vehicles. Figure C-7 outlines the mean free-flow speeds of passenger vehicles at each detector location under the USL condition. The plot indicates that the mean free-flow speed for all passenger vehicles, in both lanes, was higher than the speed limit (65 mph) by an average of 5 to 25 mph. The mean free-flow speed in the left lane is higher than that of the right lane at each location within the passing area. The speed difference between the two lanes is as great as 13 mph. In the left lane, speed increases sharply in the first 0.5 mile (around 19% increase), then decreases to a lower value at the merge location into the PL. A slightly different trend is shown for the right lane at the starting area of the PL. The probable reason is that vehicles first decelerate to move to the right lane, and then accelerate upon entering the left lane. Comparing the speed of passenger vehicles with the speed of overall vehicles indicates that passenger vehicles generally drive at the same speed as the overall vehicles.

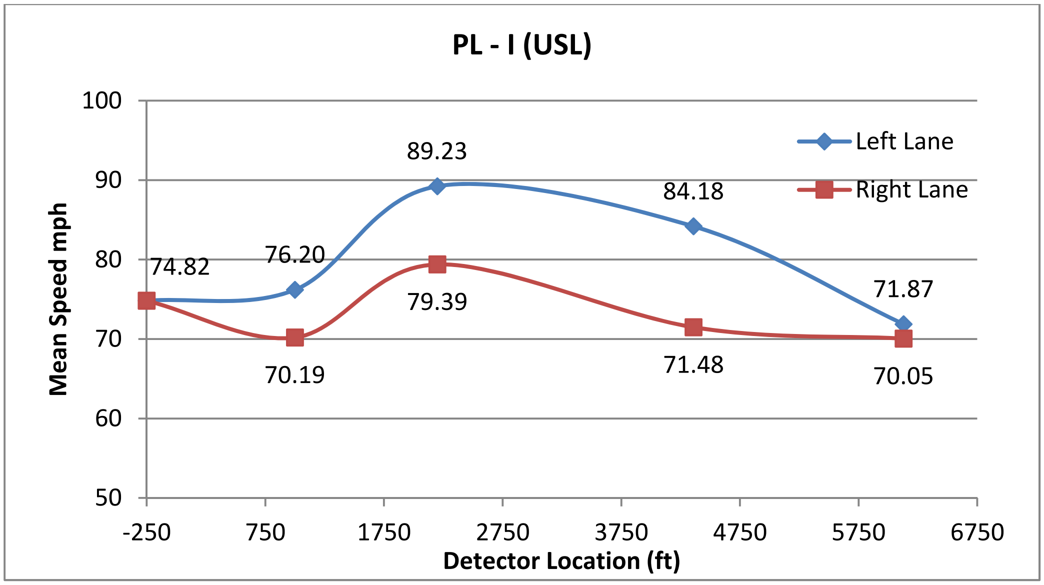


Figure C-7. Mean Speed of Passenger Vehicles under USL Condition

Figure C-8 presents the mean free-flow speed of passenger vehicles at each detector location under DSL conditions. The plot indicates that the mean free-flow speed of passenger vehicles, in both lanes, is higher than the PSL (65 and 55 mph). The speed in the left lane is higher by an average of 3 to 12 mph than the PSL (65 mph), while the speed in the right lane is higher by an average of 15 to 22 mph than the PSL (55 mph). In DSL conditions, contrary to USL conditions, the mean free-flow speed in the left lane is lower than that in the right lane at each location within the PL. The speed difference between the two lanes is relatively low, but statistically significant except at a location 4360 feet along the PL. A negative *t*-value indicates that mean speed in the left lane is lower than mean speed in the right lane. Under DSL conditions, the mean free-flow speeds in both lanes decrease upon entrance to the PL and then slightly increase to 0.5 mile in the PL. At the merge location, the mean speed difference between the two lanes was about 1 mph under USL conditions, while about -4 mph under DSL conditions. A negative sign shows that the speed in the right lane is higher than that in the left lane at the merge location. This indicates higher probability of crashes at the merging section under DSL conditions.

Passenger vehicle speeds follow the same trend as that of overall vehicles for both USL and DSL conditions. Further, the mean speed of passenger vehicles is similar to the mean speed of all the vehicles. This indicates that heavy vehicles also drive at speeds similar to passenger vehicles, reflecting a limited choice of speed in the PLs.

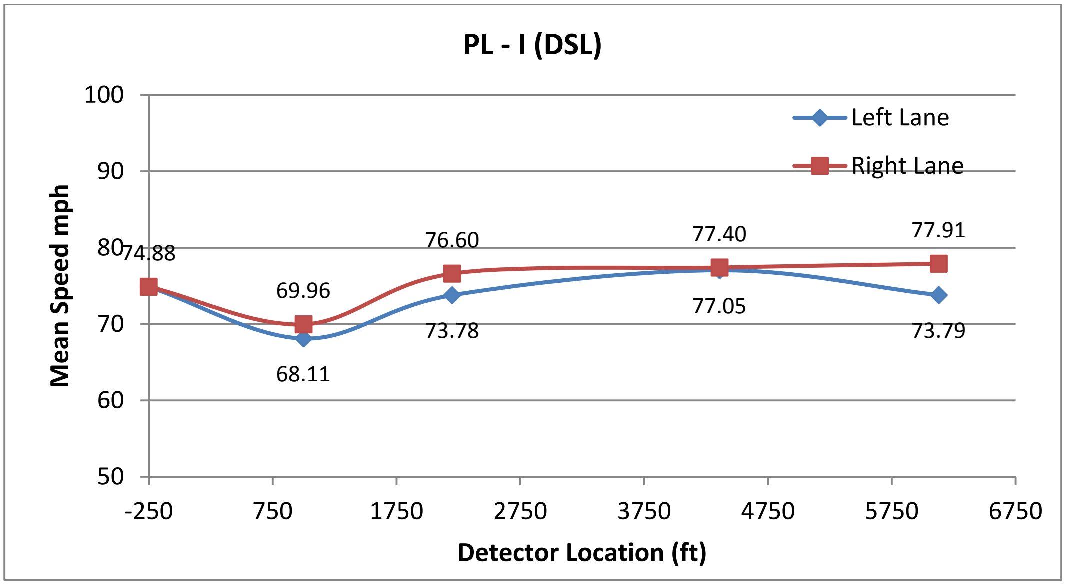


Figure C-8. Mean Speed of Passenger Vehicles under DSL Condition

Lane Utilization

Lane utilization is an important factor in traffic operation and safety. PLs are provided to improve traffic operations and safety. The main signboard at the start of the PL reads “KEEP RIGHT EXCEPT TO PASS,” which directs the driver to travel in the right lane except to pass. Figure C-9 presents the passenger vehicle distribution between left and right lanes for USL conditions. The results of this analysis indicate that the total volume of vehicles increased in the right lane, and consequently, decreased in the left lane. This movement was more consistent at the detector located 4360 feet downstream within the PL, where passenger vehicles in the left lane were 27%. Vehicles in the left lane decreased from 49% to 27%, which indicates that passenger vehicles generally move to the right lane after passing slow-moving vehicles at the start of the PL. In addition, this indicates that 27% of vehicles use the left lane as the driving lane.

Figure C-10 presents the percentage of passenger vehicles in each lane for DSL conditions. The results indicate that the percent of passenger vehicles in the left lane was 48% at the start and then increased to 55% by 2200 feet downstream of the PL. At the end of the PL, 47% of passenger vehicles were in the left lane. Analysis of the trend demonstrates that about half the passenger vehicles in the left lane avoid moving to the right lane. The probable reason for this behavior is the lower speed limit (55 mph) in the right lane.

A comparison of the results of DSL conditions with USL conditions indicates that the percentage of passenger vehicles in the left lane at each location under DSL conditions was higher than that under USL conditions and stabilized at about 45% for all passenger vehicles. This implies that drivers do not want to travel at the 55 mph speed limit in the right lane and use the left lane as the driving lane. In addition, the trend in the right lane is to slightly decrease as traffic approaches the merge lane. The comparison also shows that compliance with “KEEP RIGHT EXCEPT TO PASS” decreases with the implementation of DSLs.

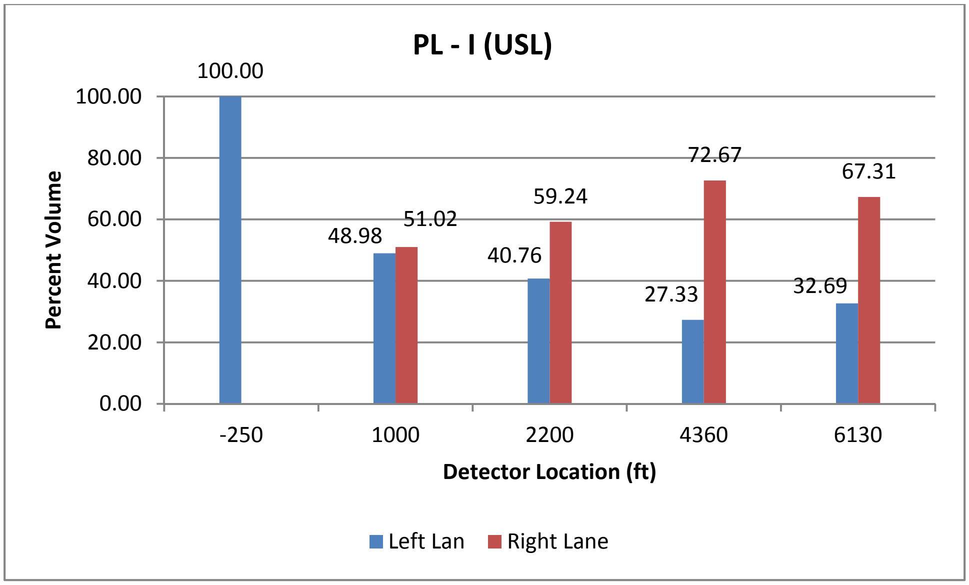


Figure C-9. Percent Passenger Vehicles on Each Lane (USL)

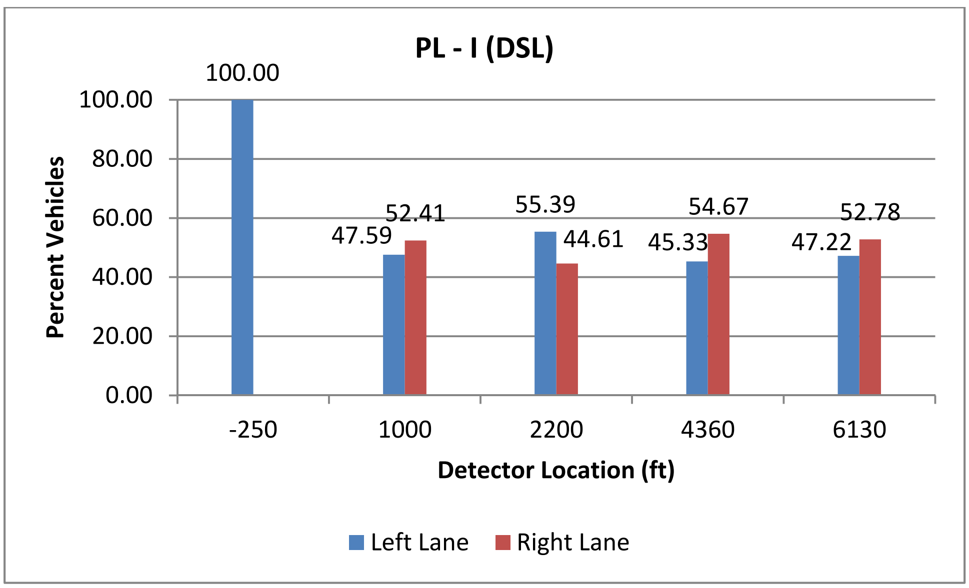


Figure C-10. Percent Passenger Vehicles on Each Lane (DSL)

Heavy Vehicles

Mean Free-Flow Speed

Discussion in this section will focus on the free-flow speed of heavy vehicles. A comparison with passenger car free-flow speed will be addressed too. Heavy vehicles defined in this research are vehicles longer than 25 feet. Figure C-11 outlines the mean free-flow speed of heavy vehicles at each detector location under USL conditions. The plot indicates that the mean free-flow speed of all heavy vehicles, in both lanes, was higher than the speed limit (65 mph) by an average of 3 to 25 mph. Mean free-flow speed in the left lane is higher than that in the right lane at each location within the PL. The difference is statistically significant, with an average of 4 to 18 mph over the PL section.

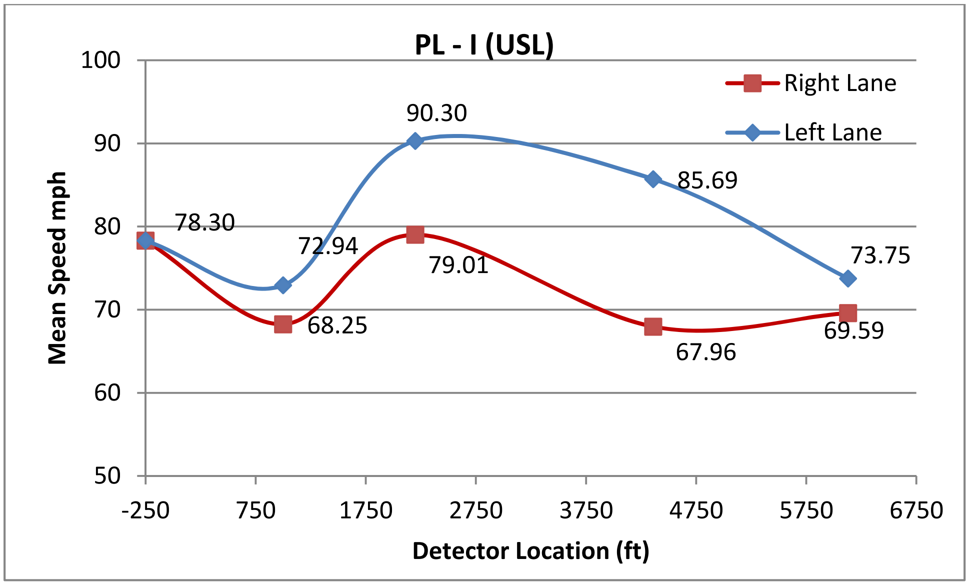


Figure C-11. Mean Speed of Heavy Vehicles under USL Conditions

Figure C-12 presents the mean free-flow speed of heavy vehicles at each detector location under DSL conditions. The plot indicates that the mean free-flow speed of all vehicles, in both lanes, was higher than the PSL (65 and 55 mph). In DSL conditions, contrary to USL conditions, the mean free-flow speed in the left lane is equal to or lower than that in the right lane at each location within the PL. The speed difference between the two lanes up to 2000 feet within the PL is statistically insignificant, while in the last 1500 feet, the speed difference is statistically significant, but the speed in the left lane is lower than that in the right lane. Under DSL conditions, the mean free-flow speeds in both lanes decrease upon entrance to the PL and then increase by 2 to 4 mph till the end of the PL. At the merge location, the mean speeds difference between the two lanes is about 4.0 mph under USL conditions, while about 3.0 mph less under DSL conditions. This indicates that the speed in the right lane is higher than that in the left lane at the merge location. In addition, it indicates that the merging speeds under both USL and DSL conditions are of concern regarding heavy vehicles.

Heavy vehicles follow the same trend as overall vehicles under both USL and DSL conditions. Further, the mean speed of heavy vehicles is similar to the mean speed of all other vehicles. Note that free-flow speed for heavy vehicles is slightly lower than that for passenger vehicles except in the middle of the PL, and the difference in free-flow speed between right and left lanes is slightly higher for heavy vehicles than for passenger vehicles.

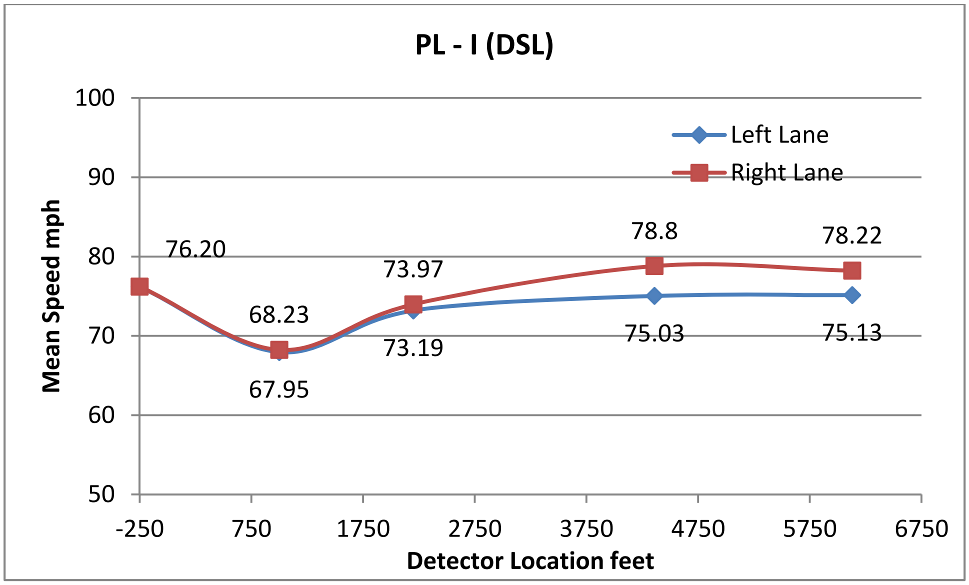


Figure C-12. Mean Speed of Heavy Vehicles under DSL Conditions

Lane Utilization

To understand lane utilization in more detail, we focused on discussing heavy vehicle lane utilization. PLs are provided for slow-moving vehicles to travel in the right lane and to allow fast-moving vehicles to pass in the left lane. Figure C-13 presents the percentage of heavy vehicles in the left and right lanes for DSL conditions. The results summarize that 84% of heavy vehicles move to the right lane upon entrance to the PL. The percentage of heavy vehicles in the left lane increases driving downstream of the diverge location, rising to 36% at 4360 feet. This indicates that heavy vehicles generally allow passenger vehicles to pass at the start of the PL and then start moving to the left lane. In addition, this indicates that 24% of vehicles use the left lane as the driving lane at the merge area of the PL.

Figure C-14 presents the percentage of heavy vehicles in each lane under DSL conditions. The results indicate that the percentage of heavy vehicles in the left lane was 38% at the start and then decreased to 15% at 2200 feet downstream within the PL. This percentage of heavy vehicles increased to 29% driving downstream.

A comparison of the results of DSL with USL conditions indicates that the percentage of heavy vehicles in the left lane within the first 1000 feet under DSL conditions was higher than that under USL conditions by 22%. In the middle area of the PL, the percentage of heavy vehicles in the left lane under DSL conditions was lower than that under USL conditions, which indicates that heavy vehicles stay in the right lane.

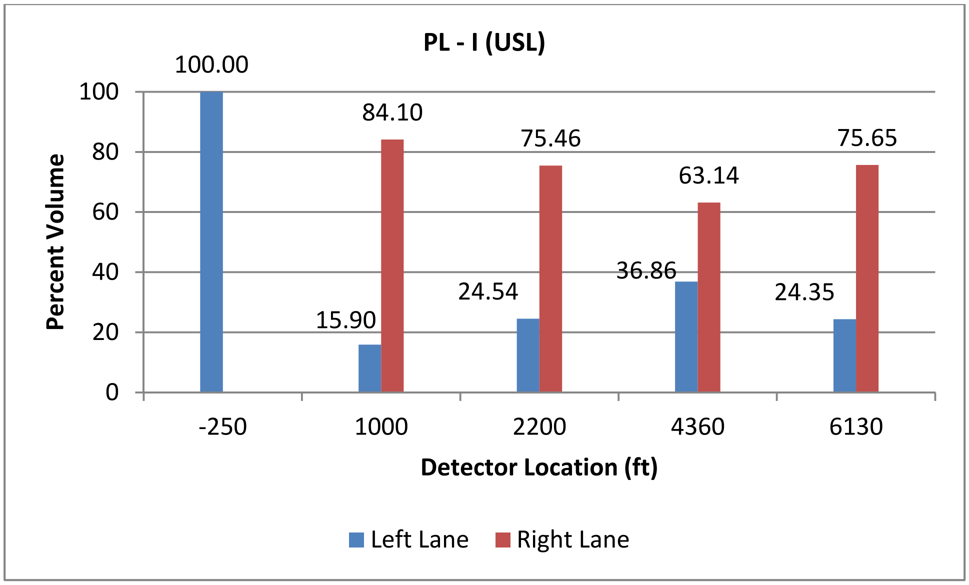


Figure C-13. Percent Heavy Vehicles in Each Lane (USL)

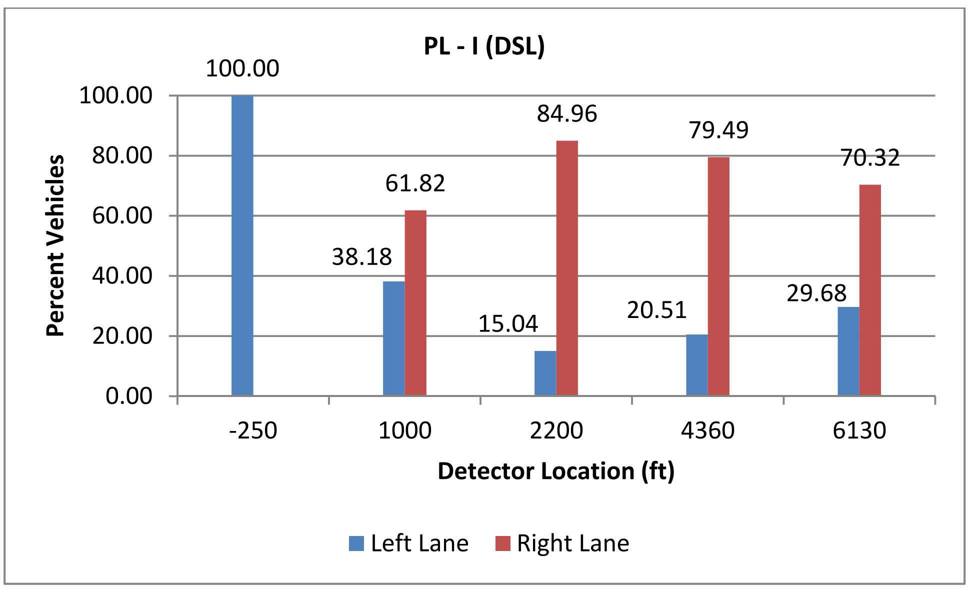


Figure C-14. Percent Heavy Vehicles in Each Lane (DSL)

Passing Lane II

Nine detectors were placed on PL-II heading toward Anchorage. The first detector was placed 250 feet upstream of the PL and account for the data on one lane of the two-lane highway. The next two detectors were placed about 400 feet downstream of the end of the taper to collect data on the diverge behavior of drivers. Four detectors in the middle area within the PL were installed to collect data of the weaving and passing behaviors of vehicles. The last two detectors were placed downstream of the “Right Lane End” sign to account for merging behavior/characteristics. For the DSL condition, the detector on the left lane at the merge location did not collect data because of a charging issue.

This section presents the results of PL-II for the USL and DSL conditions. All results were based on 8 hours of p.m.-peak time (i.e., from 1:00 p.m. to 9:00 p.m.) and dry weather conditions. The peak traffic flow was observed on Sunday toward Anchorage. The mean speed of free-flowing vehicles was analyzed. This analysis covered the mean free-flow speeds of vehicles, traffic volume, and vehicle classification.

