AN ABSTRACT OF THE THESIS OF

Megan E. Mecham for the degree of Master of Science in Civil Engineering presented on May 29, 2012

Title: Optimal Sensor Placement for Measuring Operating Speeds through Curves on Rural Two-Lane Highways

Abstract approved:____

Karen K. Dixon

Operating speed is one of the best performance measures that can tell transportation agencies how well or how poorly the transportation system is functioning. Fluctuating operating speeds often mean there is a design flaw or something about the physical road design that violates drivers' expectations. A primary example of this is a horizontal curve on a highway that had a reduced recommended advisory speed. Traditionally, researchers and transportation agencies measure operating speeds along the approach tangent to a horizontal curve and at the midpoint of the curve. This thesis looks at the significance of alternate measuring locations within the curve. It also analyzes the difference between the 85^{th} percentile maximum speed reduction and the more traditional measure of the reduction in 85^{th} percentile speeds, which is used as an indicator of safety.

Optimal Sensor Placement for Measuring Operating Speeds through Curves on Rural Two-Lane Highways

by
Megan E. Mecham

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APPROVED

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Major Professor, representing Civil Engineering

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Head of the School of Civil and Construction Engineering

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Dean of the Graduate School

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Megan E. Mecham, Author

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1.0 INTRODUCTION

Operating speed is one of the most tangible roadway performance measures apparent to the general public. Their eyes might glaze over when you start talking about volume-to-capacity ratios, Greensheild's models, split phasing, or advantages and disadvantages of actuated vs. semi-actuated traffic signals, but other than travel time, it is this author's opinion that operating speed is the best understood metric by drivers.

Drivers know when they are traveling slower than they would like to or than they usually do along a particular route, and can generally predict when there is something blocking the road ahead. Similarly, they know when they have taken a corner or a curve too fast because their stomach drops, or in the worst case scenario, they get into an accident.

This is why it is so important that engineers, designers, planners, and transportation agencies understand how people drive, so that the transportation agencies can properly design roads that do not violate drivers' expectations.

It is important that transportation agencies study traffic characteristics such as speed, but they have limited funds that restrict many of these study opportunities. The data from this thesis came from a research project where researchers collected speed data from eight sensors at each site; not many transportation agencies have the luxury of liberal placement of portable speed-measuring devices, so if they only have a few devices, where should they optimally put them?

This thesis tries to answer that question, particularly at horizontal curve locations on rural, two-lane highways. The author looked to answer the following research questions:

1. Is there a difference in the measured speed reduction when vehicles travel from the tangent approach to a point approximately one-third of the way through the curve and when they travel from the tangent approach to a point approximately two-thirds of the way through the curve? Does this speed reduction, or lack thereof, differ between passenger cars and heavy vehicles?
2. Is there a relationship between the maximum difference between 85^{th} percentile speeds at different points along a curve and the 85^{th} percentile maximum speed reduction of vehicles? If so, what is that relationship and how does that differ between passenger cars and heavy vehicles?

The outline of this thesis is as follows:

Chapter 2 is a literature review and discusses why we measure operating speeds, common types of data collection equipment, and what considerations to keep in mind when deciding on a piece of equipment.

Chapter 3 discusses how the data were collected including the site selection, the site layouts, and data applicability.

Chapter 4 presents the data analysis in two main parts. Section 4.1details how the author took the individual speed measurements and sequentially matched them to produce speed profiles and the techniques she used to filter out unwanted data.

Section 4.2 presents some summary statistics for all of the data and outlines how the author performed the statistical analyses in order to answer the research questions.

Chapter 5 presents the results of the statistical analyses.

Chapter 6 draws conclusions about the results, discusses the applicability of the author's findings, and presents opportunities for future work in this area.

2.0 LITERATURE REVIEW

In order to properly address the objective of this analysis, the author first looked at why researchers measure operating speeds and how the data are used, common data collection equipment, proper equipment selection and placement for collecting data on curves, and specific studies that used operating speeds through curves on rural, two-lane highways. This literature review presents the author's research in each of those areas.

2.1 WHY DO WE MEASURE OPERATING SPEEDS?

Researchers use operating speed for many types of studies. Robertson, Hummer, and Nelson (1994) list, among other studies, determining traffic operation and control parameters such as speed limits, advisory speeds, and traffic sign locations; establishing highway design elements; analyzing highway capacity; analyzing highway safety; and measuring effectiveness of controls or programs such as changing speed limits and enforcement programs. These studies may be performed by University researchers, transportation departments, or private companies contracted by the government.

Operating speed is a good indicator of how well a system is performing. If vehicles are constantly driving at a speed lower (by 5-10 mph) than the design speed, this indicates that either the roadway was not designed properly or there is a capacity issue. If vehicles are constantly increasing and decreasing their speed, this indicates that a particular part of the roadway is inconsistent with the rest or that it was not designed properly. This often happens at curves that are too sharp or not properly banked. Transportation agencies want to know where speeds are not consistent because "[i]t is accepted that there is a direct correlation between safety and variability in speeds." (McFadden & Elefteriadou, 2000) In other words, there is a higher likelihood of crashes at locations where drivers consistently have to decrease their speed.

Transportation agencies can use operating speed information to decide which sites are not performing adequately either at a capacity or a safety level. Some agencies also use the operating speed to set the speed limit of a road (Anderson, Bauer, Harwood, & Fitzpatrick, 1999). Both University researchers and transportation agencies most commonly use the 85^{th} percentile speed to describe the operating speed of a system. The 85^{th} percentile speed is the speed at which 85% of drivers drive at or below.

2.2 Common Data Collection Equipment

There are three main categories of speed-measuring devices: radar, manual speed traps, and automatic speed traps. Radar, and more recently lidar, guns transmit high-frequency waves that reflect off of vehicles and back to the gun. The vehicle changes the frequency of the wave and the radar or lidar device uses the ratio of the emitted and returning frequencies to calculate the speed of the vehicle (Robertson, Hummer, & Nelson, 1994). This is a direct measurement of speed, but must be done properly. Radar and lidar guns are most accurate when the angle between vehicle's direction of travel and the radar beam (as shown in Figure 2.1) is zero, i.e., the vehicle is traveling either directly toward or directly away from the radar gun. As the angle α increases,

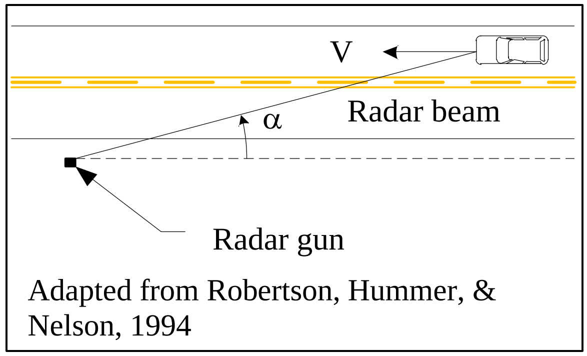


Figure 2.1: Angle of Incidence between Radar Beam and Vehicle

the radar's accuracy decreases as a function of the cosine of α. This decrease in accuracy results in a lower measured speed than the actual speed. Some radar guns correct for this error automatically, but only for preset angles.

Manual speed traps are much more "low-tech" and are rarely used now due to the prevalence of automatic speed-measuring devices. Manual speed traps estimate speed by measuring the time it takes a vehicle to travel a known distance. This distance is kept to a minimum in order to decrease any possibility of speed variation. Researchers now utilize automatic speed-measuring devices instead of manual speed traps because they are more accurate and do not need someone in the field the entire data collection period. These devices use the same methodology—measuring the time it takes a vehicle to travel a known distance—but are more accurate than manual measurements and can be analyzed quickly using computer software. These are indirect measurements of speed because they actually measure time and then calculate the speed.

There are many different types of automatic speed-measuring devices. In 2004, Gates, Schrock, and Bonneson conducted an experiment comparing the accuracy of handheld and on-pavement portable speed-measuring devices. The handheld devices were radar and lidar guns and the on-pavement devices included pneumatic tubes, piezoelectric sensors, and tape switch sensors.

The researchers instrumented a vehicle with a Nitestar distance measuring instrument (DMI) and ran it over the three on-pavement devices at a known speed (measured by the DMI) while also measuring the speed with radar and lidar guns. They ran this test at 35 mph and 55 mph to test devices' accuracies at high and low speeds against the DMI. Using paired t-tests, they found that there was a small but statistically significant difference between the DMI and the piezoelectric sensors and the DMI and radar device at 35 mph. They also found that there was a small but statistically significant difference between the DMI and all of the devices except for the radar gun at 55 mph. All of the devices except for the radar gun were less accurate at the higher speed. This is most likely due to the magnified effect of small installation errors (such as angle or length between tubes) of the on-pavement devices at higher speeds.

Although statistically significant, these differences were not large in magnitude; "for all device-DMI pairs, the mean paired difference in speed did not exceed 0.6 mph (based on the 95% confidence intervals). As a result, none of the devices were considered inaccurate in a practical sense." All of the device measurements were within ±1.5 mph of the true speed. They concluded since there was no one device that was clearly better than the others and they were all within ±1.5 mph of the true speed, other considerations should determine which device a research team uses. These considerations include the number of workers required to operate the device, installation time/process, geometry of the road, availability and price of equipment, conspicuity of devices, training and many others.

2.3 Equipment Selection for Curves

Measuring speeds on curves makes the equipment selection process a little bit more difficult. As discussed in Section 2.2, radar and lidar gun measurements must be corrected for the angle of the radar beam to the direction of travel, which changes as the vehicle travels through the curve. Automatic speed traps such as pneumatic tubes and piezoelectric sensors also depend on the angle at which the vehicle is traveling. For example, if a vehicle passes over a tube counter at any angle other than 90°, the device will record each wheel as a separate axle, thus doubling the vehicle count and making the speed calculations that much more complicated. While recording speeds on tangent sections, researchers can be confident that most, if not all, drivers will travel perpendicular to the two tubes, but drivers' travel paths differ more on curves and it would be impossible to select an angle for the tubes that would accurately count all vehicles. Sensors that record the entire vehicle instead of each axle are preferred when measuring speeds on curves.

2.4 Equipment Placement on Curves

Many studies, seeking to predict the operating speed of vehicles through horizontal curves, need to find the speed reduction of vehicles as they travel from the tangent approach into the curve. The most common configuration for this type of study is to take one measurement in the tangent section well before the curve and another one at the midpoint of the curve. Traditionally, researchers look at the reduction in the 85th percentile speed between the tangent and the midpoint of the curve, meaning they calculate the 85th percentile speed at the tangent and the 85th percentile speed at the midpoint of the curve and take the difference between them. In 2000, McFadden and Elefteriadou looked at calculating the actual speed reduction for each vehicle and finding the 85th percentile of that parameter. They collected speed data at nine points through an approach tangent and horizontal curve. They found that the 85th percentile of the maximum speed reduction is almost twice as high as the reduction in the 85th percentile speed and thus may be a more powerful predictor of crashes. They did not look at which location in the curve gave the maximum speed reduction, although they determined that nine data collection location points are better than two, "[t]he selection of two positions may be valid, but the midpoint of the approach tangent and the midpoint of the horizontal curve may not be the appropriate locations for data collection" (McFadden & Elefteriadou, 2000).

2.5 SUMMARY

Operating speed data is necessary for transportation agencies to identify locations that need improvement and may not be safe. There are many different types of speed measuring devices and no technology is more accurate than any other, so the selection of data collection equipment should depend on other needs or constraints of the study. In the case of measuring speeds on horizontal curves, radar and "speed trap" devices are not ideal because of error in the measurements as the angle of the vehicle trajectory changes. The optimal location of the speed-measuring devices through the curve is not well-known, but researchers have discovered that multiple points in the curve is more accurate than measuring only at the midpoint of the curve.

3.0 DATA COLLECTION

The data used for this research were originally collected for Dixon and Avelar's Oregon Department of Transportation (ODOT) research report, *SPR 685*: *Safety Evaluation of Curve Warning Speed Signs* (2011). This was a study on the safety effectiveness of speed advisory signs at curves on rural two-lane highways. In this chapter, the author will give a brief summary of the site selection and data collection methods used in this study, but for a more detailed description of these methods, the reader is referred to the ODOT report and Avelar's Master of Science thesis from Oregon State University (2010).

Section 3.1 reviews how the study sites were selected. Section 3.2 describes the equipment used to collect the data. Section 3.3 describes the layout of the data collection equipment in the field. Section 3.4 identifies limitations inherent in the data. Section 3.5 summarizes this chapter.

3.1 SITE SELECTION

Dixon and Avelar (2011) selected 16 sites from a pool of state-maintained, rural, two-lane highways in ODOT Regions 1, 2, and 3. Potential sites included any curve on a rural, two-lane highway with a curve warning sign. They estimated the number of potential sites in this pool to be 673 using a computer simulation based on previous studies. Using this estimate, the researchers determined that a minimum of 15 locations needed to be observed in order to have a statistically representative sample. Each location has two directions of travel which they treated as separate sites. They randomly selected 20 locations using stratified, double, and cluster sampling and collected data at 18 locations. Only 16 of the locations produced usable data; these 16 locations make up Dixon and Avelar's final speed data set.