Overall (Passenger and Heavy) Vehicles

Mean Free Flow Speed

In this section, we discuss the mean free-flow speed of all vehicles. Figure C-15 outlines the mean free-flow speed of vehicles at each detector location under USL conditions. The plot indicates that the mean free-flow speed for all vehicles, in both lanes, is higher than the speed limit (65 mph) by 4–22 mph. Mean free-flow speed in the left lane is higher than in the right lane at diverge locations and the middle of the PL (250 feet and 2000 feet, respectively) within the PL. The speed difference between the two lanes was up to 18 mph, which is statistically significant at each location within the PL. In the left lane, speed increased gradually by 37% throughout 2000 feet from the start of the taper and then decreased till the end of the PL. A slightly different trend was found for the right lane. Upon entering the PL, vehicles first accelerate, increasing speed by 11 mph at 250 feet within the PL. The mean speed decreased gradually by 5 mph at 2000 feet within the PL. The mean free-flow speed gradually increased downstream of the middle of the PL. The speed in the right lane was higher by an average of 2 mph than the speed in the left lane at the merge location.

Figure C-16 presents the mean free-flow speed of all vehicles at each detector location for DSL conditions. The plot indicates that the mean free-flow speed for all vehicles, in both lanes, was higher than the PSL (posted speed limit – 65 and 55 mph for left and right lanes, respectively). The speed in the left lane exceeds the PSL by 5–17 mph; the speed in the right lane exceeds the PSL (55 mph) by 8–21 mph. Contrary to USL conditions, for the DSL condition the mean free-flow speed in the right lane decreased from 67 mph at the upstream location to 63 mph at 250 feet downstream of the start of the taper. The speed difference between the two lanes at the diverge location (250 feet) was higher for DSL conditions than for USL conditions. Under DSL conditions, the mean free-flow speed in the left lane decreased by 5 mph at 2000 feet and 4500 feet.

Comparing USL with DSL conditions, the overall speed in the left and right lanes under DSL conditions is impacted (reduced) by the DSL sign. Moreover, drivers' speed behavior on PL-II under both USL and DSL conditions was different from PL-I and PL-III, as PL-II is located between PL-I and PL-III. The PL located less than 8 miles upstream of any traffic facility or another PL has an impact on that facility or PL located downstream (Harwood et al., 2010).

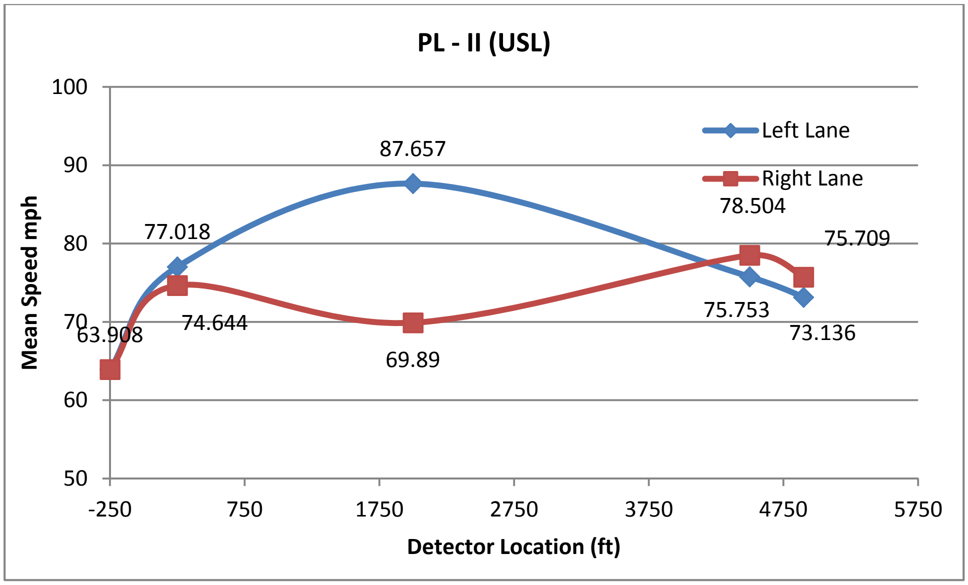


Figure C-15. Mean Speed of Overall Vehicles under USL Conditions

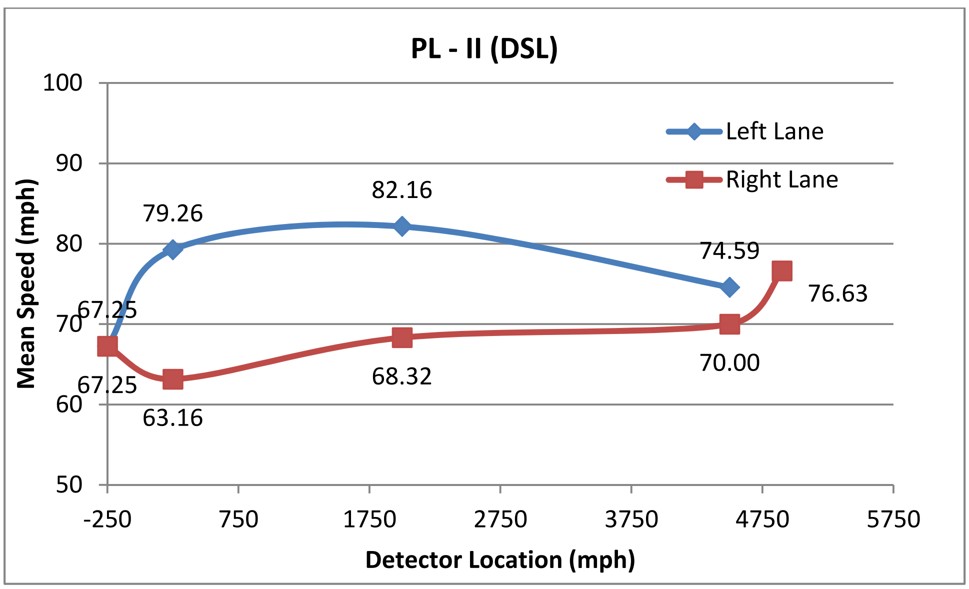


Figure C-16. Mean Speed of Overall Vehicles under DSL Conditions

Lane Utilization

This section deals with the traffic volumes under USL and DSL conditions. Three peak hours of the peak day data were analyzed. Figure C-17 summarizes the percentage of vehicles in each lane at different locations under USL conditions. The results of this analysis indicate that the total volume of vehicles increased in the right lane, and consequently, decreased in the left lane. The volume of vehicles in the left lane decreased from 40% to 37%, which indicates that vehicles generally move to the right lane after passing slow-moving vehicles. This also indicates that 37% of vehicles use the left lane as the driving lane.

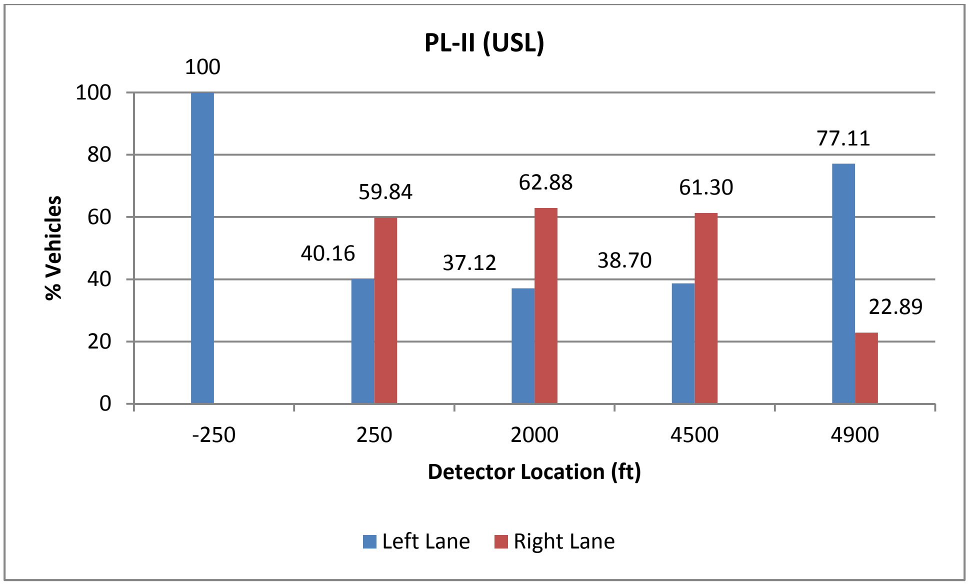


Figure C-17. Percent of Overall Vehicles on Each Lane (USL)

Figure C-18 presents the percentage of vehicles in each lane under DSL conditions. The results indicate that vehicles in the left lane were 53% at the diverge location (250 feet downstream of the taper) within the PL and decreased to 48% after traveling 1750 feet downstream. The analysis of this trend demonstrates that about half of the total drivers in the left lane avoid moving to the right lane. The probable reason of this behavior is the lower speed limit (55 mph) in the right lane.

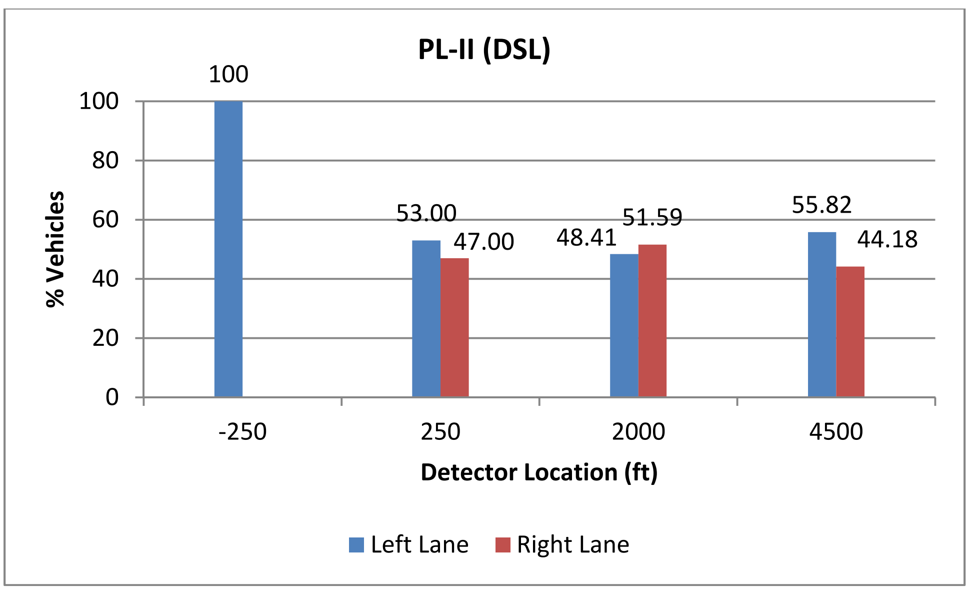


Figure C-18. Percent Overall Vehicles on Each Lane (DSL)

A comparison of the results of DSL conditions with USL conditions indicates that the percent of vehicles in the left lane at corresponding locations under DSL conditions was higher by

11–17% than under USL conditions. The results imply that left lane utilization increased due to DSLs.

Passenger Vehicles

Mean Free Flow Speed

In this section, we discuss the mean free-flow speed of passenger vehicles. Figure C-19 outlines the mean free-flow speed of passenger vehicles at each detector location under USL conditions. The plot shows that the mean free-flow speed for passenger vehicles, in both lanes, was higher than the speed limit (65 mph) by 5 to 22 mph. Mean free-flow speed in the left lane was higher than that in the right lane at diverge location and middle of PL (250 feet and 2000 feet, respectively) within the PL. The mean free-flow speed in the left lane was lower than that in the right lane at merging locations, which indicates that drivers reduce their speed in the left lane to provide space in the left lane (yield) for merging vehicles from the right lane.

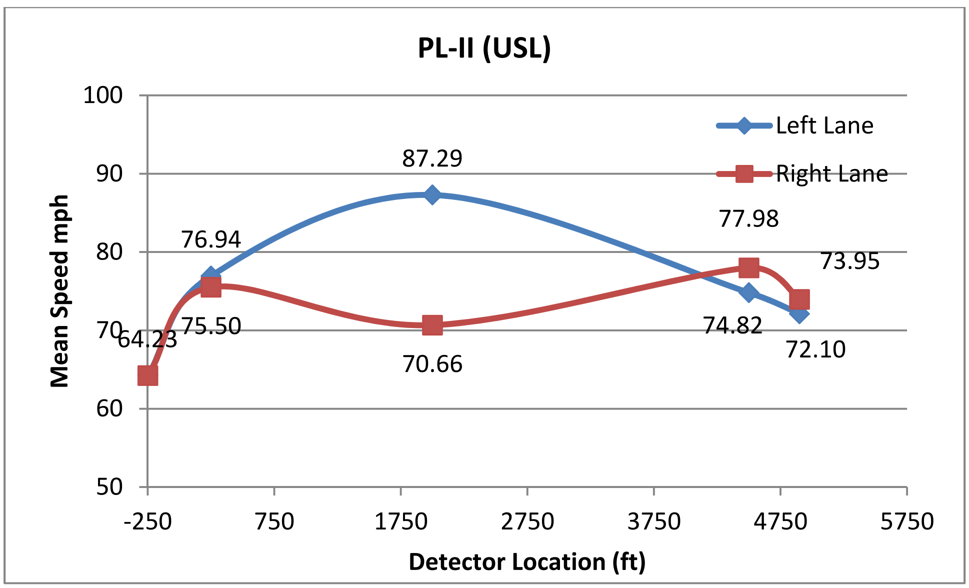


Figure C-19. Mean Speed of Passenger Vehicles under USL Conditions

The speed difference between the two lanes was up to 17 mph and is statistically significant at 2000 feet within the PL. All the statistical analysis used in this chapter is presented in Appendix A. In the left lane, speed increased gradually by 36% for 2000 feet from the start of the taper and then decreased to 72 mph until the end of the PL. A slightly different trend was shown for the right lane. Upon entering into the PL, vehicles first accelerated and increased their speed by 11 mph at 250 feet within the PL. The mean speed gradually decreased by 5 mph at 2000 feet within the PL. After the mid-section of the PL, vehicles accelerated and their speed gradually increased an average of 7 mph within 4500 feet. The speed in the right lane was higher by an average of 1.5 mph than the speed in the left lane at the merge location.

Figure C-20 presents the mean free-flow speed of passenger vehicles at each detector location for DSL conditions. The plot indicates that the mean free-flow speed for all vehicles, in both lanes, was higher than the posted speed limit (PSL) (65 and 55 mph for left and right lanes, respectively). The speed in the left lane exceeds the PSL by 5–22 mph; the speed in the right lane exceeds the PSL (55 mph) by 8–20 mph. Contrary to USL conditions, for DSL conditions, the mean free-flow speed is the right lane decreases from 68 mph at the upstream location to 63 mph 250 feet downstream of the start of the taper. The speed difference between the two lanes at the diverge location (250 feet) is statistically significantly higher for DSL conditions than that for USL conditions. Under DSL conditions, the mean free-flow speed in the left lane decreased by 5 mph at 2000 feet and 4500 feet.

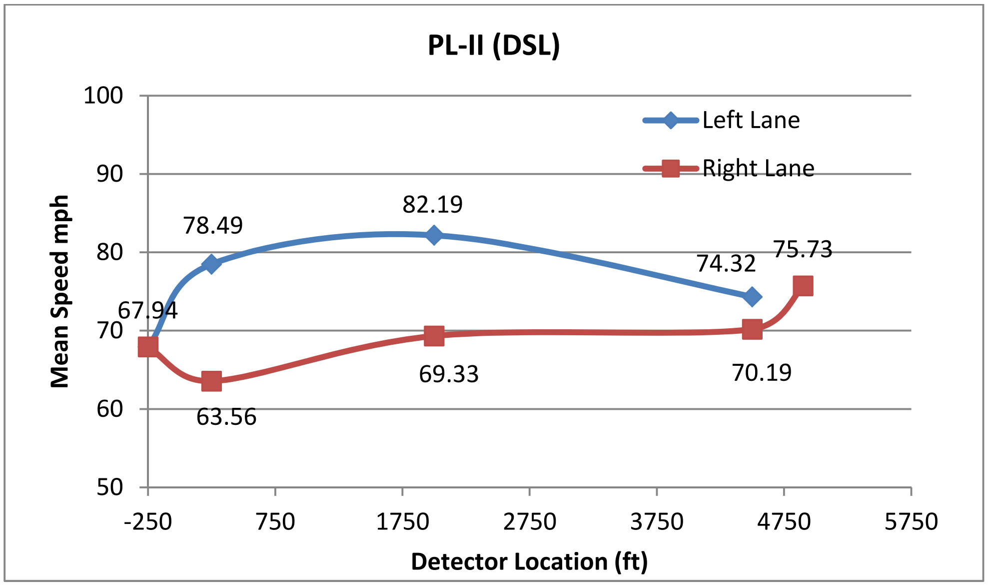


Figure C-20. Mean Speed of Passenger Vehicles under DSL Conditions

Comparing USL with DSL conditions, the overall speed of passenger vehicles in both lanes under DSL conditions is impacted (reduced) by the DSL sign. Generally, passenger vehicle speed was higher than the speed of all vehicles in the left lane, and passenger vehicle speed was lower than the speed of all vehicles in the right lane.

Lane Utilization

This section deals with the lane utilization of passenger vehicles under USL and DSL conditions. Three peak hours of the peak day data were analyzed. Figure C-21 summarizes the percentage of passenger vehicles in each lane at different locations under USL conditions. The results of this analysis indicate that the percentage of passenger vehicles increased in the right lane, and consequently, decreased in the left lane before the merging area at the end of the PL. The volume of passenger vehicles in the left lane decreased from 52% to 36%, which indicates that vehicles generally move to the right lane after passing slow-moving vehicles. In addition, this indicates that 36% of passenger vehicles use the left lane as the driving lane.

Figure C-22 presents the percentage of vehicles in each lane under DSL conditions. The results indicate that 58% of vehicles in the left lane were at the diverge location (250 feet downstream of the taper) within the PL, decreasing to 46% after traveling 1750 feet downstream. The analysis of this trend demonstrates that about half of the total passenger vehicles in the left lane avoid moving to the right lane. The probable reason of this behavior is the lower speed limit (55 mph) in the right lane.

A comparison of the results of DSL and USL conditions indicates that the percentage of passenger vehicles in the left lane at corresponding locations (except merge location) under DSL conditions was higher by 6–16% than under USL conditions, which implies that left lane utilization by passenger vehicles increased due to DSLs.

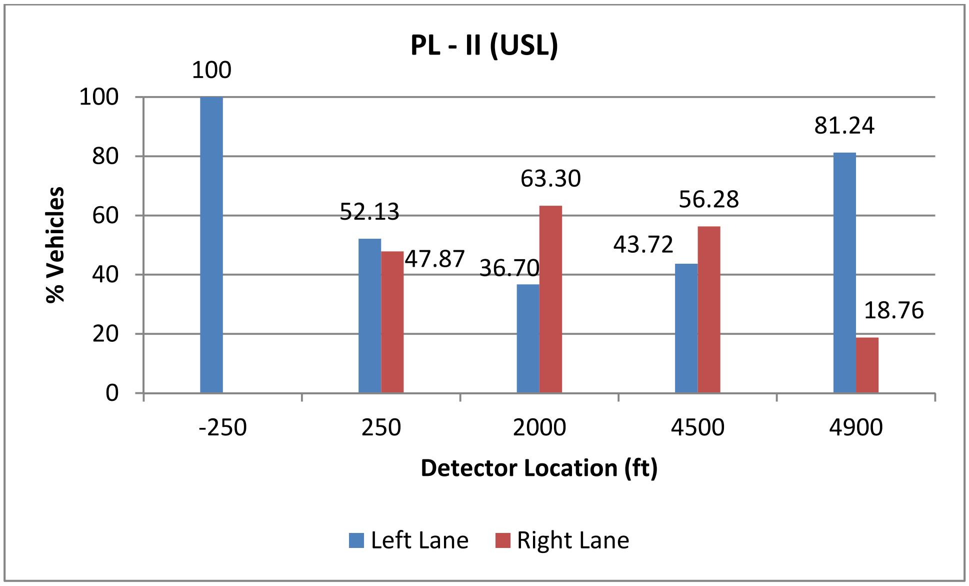


Figure C-21. Percent Passenger Vehicles on Each Lane (USL)

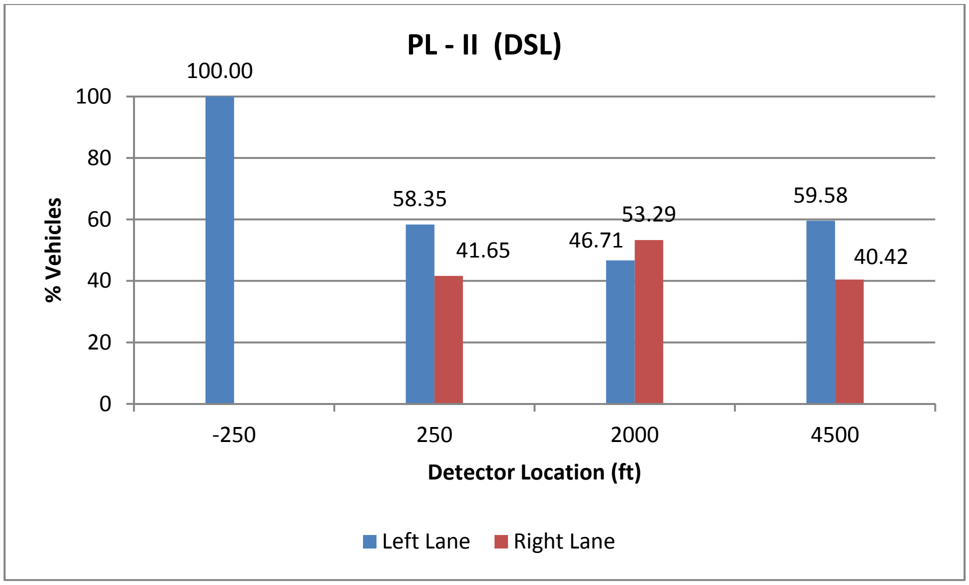


Figure C-22. Percent Passenger Vehicles on Each Lane (DSL)

Heavy Vehicles

Mean Free Flow Speed

This section explains the mean free-flow speed of heavy vehicles. Figure C-23 summarizes the mean free-flow speed of heavy vehicles at each detector location under USL conditions. The plot indicates that the mean free-flow speed of heavy vehicles, in both lanes, was higher than the speed limit (65 mph) by 2–23 mph. Mean free-flow speed in the left lane is higher than in the right lane at the diverge location and mid-section (250 feet and 2000 feet, respectively) within the PL. The speed difference between the two lanes was up to 21 mph and statistically significant. In the left lane, speed increased gradually by 40% throughout 2000 feet from the start of the taper and then decreased from 88.63 mph to 76.40 mph at the end of the PL. A slightly different trend was shown for the right lane. Upon entering into the PL, vehicles first accelerated and increased their speed by 10 mph at 250 feet within the PL. The mean speed gradually decreased by 6 mph at 2000 feet within the PL. After the mid-section of the PL, vehicles accelerated and speed gradually increased an average of 12 mph at 4500 feet. The mean free-flow speed in the right lane was higher by an average of 1.5 mph than the mean free-flow speed in the left lane at the merge location.

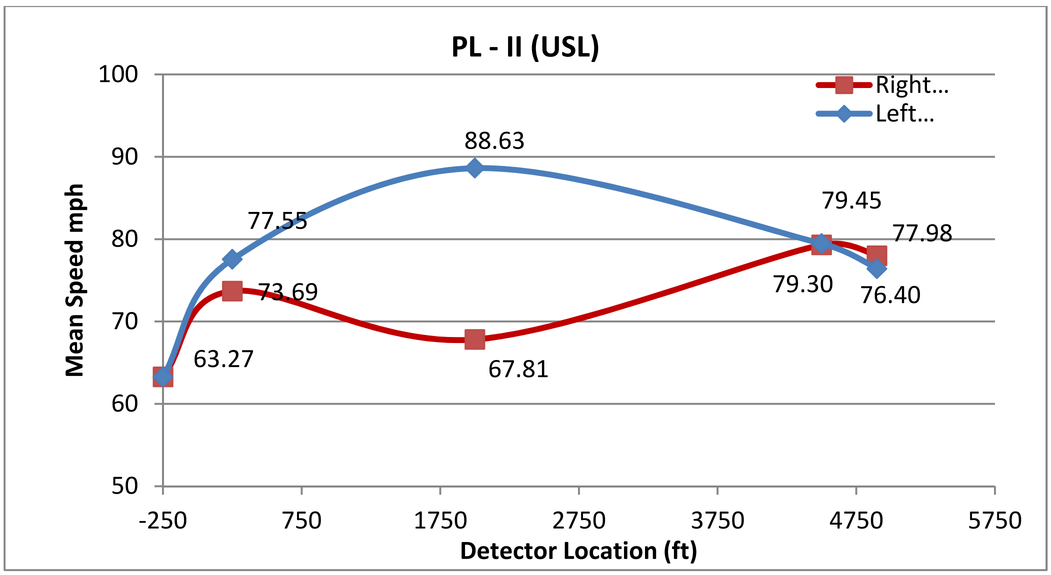


Figure C-23. Mean Speed of Heavy Vehicles under USL Condition

Figure C-24 presents the mean free-flow speed of heavy vehicles at each detector location under DSL conditions. The plot suggests that the mean free-flow speed of heavy vehicles, in both lanes, was higher than the posted speed limit (PSL) (65 and 55 mph for left and right lanes, respectively). The speed in the left lane exceeds the PSL by 10–22 mph; the speed in the right lane exceeds the PSL (55 mph) by 7–22 mph. Contrary to USL conditions, under DSL conditions, the mean free-flow speed in right lane decreased from 65 mph at the upstream location to 62 mph at 250 feet downstream of the start of the taper. The speed difference between the two lanes at the diverge location (250 feet) was significantly higher under DSL conditions than under USL conditions. The mean free-flow speed in the left lane under DSL conditions decreased by 6 mph and 4 mph at 2000 feet and 4500 feet, respectively.

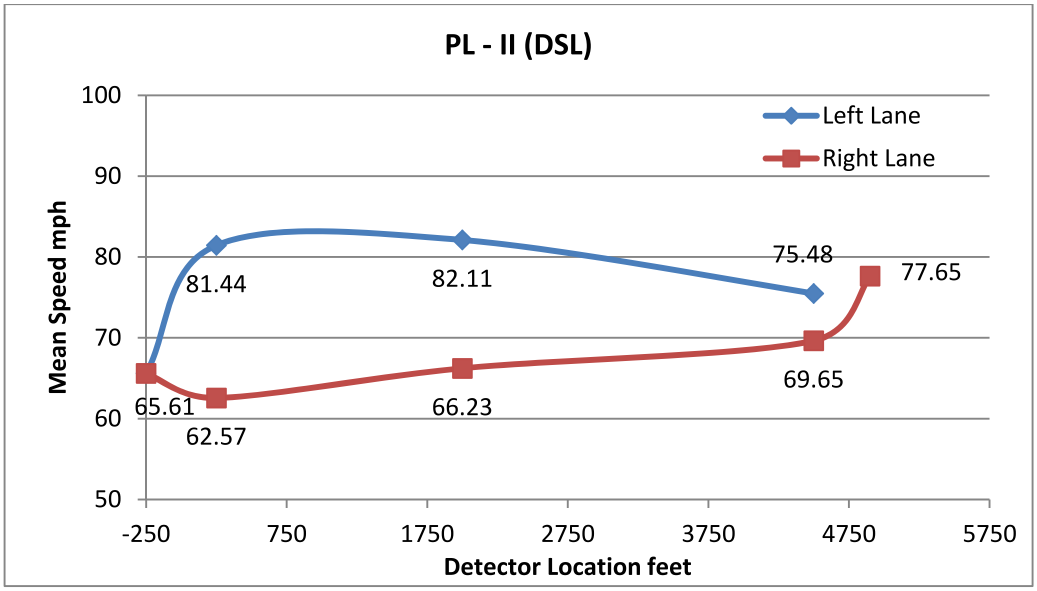


Figure C-24. Mean Speed of Heavy Vehicles under DSL Condition

In a comparison of USL and DSL conditions, the overall average speed of heavy vehicles in both lanes under DSL conditions is impacted (reduced) by DSL signs. The plots indicate that the mean free-flow speed of heavy vehicles in the left lane was relatively higher than the mean free-flow speed of passenger vehicles in the left lane. While the speed of heavy vehicles in the right lane was lower than the speed of passenger vehicles in the right lane.

Lane Utilization

To better understand the volume split between the left and the right lanes, we focused on heavy vehicle lane utilization, discussed in this section. PLs are provided so that slow-moving vehicles can travel in the right lane, allowing fast-moving vehicles to pass in the left lane. Figure C-25 presents the percentage of heavy vehicles in the left and right lanes under USL conditions. The plot shows that 85% of vehicles generally moved to the right lane at the start of the PL (diverge location). The results summarize that 61% of heavy vehicles drive in the right lane at the mid-section of the PL. The percentage of heavy vehicles in the left lane increased driving downstream 4500 feet, rising to 65% at 4900 feet, which indicates that 65% of heavy vehicles generally merged (moved to the left lane) in this area between 4500 feet and 4900 feet.

Figure C-26 presents the percentage of heavy vehicles in each lane under DSL conditions. The results indicate that 42% of drivers of heavy vehicles avoided moving to the right lane at the start of the PL. The plot shows that 46% of heavy vehicles used the left lane as the driving lane at 4500 feet.

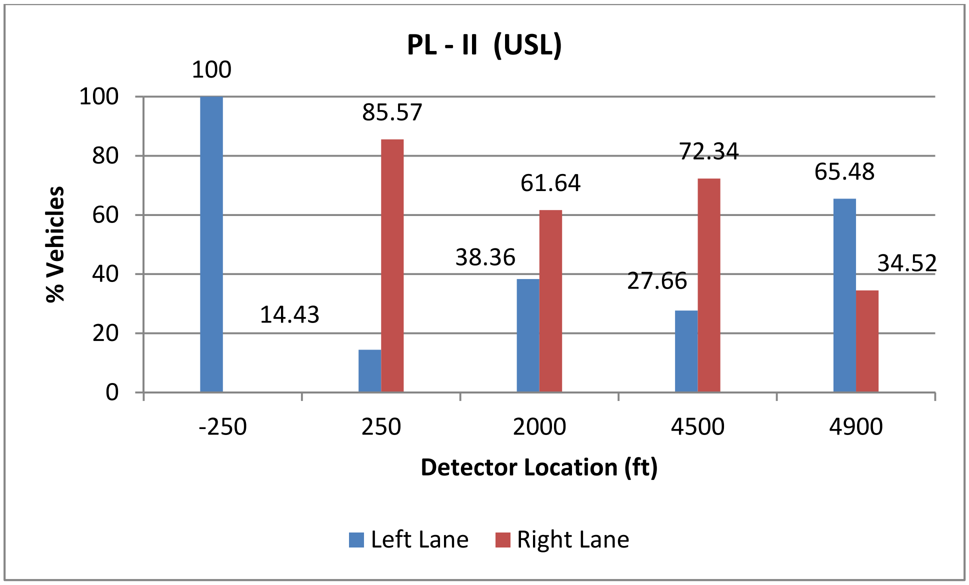


Figure C-25. Percent Heavy Vehicles on Each Lane (USL)

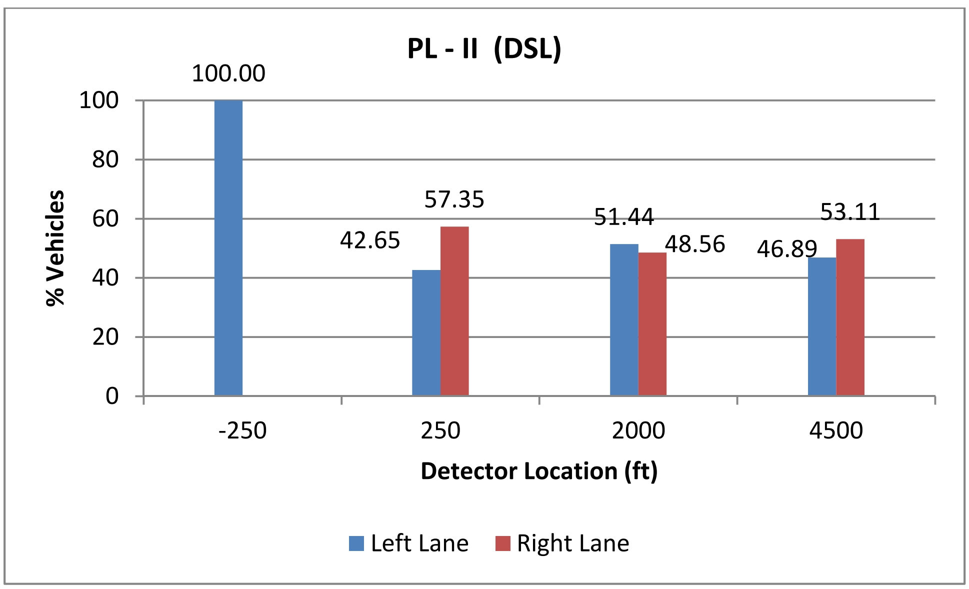


Figure C-26. Percent Heavy Vehicles on Each Lane (DSL)

A comparison of the results of DSL and USL conditions indicates that the percentage of heavy vehicles in the left lane at corresponding locations under the DSL condition was higher than under the USL condition by 13–28%.

Passing Lane III

Five detectors were placed on PL-III heading toward Anchorage. The first detector was placed 250 feet upstream of the PL and accounts for the data for one lane of the two-lane highway. Four detectors were installed in the middle area (around 2100 feet and 3500 feet) within the PL to collect data on weaving and passing behaviors of vehicles.

This section presents the results of PL-III for the USL and DSL conditions. All results were based on 4 hours of evening peak time and dry weather conditions. The peak traffic flow was observed on Sunday toward Anchorage. The mean speed of free-flowing vehicles was analyzed.

Overall Vehicles (Passenger + Heavy Vehicles)

Mean Free Flow Speed

In this section, we discuss the mean free-flow speed of all vehicles. Figure C-27 outlines the mean free-flow speed of vehicles at each detector location under USL conditions. The plot indicates that the mean free-flow speed of all vehicles, in both lanes, was higher than the speed limit (65 mph) by 2–19 mph. The mean free-flow speed in the left lane is higher than in the right lane at each location within the PL. The speed difference between the two lanes was up to 13 mph and is statistically significant at each location within the PL. All the statistical analysis used in this section is presented in Appendix A. In the left lane, speed increased gradually by 26% throughout 3500 feet from the start of the taper. A slightly different trend was shown for the right lane upon merging into the PL. The vehicles first maintained the same speed as that on the two-lane highway section throughout 2100 feet downstream of the beginning of the taper and then gradually increased by an average of 4 mph to reach 71 mph at 3500 feet.

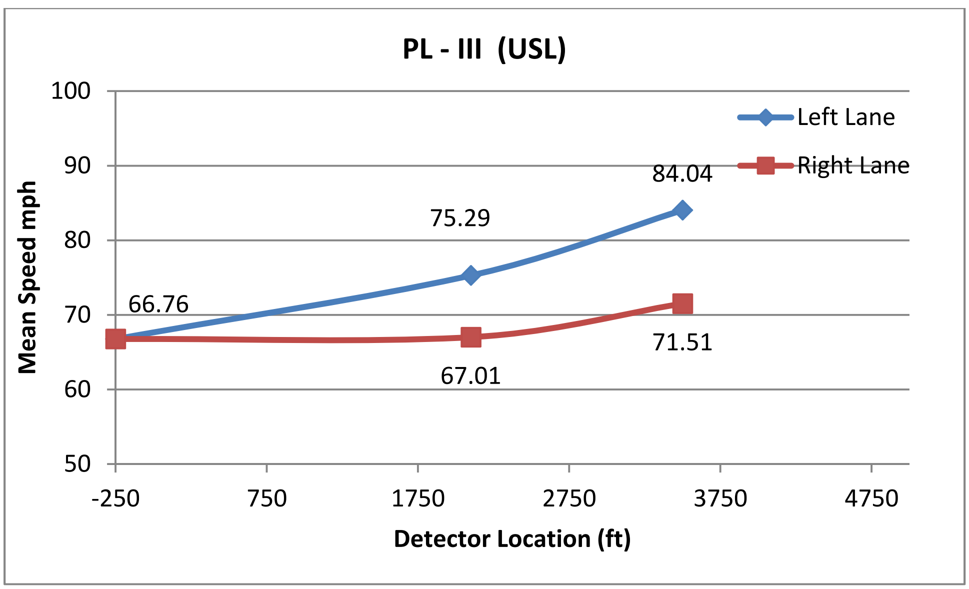


Figure C-27. Mean Speed of Overall Vehicles under USL Conditions

Figure C-28 presents the mean free-flow speed of vehicles at each detector location under DSL conditions. The plot indicates that the mean free-flow speed of all vehicles, in both lanes, was higher than the posted speed limit (PSL) (65 and 55 mph for left and right lanes, respectively). The speed in the left lane exceeds the PSL by 2–11 mph; the speed in the right lane exceeds the PSL by 12–17 mph. Contrary to USL conditions, under DSL conditions the mean free-flow speed in the left lane is equal to that in the right lane at 2100 feet within the PL. The speed difference between the two lanes is relatively low, but statistically significant at 3500 feet within the PL. Under DSL conditions, the mean free-flow speeds in both lanes were about equal to speeds at the upstream location throughout 2100 feet and then gradually increased by 5 mph in the right lane and 8 mph in the left lane.

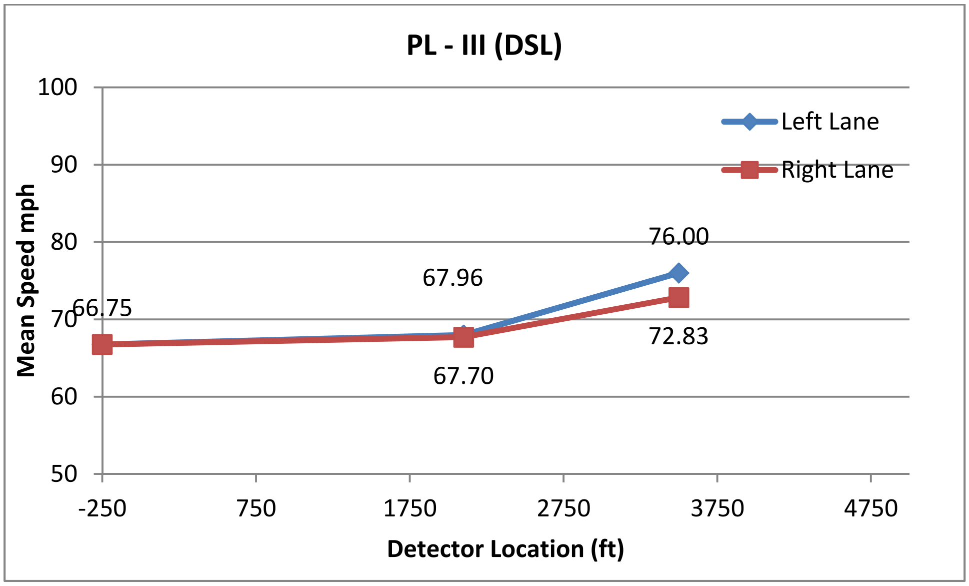


Figure C-28. Mean Speed of Overall Vehicles under DSL Conditions

In a comparison of results of the USL and DSL conditions, the speed in the left lane under the DSL condition decreased by up to 8 mph, and the speed in the right lane increased by 1 mph by 3500 feet of the PL, which can cause a safety issue with respect to maneuvering between lanes. Moreover, the speed difference between the two lanes under USL conditions decreased under DSL conditions to a significant difference.

Lane Utilization

This section deals with traffic volumes under USL and DSL conditions. Three peak hours of the peak day data were analyzed. Figure C-29 summarizes the volume of vehicles in each lane under USL conditions. The figure presents the percentage of vehicles at different locations upstream and within the PL. The results of this analysis indicate that the total volume of vehicles increased in the right lane, and consequently, decreased in the left lane. The volume of vehicles in the left lane decreased from 42% to 40%, which indicates that vehicles generally move to the right lane after passing the slow-moving vehicles. In addition, 40% of vehicles use the left lane as the driving lane.

Figure C-30 presents the percentage of vehicles in each lane under DSL conditions. The results indicate that 52% of vehicles were in the left lane at 2100 feet within the PL, decreasing to 50% after traveling 1400 feet downstream. The analysis of this trend demonstrates that drivers in the left lane avoided moving to the right lane. The probable reason of this behavior is the lower speed limit (55 mph) in the right lane.

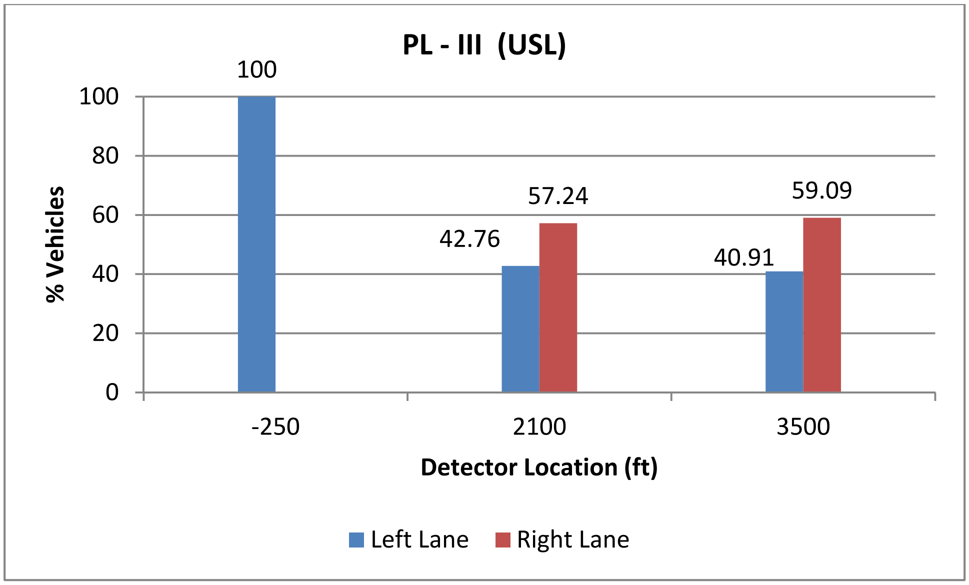


Figure C-29. Percent Overall Vehicles in Each Lane (USL)

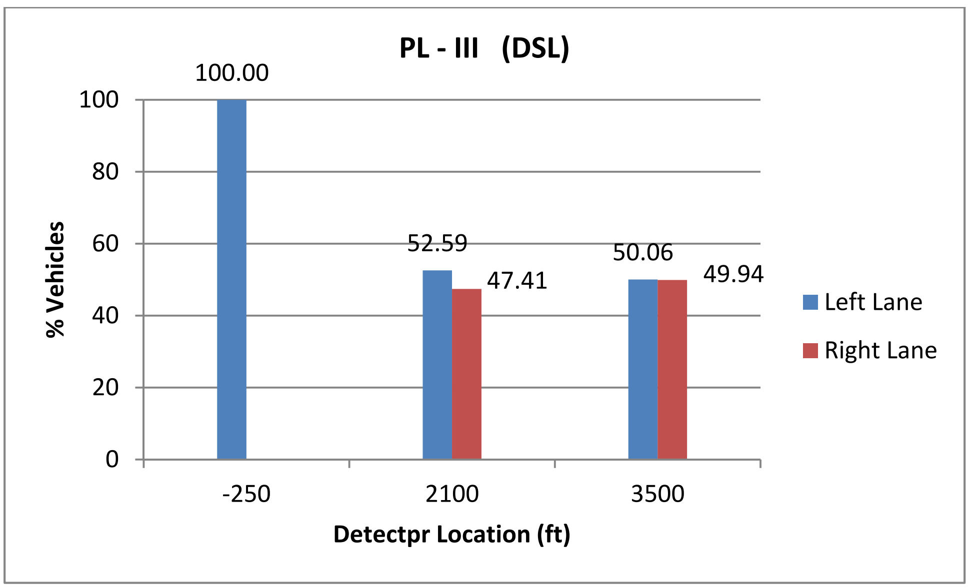


Figure C-30. Percent Overall Vehicles in Each Lane (DSL)

A comparison of the results of the DSL and USL condition indicates that the percentage of traffic volume in the left lane at corresponding locations under DSL conditions was higher by 10% than that under USL conditions and stabilized at about 50% for overall traffic. It implies that half of all drivers do not want to travel at 55 mph in the right lane and use the left lane as the driving lane.

Passenger Vehicles

Mean Free-Flow Speed

To further understand driver behavior at PLs, we focused on passenger vehicles. Figure C-31 outlines the mean free-flow speed of passenger vehicles at each detector location under USL conditions. The plot indicates that the mean free-flow speed for all passenger vehicles, in both lanes, was higher than the speed limit (65 mph) by an average of 3–18 mph. Mean free-flow speed in the left lane is higher than in the right lane at each location within the PL. The speed difference between the two lanes is up to 11 mph. In the left lane, speed increased sharply to about 23% throughout a length of 3500 feet. A slightly different trend was shown for the right lane up to 2100 feet in the PL. The passenger vehicles maintained the same speed as that on the upstream location and then gradually increased by 4 mph. The probable reason is that slow-moving vehicles first allow some vehicles to pass and then accelerate. A comparison of the speed of passenger vehicles with the speed of overall vehicles indicates that passenger vehicles in the left lane generally drive at about the same speed as overall vehicles, while in the right lane, passenger vehicles drive faster by about 1 mph.