Of the 16 locations, four of them have intersections in the middle of the curve and were excluded from this analysis. One of the locations has a passing lane in one direction so the researchers installed two sensors in each lane for that direction of traffic and four sensors in the opposing lane following the general layout described in Section 3.3. The data from the two passing lanes was not included in this analysis. This results in the analysis of 12 locations, 11 of which have two directions of traffic for a total of 23 sites. The researchers considered each direction of travel at a single location to be independent of the other. From this point forward, the word "site" refers to a set of four devices in one travel direction and the word "location" refers to the curve or set of curves where the research team placed all eight devices. Figure 3.1 shows each of the 12 locations on a map of Oregon and they are listed in Table 3.1. The speed limit at each site was 55 mph and they had advisory speeds ranging from 35 to 40 mph. Three locations did not have an advisory speed sign.

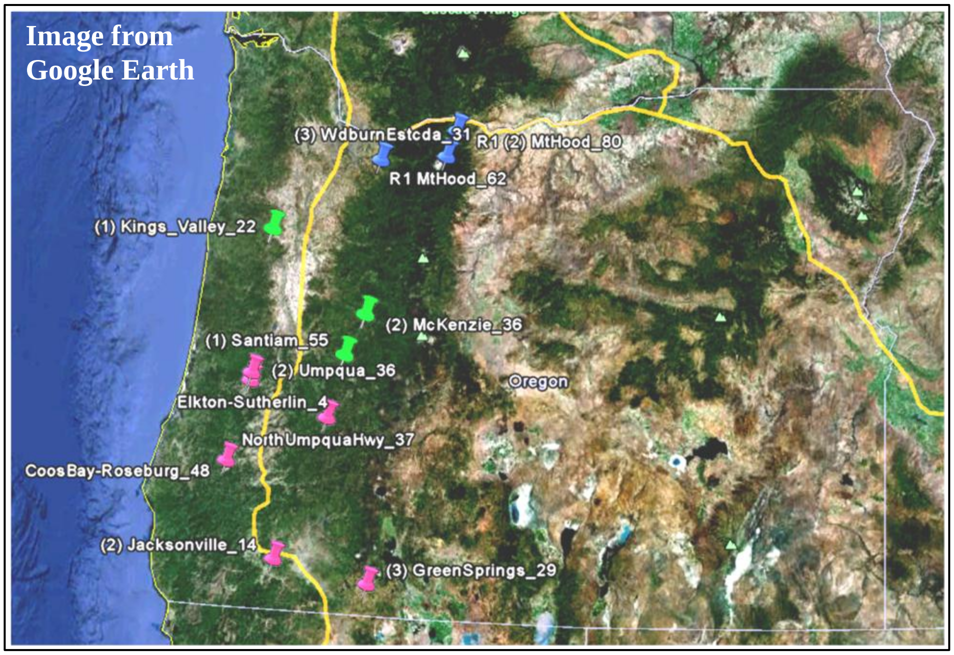


Figure 3.1: Map of Data Collection Locations

Table 3.1: List of Data Collection Locations

ODOT Region	Highway Name	Direction	No. of Lanes Collected	Notes
1	Mt. Hood (62)	North-South	2	
	Mt. Hood (80)	North-South	2	
	Woodburn-Estacada	North-South	2	
2	Kings Valley	North-South	2	
	McKenzie	East-West	2	
	Santiam	East-West	2	
3	Umpqua	East-West	2	Westbound traffic only, in right and passing lanes.
	Elkton-Sutherlin	North-South	2	
	North Umpqua	East-West	2	
	Coos Bay-Roseburg	East-West	1	Westbound traffic only.
	Jacksonville	East-West	2	
	Green Springs	East-West	2	

3.2 DATA COLLECTION EQUIPMENT

The research team collected data using on-pavement sensors that measure the speed and length of a vehicle as it passes over the sensor. The devices were NC-200 HiStar® Traffic Analyzers from Quixote Transportation Technologies, Inc., now owned by Vaisala. They "monitor the earth's magnetic field and identify disruptions in the form of approaching speed, as vehicles enter and therefore interrupt the magnetic field" (Dixon & Avelar, 2011). Figure 3.2 shows a photograph of the eight sensors lined up for calibration, and Figure 3.3 shows one sensor installed on the Jacksonville Hwy.

Figure 3.2: NC-200 Traffic Analyzers Lined up for Calibration

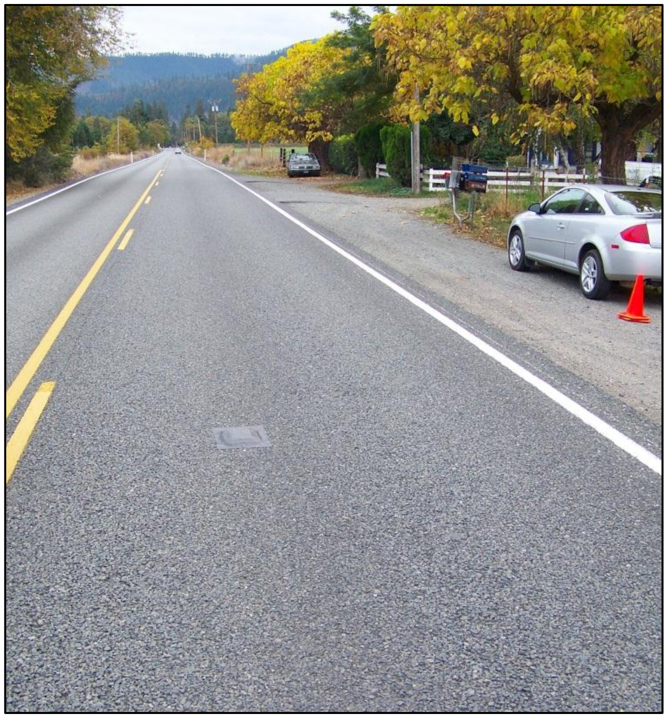


Figure 3.3: NC-200 Traffic Analyzer Installed in the Field

3.3 Site Layout

Each speed data collection configuration includes the use of eight devices at each location, four in each direction of travel. Nine locations had only one curve and the sensors in each direction of travel were laid out symmetrically. One device was placed upstream of the curve, prior to the curve warning sign. Two devices were placed in the curve, approximately one-third and two-thirds of the way through the curve (measured from the point of curvature [PC] to the point of tangency [PT]). The final device was placed downstream of the curve, a distance from the PT approximately equal to the distance between the PC and the first device. Figure 3.4 shows this general layout.

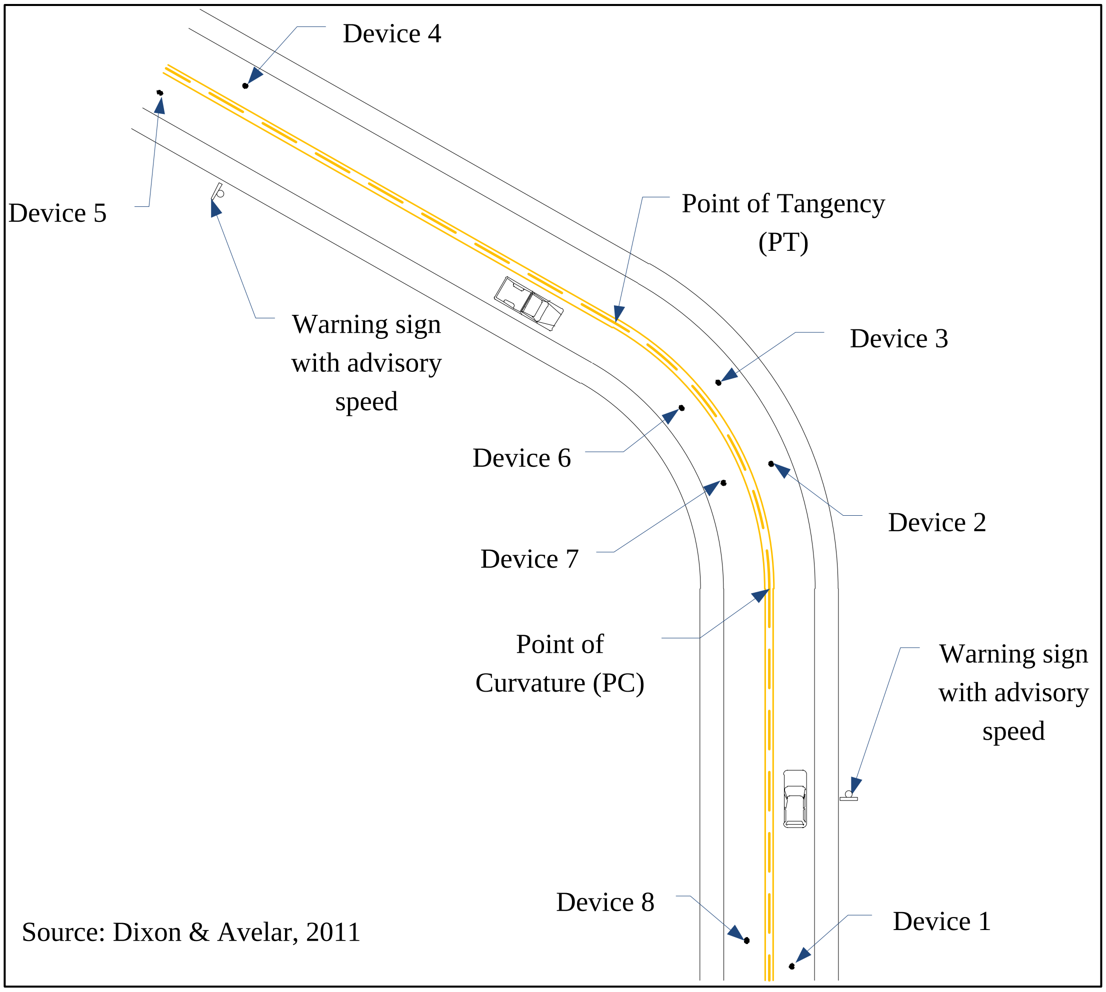


Figure 3.4: General Site Layout

Three of the locations had reverse or closely spaced multiple curves, so these locations required alternative device configuration. At these locations, devices 1-4 were placed on one curve and devices 5-8 were placed on the other, recording traffic going in the opposite direction. For both curves, the devices were placed so that a vehicle traveling in the direction going from one curve to the second—no matter the general direction of travel—would pass over the devices in increasing order (1 to 4 or 5 to 8). Figure 3.5 shows the layout of the devices at these three locations. From this point forward, the author will refer to the data collection points on the approach

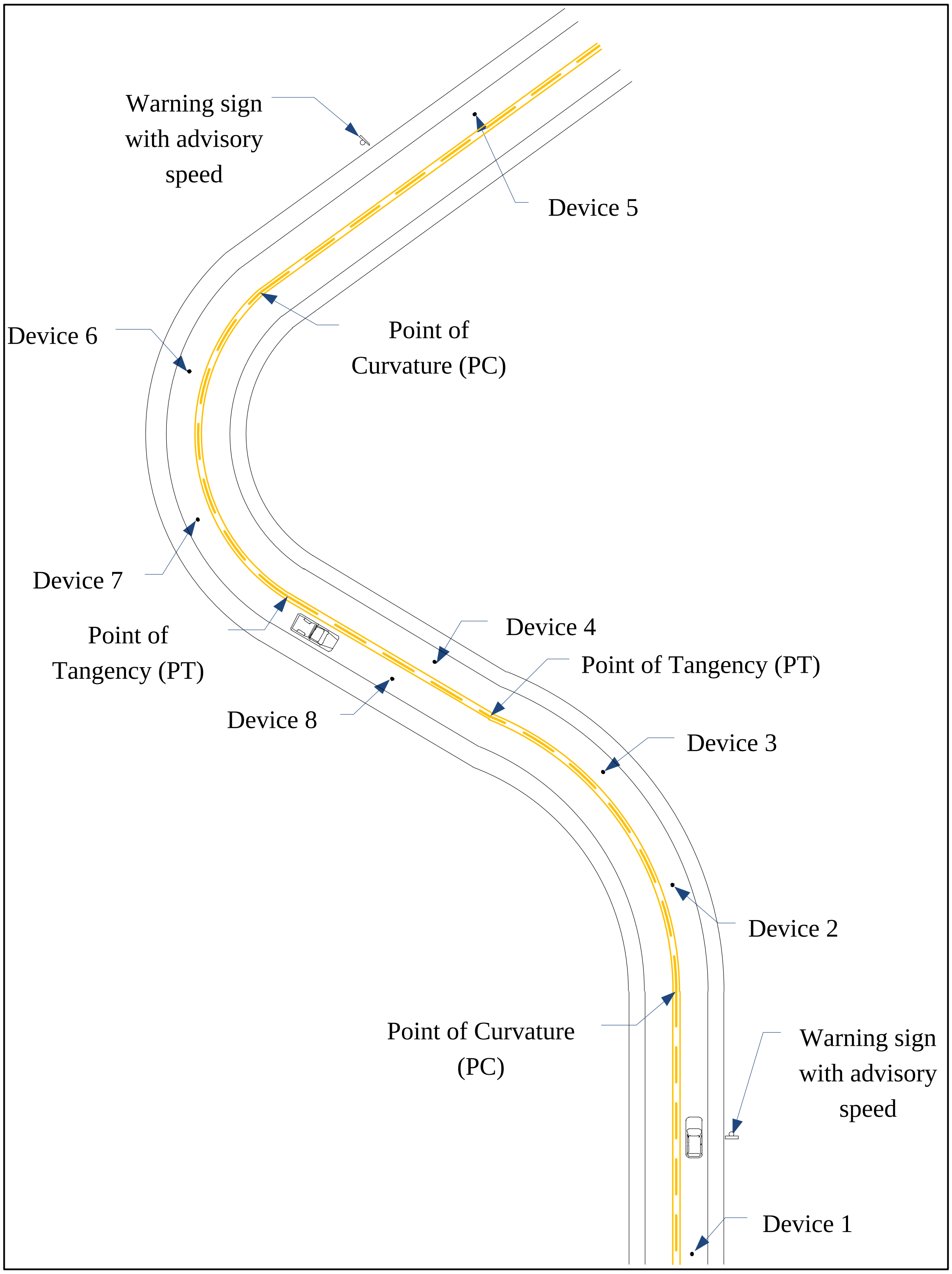


Figure 3.5: General Site Layout at Reverse Curves

tangent, one-third of the way through the curve, two-thirds of the way through the curve, and on the exit tangent as Point 1, Point 2, Point 3, and Point 4, respectively.