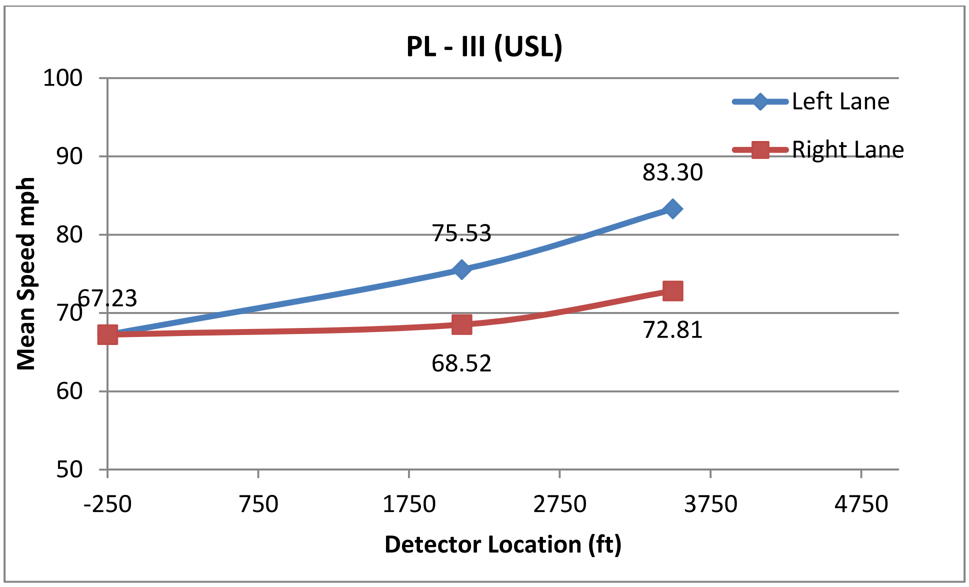


Figure C-31. Mean Speed of Passenger Vehicles under USL Condition

Figure C-32 presents the mean free-flow speed of passenger vehicles at each detector location under DSLs. The plot indicates that the mean free-flow speed of passenger vehicles, in both the lanes, was higher than the PSL (65 and 55 mph). The speed in the left lane is higher by an average of 3–11 mph than the PSL (65 mph), while in the right lane, the speed is higher than PSL (55 mph) by an average of 14–20 mph. Under DSL conditions, contrary to USL conditions, the mean free-flow speed in the left lane is lower than that in the right lane at 2100 feet within the PL. The speed difference between the two lanes is relatively low and statistically insignificant at 3500 feet within the PL. A negative *t*-value indicates that the mean speed in the left lane is lower than that in the right lane. Passenger vehicle speeds follow the same trend as overall vehicle speeds for both USL and DSL conditions. Further, the mean speed of passenger vehicles is similar to the mean speed of all the vehicles, indicating that heavy vehicles also drive at speeds similar to passenger vehicles, reflecting a limited choice of speed in the PL.

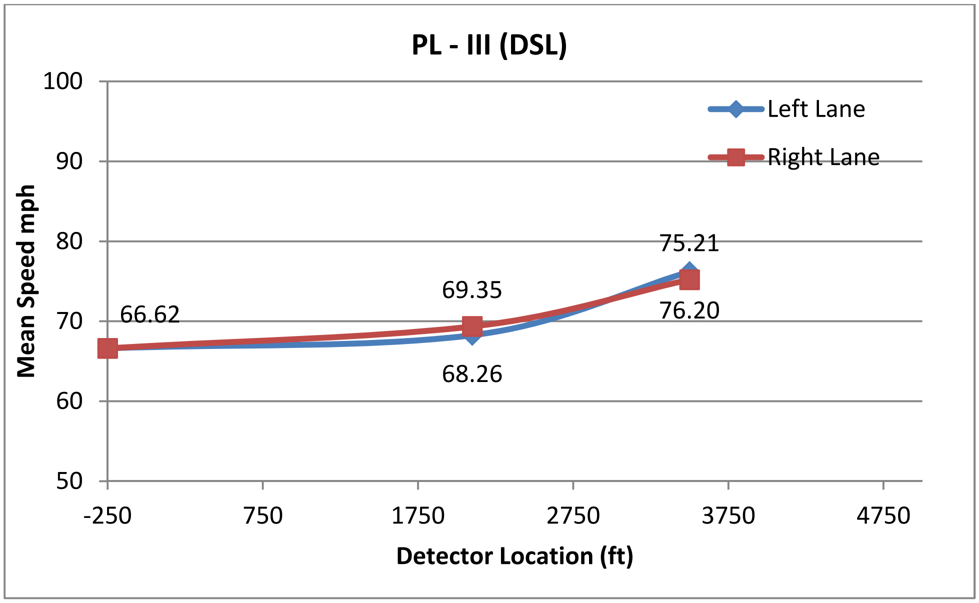


Figure C-32. Mean Speed of Passenger Vehicles under DSL Condition

Lane Utilization

Lane utilization is an important factor in traffic operation and safety. PLs are provided to improve traffic operations and safety. Figure C-33 presents the distribution of passenger vehicles in the left and right lanes under USL conditions. The results of this analysis indicate that the total volume split of passenger vehicles remained the same at 2100 feet and 3500 feet within the PL. Around 47% of vehicles were in the left lane, and 53% of vehicles were in the right lane, indicating that passenger vehicles mostly use the left lane as the driving lane.

Figure C-34 presents the percentage of passenger vehicles in each lane under DSL conditions. The results indicate 54% of passenger vehicles were in the left lane at 2100 feet, increasing to 58% at 3500 feet downstream within the PL. The analysis of the trend demonstrates that more than half of the passenger vehicles in the left lane avoided moving to the right lane. The probable reason of this behavior is the lower speed limit (55 mph) in the right lane.

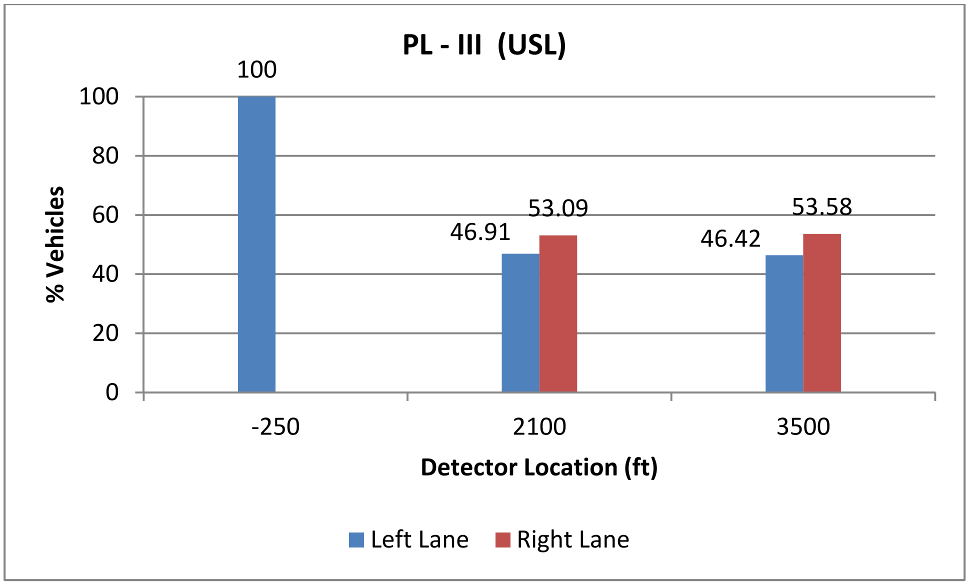


Figure C-33. Percent Passenger Vehicles in Each Lane (USL)

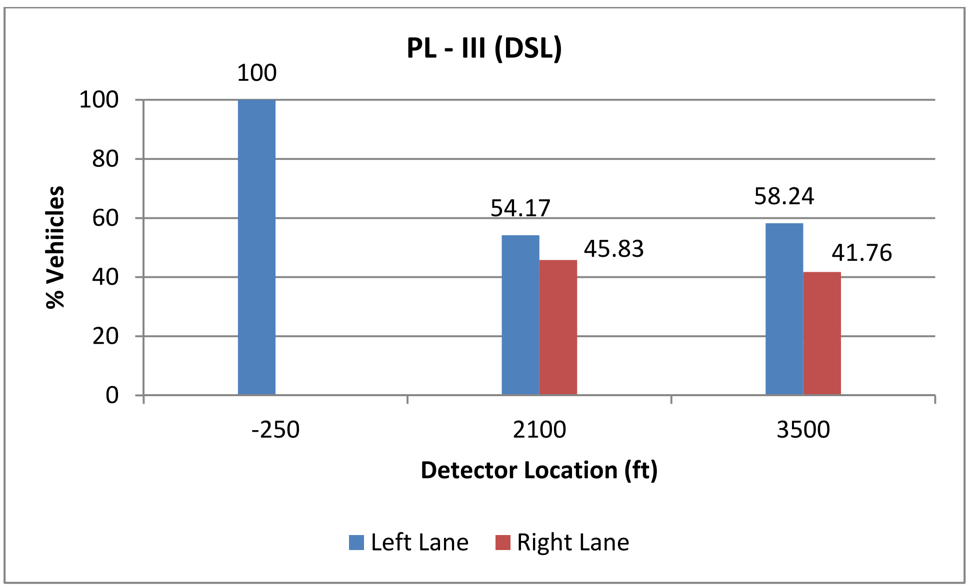


Figure C-34. Percent Passenger Vehicles in Each Lane (DSL)

Heavy Vehicles

Mean Free Flow Speed

Discussion in this section focuses on the free-flow speed of heavy vehicles. A comparison with passenger vehicle free-flow speed will be addressed also. Figure C-35 outlines the mean free-flow speed of heavy vehicles at each detector location under USL conditions. The plot indicates that the mean free-flow speed for all heavy vehicles in the left lane was higher than the speed limit (65 mph) by an average of 8–21 mph. Mean free-flow speed in the right lane was around equal to PSL at 2100 feet and higher by 5 mph at 3500 feet within the PL. Mean free-flow speed in the left lane is higher than that in the right lane at each location within the

PL. The difference is statistically significant with an average of 9–16 mph over the PL section.

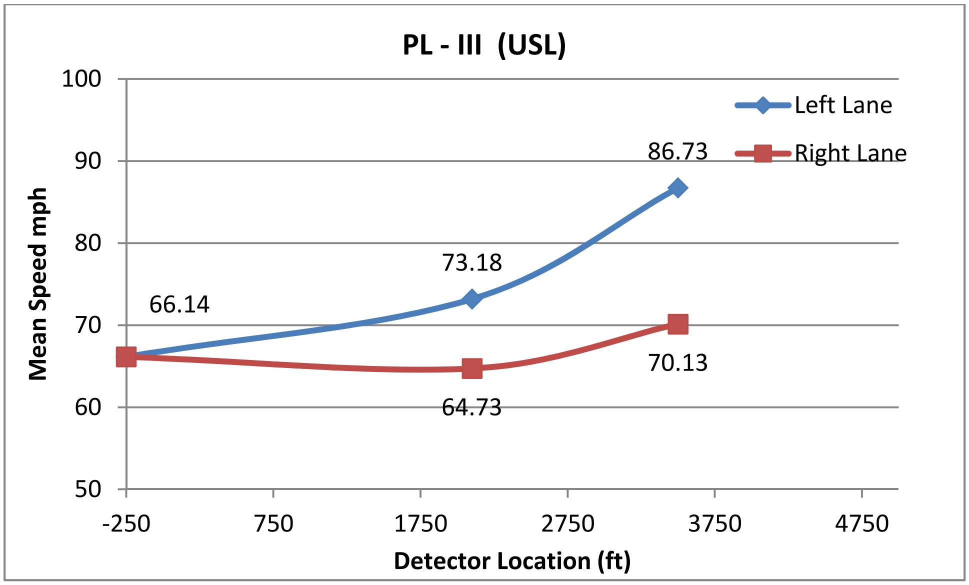


Figure C-35. Mean Speed of Heavy Vehicles under USL Conditions

Figure C-36 presents the mean free-flow speed of heavy vehicles at each detector location under DSL conditions. The plot indicates that the mean free-flow speed for all vehicles, in both lanes, was higher than the PSL (65 and 55 mph). The speed difference between the two lanes was relatively low, but statistically significant. Under DSL condition, the mean free-flow speeds in the right lane decreased upon entrance to the PL by 1 mph and then gradually increased by 5 mph. The mean speed in the left lane remained the same as that at the upstream location throughout 2100 feet and then gradually increased by 5 mph.

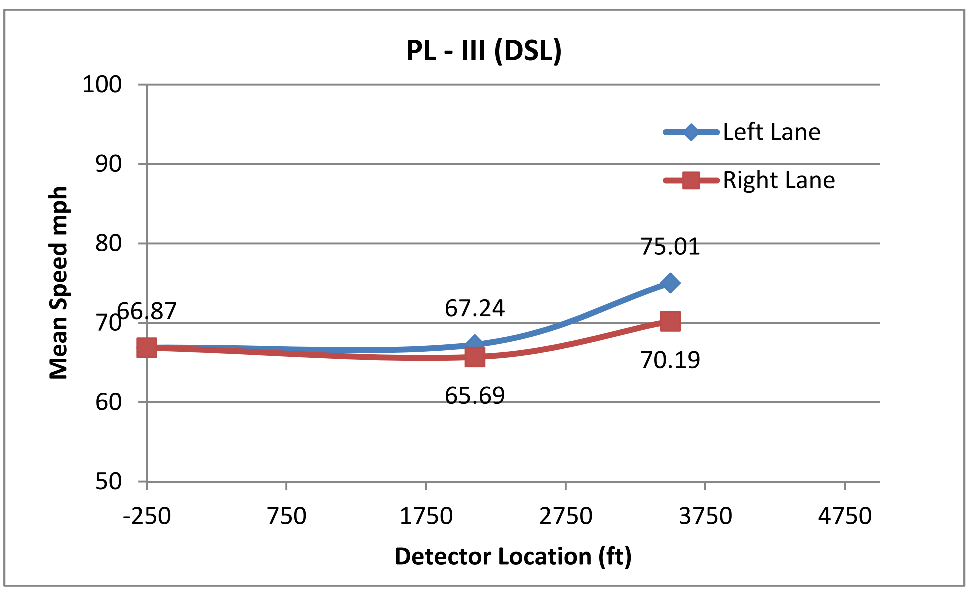


Figure C-36. Mean Speed of Heavy Vehicles under DSL Conditions

Heavy vehicles follow the same trend as overall vehicles for both USL and DSL conditions. Further, the mean speed of heavy vehicles is similar to the mean speed of all the vehicles. Note here that the free-flow speed of heavy vehicles is slightly lower than that of passenger vehicles except at a location of 3500 feet in the PL, and the difference in the free-flow speed between right and left lanes is slightly higher for heavy vehicles than for passenger vehicles.

Lane Utilization

To understand lane utilization more fully, we focused on heavy vehicle lane utilization. PLs are provided for slow-moving vehicles to travel in the right lane, allowing fast-moving vehicles to pass in the left lane. Figure C-37 presents the percentage of heavy vehicles in the left and right lanes under USL conditions. The results show that 76% of heavy vehicles drive in the right lane at the middle section of the PL. The percentage of heavy vehicles in the left lane increased driving downstream at 2100 feet, rising to 29% at a location of 3500 feet, indicating that heavy vehicles generally allow passenger vehicles to pass and then heavy vehicles start moving to the left lane. This finding also indicates that 29% of vehicles use the left lane as the driving lane by 3500 feet of the PL.

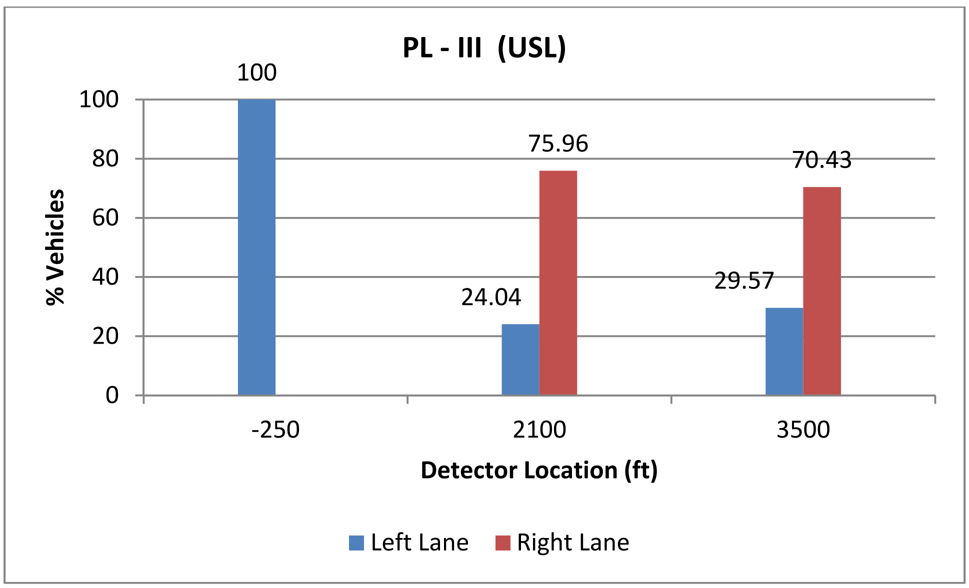


Figure C-37. Percent Heavy Vehicles in Each Lane (USL)

Figure C-38 presents the percentage of heavy vehicles in each lane under DSL conditions. The results indicate that 48% of heavy vehicles were in the left lane by the middle area, and this percentage decreased to 26% at 3500 feet downstream within the PL.

A comparison of the results of DSL and USL conditions indicates that the percentage of heavy vehicles in the left lane at a location of 2100 feet under DSL conditions was higher than under USL conditions by 24%. At 3500 feet downstream within the PL, the percentage of heavy vehicles in the left lane under DSL conditions was lower than that under USL conditions, which indicates that heavy vehicles stay in the right lane.

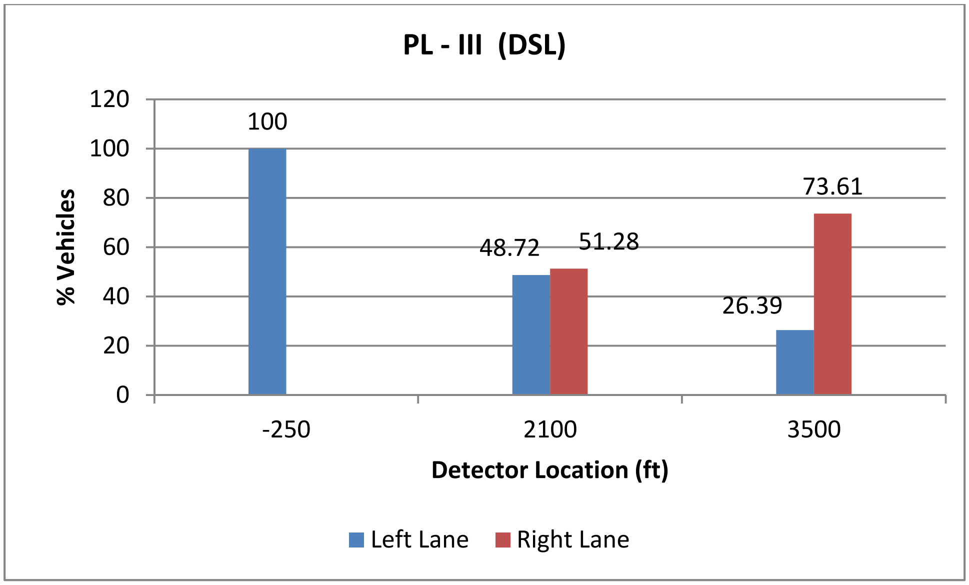


Figure C-38. Percent Heavy Vehicles in Each Lane (DSL)

Overall Speed by Lane

Figure C-39 presents the mean speeds in the left lane for all three PLs under USL conditions. Drivers' speed behavior on PL-I and PL-III is quite similar, suggesting that mean speed gradually increased to the mid-section of the PL. Both PLs are at the ends, while PL-II is located in between PL-I and PL-III. As the vehicle platoons are already split down due to the PL located upstream, drivers accelerate upon entrance to PL-II. Speeds started declining after crossing the mid-section of the PL as the driver approached the merge signboard (RIGHT LANE ENDS). The mean speed in the left lane of PL-I under DSL conditions, gradually decreased upon entrance to the PL and then slightly increased and maintained a speed of around 75 mph, as shown in Figure C-40. The speed trend in the left lane of PL-II under DSL conditions is similar to that under USL conditions, but the average speed along the PL decreased due to DSLs. The speed in the left lane of PL-III under DSLs remained the same until 2000 feet downstream of the first detector; it then slightly increased.

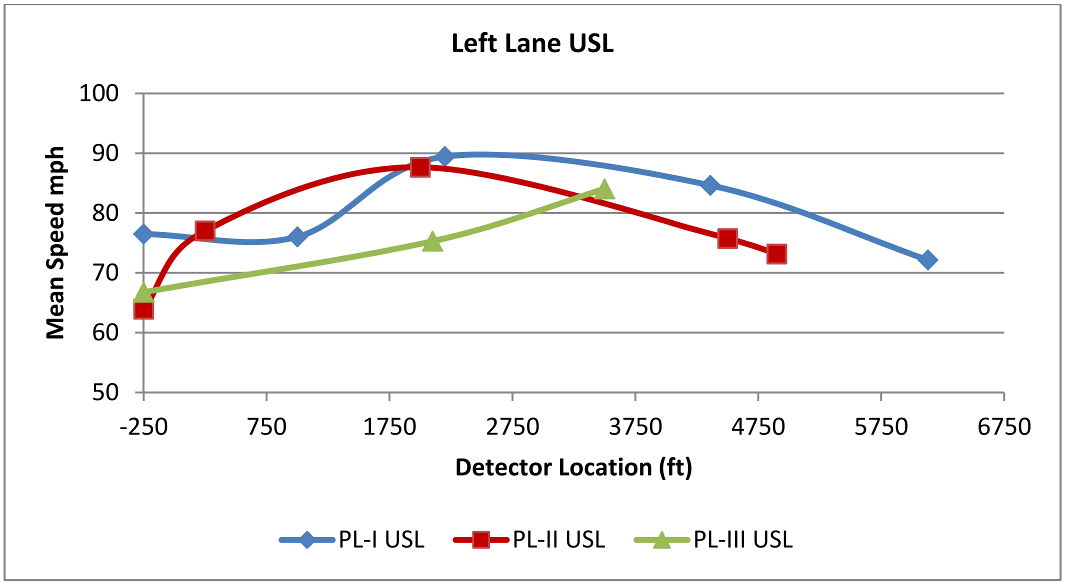


Figure C-39. Mean Speed of Overall Vehicles in the Left Lane (USL)

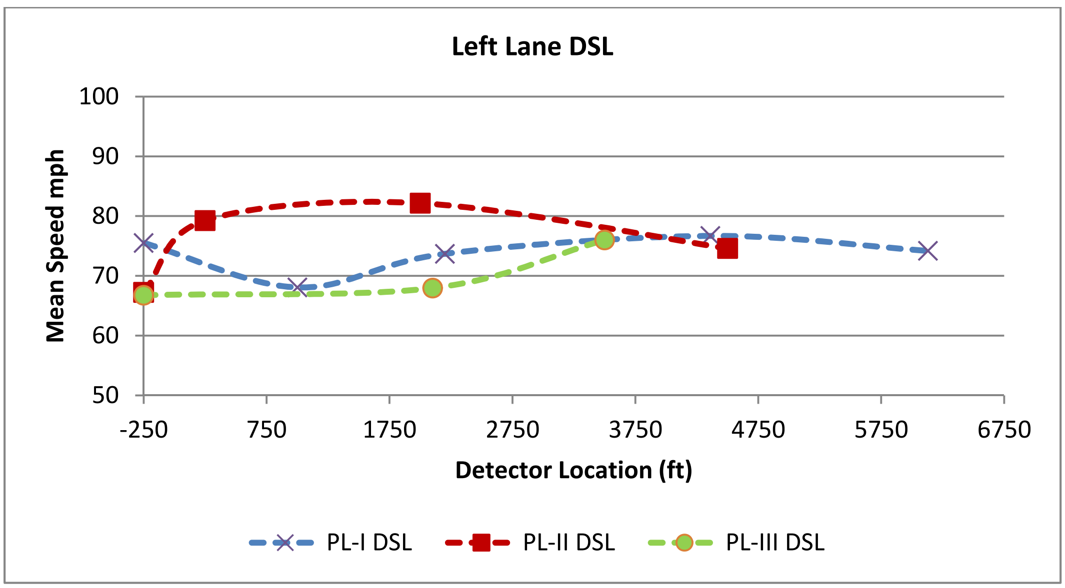


Figure C-40. Mean Speed of Overall Vehicles in the Left Lane (DSL)

As PLs are provided to increase passing opportunities, slow-moving vehicles move to the right lane. The speed in the right lane was lower than in the left lane for all three PLs under USL conditions, as presented in Figure C-41. The trend of mean speed in the right lane for each PL was similar to the corresponding left-lane speed.

Figure C-42 presents the mean speeds in the right lane of each PL under DSL conditions. On PL-I, mean speed gradually decreased at the start of the PL and then slightly increased. After 2000 feet downstream of the taper, the average speed remained constant. Similar trends were observed on PL-II and PL-III, but the mean speeds on PL-II and PL-III were lower than on PL-I.

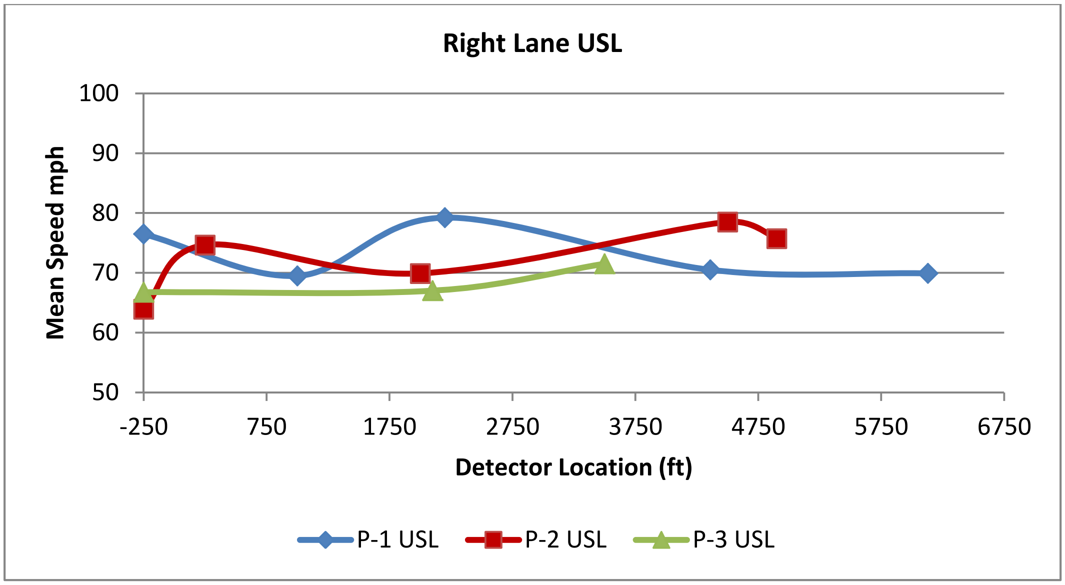


Figure C-41. Mean Speed of Overall Vehicles on Right Lane (USL)

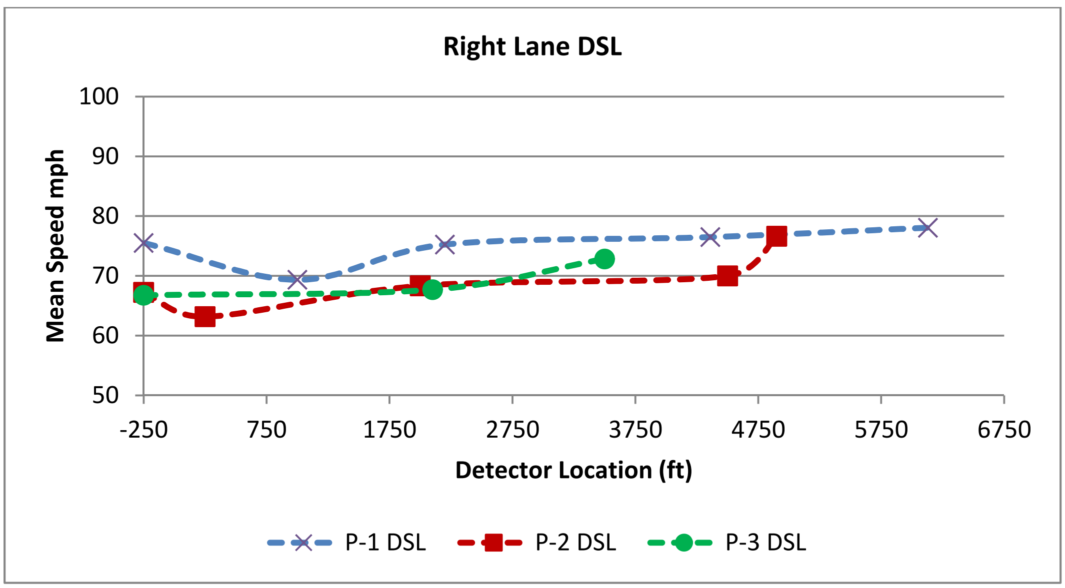


Figure C-42. Mean Speed of Overall Vehicles on Right Lane (DSL)

Statistical Analysis of PL-1

This section presents the results of the statistical analysis of PL-I under USL and DSL conditions. Two sample independent *t*-tests were conducted to analyze if mean speeds in the left and right lanes are equal. The hypothesis for the test was:

H_0: $\mu_{SL} = \mu_{SR}$, reject H_0 when p-value < 0.05
H_1: $\mu_{SL} \neq \mu_{SL}$, fail to reject H_0 when p-value > 0.05

A negative *t*-value indicates that the speed in the left lane was lower than the mean speed in the right lane.

Table C-3 presents the comparison of mean speeds between USL and DSL conditions at the upstream location. The table demonstrates that mean speeds at the upstream location under USL and DSL conditions were equal for all three types of vehicles. Table C-4 summarizes the results of a comparison of mean speeds between left and right lanes for all three vehicle categories. The results indicate that the means speeds between the left and the right lanes were significantly different under USL conditions for all three categories of vehicle. For DSL conditions, the mean speeds in the left lane at Locations 1, 2, and 4 were statistically significantly lower than mean speeds in the right lane for overall vehicles and passenger vehicles. The mean speeds at Location 3 were equal.

Table C-3. Comparison of Means Speeds between USL and DSL at Upstream (PL-I)

Upstream	**Vehicles Type**	**p-value (t-value)**
USL- DSL	Overall Vehicle	0.126 (1.53)
USL- DSL	Heavy Vehicle	0.026 (2.24)
USL- DSL	Passenger Vehicle	0.941 (-0.07)

Table C-4. Comparison of Means Speeds between Left and Right Lanes (PL-I)

Condition	**Vehicle Type**	**Location 1**	**Location 2**	**Location 3**	**Location 4**
USL	Overall Vehicle	0.000 (14.03)	0.000 (15.51)	0.000 (22.01)	0.001 (3.32)
DSL	Overall Vehicle	*0.003 (-2.97)*	*0.003 (-2.99)*	0.718 (0.36)	*0.000 (-4.87)*
USL	Heavy Vehicle	0.006 (2.76)	0.000 (7.96)	0.000 (16.49)	0.025 (2.27)
DSL	Heavy Vehicle	0.697 (-0.39)	0.467 (-0.73)	0.832 (0.21)	*0.033 (-2.14)*
USL	Passenger Vehicle	0.000 (11.95)	0.000 (12.93)	0.000 (16.36)	0.011 (2.56)
DSL	Passenger Vehicle	*0.001 (-3.45)*	*0.000 (-4.34)*	0.604 (-0.52)	*0.000 (-4.32)*

Statistical Analysis of PL-II

This section presents the results of a statistical analysis of PL-II under USL and DSL conditions. Table C-5 summarizes the results of the comparison of mean speeds between left and right lanes for all three vehicle categories. The results indicate that the means speeds between the left and the right lanes were statistically significantly different under USL and DSL conditions for all three categories of vehicle. For USL conditions, the mean speeds difference of heavy vehicles at Location 3 and Location 4 were not significant.

Table C-5. Comparison of Mean Speeds between Left and Right Lanes (PL-II)

Condition	Vehicles Type	Location 1		Location 2		Location 3		Location 4	
		p-value	t-value	p-value	t-value	p-value	p-value	p-value	p-value
USL (left – right)	Overall	**0.000**	6.80	**0.000**	48.91	**0.000**	-4.83	**0.001**	-3.41
DSL (left – right)	Overall	**0.000**	39.12	**0.000**	36.57	**0.000**	10.09	-	-
USL (left – right)	Heavy	**0.000**	4.48	**0.000**	32.10	0.903	0.12	0.266	-1.12
DSL (left – right)	Heavy	**0.000**	25.93	**0.000**	26.07	**0.000**	6.20	-	-
USL (left – right)	passenger	**0.000**	3.53	**0.000**	38.59	**0.000**	-4.89	**0.040**	-2.06
DSL (left – right)	passenger	**0.000**	29.65	**0.000**	26.89	**0.000**	7.96	-	-

Statistical Analysis of PL-III

This section presents the results of statistical analysis of PL-III under USL and DSL conditions. Table C-6 summarizes the results of the comparison of mean speeds between left and right lanes for all three vehicle categories. The results indicate that means speeds between the left and the right lanes were significantly different under USL conditions for all three categories of vehicle. For DSL conditions, the mean speeds difference at Location 2 within the PL were not significant for overall vehicles while significant for passenger and heavy vehicles. At PL-III the mean speeds were significantly different for all three categories of vehicle.

Table C-6. Comparison of Means Speeds between Left and Right Lanes (PL-III)

Condition	Vehicles Type	Location -2		Location - 3	
		p-value	t-value	p-value	t-value
USL (left – right)	Overall	**0.000**	16.98	**0.000**	19.28
DSL (left – right)	Overall	0.490	0.69	**0.000**	6.21
USL (left – right)	Heavy	**0.000**	6.05	**0.000**	12.36
DSL (left – right)	Heavy	0.011	2.56	**0.000**	4.56
USL (left – right)	Passenger	**0.000**	14.43	**0.000**	14.03
DSL (left – right)	Passenger	0.027	-2.22	0.101	1.64

Discussion

This report presents the results of analysis of data collected on the Seward Highway during summer 2016 on three PLs between Mileposts 59 and 66. Traffic volume and speed data were collected on one side of each PL using automatic data recorders.

For PL–I, due to DSL deployment, right-lane utilization in terms of traffic volume decreased because of the lower speed limit. This finding indicates drivers' preference for driving in the left lane at higher speeds compared with driving at a lower speed in the right lane. The speed difference between the two lanes within the PL was drastically reduced due to the deployment of the DSL compared with the USL. The reduction of the speed difference between the two lanes may result in a decrease of the probability of passing frequency within the PL. Statistical analysis of speeds after DSL deployment showed that the speed difference between the left and right lanes significantly decreased. The speed of vehicles in the left lane was affected by the DSL and decreased significantly compared with the USL.

The results of PL-II analysis demonstrate that the speed difference between the two lanes within the PL increased due to deployment of the DSL compared with the USL condition. The average speed in both lanes decreased due to the DSL. In terms of lane utilization, due to DSL deployment, right lane utilization decreased due to the lower speed limit. This finding indicates that drivers avoid driving at a lower speed limit (55 mph) if an adjacent lane with a higher posted speed limit is available to use. The speed of vehicles in the left lane was impacted by the DSL. The results of PL-II are different from PL-I and PL-III, as this PL is located between PL-I and PL-III. The PL located in the same direction with spacing less than 8 miles can be considered to work together as a system (Harwood et al., 2010). Therefore, PL-III has an impact on the operation of PL-II, since it is located downstream of PL-III (northbound).

The findings of PL–III analysis indicate that the speed difference between the two lanes within the PL was reduced due to deployment of the DSL compared with the USL condition. The reduction of the speed difference between the left and the right lanes may result in a decrease of passing frequency within the PL. In terms of lane utilization, due to DSL deployment, right lane utilization decreased because of the lower speed limit. This finding indicates that drivers avoid driving at a lower speed limit (55 mph) if an adjacent lane with a higher posted speed limit is available to use. Due to DSL deployment, statistical analysis showed that the speed difference between the left and right lanes was significantly reduced. The speed of vehicles in the left lane was impacted by the DSL and reduced significantly compared with the USL. Ultimately, these findings from PL-III and PL-I present evidence to potentially explain that DSLs may have an adverse effect on traffic operation and safety if implemented at PLs.

Conclusions

This section presents the conclusions of the traffic data, based on analysis of speeds and lane utilization.

The findings for USL conditions are as follows:

- The mean free-flow speed of overall vehicles, passenger vehicles, and heavy vehicles shows a natural speed difference of up to 18 mph between the left lane and the right lane at all PLs.
- The mean free-flow speed in the left lane was higher than that in the right lane up to 14 mph, which is one of the main objectives of this project.

- At PL-I, mean free-flow speed in the right lane slightly decreased through the first 1000 feet and then gradually increased. The probable reason for speed reduction at the start of the PL is the changing from the left lane to the right lane (diverging).
- The mean free-flow speed of passenger vehicles and heavy vehicles was about the same and had a similar trend.
- The mean free-flow speed of overall vehicles, passenger vehicles, and heavy vehicles was higher than the posted speed limit by an average of 3 mph to 25 mph (65 mph).
- On the two-lane highway (upstream location), the mean free-flow speed of overall vehicles was 76 mph for PL-I, 64 mph for PL-II, and 66 mph for PL-III. This finding suggests that vehicles are generally traveling at a speed equal to or higher than the posted speed limit on this highway.
- About 58% of overall vehicles on PL-I moved to the right lane, traveling up to 1000 feet downstream of the start of the taper; 84% of heavy vehicles and 51% of passenger vehicles moved to the right lane up to 1000 feet downstream of the start of the taper.
- Driving downstream 1000 feet, the percentage of passenger vehicles and overall vehicles in the right lane increased gradually, while the percentage of heavy vehicles decreased until the merge signboard location. This behavior suggests that passenger vehicles generally move to the right after passing slow-moving vehicles, while heavy vehicles start moving to the left lane after allowing fast-moving vehicles to pass.

The findings for DSL conditions are as follows:

- The already existing difference of speeds between the left and the right lane for PL-I and PL-III were statistically significantly reduced, which is contrary to the expected results.
- The mean free-flow speed in the left lane was equal to or lower than the mean free-flow speed in the right lane of PL-I and PL-III.
- For PL-II, the difference of average speeds between the left and the right lanes was enhanced for overall vehicles, passenger vehicles, and heavy vehicles. Mean free-flow speed in the left lane was higher than that in the right lane of PL-II.
- At PL-I, mean free-flow speed in both lanes slightly decreased through the first 1000 feet and then gradually increased. After 2000 feet, the mean free-flow speed was stable at around 76 mph.
- At PL-III, mean free-flow speed in both lanes was the same up to 2000 feet within the PL; then speed in the left lane slightly increased over speed in the right lane.
- The mean free-flow speed of passenger vehicles and heavy vehicles was about the same and showed a similar trend at PL-I and PL-III.
- The mean free-flow speed of overall vehicles, passenger vehicles, and heavy vehicles was higher than the posted speed limits (65 mph and 55 mph).

- Mean free-flow speed of heavy vehicles in the left lane is higher than that in the right lane at each location within the PL. The difference is statistically significant with an average of 9–16 mph over the PL section.

- On the two-lane highway (upstream location), mean free-flow speeds were higher than the posted speed limit (65 mph). This finding suggests that drivers generally drive at a higher speed than the posted speed limit on this highway.
- Right lane utilization decreased due to the lower posted speed limit of 55 mph. This finding suggests that drivers prefer to use the left lane as the driving lane due to the higher speed limit.

The aforementioned findings of this study suggest that DSLs have an adverse effect on driver behavior and PLs operations. One of the main objectives of this project was to decrease vehicle speed in the right lane and increase the vehicle speed difference between the left and the right lanes. The deployment of DSLs, however, has impacted and lowered vehicle speed in the left lane and reduced the speed difference between the left and the right lanes.

Appendix D – Video Analysis

In 2016, the Alaska Department of Transportation and Public Facilities (DOT&PF) introduced a differential speed limit (DSL) study along the Seward Highway, between Mileposts 59 and 66. The purpose of the DSL is to slow vehicles down in the right lane to allow vehicles to pass in the designated PL to the left. This study explains the effects of DSLs on traffic flow and drivers' perception of the effects. Cameras were placed at several strategic locations to record driver behavior under the "current" conditions (no DSL) and "after" conditions (DSLs). In current conditions, the speed limit in both lanes (left and right) is 65 miles per hour (mph). In the "after" condition, the speed limit is 65 mph in the left lane and 55 mph in the right lane. Three PLs were evaluated for traffic flow as well as driver and platooning behavior.

Traffic Flow

Four different types of passing are unique to this study: Types 1, 2, 3, and 4, with Type 1 being the ideal/preferred type of passing.

Type 1 passing: The left lane vehicle passes the right lane vehicle. At diverge (beginning of the PL), the slower vehicle moves into the right lane to allow the vehicle(s) behind to proceed in the left lane. If vehicles are allowed to pass in the left lane, there should be a decrease in platooning behavior. A platoon consists of vehicles traveling within 10 seconds of each other and in the same direction. A platoon indicates slower vehicles are leading faster vehicles and causing delay. Delay can lead to impulsive driver behavior and accidents.

Passing Lane I

Figure D-1 depicts the Type 1 passing vehicles in Passing Lane I (PL-I) as percentages of the total number of vehicles for both the uniform speed limit (USL) and DSL in military time. Overall, the percentage of passing vehicles is about 10% greater under the DSL test sample, but hour 1700 to 1800 was lower for the DSL. Figure D-2 shows the Type 1 passed vehicles as the average percentage of the total number of vehicles for both conditions. Results show that USL and DSL counts are approximately the same and vary within 10% of each other throughout the 8-hour period.

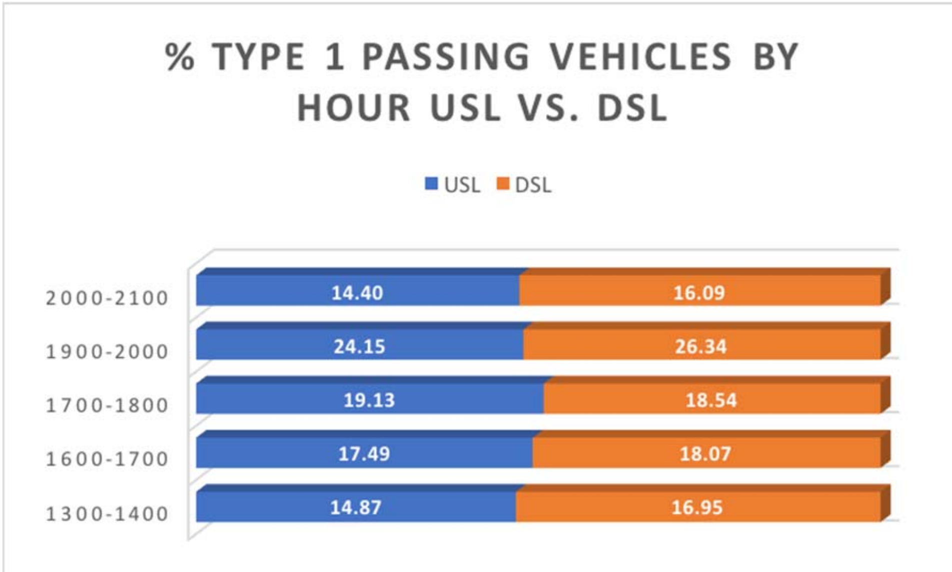


Figure D-1. Percentage of Type 1 Passing Vehicles by Hour for USL vs. DSL, Passing Lane I

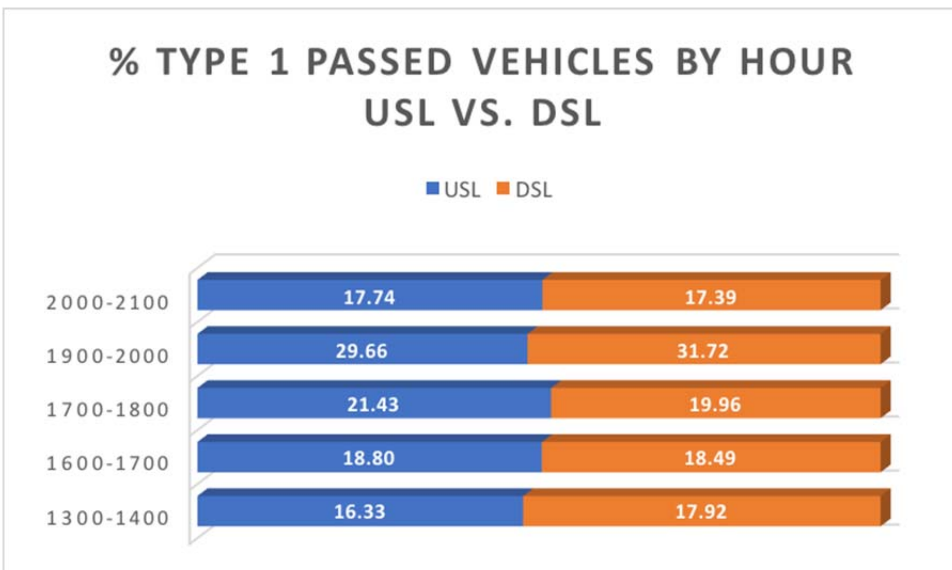


Figure D-2. Percentage of Type 1 Passed Vehicles by Hour for USL vs. DSL, Passing Lane I

Traffic flow can be easily affected by vehicles changing lanes and speeds. There are two cameras in PL-I. One camera is located at the diverge to observe whether a driver makes a mandatory diverge lane change and enters the right lane or stays in the left lane intending to pass. The second camera is located farther down the PL to observe the driver's final lane choice before the merge. Figures D-3 and D-4 show the percentage of vehicles in each lane out of the total number of vehicles for both the USL and the DSL, cameras one and two, respectively. We hoped to see an increase in the percentage of vehicles in the right lane in the "after" condition (DSL). If this increase were to occur, it would indicate that because of the DSL, drivers are more likely to move to the right lane, which allows faster vehicles to pass in the left lane, improving traffic flow.

However, it can be seen in Figures D-3 and D-4 that the DSL has a larger percentage of vehicles in the right lane than the USL does for 1 hour in camera one, and the DSL has a smaller percentage of vehicles in the right lane for all hours in camera two. Therefore, the DSL did not cause more drivers to move to the right lane to allow faster drivers to pass.