3.4 DATA APPLICABILITY

The researchers selected sites from a very specific pool of possible sites. Consequently, the results of this analysis will be applicable only to similar sites. However, this opens the possibility to replicate this analysis on a broader set of curves. This analysis is relevant to curves that:

1. Are on rural, two-lane highways,
2. Have curve advisory signs—because the original study was done to analyze the effectiveness of curve warning and speed advisory signs, the research team only collected data at curves with such signs.
3. Are in ODOT Regions 1, 2, and 3—researchers only collected data in these three regions because the majority of Oregon's population lives in these three regions and thus any results of the previous analysis could be "relevant at a policy making level" (Dixon & Avelar, 2011) .

3.5 SUMMARY

Originally, Dixon and Avelar (2011) selected 20 locations using stratified, double, and cluster sampling. They used data from 16 of these locations for their analysis and the author analyzed data from twelve of them. The research team used eight NC-200 HiStar® Traffic Analyzers from Quixote Transportation Technologies, Inc., placing four on each curve. They placed one device on the approach tangent, two in the curve, and one on the exiting tangent. While the scope of Dixon and Avelar's analysis narrowed the pool of possible sample curves, this presents opportunities to future researchers to analyze curves without warning signs.

4.0 DATA ANALYSIS

This chapter summarizes the author's procedure for taking the raw data from the NC-200 traffic analyzers, developing speed profiles for individual vehicles, and performing the subsequent statistical analyses.

Section 4.1 discusses how the author processed the data in order to analyze it. Section 4.2 presents summary statistics of the speed data and the procedure the author followed for the statistical analysis of the data in terms of answering the research questions presented in the introduction.

4.1 DATA PROCESSING

Before the author could run any statistical analyses, she first had to develop each vehicle's speed profile. The process that she used is presented in Section 4.1.1. Once she developed the speed profiles, she had to decide which data points were usable. She looked at the diagnostic tag that the NC-200 traffic analyzers assigned each vehicle and the time headway of each vehicle. Section 4.1.2 summarizes the data filtering process.

4.1.1 Obtaining Speed Profiles

The raw sequential data from the NC-200 devices consisted of a vehicle number, time stamp, diagnostic tag, speed measurement, length measurement, time headway, distance headway, and a tailgating tag for each vehicle that passed. Table 4.1shows the first five lines of raw data from the first sensor on northbound Mt. Hood Hwy (62).

Table 4.1: Example of Raw Data from Traffic Analyzers

Veh. No.	Time Stamp	Diagnostic	Speed	Length	Time Headway	Distance Headway	Tailgating
1	2009/09/24 10:00:09.00	Normal	48 MPH	12.00 FT	0	0	No
2	2009/09/24 10:02:58.00	Normal	70 MPH	16.00 FT	169	17,351	No
3	2009/09/24 10:05:02.00	Normal	46 MPH	44.00 FT	124	8,366	No
4	2009/09/24 10:08:03.00	Normal	49 MPH	10.00 FT	181	13,008	No
5	2009/09/24 10:11:33.00	Less than Minimum	0 MPH	0.00 FT	210	0	No

Each site had four separate spreadsheets of data that the author combined for this effort. The four sensors in each lane were not interconnected or coordinated, so in order to create speed profiles of individual vehicles, the author had to manually match vehicles across the four sensors. This proved to be much more tedious than originally anticipated because although each measurement had a time stamp, the clocks on all four sensors were also not well-coordinated. As the author scanned the data, it became obvious that sensors would often miss a vehicle, throwing off the profiles of the subsequent vehicles. The author needed to move these data points up and down until the four measurements of each vehicle were all in the same row of the spreadsheet. The process she developed is as follows:

Step 1: Combine data from all four sensors in one spreadsheet.

The author created a table with the vehicle number, time stamp, speed measurement, and length measurement of every vehicle at all four sensors for each site as shown in Figure 4.1. If vehicles were tagged with any diagnostic other than “Normal,” the author highlighted them.

Veh.	Time Stamp				Speed (s)				Length (ft)			
	1	2	3	4	1	2	3	4	1	2	3	4
1	2009/09/24 10:00:09.00	2009/09/24 10:00:17.00	2009/09/24 10:00:23.00	2009/09/24 10:00:31.00	48	56	52	54	12	20	23	23
2	2009/09/24 10:02:58.00	2009/09/24 10:03:06.00	2009/09/24 10:03:13.00	2009/09/24 10:03:21.00	70	50	51	56	16	16	15	17
3	2009/09/24 10:05:02.00	2009/09/24 10:05:10.00	2009/09/24 10:05:16.00	2009/09/24 10:05:25.00	46	51	50	47	44	62	64	35
4	2009/09/24 10:08:03.00	2009/09/24 10:08:10.00	2009/09/24 10:11:46.00	2009/09/24 10:05:25.00	49	57	59	47	10	13	14	10
5	2009/09/24 10:11:33.00	2009/09/24 10:11:40.00	2009/09/24 10:14:34.00	2009/09/24 10:08:23.00	0	38	44	49	0	12	14	10
6	2009/09/24 10:14:19.00	2009/09/24 10:14:28.00	2009/09/24 10:15:21.00	2009/09/24 10:11:53.00	52	49	25	58	17	18	68	18
7	2009/09/24 10:14:54.00	2009/09/24 10:15:10.00	2009/09/24 10:17:04.00	2009/09/24 10:14:43.00	32	0	53	60	70	0	17	19
8	2009/09/24 10:16:51.00	2009/09/24 10:16:58.00	2009/09/24 10:17:37.00	2009/09/24 10:15:38.00	58	51	47	27	16	15	18	76
9	2009/09/24 10:17:23.00	2009/09/24 10:17:30.00	2009/09/24 10:17:58.00	2009/09/24 10:17:12.00	58	49	41	52	18	14	19	16
...	...	...	...	...	...	...	...	...	...	...	...	...

Figure 4.1: Step 1 of Speed Profile Development-Composite Spreadsheet

Step 2: Calculate time between sensors and time between vehicles.

The author added columns to the spreadsheet that calculated the time between sensors for each vehicle and the time between vehicles at each sensor (known as the time headway). This is shown in Figure 4.2.

Veh.	Time Stamp				Time Headway (s)				Travel Time (s)			
	1	2	3	4	1	2	3	4	1-2	2-3	3-4	1-4
1	2009/09/24 10:00:09.00	2009/09/24 10:00:17.00	2009/09/24 10:00:23.00	2009/09/24 10:00:31.00					8	6	8	22
2	2009/09/24 10:02:58.00	2009/09/24 10:03:06.00	2009/09/24 10:03:13.00	2009/09/24 10:03:21.00	169	169	170	170	8	7	8	23
3	2009/09/24 10:05:02.00	2009/09/24 10:05:10.00	2009/09/24 10:05:16.00	2009/09/24 10:05:25.00	124	124	123	124	8	6	9	23
4	2009/09/24 10:08:03.00	2009/09/24 10:08:10.00	2009/09/24 10:11:46.00	2009/09/24 10:05:25.00	181	180	390	0	7	216	-381	-158
5	2009/09/24 10:11:33.00	2009/09/24 10:11:40.00	2009/09/24 10:14:34.00	2009/09/24 10:08:23.00	210	210	168	178	7	174	-371	-190
6	2009/09/24 10:14:19.00	2009/09/24 10:14:28.00	2009/09/24 10:15:21.00	2009/09/24 10:11:53.00	166	168	47	210	9	53	-208	-146
7	2009/09/24 10:14:54.00	2009/09/24 10:15:10.00	2009/09/24 10:17:04.00	2009/09/24 10:14:43.00	35	42	103	170	16	114	-141	-11
8	2009/09/24 10:16:51.00	2009/09/24 10:16:58.00	2009/09/24 10:17:37.00	2009/09/24 10:15:38.00	117	108	33	55	7	39	-119	-73
9	2009/09/24 10:17:23.00	2009/09/24 10:17:30.00	2009/09/24 10:17:58.00	2009/09/24 10:17:12.00	32	32	21	94	7	28	-46	-11
...	...	...	...	...	...	...	...	...	...	...	...	...

Figure 4.2: Step 2 of Speed Profile Development-Time Calculations

Originally, the author intended to check whether or not two data points belonged to the same vehicle by using the time stamp and the speed measured at the first sensor to predict the time stamp at the second sensor and comparing the predicted time value to the actual time stamp. For example, if the first sensor detects a vehicle at 10:32:43 and measures its speed as 60 mph, one would predict that the vehicle would reach the second sensor, 420 ft downstream, around 10:32:48 (five seconds later), allowing for some leeway due to rounding and non-constant speeds. However, since the clocks were not coordinated, it was not uncommon to see a vehicle detected at a downstream sensor at a time stamp before an upstream sensor or to have a vehicle that could travel 1,000 ft in two seconds, but took 20 seconds to travel 200 ft.

Step 3: Graph the time between sensors and look for peaks/valleys.

Although the clocks were not coordinated, the calculated time that it took each vehicle to travel from one sensor to the next should still be fairly similar—allowing for some variation due to changing speeds. In order to find the data points where this was not true, the author graphed the time between sensors vs. vehicle number as shown in Figure 4.3. If the lines are relatively straight, the data points are matched up properly (section *(a)* of Figure 4.3). If there is a sharp peak or valley (point *(b)* of Figure 4.3), that indicates that one or more of the sensors has missed a vehicle and the profiles no longer match up. Using this graph, the author could see where the data points did not match up and use the time headways to determine which sensor or sensors had missed the vehicle. Figure 4.3 indicates that vehicle 4 has an irregularity.

Step 4: Determine which sensor or sensors missed a vehicle and adjust data accordingly.

The time headway between two vehicles should be the approximately equal at every sensor. If one time headway is larger than the other three, that indicates that that sensor has missed a vehicle. When this happened, the author moved that column of data down until all four time headways were approximately equal again and the time between sensors was similar to the rest of the data. After the author adjusted the time stamp values, she also moved the speed and length data accordingly. She then inspected the graph again to find the next irregularity. Figures 4.4-4.7 illustrate this process.

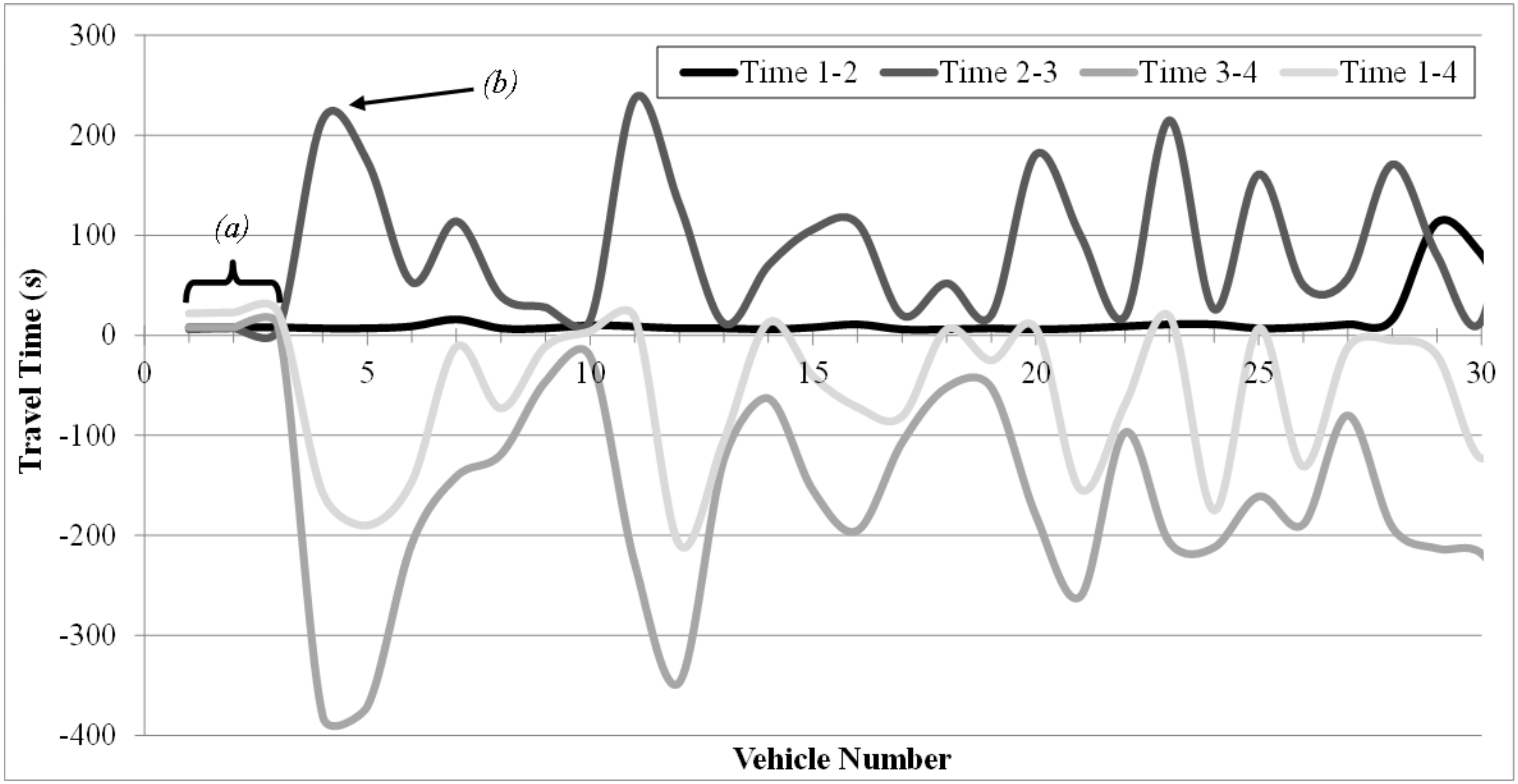


Figure 4.3: Graph Showing Travel Time Irregularities

Veh.	Time Stamp				Time Headway (s)				Travel Time (s)			
	1	2	3	4	1	2	3	4	1-2	2-3	3-4	1-4
1	2009/09/24 10:00:09.00	2009/09/24 10:00:17.00	2009/09/24 10:00:23.00	2009/09/24 10:00:31.00					8	6	8	22
2	2009/09/24 10:02:58.00	2009/09/24 10:03:06.00	2009/09/24 10:03:13.00	2009/09/24 10:03:21.00	169	169	170	170	8	7	8	23
3	2009/09/24 10:05:02.00	2009/09/24 10:05:10.00	2009/09/24 10:05:16.00	2009/09/24 10:05:25.00	124	124	123	124	8	6	9	23
4	**2009/09/24 10:08:03.00**	**2009/09/24 10:08:10.00**	**2009/09/24 10:11:46.00**	**2009/09/24 10:05:25.00**	**181**	**180**	**390**	**0**	**7**	**216**	**-381**	**-158**
5	2009/09/24 10:11:33.00	2009/09/24 10:11:40.00	2009/09/24 10:14:34.00	2009/09/24 10:08:23.00	210	210	168	178	7	174	-371	-190
6	2009/09/24 10:14:19.00	2009/09/24 10:14:28.00	2009/09/24 10:15:21.00	2009/09/24 10:11:53.00	166	168	47	210	9	53	-208	-146
7	2009/09/24 10:14:54.00	2009/09/24 10:15:10.00	2009/09/24 10:17:04.00	2009/09/24 10:14:43.00	35	42	103	170	16	114	-141	-11
8	2009/09/24 10:16:51.00	2009/09/24 10:16:58.00	2009/09/24 10:17:37.00	2009/09/24 10:15:38.00	117	108	33	55	7	39	-119	-73
9	2009/09/24 10:17:23.00	2009/09/24 10:17:30.00	2009/09/24 10:17:58.00	2009/09/24 10:17:12.00	32	32	21	94	7	28	-46	-11
...	...	...	...	...	...	...	...	...	...	...	...	...

Headways are not equal

Travel times are not consistent

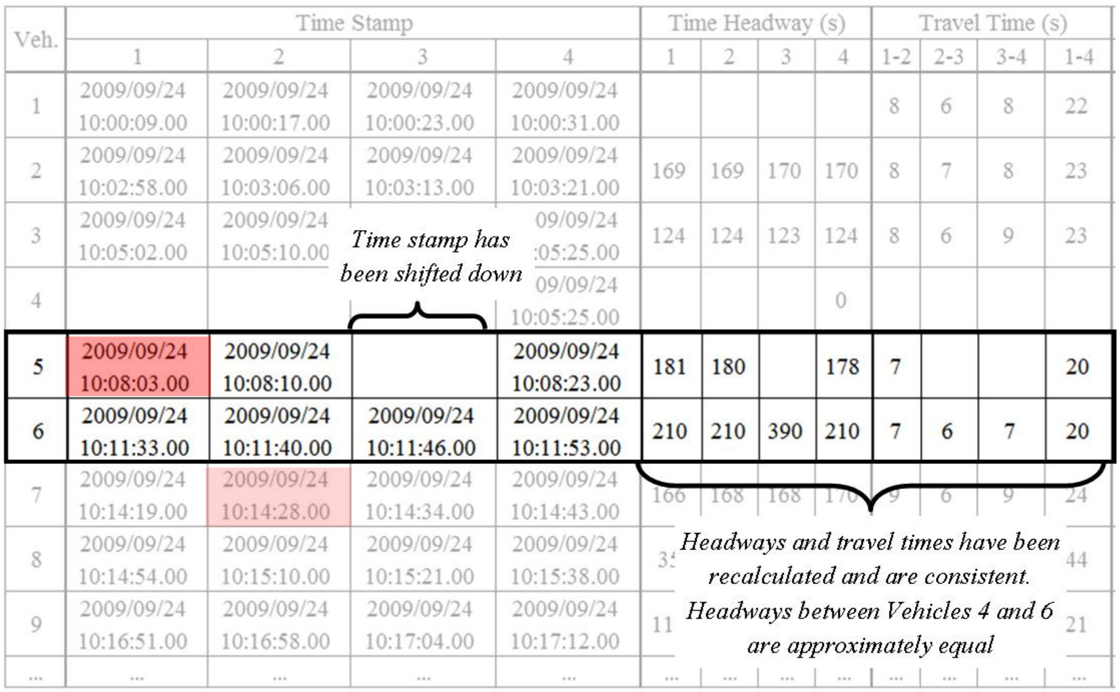
Figure 4.4: Speed Profile Development: Identifying Irregular Data Points

Veh.	Time Stamp				Time Headway (s)				Travel Time (s)			
	1	2	3	4	1	2	3	4	1-2	2-3	3-4	1-4
1	2009/09/24 10:00:09.00	2009/09/24 10:00:17.00	2009/09/24 10:00:23.00	2009/09/24 10:00:31.00					8	6	8	22
2	2009/09/[illegible] 10:02:58.[illegible]	[illegible]	[illegible]09/09/24 [illegible]03:13.00	2009/09/24 10:03:21.00	169	169	170	170	8	7	8	23
3	2009/09/[illegible] 10:05:02.00	[illegible] 10:05:10.00	[illegible]09/09/24 10:05:16.00	2009/09/24 10:05:25.00	124	124	123	124	8	6	9	23
4				**2009/09/24 10:05:25.00**				**0**				
5	**2009/09/24 10:08:03.00**	**2009/09/24 10:08:10.00**	**2009/09/24 10:11:46.00**	**2009/09/24 10:08:23.00**	**181**	**180**	**390**	**178**	**7**	**216**	**-203**	**20**
6	2009/09/24 10:11:33.00	2009/09/24 10:11:40.00	2009/09/24 10:14:34.00	2009/09/24 10:11:53.00	210	210	168	210	[illegible]	174	-161	20
7	2009/09/24 10:14:19.00	2009/09/24 10:14:28.00	2009/09/24 10:15:21.00	2009/09/24 10:14:43.00	166	1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24
8	2009/09/24 10:14:54.00	2009/09/24 10:15:10.00	2009/09/24 10:17:04.00	2009/09/24 10:15:38.00	35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44
9	2009/09/24 10:16:51.00	2009/09/24 10:16:58.00	2009/09/24 10:17:37.00	2009/09/24 10:17:12.00	117	108	33	94	7	39	-25	21
...	...	...	...	...	...	...	...	...	...	...	...	...

Time stamps have been shifted down

Headways and travel times have been recalculated, but still are not consistent

Figure 4.5: Speed Profile Development: Shifting Data Points



Veh.	Time Stamp 1	Time Stamp 2	Time Stamp 3	Time Stamp 4	Time Headway (s) 1	2	3	4	Travel Time (s) 1-2	2-3	3-4	1-4
1	2009/09/24 10:00:09.00	2009/09/24 10:00:17.00	2009/09/24 10:00:23.00	2009/09/24 10:00:31.00					8	6	8	22
2	2009/09/24 10:02:58.00	2009/09/24 10:03:06.00	2009/09/24 10:03:13.00	2009/09/24 10:03:21.00	169	169	170	170	8	7	8	23
3	2009/09/24 10:05:02.00	2009/09/24 10:05:10.00	[illegible]	09/09/24 :05:25.00	124	124	123	124	8	6	9	23
4				09/09/24 10:05:25.00				0				
5	2009/09/24 10:08:03.00	2009/09/24 10:08:10.00		2009/09/24 10:08:23.00	181	180		178	7			20
6	2009/09/24 10:11:33.00	2009/09/24 10:11:40.00	2009/09/24 10:11:46.00	2009/09/24 10:11:53.00	210	210	390	210	7	6	7	20
7	2009/09/24 10:14:19.00	2009/09/24 10:14:28.00	2009/09/24 10:14:34.00	2009/09/24 10:14:43.00	166	168	168	170	9	6	9	24
8	2009/09/24 10:14:54.00	2009/09/24 10:15:10.00	2009/09/24 10:15:21.00	2009/09/24 10:15:38.00	3[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	44
9	2009/09/24 10:16:51.00	2009/09/24 10:16:58.00	2009/09/24 10:17:04.00	2009/09/24 10:17:12.00	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21
...	...	...	...	...	...	...	...	...	...	...	...	...