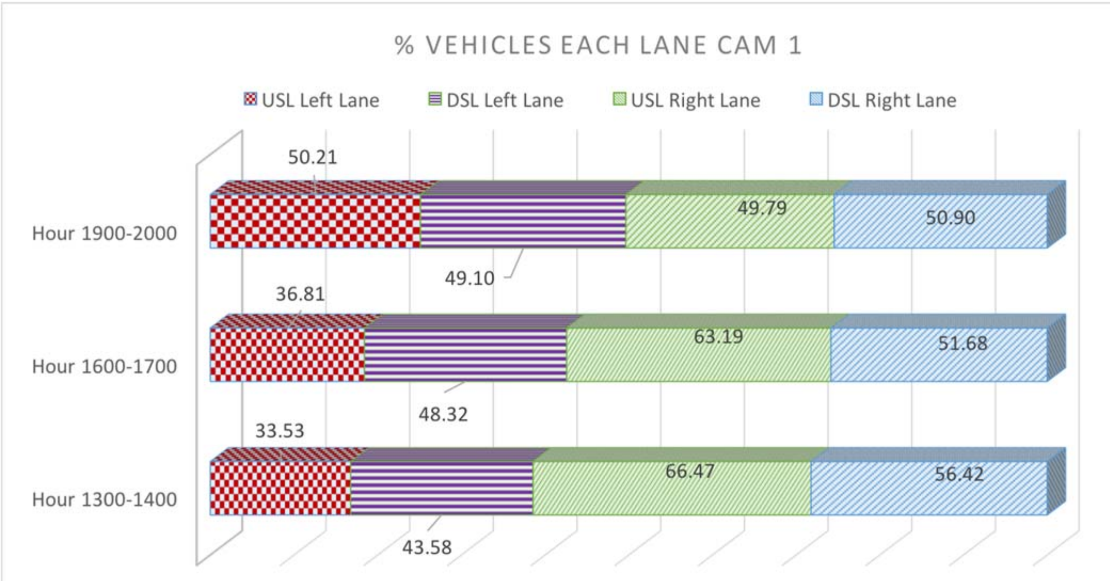


Figure D-3. Camera One – % Vehicles Each Lane USL vs. DSL, Passing Lane I

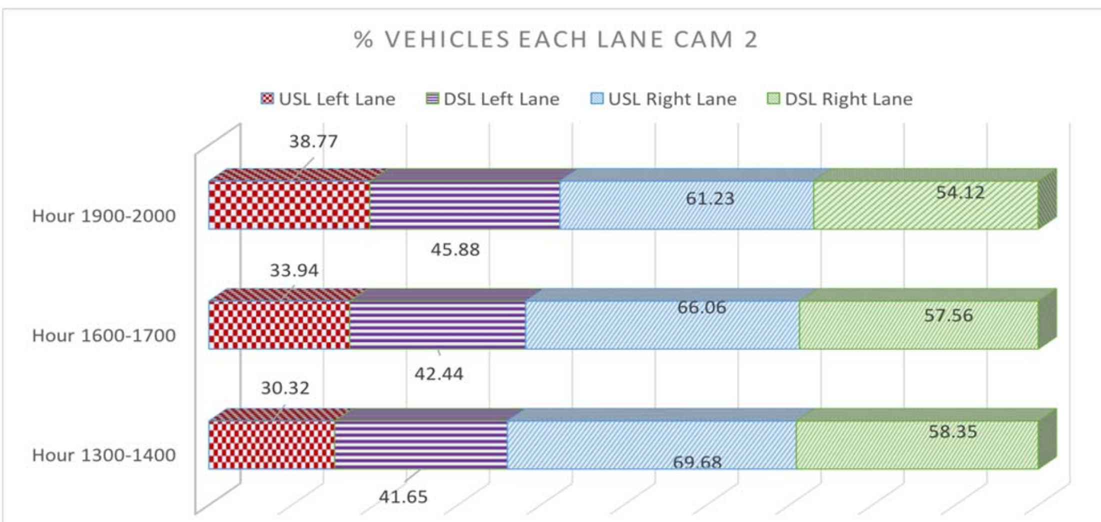


Figure D-4. Camera Two – % Vehicles Each Lane USL vs. DSL, Passing Lane I

Passing Lane II

Figure D-5 shows Type 1 passing vehicles in PL-II as percentages of the total volume each hour for the USL and DSL. Overall, the percentage of passing vehicles is 5–10% greater under the USL test sample, and the percentage of passing vehicles for every hour is lower for the DSL, contradicting the idea that the DSL improves the percentage of Type 1 Passing vehicles each hour. Figure D-6 shows the Type 1 Passed vehicles as the average percentage of the total number of vehicles for both conditions. Results show that Type 1 passed vehicles in the USL are 10–20% higher than those in the DSL. This confirms that fewer vehicles are being passed in a Type 1 scenario due to the DSL in PL-II.

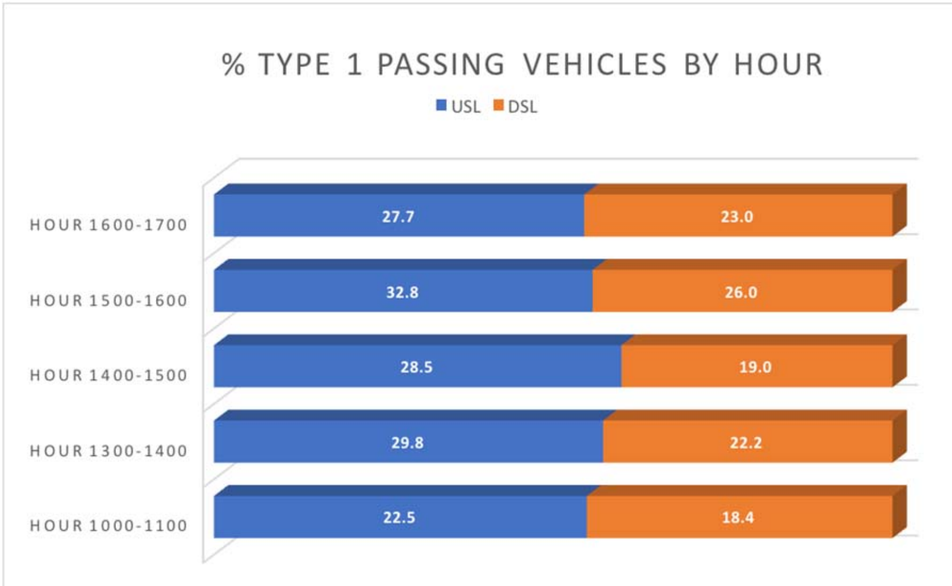


Figure D-5. Percentage of Type 1 Passing Vehicles by Hour for USL vs. DSL, Passing Lane II

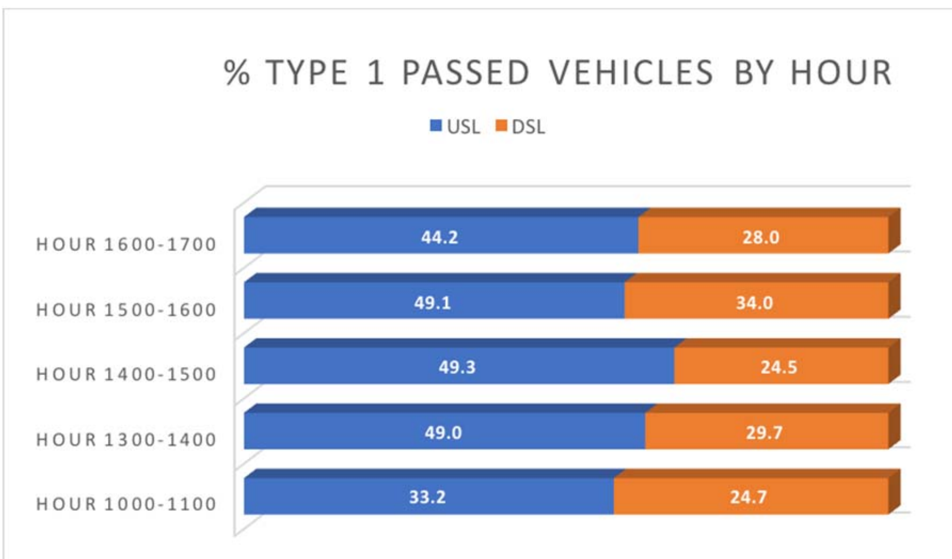


Figure D-6. Percentage of Type 1 Passed Vehicles by Hour for USL vs. DSL, Passing Lane II

Figures D-7 and D-8 show the percentages of vehicles in each lane out of the total volume per hour for both the USL and the DSL for PL-II. The percentage of vehicles in the right lane in the USL test sample is anywhere between 5–10% greater than the percentage of vehicles in the right lane in the DSL test sample. This finding indicates that more drivers prefer to travel in the left lane due to the DSL, which is not what the study predicted. The DSL is supposed to persuade drivers to move to the right lane to allow faster vehicles to pass, but it appears that the DSL actually causes more vehicles to travel in the left lane than the USL does.

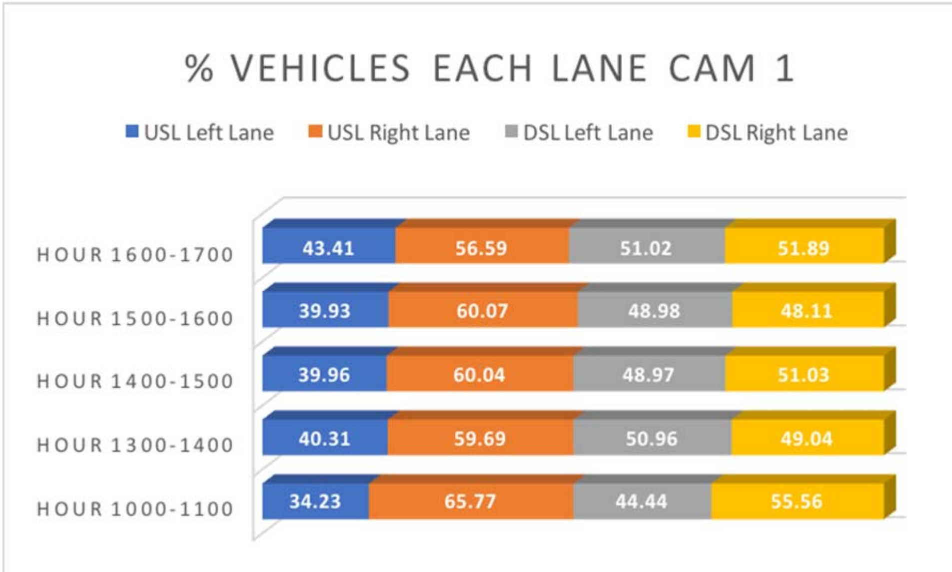


Figure D-7. Camera One – % Vehicles Each Lane USL vs. DSL, Passing Lane II

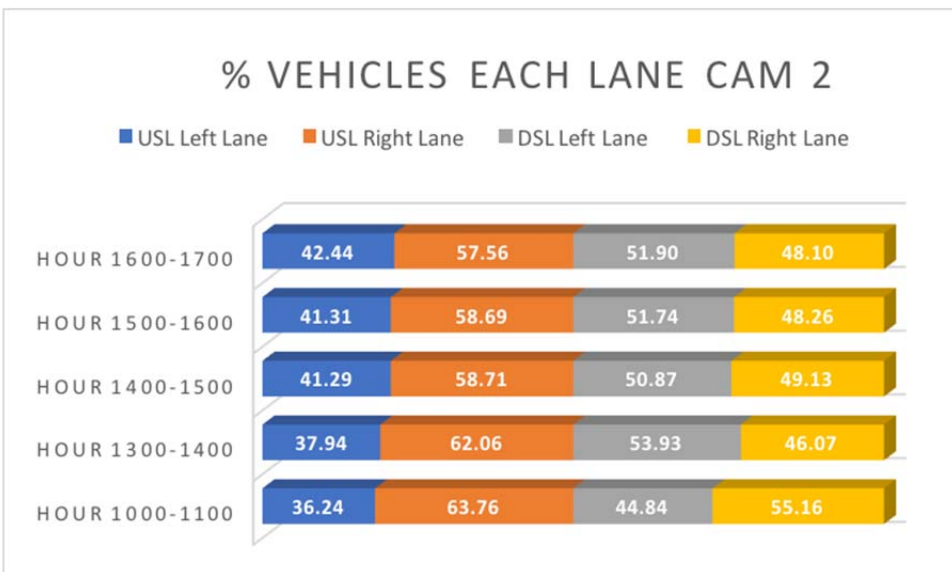


Figure D-8. Camera Two – % Vehicles Each Lane USL vs. DSL, Passing Lane II

Passing Lane III

Passing Lane III was also evaluated for traffic flow, but due to a technological malfunction, only one camera, the one located at the diverge of the PL, was actively recording. The recording camera's video data allow for analysis of the percent of vehicles in each lane for camera 1, but not for camera 2, which means that the percent of Type 1 passed and passing vehicles for PL-III also cannot be determined. Figures D-9 and D-10 show the percent of vehicles in each lane for the USL and DSL, respectively, by hour. In comparing USL and DSL test samples, it is clear that the percent of vehicles in the left lane increased due to the DSL. This finding is the opposite of the effect that the DSL is supposed to have. Differential speed limits cause an uneven distribution in traffic where more vehicles than usual travel in the left lane, which negatively affects traffic flow and causes platooning behavior, leading to safety concerns on the highway.

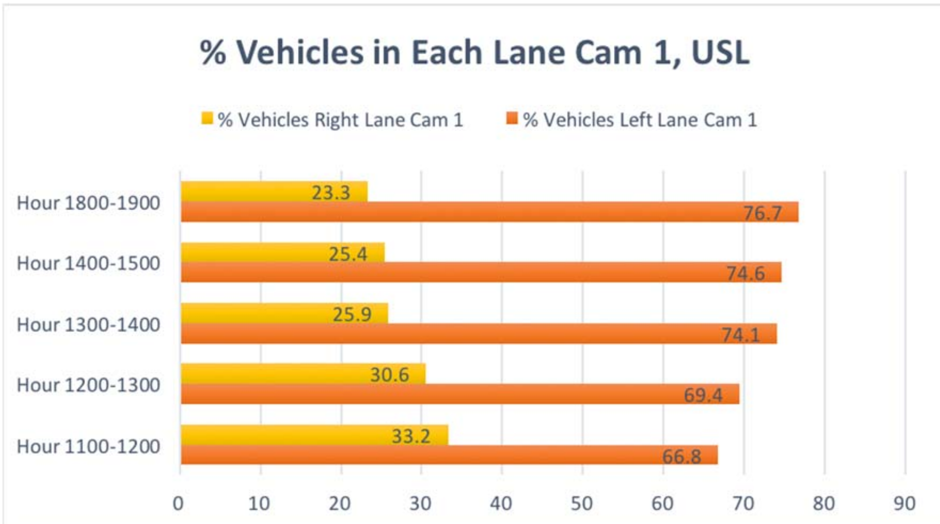


Figure D-9. % Vehicles in Each Lane Camera 1, Uniform Speed Limit

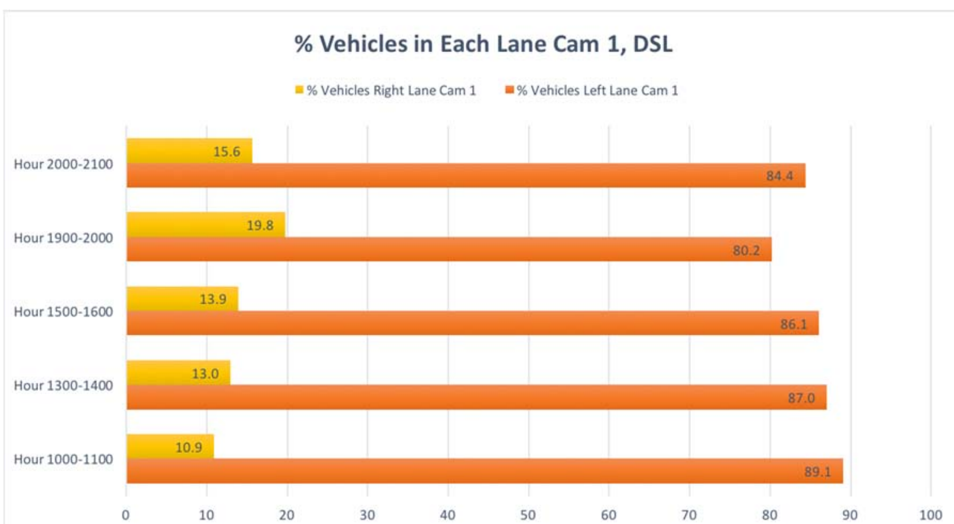


Figure D-10. % Vehicles in Each Lane Camera 1, Differential Speed Limit

Driver Behavior

Passing Lane I

A useful characteristic for determining change in driver behavior due to the DSL in the PL is percentage of total passing maneuvers. Differential speed limits should allow vehicles that travel 55 mph to diverge to the right at the start of the PL, allowing faster-moving vehicles to pass in the left lane. Therefore, there should be a decrease in the total percentage of passing maneuvers due to the DSL in the PL. Figure D-11 shows right side and wrong side passing maneuver totals for both USLs and DSLs. The percentage of wrong side maneuvers increased for 3 out of the 5 hours analyzed under DSL conditions, but the percentage of right side maneuvers decreased for 3 of the 5 hours under DSL conditions, except in hour 1900–2000, where it increased substantially. Figure D-12 shows the percentage of total passing maneuvers by hour for both conditions, which includes both wrong side and right side maneuvers. For 3 of the 5 hours shown in Figure D-12, the passing maneuver total is lower under the DSL condition.

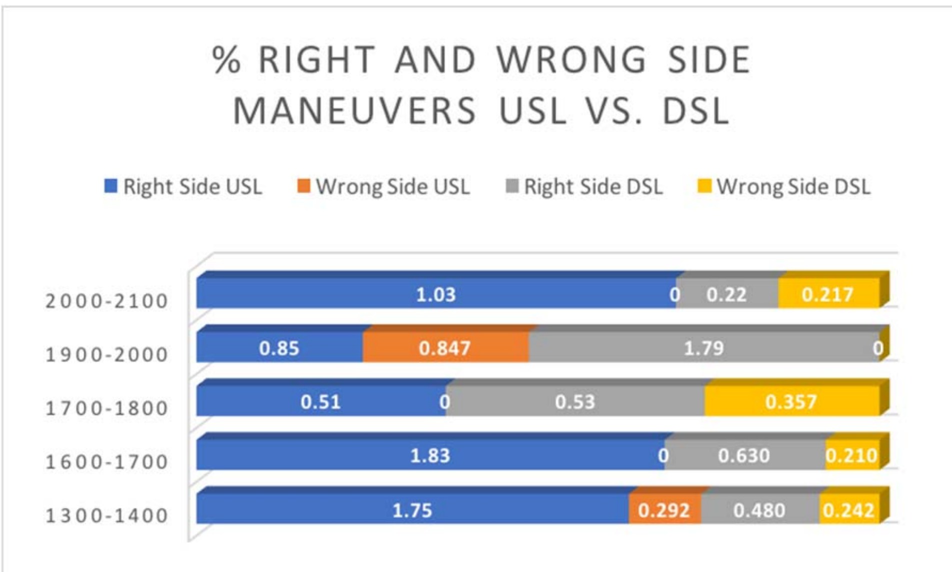


Figure D-11. Percentages of Right Side (Left Lane) and Wrong Side (Right Lane) Passing Maneuvers of Total Vehicles USL vs. DSL, Passing Lane I

The change in percentage of mandatory diverge lane changes made at the start of the merge also helps to determine driver behavior due to the DSL. The left lane is to be used for passing only, so drivers are supposed keep right unless they are passing. Because of this, drivers entering the PL should make a mandatory diverge lane change into the right lane unless intending to use the left lane to pass slower vehicles that are traveling in the right lane. There should be an increase in the percentage of mandatory diverge lane changes out of the total number of vehicles each hour due to the DSL being introduced in the PL. Figure D-13 shows the percentages of total vehicles in each hour of mandatory diverge lane changes for the USL and DSL. The data show the mandatory diverge lane change count went down from the USL to DSL, which means the drivers may prefer to travel at 65 mph (use the left lane) rather than at 55 mph (use the right lane.)

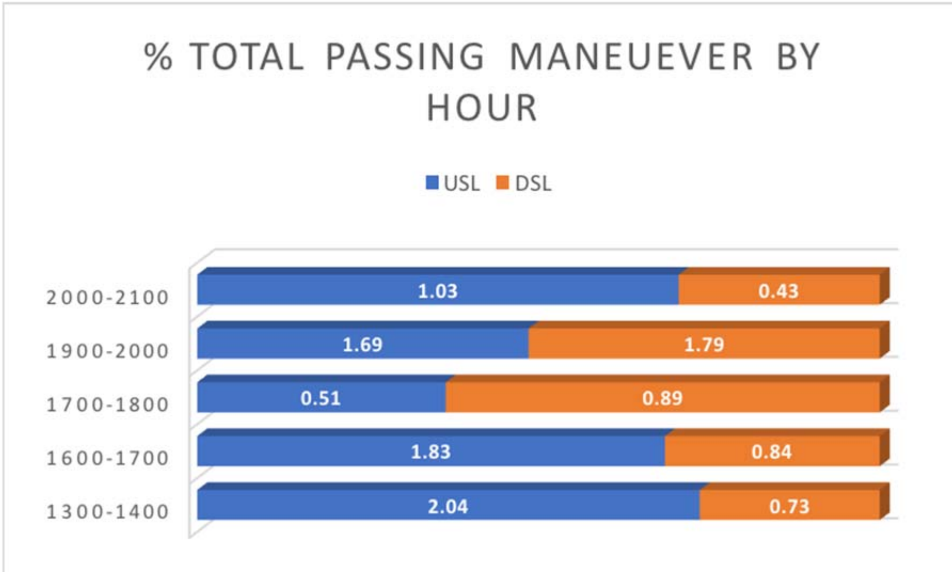


Figure D-12. Percentages of Total Passing Maneuvers by Hour for USL and DSL, Passing Lane I

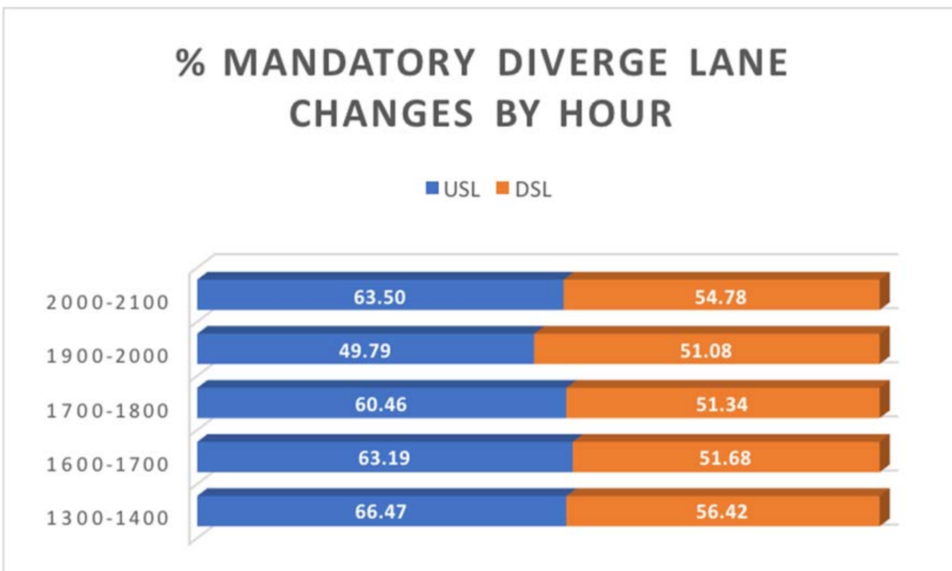


Figure D-13. Percent Mandatory Diverge Lane Changes by Hour for Uniform vs. Differential Speed Limit, Passing Lane I

Passing Lane II

Figure D-14 shows the right side and wrong side passing maneuver totals for both the USL and DSL. Right side passing maneuvers decreased as a result of the DSL, but wrong side passing maneuvers actually increased. This is explained by drivers traveling in the left lane who refuse to move over to let faster-traveling vehicles pass. The result is a wrong side maneuver, where the faster vehicle travels from the left lane to the right lane in order to pass the slow vehicle moving in the left lane. The impulsivity of this action and the anger caused by driving behind a vehicle whose driver is unaware of the surroundings cause risky maneuvers, such as that of a wrong side maneuver. The increase of wrong side maneuvers due to the DSL is much greater than the decrease of the right side maneuvers due to the DSL, so the percentage of total passing maneuvers did decrease in every hour from the USL test sample to the DSL sample. In Figure D-15, it can be seen that the percentages of the passing maneuver totals by hour were higher for every hour in the USL condition.

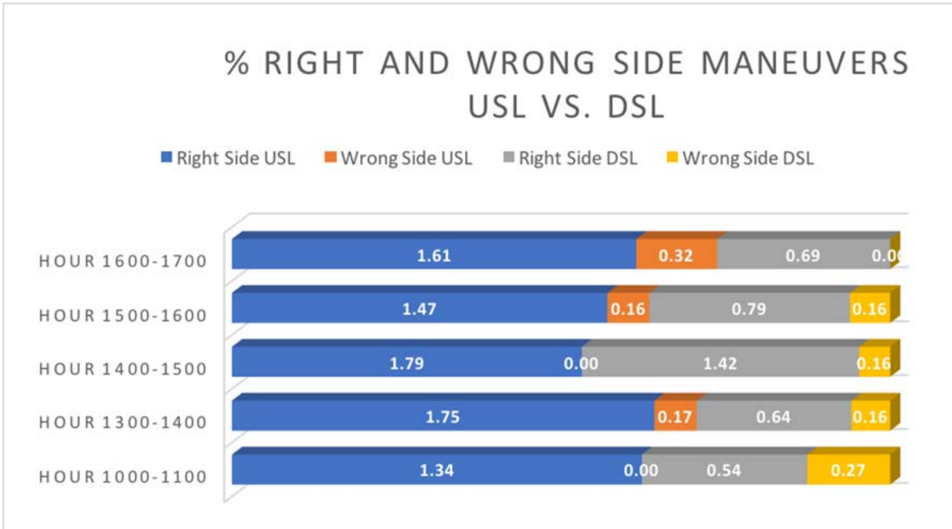


Figure D-14. Percentages of Right Side (Left Lane) and Wrong Side (Right Lane) Passing Maneuvers of Total Vehicles USL vs. DSL, Passing Lane II

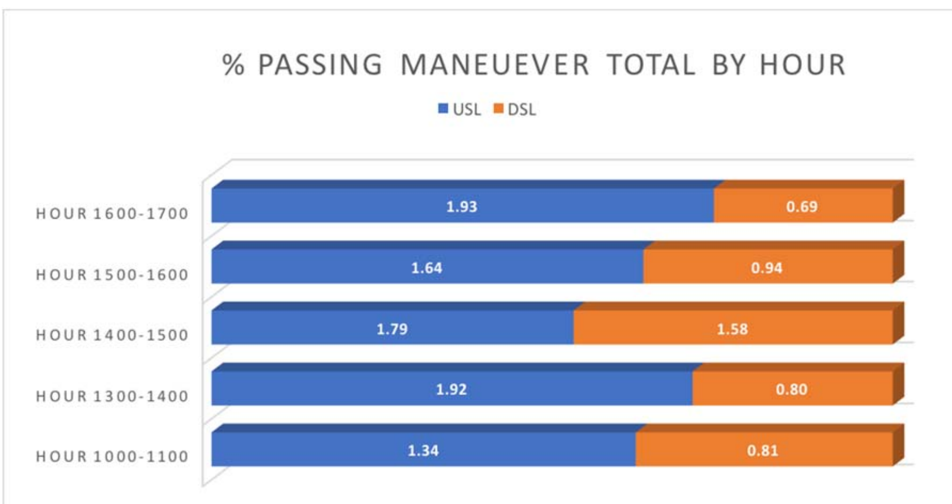


Figure D-15. Percentages of Total Passing Maneuver by Hour for USL and DSL, Passing Lane II

Figure D-16 depicts the percentages for each hour of mandatory diverge lane changes for both the USL and DSL for PL-II. The data show that the mandatory diverge lane change count went down from USL to DSL conditions, which means that fewer drivers moved into the right lane due to the DSL in Passing Lane II.

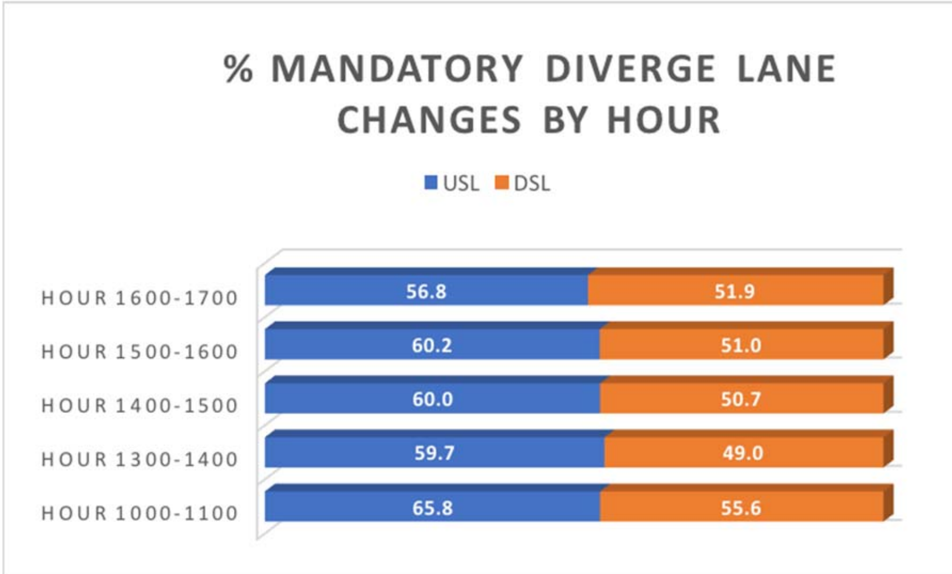


Figure D-16. Percent Mandatory Diverge Lane Changes by Hour for Uniform vs. Differential Speed Limit, Passing Lane II

Passing Lane III

Passing Lane III was also evaluated for driver behavior, but due to a technological malfunction, only one camera was recording the PL. The recording camera allowed for analysis of the diverge behavior, but passing behavior could not be evaluated for PL-III with only one camera's data available. Figures D-17 and D-18 show the percent mandatory diverge lane changes by hour for the USL and DSL, respectively. Because different hours were analyzed for the DSL and USL, individual hours are not compared, but it is clear that the percent of diverge mandatory lane changes decreased from the USL test sample to the DSL test sample, showing that the DSL causes more drivers to want to travel in the left lane, at 65 mph.

Platooning Behavior

Studying platooning behavior under USL and DSL conditions is important for determining if traffic flow has improved due to the DSL. A platoon is defined as a group of vehicles traveling within 10 seconds of each other. Platooning behavior can cause backups in the flow of traffic, which can be a cause for safety concern if the regular speed limits are between 55 and 65 mph. A driver may have to apply the brakes at short sight distance if traffic is backed up around a curve due to excessive platooning.

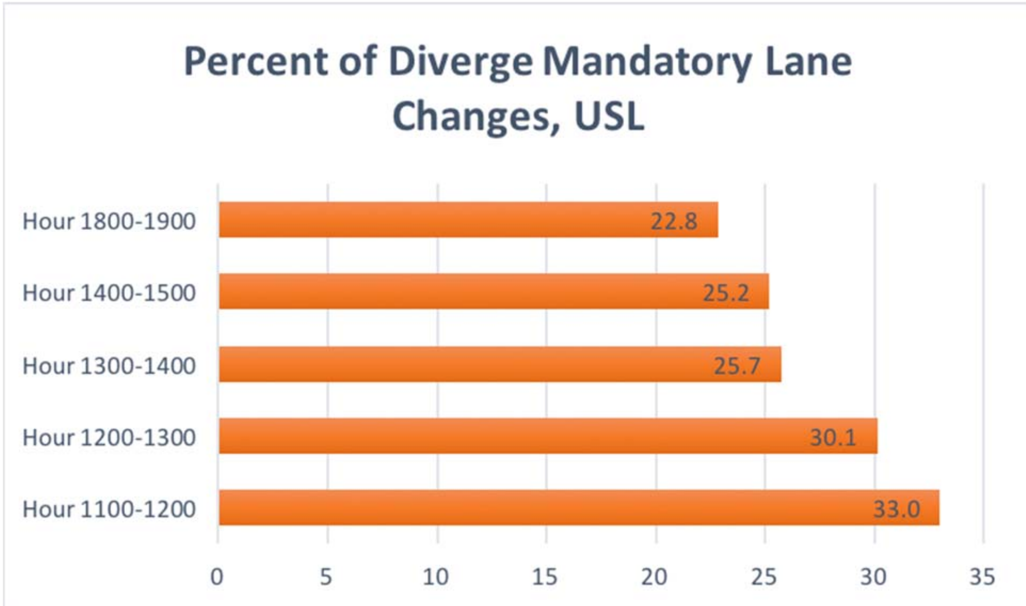


Figure D-17. Percent Diverge Mandatory Lane Changes, Uniform Speed Limit

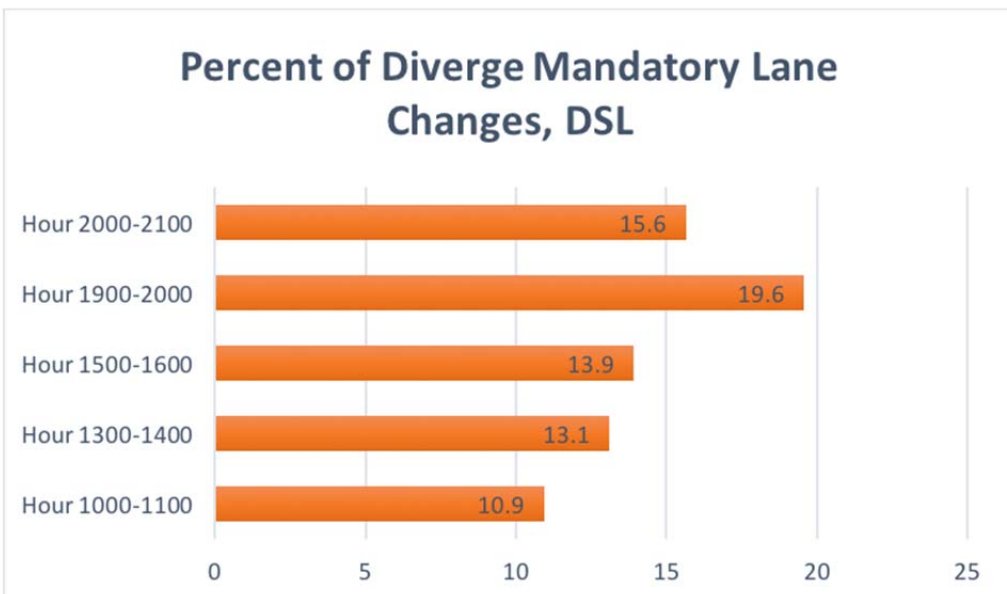


Figure D-18. Percent Diverge Mandatory Lane Changes, Differential Speed Limit

Passing Lane I

Figure D-19 shows the percent of platoons longer than one vehicle in PL-I. Depicting more than one vehicle platoon will enable a micro level analysis. Four out of the 5 hours depicted in Figure D-19 had lower percentages of platoons greater than one vehicle due to the DSL. This indicates that there are fewer platoons relative to the total number of vehicles due to the DSL. Figure D-20 shows the mean size of the platoons that are longer than one vehicle. The mean platoon size decreased due to the DSL in only 1 of the 5 hours shown, *Hour 1300–*

1400. This means that the number of vehicles in each platoon increased from the USL to the DSL sample.

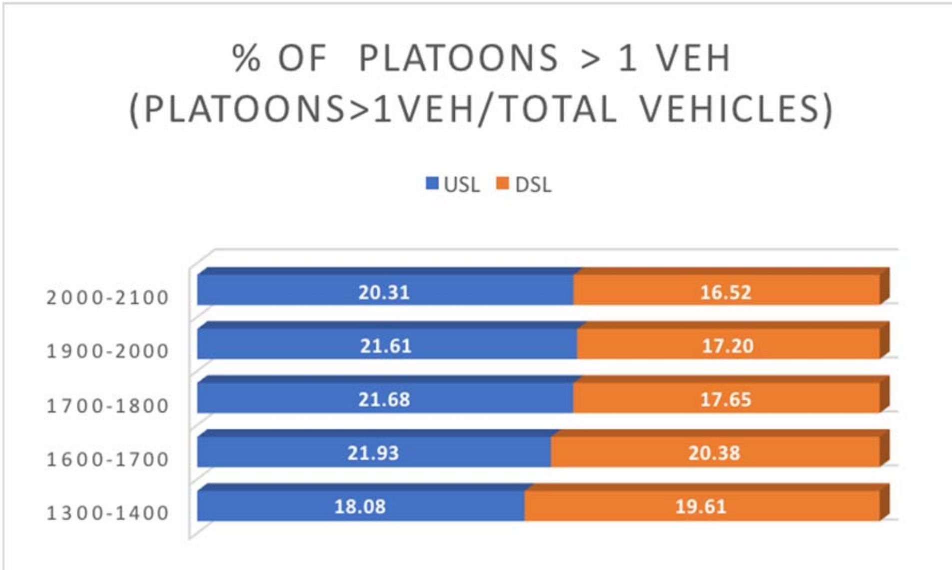


Figure D-19. Percentage of Platoons Longer than One Vehicle for USL vs. DSL, Passing Lane I

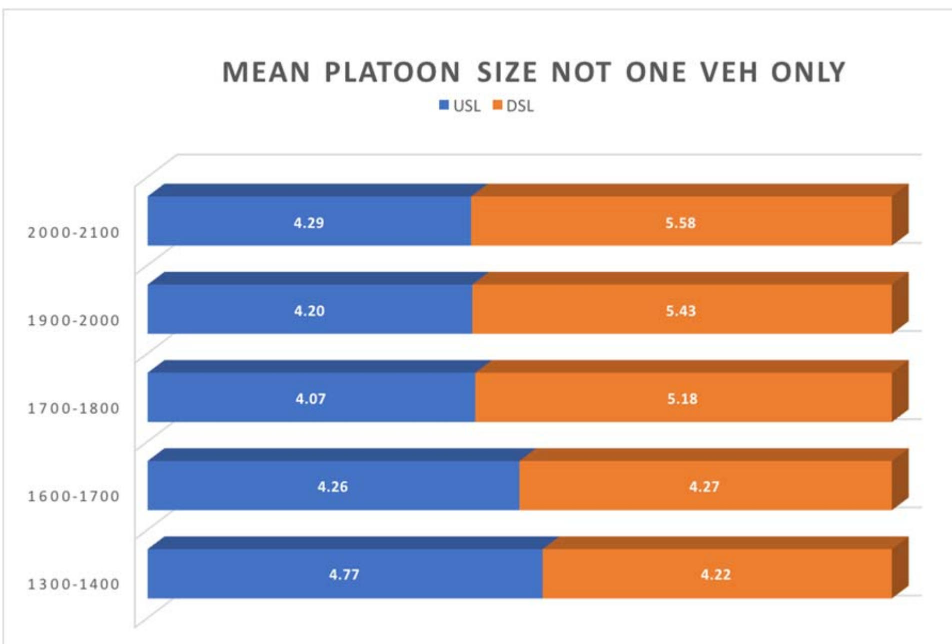


Figure D-20. Mean Size of Platoons Longer than One Vehicle for USL vs. DSL, Passing Lane I

Since large platoons can cause traffic flow and safety concerns, the sizes of the longest platoons out of the total traffic volume were extracted to evaluate if the DSL decreased platooning behavior as expected. Figure D-21 shows the percentage of vehicles in the longest platoon of the hour out of the total volume of vehicles. For 4 out of 5 hours, the percentage of vehicles in the longest platoon decreased due to the DSL, but as we have seen from earlier figures, the mean platoon size increased for 4 out of 5 hours, so this measure is probably more reliable than only comparing the longest of the platoons.

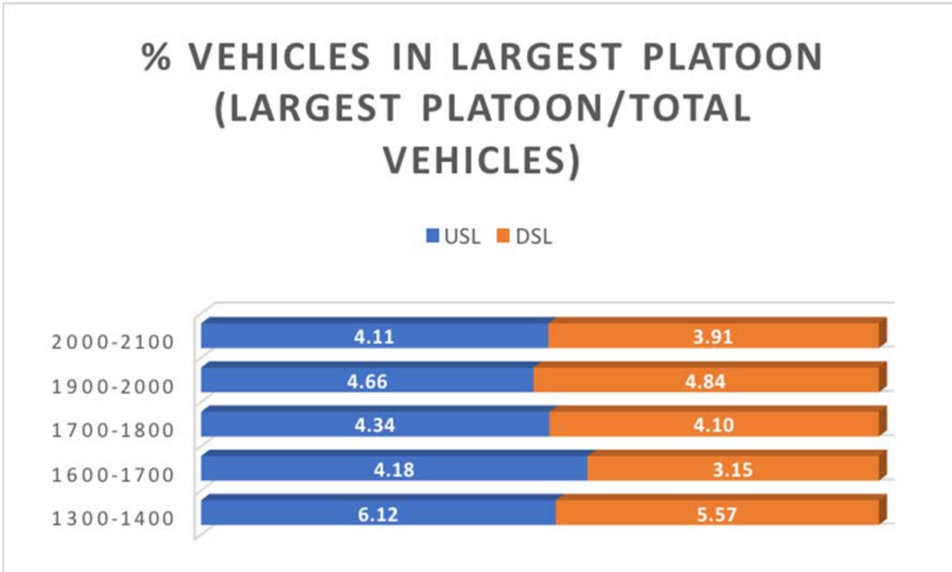


Figure D-21. Percentage of Vehicles in the Longest Platoon Out of Total Vehicles, Passing Lane I

Since the DSL is supposed to reduce platooning behavior, there should be a reduction in the size of each platoon, but this means that more platoons are formed in total. Since there are many one-vehicle platoons, Figure D-22 contains the percentage of the total number of platoons out of the total traffic volume. It appears that the number of platoons relative to the total traffic volume increased for 2 of the 5 hours going from the USL to the DSL, but decreased for 3 of the hours. The decrease in total percentage of platoons means that there are fewer platoons forming, but as seen in Figure D-20, the mean size of the platoons increased.

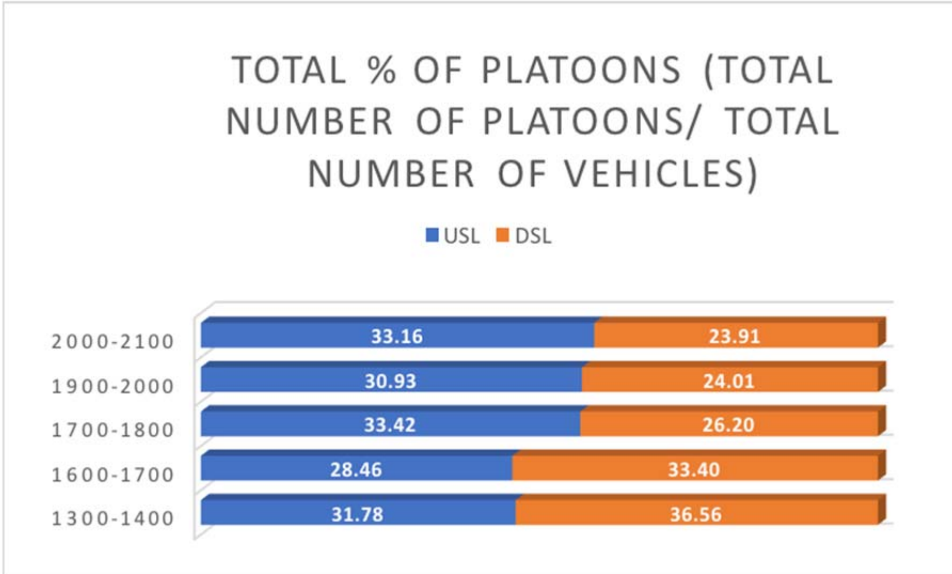


Figure D-22. Total Percentage of Platoons for USL vs. DSL, Passing Lane I

Passing Lane II

Figure D-23 shows the percent of platoons longer than one vehicle in PL-II. Two out of the 5 hours shown here have lower percentages of platoons longer than one vehicle due to the DSL; therefore, it is inconclusive whether the DSL caused a decrease in platooning behavior. Figure D-24 shows the mean size of the platoons that are longer than one vehicle. The mean platoon size decreased due to the DSL in only 2 out of the 5 hours shown. Therefore, it can be said that the DSL did not work effectively in decreasing the size of platoons in PL-II

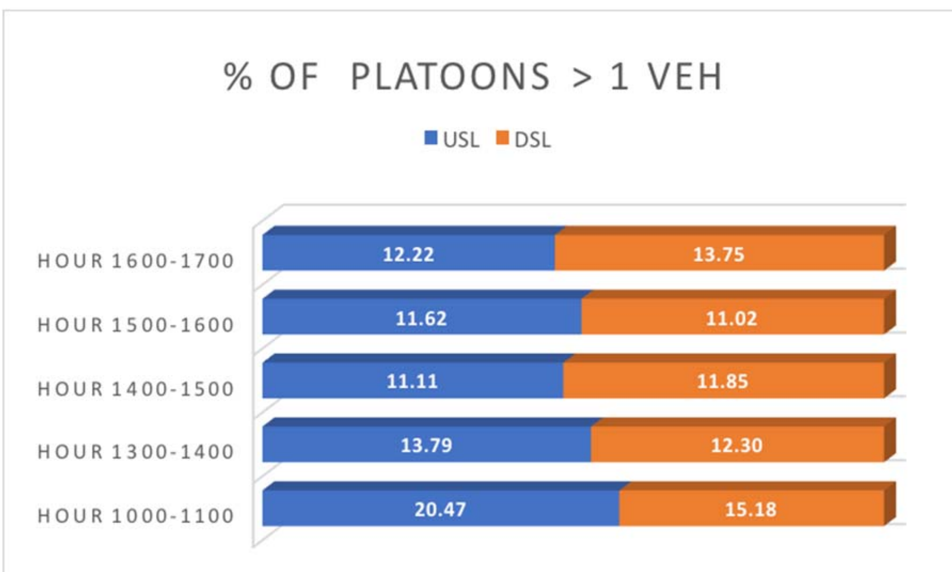


Figure D-23. Percentage of Platoons Longer than One Vehicle for USL vs. DSL, Passing Lane II

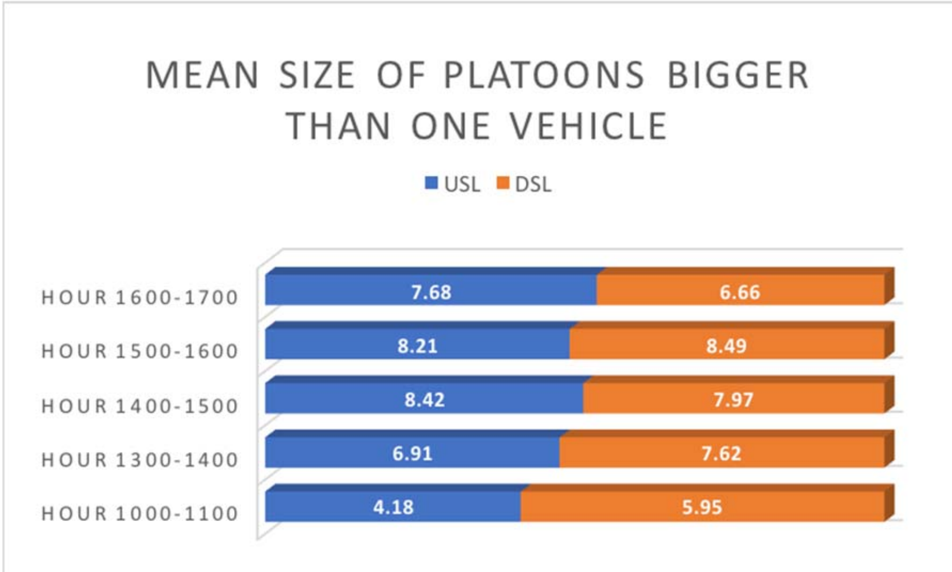


Figure D-24. Mean Size of Platoons Bigger than One Vehicle for USL vs. DSL, Passing Lane II

Figure D-25 shows the percentage of vehicles in the longest platoon of each hour out of the total volume of vehicles. For 3 out of 5 hours, the percentage of vehicles in the longest platoon decreased in the DSL sample. Out of the total volume of vehicles in hour 1400–1500 under the DSL condition, 9.32% of them were contained in the longest platoon. Figure D-26 depicts the total percentage of platoons in each hour for both USL and DSL conditions in PL-II. It appears as though the total percentage of platoons increased due to the DSL anywhere from 1% to 5% in 2 out of the 5 hours. In hour 1300–1400, there is only a difference between the USL and DSL of .03%, so it does not contribute to the comparison. That means the total percentage of platoons increased in the DSL sample for two of the hours and the total percentage of platoons decreased in the DSL sample for two of the hours. Therefore, the data given by the total percentage of platoons in PL II is inconclusive.