Figure 4.6: Speed Profile Development: Shifting Data Points Again

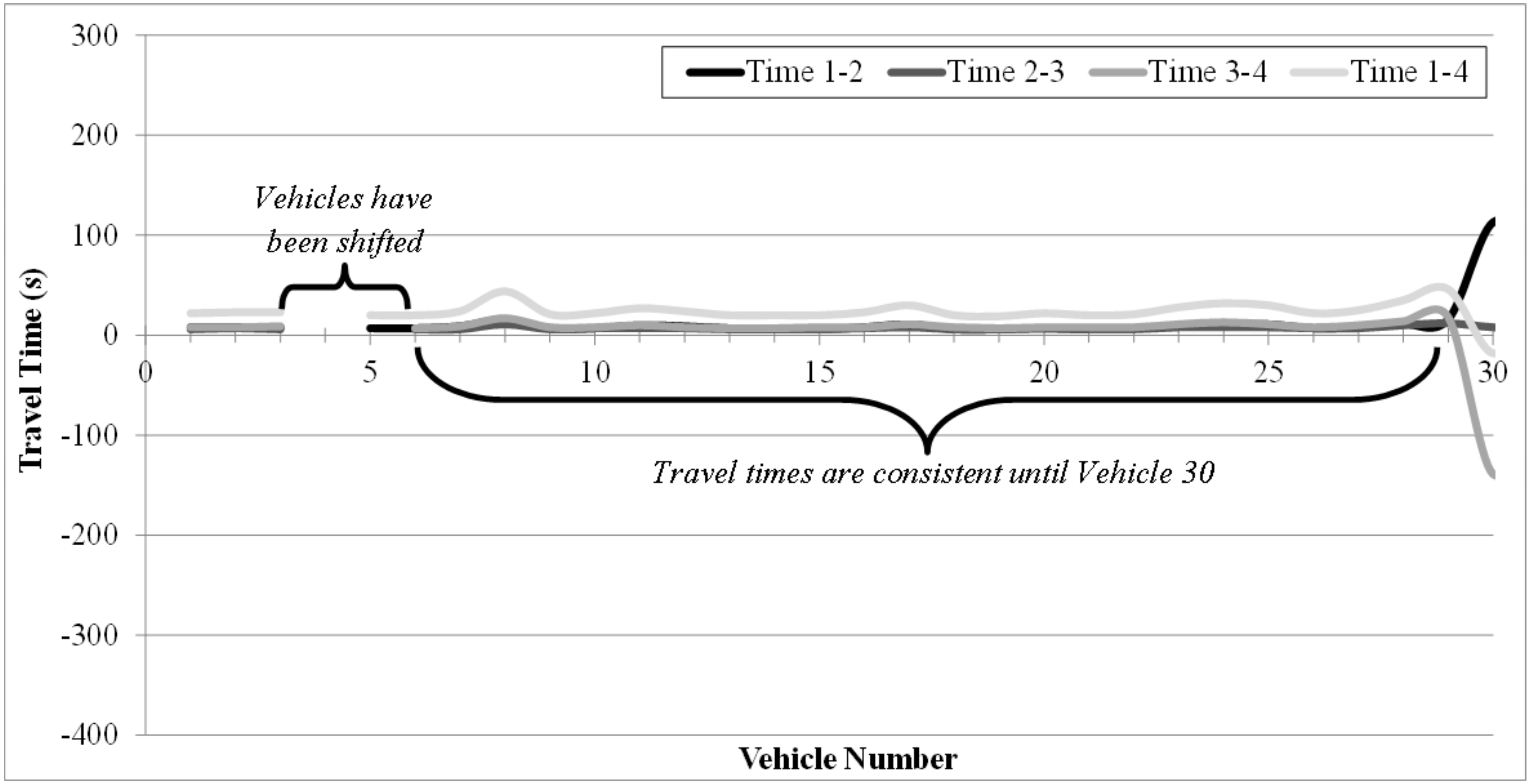


Figure 4.7: Developing Speed Profiles-Checking Graph for Next Irregularity

The length measurements also indicated which data points belonged together. For example, if the four sensors measure the length of one vehicle as 20 ft, 23 ft, 72 ft, and 20 ft and they measure the next vehicle as 75 ft, 67 ft, 30 ft, and 73 ft, it is likely that the third sensor missed the first vehicle and the 72-ft measurement belongs to the second vehicle. The length is not always useful because it is not very accurate, but it can be used if there is a large difference between measurements. Figure 4.8 shows the speed profiles of five randomly selected vehicles traveling west on North Umpqua Hwy plotted against the mean, median, 85th percentile, and 95th percentile speeds of that site.

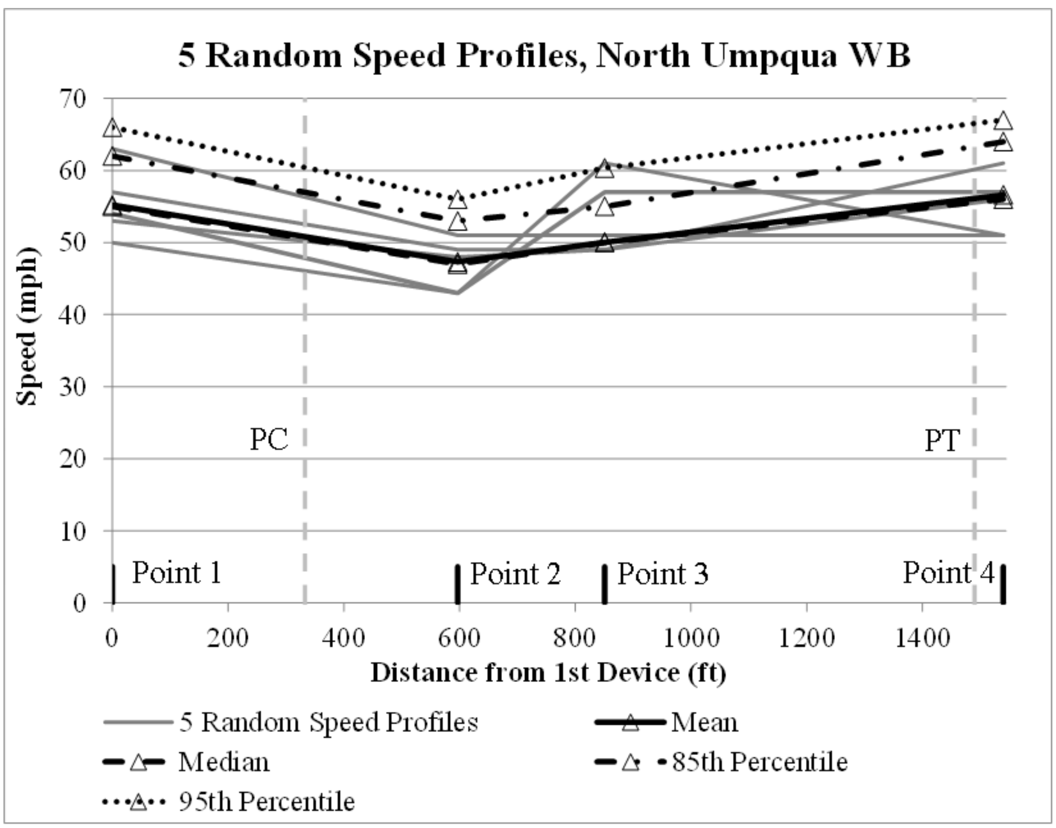


Figure 4.8: Random Speed Profiles

4.1.2 Data Filtering

Once the author matched up vehicles at all 23 sites, she discarded any vehicles that did not have a full speed profile, vehicles that were following the previous vehicle too closely, and any vehicle that had any diagnostic tag other than “Normal” at any of the four sensors.

The author discarded vehicles without full speed profiles because this analysis focuses on how each vehicle travels through curves, not point measurements of speed. On average, the author discarded approximately 12% of vehicles because they did not have a full profile.

4.1.2.1 Diagnostic Tags

The two most common diagnostic tags other than “Normal” were “Exceeded Maximum Length” and “Less than Minimum Length.” When the traffic analyzer classified a vehicle as “Exceeded Maximum Length,” it automatically set the vehicle length to 14 ft. The author discarded these vehicles because the analyzer uses the length of the vehicle to calculate the speed, so the author did not feel comfortable using these data. When a device classified a vehicle as “Less than Minimum Length,” the traffic analyzer set the vehicle length to zero feet and the vehicle speed to zero miles per hour. These data were obviously incorrect and thus discarded.

Other diagnostic tags included “Average Speed Only” and “Averaged Speed/Factored Length.” The author also discarded these data because she could not find any information from the manufacturer about how these tags affected the calculation of the speed and whether or not the speed was still accurate.

4.1.2.2 Tailgating Vehicles

The author looked at multiple methods to determine whether each vehicle acted independently of other vehicles on the road, in particular the vehicle in front of it. Studies similar to this typically use a time headway threshold of five seconds to distinguish independent vehicles (Avelar, 2010; Fizpatrick, Elefteriadou, Harwood, Collins, McFadden, Anderson, Krammes, Irizarry, Parma, Bauer, & Passetti, 2000; McFadden & Elefteriadou, 2000), and Avelar used a threshold of seven seconds in his analysis. The author wanted to explore using distance headway and car-following studies to determine vehicle independence so as not to discard more vehicles than necessary. Equation 4.1 gives the distance headway between two vehicles.

$$d_{F-L} = h_{F-L} v_L$$

Equation 4.1: Distance Headway, Adapted from May, 1990.

Where the subscripts L and F denote the "lead" and "following" vehicles, respectively and,

d_{F-L} = the distance headway between the following and lead vehicles (ft)

h_{F-L} = the time headway between the following and lead vehicles (s)

v_L = the velocity of the lead vehicle (ft/s)

In 1953, Pipes studied how vehicles interact in a line of traffic using the following statement from the California Motor Vehicle Code, "A good rule for following another vehicle at a safe distance is to allow yourself the length of a car (about fifteen feet) for every ten miles per hour you are traveling." Equation 4.2 describes this mathematically.

$$d_{F-L} = L_L + \left[\frac{v_F}{1.47(10)}\right] L_L$$

Equation 4.2: Pipes' Safe Distance Headway Equation, Adapted from May, 1990

Where,

$L_L =$ the length of the lead vehicle

10 is the constant, 10 mph

1.47 converts the 10 mph to ft/s

and all other terms are as previously defined.

The author calculated the actual and allowable distance headways for each vehicle using Equation 4.1 and Equation 4.2, respectively. She looked at discarding all vehicles that had an actual distance headway less than the allowable headway, but that resulted in keeping vehicles with time headways as low at three seconds, which has been established as too low of a threshold (Anderson, Bauer, Harwood, & Fitzpatrick, 1999; Fitzpatrick, Elefteriadou, Harwood, Collins, McFadden, Anderson, Krammes, Irizarry, Parma, Bauer, & Passetti, 2000; McFadden & Elefteriadou, 2000).

The author then checked the Oregon Driver's Manual to see what it recommends as a safe following distance. It says, "For speeds greater than 30 mph, a safe following distance should be 4 seconds or more" (ODOT, 2012). Four seconds has also been established as too low of a threshold (Anderson, Bauer, Harwood, & Fitzpatrick, 1999; Fitzpatrick, Elefteriadou, Harwood, Collins, McFadden, Anderson, Krammes, Irizarry, Parma, Bauer, & Passetti, 2000; McFadden & Elefteriadou, 2000). In the end, the author decided to discard vehicles with time headways less than five seconds.

4.1.2.3 Vehicle Classification

The final step of the data filtering process required classifying each vehicle as either a passenger car or a heavy vehicle. The author used the length measurement to do this. According to the Institute of Transportation Engineers' turning templates, a passenger car is 18 ft long, a single unit truck (for example, a large delivery truck) is 30 ft in length, and the shortest heavy vehicle is 40 ft long. Allowing for measurement error from the traffic analyzers, the author classified vehicles 25 ft or shorter as passenger cars, vehicles 35 ft or longer as heavy vehicles, and vehicles 26-34 ft as single unit trucks. The author first classified each vehicle at all four sensors independently, then used the process shown in Figure 4.9 to determine the final classification of the vehicle.

The traffic analyzers are more accurate at measuring length when the road is straight, therefore the author trusted those measurements over the curve location measurements. If all four of the analyzers' classifications were not the same but the two tangent analyzers were, the author selected the tangent classification. If three of the classifications matched and the difference between the largest and the smallest length measurements was less than or equal to eight feet, the author selected the classification that was repeated. The author selected the eight-foot threshold because according to the NC-200 data sheet, the analyzers are within ±4 ft of the actual vehicle length 90% of the time (Vaisala, 2010).

If a vehicle could not be classified, the author retained it for the overall analysis, but discarded it when comparing passenger cars to heavy vehicles. Table 4.2 shows the percentage of passenger cars, heavy vehicles, single unit trucks, and unclassified vehicles at each site.