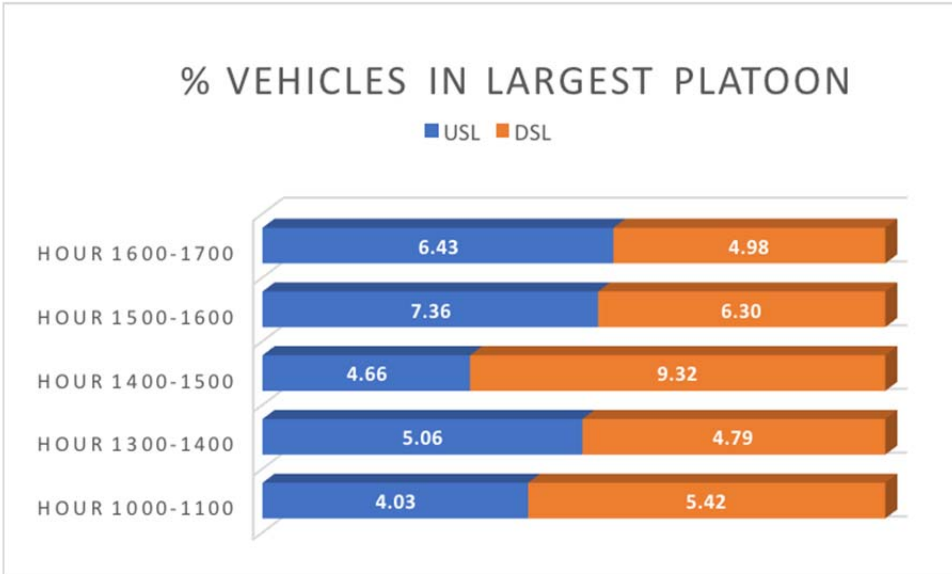


Figure D-25. Percentage of Vehicles in the Longest Platoon Out of Total Vehicles, Passing Lane II

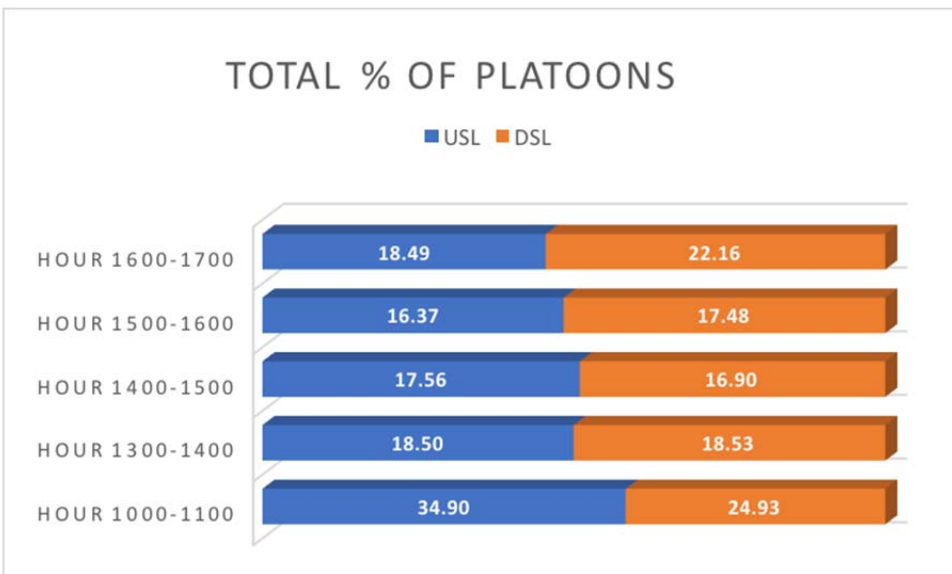


Figure D-26. Total Percentage of Platoons for USL vs. DSL, Passing Lane II

Passing Lane III

Figures D-27 and D-28 show the percentage of platoons longer than one vehicle in PL-III by each hour for the USL and DSL, respectively. Since the hours of each test sample are not the same, the results cannot be compared hour by hour, but it is clear by comparing the USL and DSL test samples that the DSL did not have a substantial effect on the percentage of platoons out of the total number of vehicles.

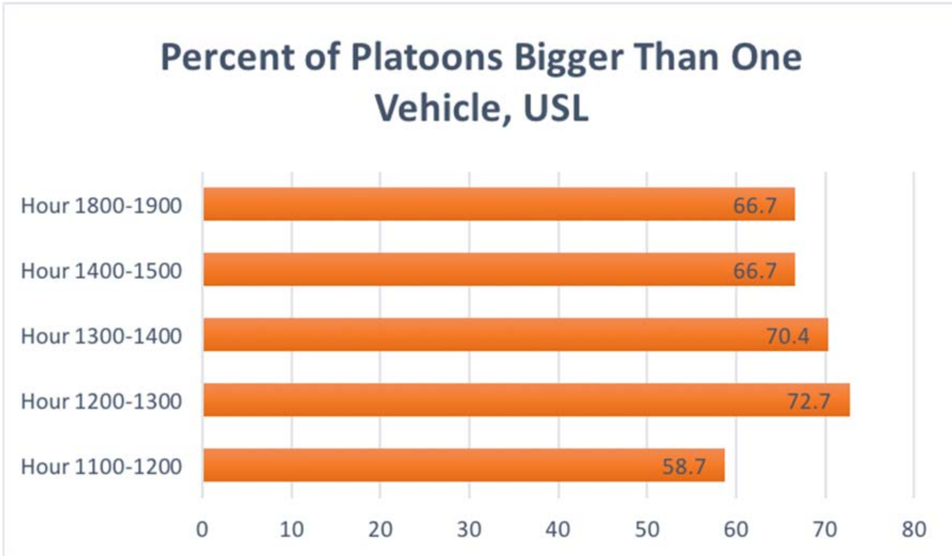


Figure D-27. Percent of Platoons Longer Than One Vehicle, USL, Passing Lane III

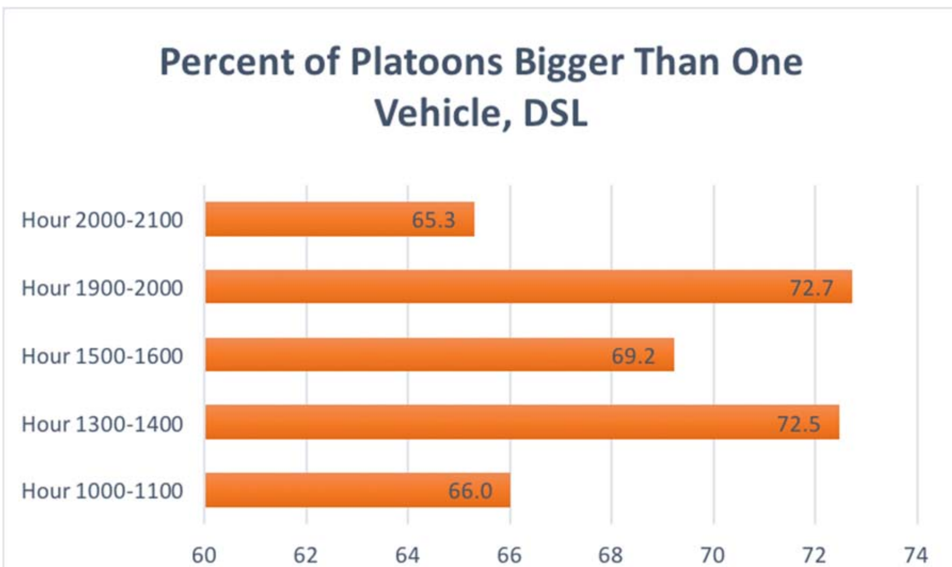


Figure D-28. Percent of Platoons Longer Than One Vehicle, DSL, Passing Lane III

Figures D-29 and D-30 show the mean size of platoons for platoons that are longer than one vehicle in PL-III by each hour for the USL and DSL, respectively. Hours cannot be compared independently for mean platoon size, and there is no general trend in numbers; therefore, the data in this set are inconclusive.

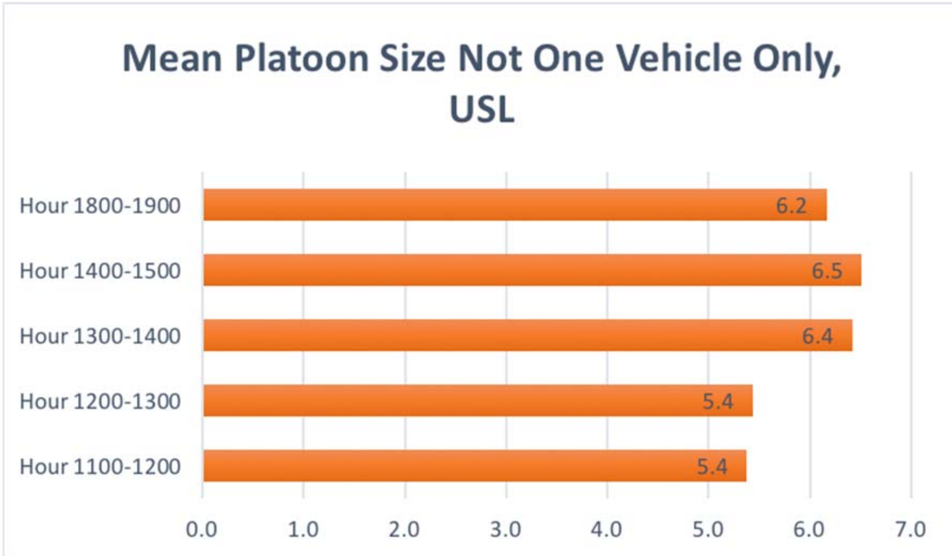


Figure D-29. Mean Platoon Size Not One Vehicle Only, USL, Passing Lane III

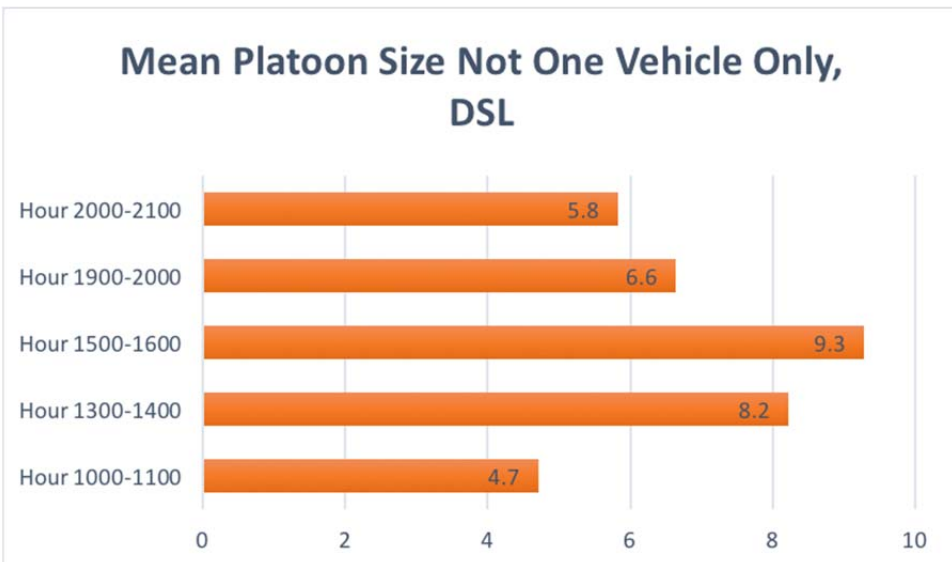


Figure D-30. Mean Platoon Size Not One Vehicle Only, DSL, Passing Lane III

Figures D-31 and D-32 show the percent of vehicles in the longest platoon in PL-III for the USL and the DSL, respectively. For both the USL and DSL test samples, the results show between 4% and 5% of vehicles in the longest platoon, with only a couple of outliers. Therefore, the DSL was not effective in reducing the percent of vehicles in the longest platoon.

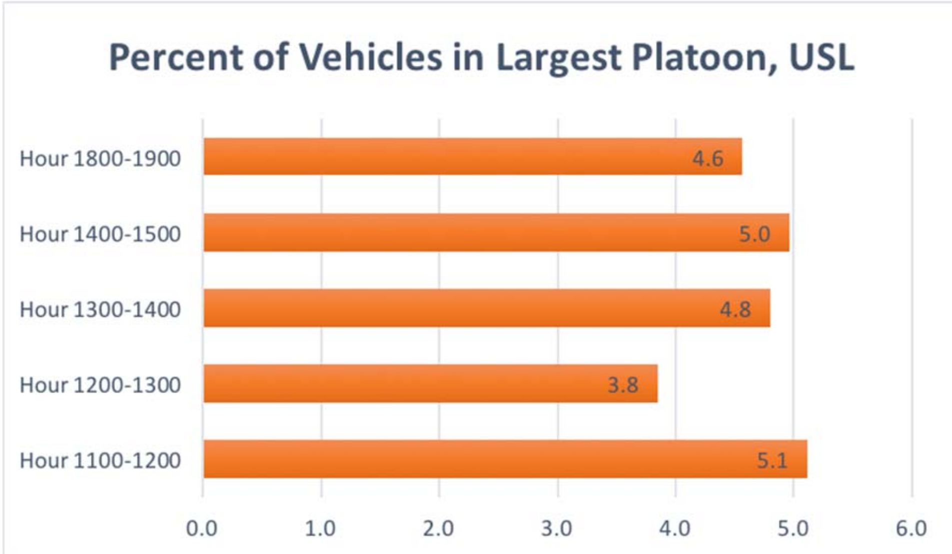


Figure D-31. Percent of Vehicles in the Longest Platoon, USL, Passing Lane III

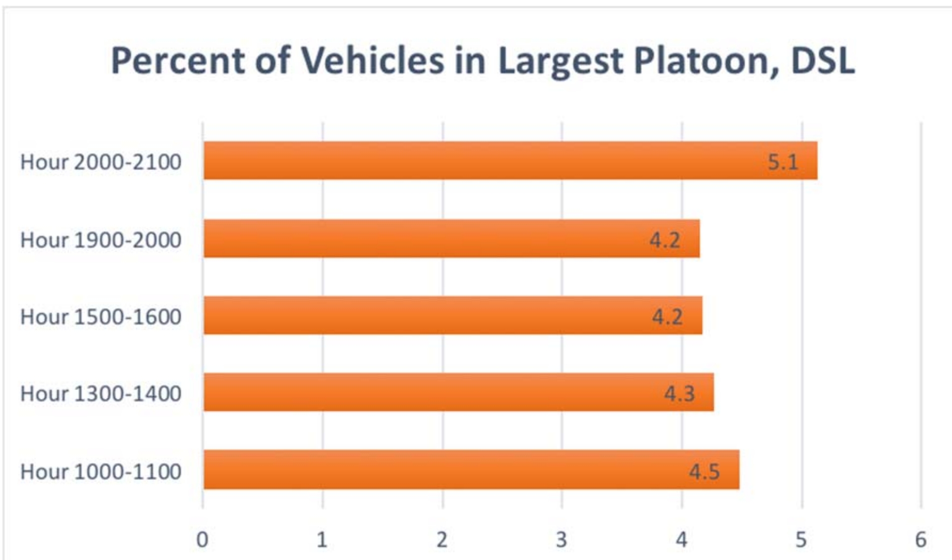


Figure D-32. Percent of Vehicles in the Longest Platoon, DSL, Passing Lane III

Figures D-33 and D-34 show the total percentage of platoons out of the total number of vehicles in PL-III for the USL and the DSL, respectively. It appears as though there is a general trend downward in percentages of platoons out of the total number of vehicles in the DSL condition. This signifies that the DSL may have decreased the percentage of platoons in PL-III, but from the mean platoon size analysis, it is clear that the vehicles are creating longer platoons.

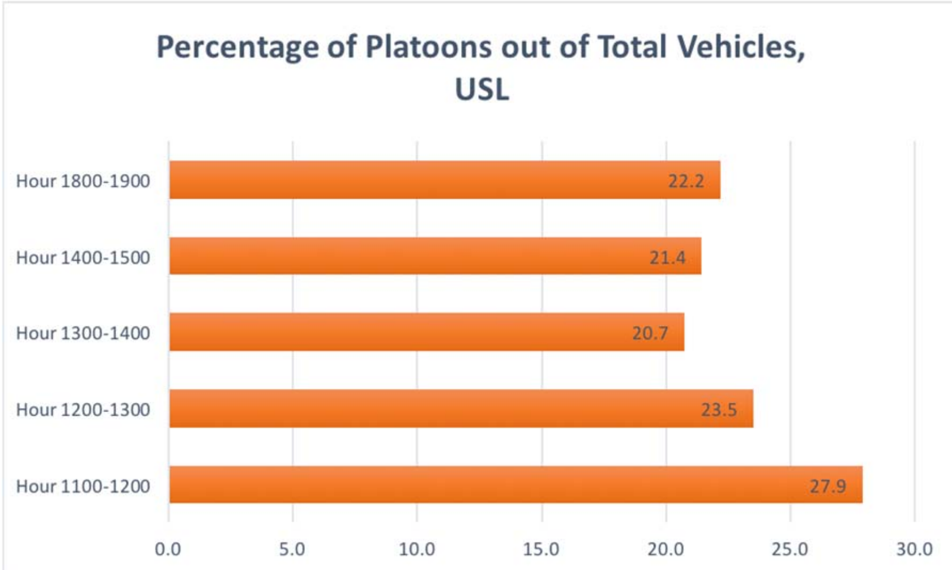


Figure D-33. Percent of Platoons Out of Total Vehicles, USL, Passing Lane III

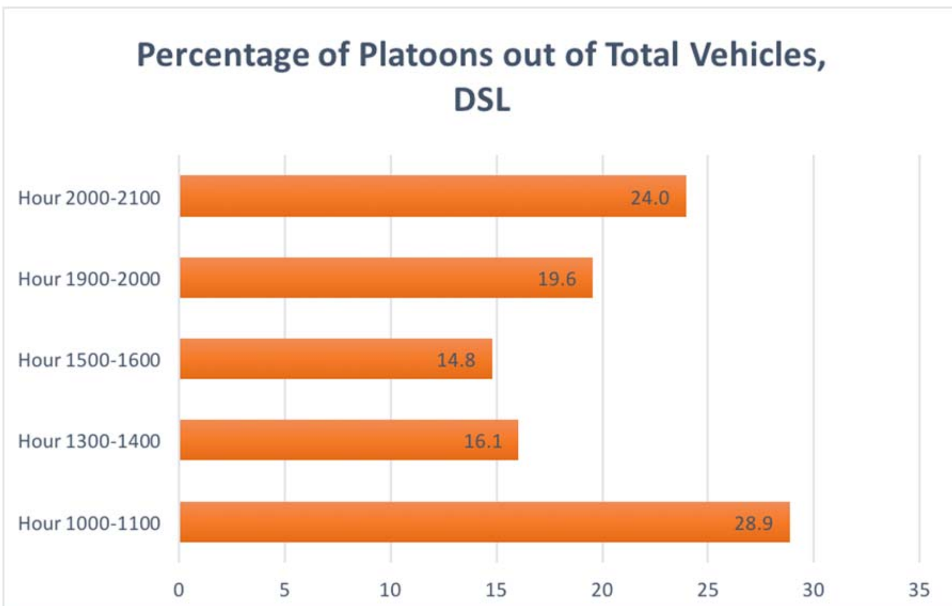


Figure D-34. Percent of Platoons Out of Total Vehicles, DSL, Passing Lane III

In conclusion, there are many deciding factors in determining whether DSLs in PL zones on two-lane, two-way undivided highways are effective in increasing traffic flow. One reason that some data were not completely conclusive is because the implementation of DSLs was only for a short period before video data were collected for analysis. Some amount of "shock" factor occurs after implementing a different traffic pattern on a busy highway. For example, we may actually see an increase in right side maneuvers (vehicles moving from the right lane to the left lane to pass a slower vehicle traveling in the right lane), because drivers enter the right lane of the PL expecting to be able to travel at 65 mph from their past experiences, but some may realize the speed limit is 55 mph and want to re-enter the left lane, which would require a passing maneuver. For this reason, DSLs in PL should be implemented for quite some time before taking video data in order to ensure that drivers who often travel the roadway are aware of the two speed limits and can choose a lane accordingly.