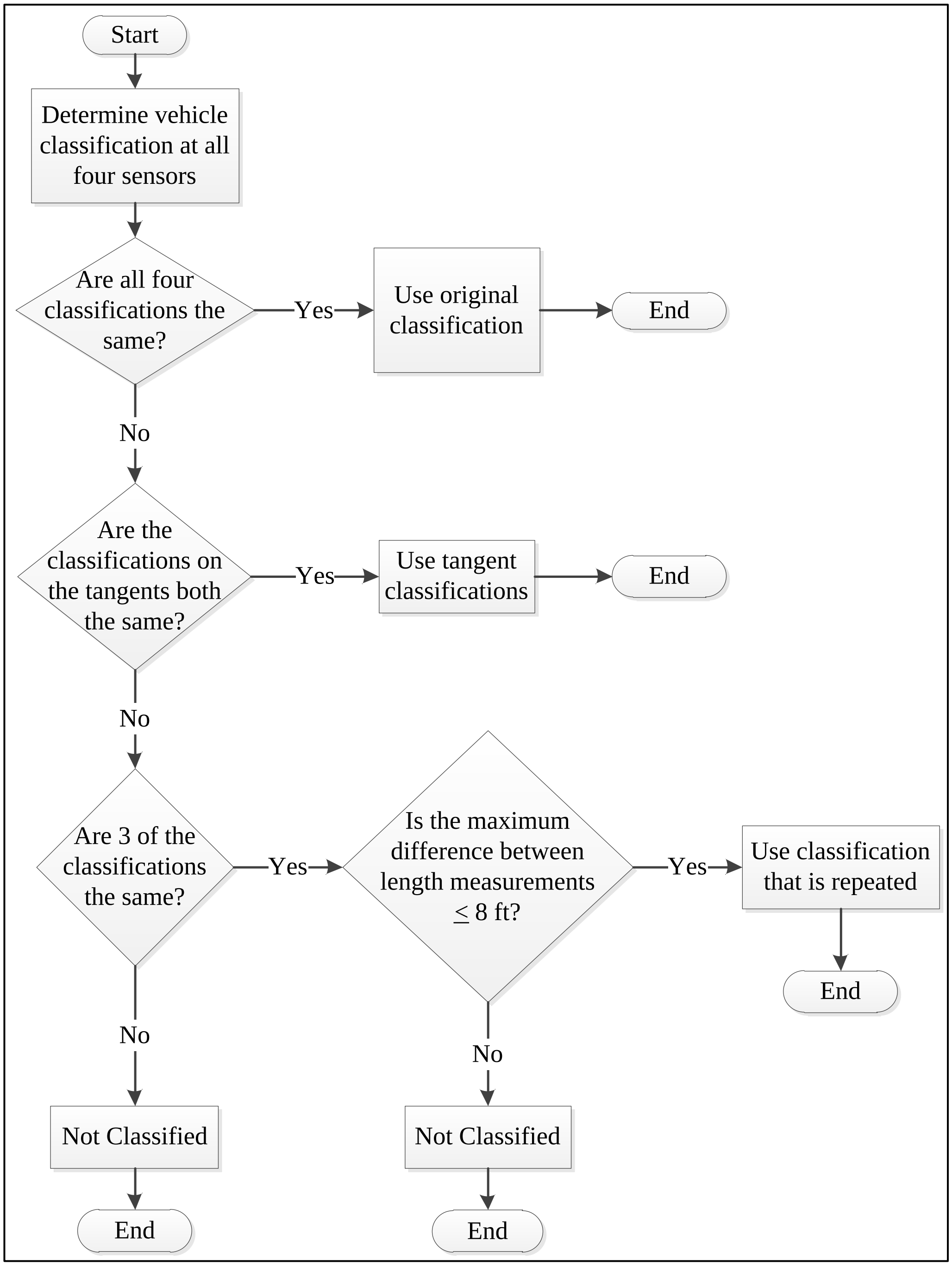


Figure 4.9: Vehicle Classification Flow Chart

Table 4.2: Vehicle Counts by Vehicle Type

Site	Tot. Vehicles	Passenger Cars		Heavy Vehicles		Single Unit Trucks		Other	
Kings Valley NB	171	144	84.2%	16	9.4%	4	2.3%	7	4.1%
Kings Valley SB	131	107	81.7%	14	10.7%	4	3.1%	6	4.6%
McKenzie EB	262	198	75.6%	35	13.4%	6	2.3%	23	8.8%
McKenzie WB	479	396	82.7%	48	10.0%	17	3.5%	18	3.8%
North Umpqua EB	185	145	78.4%	23	12.4%	4	2.2%	13	7.0%
North Umpqua WB	311	274	88.1%	23	7.4%	8	2.6%	6	1.9%
Mt. Hood (80) NB	218	181	83.0%	22	10.1%	6	2.8%	9	4.1%
Mt. Hood (80) SB	262	206	78.6%	29	11.1%	5	1.9%	22	8.4%
Mt. Hood (62) NB	245	179	73.1%	39	15.9%	11	4.5%	16	6.5%
Mt. Hood (62) SB	330	258	78.2%	36	10.9%	18	5.5%	18	5.5%
Santiam EB	376	328	87.2%	22	5.9%	15	4.0%	11	2.9%
Santiam WB	313	259	82.7%	27	8.6%	6	1.9%	21	6.7%
Umpqua LL	22	20	90.9%	1	4.5%	0	0.0%	1	4.5%
Umpqua RL	282	235	83.3%	25	8.9%	9	3.2%	13	4.6%
Elkton-Sutherlin NB	295	256	86.8%	21	7.1%	7	2.4%	11	3.7%
Elkton-Sutherlin SB	377	280	74.3%	64	17.0%	16	4.2%	17	4.5%
Coos Bay-Rosburg WB	405	309	76.3%	68	16.8%	28	6.9%	0	0.0%
Woodburn-Estacada NB	442	382	86.4%	15	3.4%	18	4.1%	27	6.1%
Woodburn-Estacada SB	608	541	89.0%	26	4.3%	25	4.1%	16	2.6%
Jacksonville EB	313	296	94.6%	4	1.3%	4	1.3%	9	2.9%
Jacksonville WB	306	294	96.1%	5	1.6%	6	2.0%	1	0.3%
Green Springs EB	56	53	94.6%	2	3.6%	0	0.0%	1	1.8%
Green Springs WB	59	55	93.2%	0	0.0%	2	3.4%	2	3.4%
Total	6,448	5,396	83.7%	565	8.8%	219	3.4%	268	4.2%

One of the primary objectives of this study is to compare the operations of passenger cars to heavy vehicles, but because of the high percentage of single unit trucks, the author did not want to discard that data. She combined the single unit trucks with the heavy vehicles because their operating characteristics are more similar than single unit trucks and passenger cars (Mugarula & Mussa, 2003).

4.2 STATISTICAL ANALYSIS

This section presents the summary statistics for some sample sites (Section 4.2.1) and the process the author used to answer the research questions presented in the introduction (Sections 4.2.2-4.2.3).

4.2.1 Descriptive Statistics

Tables 4.3-4.5 present the mean, standard deviation, median, and 85th percentile speed of each sensor and overall in one direction at three sample sites. All parameters are in units of miles per hour; the rest of the tables are in Appendix A.

Table 4.3: Summary Statistics of Kings Valley Northbound

	KINGS VALLEY NORTHBOUND (NO ADVISORY SPEED)		
	All Vehicles (N = 171)	Passenger Cars (N = 144)	Heavy Vehicles (N = 20)
Sensor 1	Mean = 50.44	Mean = 51.05	Mean = 46.65
	Std. Dev = 6.60	Std. Dev = 6.07	Std. Dev = 8.58
	Median = 51	Median = 52	Median = 45.5
	85th % Speed = 56.50	85th % Speed = 56.55	85th % Speed = 51.05
Sensor 2	Mean = 49.27	Mean = 49.90	Mean = 45.55
	Std. Dev = 7.85	Std. Dev = 8.08	Std. Dev = 5.29
	Median = 48	Median = 49	Median = 46
	85th % Speed = 56.00	85th % Speed = 56.55	85th % Speed = 50.00
Sensor 3	Mean = 50.64	Mean = 51.47	Mean = 44.75
	Std. Dev = 7.65	Std. Dev = 7.51	Std. Dev = 6.20
	Median = 50	Median = 51	Median = 45
	85th % Speed = 57.00	85th % Speed = 58.00	85th % Speed = 49.00
Sensor 4	Mean = 53.29	Mean = 53.32	Mean = 52.80
	Std. Dev = 6.67	Std. Dev = 6.92	Std. Dev = 5.20
	Median = 53	Median = 53	Median = 53.5
	85th % Speed = 59.00	85th % Speed = 59.00	85th % Speed = 56.30
All	Mean = 50.91	Mean = 51.43	Mean = 47.44
	Std. Dev = 7.35	Std. Dev = 7.27	Std. Dev = 7.09
	Median = 50	Median = 51	Median = 47
	85th % Speed = 58.00	85th % Speed = 58.00	85th % Speed = 54.15

Table 4.4: Summary Statistics of McKenzie Westbound

	MCKENZIE WESTBOUND (40 MPH ADVISORY SPEED)		
	All Vehicles (N = 479)	Passenger Cars (N = 396)	Heavy Vehicles (N =64)
Sensor 1	Mean = 57.82	Mean = 58.45	Mean = 54.20
	Std. Dev = 6.56	Std. Dev = 6.29	Std. Dev = 4.46
	Median = 58	Median = 58.5	Median = 54
	85th % Speed = 63.00	85th % Speed = 64.00	85th % Speed = 57.85
Sensor 2	Mean = 57.80	Mean = 58.52	Mean = 54.45
	Std. Dev = 6.50	Std. Dev = 6.39	Std. Dev = 5.80
	Median = 57	Median = 58	Median = 55
	85th % Speed = 65.00	85th % Speed = 65.00	85th % Speed = 60.00
Sensor 3	Mean = 55.03	Mean = 55.78	Mean = 51.26
	Std. Dev = 6.48	Std. Dev = 6.25	Std. Dev = 6.27
	Median = 55	Median = 55	Median = 50
	85th % Speed = 61.75	85th % Speed = 62.00	85th % Speed = 57.00
Sensor 4	Mean = 52.44	Mean = 53.14	Mean = 48.95
	Std. Dev = 6.06	Std. Dev = 5.40	Std. Dev = 6.92
	Median = 52	Median = 53	Median = 47.5
	85th % Speed = 59.00	85th % Speed = 59.00	85th % Speed = 53.85
All	Mean = 55.77	Mean = 56.47	Mean = 52.20
	Std. Dev = 6.78	Std. Dev = 6.49	Std. Dev = 6.28
	Median = 56	Median = 56	Median = 52
	85th % Speed = 62.00	85th % Speed = 63.00	85th % Speed = 58.00

Table 4.5: Summary Statistics of Santiam Eastbound

	SANTIAM EASTBOUND (35 MPH ADVISORY SPEED)		
	All Vehicles (N = 376)	Passenger Cars (N = 328)	Heavy Vehicles (N = 37)
Sensor 1	Mean = 38.76	Mean = 39.22	Mean = 35.16
	Std. Dev = 4.68	Std. Dev = 4.26	Std. Dev = 4.04
	Median = 39	Median = 39	Median = 35
	85th % Speed = 43.00	85th % Speed = 43.00	85th % Speed = 39.00
Sensor 2	Mean = 38.61	Mean = 38.81	Mean = 37.38
	Std. Dev = 4.36	Std. Dev = 4.19	Std. Dev = 5.31
	Median = 38	Median = 38.5	Median = 37
	85th % Speed = 43.00	85th % Speed = 43.00	85th % Speed = 40.00
Sensor 3	Mean = 39.92	Mean = 40.35	Mean = 36.86
	Std. Dev = 4.45	Std. Dev = 4.38	Std. Dev = 3.83
	Median = 40	Median = 40	Median = 37
	85th % Speed = 44.00	85th % Speed = 44.00	85th % Speed = 40.60
Sensor 4	Mean = 41.92	Mean = 42.43	Mean = 38.41
	Std. Dev = 5.82	Std. Dev = 5.70	Std. Dev = 3.75
	Median = 41	Median = 41	Median = 38
	85th % Speed = 47.00	85th % Speed = 47.00	85th % Speed = 42.00
All	Mean = 39.80	Mean = 40.20	Mean = 36.95
	Std. Dev = 5.03	Std. Dev = 4.88	Std. Dev = 4.40
	Median = 39	Median = 40	Median = 37
	85th % Speed = 44.00	85th % Speed = 45.00	85th % Speed = 41.00

4.2.2 Speed Reduction Differences between Two Possible Measurement Points

Looking at all vehicle types, the author first calculated the speed reduction from Point 1 to Point 2 as well as the speed reduction from Point 1 to Point 3. She then performed a paired t-test to determine if there was a statistically significant difference between the two and to determine which location experienced a larger speed reduction. She then repeated this process looking only at passenger cars, then heavy vehicles/single unit trucks. Section 5.1 presents these results.

4.2.3 Difference between 85th Percentile Speeds vs. the 85th Percentile Maximum Speed Reduction

As indicated in the literature review, McFadden and Elefteriadou (2000) looked at calculating the 85th percentile of the maximum speed reduction (85MSR) instead of taking the difference between 85th percentile speeds at two points (85S2). The author looked at replicating that analysis with these data and calculated an 85MSR value for each site by calculating the maximum speed reduction for each vehicle and finding the 85th percentile value.

As is discussed further in Section 5.1, some of the speed reduction values were negative, indicating an increase in speed. The author only looked at reductions in speed for the following two reasons. From a safety standpoint, we are more concerned with vehicles that have to reduce their speed in order to safely drive through a curve than vehicles that are able to increase their speed. The other reason the author only looked at speed reductions is because that is how McFadden and Elefteriadou analyzed their data, so in order to compare the two analyses, the author needed to follow their guidelines.

For each vehicle, the author had two speed reduction values, as opposed to McFadden and Elefteriadou's nine, to select from. If both of the speed reduction values were zero, she discarded them. If one of them was less than zero but the other was greater than or equal to zero, she selected that one. If they were both greater than or equal to zero, she selected the larger one.

The author then found the 85th percentile speeds at each of the first three sensors for each site and subtracted the 85th percentile speed at Point 2 from the 85th percentile speed at Point 1 and the 85th percentile speed at Point 3 from the 85th percentile speed at Point 1. The author did not calculate the 85th percentile speed at the fourth sensor because the maximum speed reduction only takes into consideration speeds through the curve, not after the curve. She discarded negative values for the same reasons presented above and calculated the 85S2 value for each site. Table 4.6 presents the maximum difference in 85th percentile speeds from Point 1 to 2 and Point 1 to 3 and 85th percentile maximum reduction for all vehicle types at each site. Tables and calculations for passenger cars and heavy vehicles are in Appendix B.

McFadden and Elefteriadou calculated that the 85th percentile of the maximum reduction in speeds is approximately twice as high as the maximum difference in 85th percentile speeds. To find the relationship using this data, the author first defined a new parameter, M, shown in Equation 4.3.

$$M = \frac{85MSR}{85S2} - 1$$

Equation 4.3: New Ratio Parameter

When this parameter is equal to zero, the ratio of the 85MSR value to the 85S2 value is 1, i.e., they are equal. The author then calculated this parameter for each site and performed a two-sided t-test to find the relationship between the two values. Some sites had an 85S2 value of zero or a negative value so the author did not include them in this analysis. She did, however, perform another paired t-test with the values that were zero to find an arithmetic difference between the two parameters. Section 5.2 presents these results.

Table 4.6: Maximum Difference of 85S2 and 85MSR for All Vehicles

Site	Maximum Difference of 85th Percentile Speeds (mph)	85th Percentile of Maximum Reduction in Speeds (mph)
Kings Valley NB	0.5	7.4
Kings Valley SB	10.0	14.0
McKenzie EB	0.0	13.0
McKenzie WB	1.7	8.8
North Umpqua EB	9.0	13.0
North Umpqua WB	8.0	13.0
Mt. Hood (80) NB	9.0	14.0
Mt. Hood (80) SB	2.0	6.0
Mt. Hood (62) NB	5.4	11.0
Mt. Hood (62) SB	5.6	12.0
Santiam EB	0.0	5.0
Santiam WB	2.8	7.0
Umpqua LL	15.3	15.0
Umpqua RL	3.0	11.0
Elkton-Sutherlin NB	9.0	15.0
Elkton-Sutherlin SB	11.0	14.0
Coos Bay-Roseburg WB	1.0	11.0
Woodburn-Estacada NB	9.0	15.0
Woodburn-Estacada SB	5.0	9.0
Jacksonville EB	6.0	10.0
Jacksonville WB	0.0	9.0
Green Springs EB	11.0	17.8
Green Springs WB	13.0	17.0

4.3 SUMMARY

The author manually matched vehicles across the four sensors using the time headway and travel time for each vehicle, then filtered the data using the diagnostic tag and time headway to discard vehicles that were not tagged as “Normal” and that were following too closely. She then used the length measurement to classify each vehicle as a passenger car, single unit truck, heavy vehicle, or other and analyzed the single unit trucks with the heavy vehicles.

She used a paired t-test to determine if there was a statistically significant difference between vehicles' speed reductions from Point 1 to Point 2 and Point 1 to Point 3. She then used a two-sided t-test to look at the difference between using the reduction in 85^{th} percentile speeds and the 85^{th} percentile maximum speed reduction in speed prediction models.

5.0 RESULTS

This chapter summarizes the results of the statistical analyses. Specifically, Section 5.1 reviews the difference in speed reduction from Point 1 to Point 2 and Point 1 to Point 3, and Section 5.2 summarizes the difference between the 85th percentile speeds and the 85th percentile maximum speed reduction.

5.1 SPEED REDUCTION DIFFERENCES BETWEEN TWO POSSIBLE MEASUREMENT POINTS

Paired t-tests indicate that at a 95% significance level, there is a difference between the speed reductions between Point 1 and Point 2 at 20 of the 23 sites when looking at all vehicle types. Table 5.1 shows the estimated difference in speed reductions, p-value, and 95% confidence interval for each site. P-values less than 0.05 indicate that an estimated difference is statistically significant and positive estimated differences indicate that the speed reduction from Point 1 to Point 2 is greater than the reduction from Point 1 to Point 3, i.e., the vehicle’s speed increased between Point 2 and Point 3. Table 5.2 and Table 5.3 show the same information for passenger cars and heavy vehicles/single unit trucks, respectively. Appendix C has more detailed tables with the number of vehicles, average speed reductions, and standard deviations.

Although there are many statistically significant differences between the two measurement locations, the magnitude of the estimated difference is not very large.

Table 5.1: Paired T-Test Results-All Vehicles

Site	Estimated Speed Reduction Difference (mph)	p-value	95% Confidence Interval (mph)
Mt. Hood (62) NB	-1.73	6.08×10^{-6}	-2.46 to -0.99
Mt. Hood (62) SB	2.91	$<2.20 \times 10^{-16}$	2.29 to 3.53
Mt. Hood (80) NB*	0.23	0.47	-0.40 to 0.86
Mt. Hood (80) SB	-3.58	$<2.20 \times 10^{-16}$	-4.14 to -3.01
Woodburn-Estacada NB	5.37	$<2.20 \times 10^{-16}$	4.79 to 5.96
Woodburn-Estacada SB	-4.90	$<2.20 \times 10^{-16}$	-5.29 to -4.50
Kings Valley NB	1.36	0.01	0.31 to 2.42
Kings Valley SB	5.48	1.40×10^{-15}	4.29 to 6.67
McKenzie WB	0.76	0.01	0.16 to 1.37
McKenzie EB	-2.76	$<2.20 \times 10^{-16}$	-3.21 to -2.31
Santiam EB	1.33	1.29×10^{-9}	0.91 to 1.75
Santiam WB	-0.71	0.02	-1.29 to -0.13
Umpqua LL*	0.73	0.62	-2.32 to 3.76
Umpqua RL	5.09	$<2.20 \times 10^{-16}$	4.26 to 5.93
Elkton-Sutherlin NB	2.27	1.28×10^{-14}	1.72 to 2.82
Elkton-Sutherlin SB	-2.69	$<2.20 \times 10^{-16}$	-3.24 to -2.15
North Umpqua EB	-5.98	4.07×10^{-16}	-7.30 to -4.66
North Umpqua WB	2.72	$<2.20 \times 10^{-16}$	2.25 to 3.19
Coos Bay-Roseburg WB	-1.87	1.27×10^{-4}	-2.82 to -0.92
Jacksonville EB	-1.95	5.06×10^{-6}	-2.77 to -1.12
Jacksonville WB	1.87	6.27×10^{-7}	1.15 to 1.27
Green Springs EB*	-0.50	0.574	-2.27 to 1.27
Green Springs WB	-1.66	0.03	-3.18 to -0.14

*Denotes sites with p-values > 0.05

Table 5.2: Paired T-Test Results-Passenger Cars

Site	Estimated Speed Reduction Difference (mph)	p-value	95% Confidence Interval (mph)
Mt. Hood (62) NB	-1.40	3.35×10^{-3}	-2.33 to -0.47
Mt. Hood (62) SB	2.76	3.99×10^{-15}	2.11 to 3.41
Mt. Hood (80) NB*	0.36	0.32	-0.36 to 1.08
Mt. Hood (80) SB	-3.42	$<2.20 \times 10^{-16}$	-4.02 to -2.83
Woodburn-Estacada NB	5.52	$<2.20 \times 10^{-16}$	4.91 to 6.13
Woodburn-Estacada SB	-5.04	$<2.20 \times 10^{-16}$	-5.46 to -4.63
Kings Valley NB	1.58	0.01	0.43 to 2.73
Kings Valley SB	5.68	1.60×10^{-12}	4.28 to 7.09
McKenzie WB*	0.72	0.05	0.00 to 1.44
McKenzie EB	-2.74	$<2.20 \times 10^{-16}$	-3.26 to -2.22
Santiam EB	1.54	1.95×10^{-11}	1.11 to 1.98
Santiam WB	-1.06	1.56×10^{-3}	-1.71 to -0.41
Umpqua LL*	0.85	0.59	-2.38 to 4.04
Umpqua RL	5.39	$<2.20 \times 10^{-16}$	4.48 to 6.30
Elkton-Sutherlin NB	2.18	1.30×10^{-11}	1.58 to 2.79
Elkton-Sutherlin SB	-2.78	9.78×10^{-14}	-3.48 to -2.08
North Umpqua EB	-6.23	6.17×10^{-12}	-7.88 to -4.59
North Umpqua WB	2.72	$<2.20 \times 10^{-16}$	2.22 to 3.23
Coos Bay-Roseburg WB	-2.03	4.48×10^{-4}	-3.15 to -0.90
Jacksonville EB	-1.84	3.53×10^{-05}	-2.70 to -0.98
Jacksonville WB	1.81	2.61×10^{-6}	1.06 to 2.55
Green Springs EB*	-0.53	0.57	-2.40 to 1.37
Green Springs WB	-1.96	0.02	-3.54 to -0.38

*Denotes sites with p-values > 0.05

Table 5.3: Paired T-Test Results-Heavy Vehicles/Single Unit Trucks

Site	Estimated Speed Reduction Difference (mph)	p-value	95% Confidence Interval (mph)
Mt. Hood (62) NB	-3.06	4.52×10^{-6}	-4.25 to -1.87
Mt. Hood (62) SB	3.54	9.08×10^{-7}	2.26 to 4.81
Mt. Hood (80) NB*	-0.29	0.66	-1.59 to 1.02
Mt. Hood (80) SB	-4.91	1.17×10^{-4}	-7.20 to -2.62
Woodburn-Estacada NB	2.79	0.04	0.13 to 5.44
Woodburn-Estacada SB	-3.69	1.48×10^{-10}	-4.61 to -2.76
Kings Valley NB*	-0.80	0.65	-4.47 to 2.87
Kings Valley SB	4.56	6.84×10^{-4}	2.23 to 6.88
McKenzie WB*	0.61	0.18	-0.29 to 1.51
McKenzie EB	-2.98	3.06×10^{-8}	-3.93 to -2.04
Santiam EB*	-0.51	0.50	-2.05 to 1.03
Santiam WB	1.39	0.04	0.09 to 2.69
Umpqua LL	*n/a*	*n/a*	*n/a*
Umpqua RL	2.97	0.01	0.88 to 5.06
Elkton-Sutherlin NB	3.07	5.45×10^{-4}	1.46 to 4.68
Elkton-Sutherlin SB	-2.21	5.81×10^{-8}	-2.95 to -1.48
North Umpqua EB	-5.26	3.72×10^{-6}	-7.11 to -3.41
North Umpqua WB	2.87	5.21 x 10-04	1.36 to 4.38
Coos Bay-Roseburg WB*	-1.38	0.13	-3.14 to 0.39
Jacksonville EB*	-2.38	0.06	-4.90 to 0.15
Jacksonville WB*	3.55	0.08	-0.52 to 7.61
Green Springs EB	*n/a*	*n/a*	*n/a*
Green Springs WB	*n/a*	*n/a*	*n/a*

*Denotes sites with p-values > 0.05

When looking only at passenger cars, there are statistically significant differences between speed reductions between Point 1 and Point 2 at 19 of the 23 sites. When looking at heavy vehicles/single unit trucks, the author did not compare speed reductions on Umpqua Hwy in the left lane or in either direction of travel on Green Springs Hwy because there were only two heavy vehicles in both lanes of Green Springs Hwy and one single unit truck in the left lane of Umpqua Hwy. This leaves

20 sites to compare, 13 of which had statistically significant differences in speed reductions.

Of the 20 statistically significant differences regarding all vehicles, ten of them (50%) are positive, meaning that the speed reduction from Point 1 to Point 2 was larger than the speed reduction from Point 1 to Point 3. In other words, drivers decreased their speed from Point 1 to Point 2 then increased their speed before reaching Point 3, but not above their original speed at Point 1. Looking at the passenger cars, 47% (9 of 19) of the sites had a positive difference in speed directions and 53% (7 of 13) of the sites had a positive difference for heavy vehicles/single unit trucks.

In order to determine whether or not passenger cars and heavy vehicles behave in a similar fashion, the author looked at the estimated differences and confidence intervals of both the passenger cars and heavy vehicles at all sites that had statistically significant differences for both vehicles types. If the estimated difference in speed reduction of the passenger cars was within the confidence interval for the heavy vehicles/single unit trucks and vice versa, the author determined that there was no difference between the vehicle types. If neither estimate was in the other's confidence interval, the author determined that there was a difference between vehicle types. Table 5.4 shows the sites with significant differences between passenger cars and heavy vehicles.

Table 5.4: Sites with Significant Difference in Speed Reduction between Passenger Cars and Heavy Vehicles

	Mt. Hood (62) NB	Woodburn-Estacada SB	Santiam WB	Umpqua RL
Passenger Car Estimated Speed Reduction Difference (mph)	-1.40	-5.04	-1.06	5.39
Heavy Vehicle 95% Confidence Interval	-4.25 -1.87	-4.61 -2.76	0.09 2.69	0.88 5.06
Heavy vehicle Estimated Speed Reduction Difference (mph)	-3.06	-3.69	1.39	2.97
Passenger Car 95% Confidence Interval	-2.33 -0.47	-5.46 -4.63	-1.71 -0.41	4.48 3.30

Table 5.4 indicates that there is a wide variety of interactions at these sites. On Mt. Hood Hwy, the negative differences indicate that both passenger cars and heavy vehicles continue to slow down between Points 2 and 3 and the larger magnitude of difference indicates that heavy vehicles slow down more than passenger cars. This is the type of result one would intuitively expect at a sharp curve. On the Woodburn-Estacada Hwy, however, the larger magnitude of the passenger cars' estimated difference in speed reduction indicates that while both vehicle types continue to slow down from Point 2 to point 3, the passenger cars slow down more than the heavy vehicles.

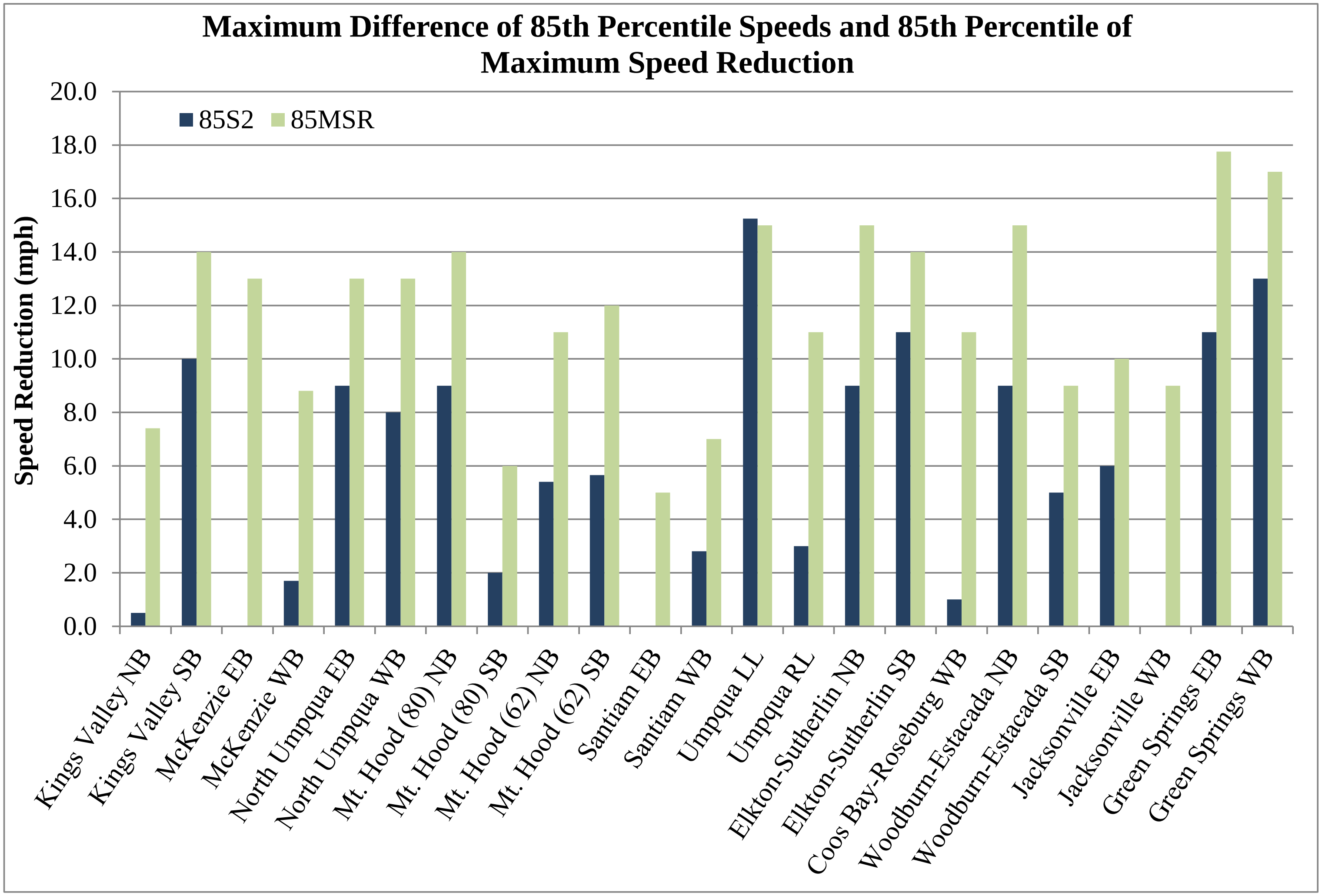
The author's hypothesis is that passenger cars are more likely to be driving too fast to safely negotiate the curve as they approach, and thus would need to slow down more than heavy vehicles. Looking at the summary tables in Appendix B, one will see that at all sites except for the southbound direction of Green Springs Hwy, the average speed of passenger cars at each sensor was greater than the average speed for heavy vehicles. At Green Springs Hwy westbound, the average passenger car speed was less than the average heavy vehicle speed at only the two interior locations, the two on the curve. The average passenger car speed was greater than the advisory speed for every sensor at every site. The average heavy vehicle speed, however, was less than the advisory speed at all four sensors at two sites: Mt. Hood Hwy (62) northbound and Santiam Hwy westbound; the rest of the average heavy vehicle speeds were above the advisory speeds.

5.2 DIFFERENCE BETWEEN 85TH PERCENTILE SPEEDS VS. THE 85TH PERCENTILE MAXIMUM SPEED REDUCTION

When looking at all vehicle types, the author estimates that the 85MSR (85^{th} percentile maximum speed reduction) value is 3.1 times the 85S2 (reduction in 85^{th} percentile speeds) value (95% confidence interval: 1.5 to 4.8). When looking at only passenger cars, the author estimates that the 85MSR value is 2.0 times the 85S2 value (95% confidence interval: 1.5 to 2.5). When looking at heavy vehicles/single unit trucks, the author estimates that the 85MSR value is 2.9 times the 85S2 value (95% confidence interval: 1.7 to 4.1).

Looking at an arithmetic difference, the author estimates that the 85MSR value is approximately 5.7 mph, 5.3 mph, and 4.4 mph greater than the 85S2 value with respect to all vehicle types, passenger cars, and heavy vehicles (95% confidence intervals: 4.5 to 6.3, 4.1 to 6.5, and 3.1 to 5.8). Figure 5.1 shows the speed reductions at each site, so the reader may better visualize the differences in magnitude.

Figure 5.1: Bar Chart of 85S2 and 85MSR for All Vehicle Types



6.0 CONCLUSIONS AND FUTURE WORK

Although the results of the statistical analysis indicate a statistically significant difference between measuring the speed reduction at Point 3 vs. Point 2, the magnitude of that difference is not very high. The highest estimated difference is just above 5.5 mph, which is less than most of the standard deviations of the speeds at individual sensors. And while most of the differences are significant, there is an approximately fifty-fifty split of sites that indicate measurements at Point 2 will give a larger reduction and sites that indicate Point 3 will give a larger reduction.

If the author were pressed to give a recommendation on whether to place the second speed-measuring device at Point 2 or Point 3, she would recommend Point 3 only because the average speed at that location was less than the average speed at Point 2 at 13 of the 20 sites.

As for the question of whether to use the 85S2 or 85MSR value to predict driver behavior and crashes, the author agrees with McFadden and Elefteriadou that there is a difference and since the magnitude of that difference can get as high as 13 mph, it might be a better parameter to use. However, since the relationship between the two values is so simple, it would not matter which value you calculate first.

6.1 APPLICABILITY OF RESULTS

As indicated in Section 3.1, the locations from which the research team collected the data came from a very particular pool of possible locations. These conditions are useful though in looking at how drivers react to uncomfortable or unfavorable geometric designs. This also opens the possibilities of future work. The results that this thesis presents could be validated or augmented by expanding the possible locations to any and all curves on rural two-lane highways.

6.2 FUTURE WORK

In addition to expanding the sample type, future researchers may also decide to put all eight devices in one lane of travel so as to possibly more accurately predict the best place to collected speed data on Oregon's curving highways. The author would also like to know why the data is almost split in half as to which point they indicate would give the highest speed reduction and why the difference between the 85S2 and 85MSR values has such a large range. The author hypothesizes that both of these have something to do with the geometry of the curves, but that was outside the scope of this analysis.

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Appendices

APPENDIX A: Descriptive Statistics for All Sites

Table A.1: Summary Statistics of Kings Valley Northbound

	KINGS VALLEY NORTHBOUND (NO ADVISORY SPEED)		
	All Vehicles (N = 171)	Passenger Cars (N = 144)	Heavy Vehicles (N = 20)
Sensor 1	Mean = 50.44	Mean = 51.05	Mean = 46.65
	Std. Dev = 6.60	Std. Dev = 6.07	Std. Dev = 8.58
	Median = 51	Median = 52	Median = 45.5
	85th % Speed = 56.50	85th % Speed = 56.55	85th % Speed = 51.05
Sensor 2	Mean = 49.27	Mean = 49.90	Mean = 45.55
	Std. Dev = 7.85	Std. Dev = 8.08	Std. Dev = 5.29
	Median = 48	Median = 49	Median = 46
	85th % Speed = 56.00	85th % Speed = 56.55	85th % Speed = 50.00
Sensor 3	Mean = 50.64	Mean = 51.47	Mean = 44.75
	Std. Dev = 7.65	Std. Dev = 7.51	Std. Dev = 6.20
	Median = 50	Median = 51	Median = 45
	85th % Speed = 57.00	85th % Speed = 58.00	85th % Speed = 49.00
Sensor 4	Mean = 53.29	Mean = 53.32	Mean = 52.80
	Std. Dev = 6.67	Std. Dev = 6.92	Std. Dev = 5.20
	Median = 53	Median = 53	Median = 53.5
	85th % Speed = 59.00	85th % Speed = 59.00	85th % Speed = 56.30
All	Mean = 50.91	Mean = 51.43	Mean = 47.44
	Std. Dev = 7.35	Std. Dev = 7.27	Std. Dev = 7.09
	Median = 50	Median = 51	Median = 47
	85th % Speed = 58.00	85th % Speed = 58.00	85th % Speed = 54.15

Table A.2: Summary Statistics of Kings Valley Southbound

	KINGS VALLEY SOUTHBOUND (NO ADVISORY SPEED)		
	All Vehicles (N = 131)	Passenger Cars (N = 107)	Heavy Vehicles (N = 18)
Sensor 1	Mean = 55.76	Mean = 56.35	Mean = 52.78
	Std. Dev = 8.83	Std. Dev = 7.71	Std. Dev = 11.50
	Median = 57	Median = 57	Median = 51.5
	85th % Speed = 64.00	85th % Speed = 64.00	85th % Speed = 63.25
Sensor 2	Mean = 47.25	Mean = 47.88	Mean = 43.89
	Std. Dev = 6.52	Std. Dev = 6.16	Std. Dev = 6.88
	Median = 48	Median = 48	Median = 45
	85th % Speed = 54.00	85th % Speed = 55.00	85th % Speed = 48.90
Sensor 3	Mean = 52.73	Mean = 53.56	Mean = 48.44
	Std. Dev = 9.20	Std. Dev = 8.90	Std. Dev = 8.57
	Median = 52	Median = 52	Median = 48.5
	85th % Speed = 61.00	85th % Speed = 61.10	85th % Speed = 54.90
Sensor 4	Mean = 48.99	Mean = 49.55	Mean = 45.44
	Std. Dev = 6.74	Std. Dev = 6.28	Std. Dev = 7.88
	Median = 49	Median = 50	Median = 45
	85th % Speed = 55.50	85th % Speed = 56.00	85th % Speed = 52.00
All	Mean = 51.19	Mean = 51.83	Mean = 47.64
	Std. Dev = 8.56	Std. Dev = 8.05	Std. Dev = 9.33
	Median = 50.5	Median = 51	Median = 48
	85th % Speed = 60.00	85th % Speed = 60.00	85th % Speed = 55.35

Table A.3: Summary Statistics of McKenzie Eastbound

	McKENZIE EASTBOUND (40 MPH ADVISORY SPEED)					
	All Vehicles (N = 262)		Passenger Cars (N = 198)		Heavy Vehicles (N = 41)	
Sensor 1	Mean =	51.50	Mean =	52.04	Mean =	48.41
	Std. Dev =	9.87	Std. Dev =	9.21	Std. Dev =	7.10
	Median =	52	Median =	53	Median =	47
	85th % Speed =	60.00	85th % Speed =	61.00	85th % Speed =	57.00
Sensor 2	Mean =	53.75	Mean =	55.18	Mean =	48.12
	Std. Dev =	7.03	Std. Dev =	7.01	Std. Dev =	4.98
	Median =	53	Median =	55	Median =	49
	85th % Speed =	60.00	85th % Speed =	61.00	85th % Speed =	51.00
Sensor 3	Mean =	54.52	Mean =	55.90	Mean =	48.73
	Std. Dev =	6.55	Std. Dev =	5.88	Std. Dev =	5.71
	Median =	54	Median =	56	Median =	49
	85th % Speed =	61.00	85th % Speed =	62.00	85th % Speed =	53.00
Sensor 4	Mean =	52.72	Mean =	53.89	Mean =	47.78
	Std. Dev =	6.03	Std. Dev =	5.92	Std. Dev =	4.23
	Median =	53	Median =	54	Median =	48
	85th % Speed =	58.00	85th % Speed =	59.00	85th % Speed =	53.00
All	Mean =	53.12	Mean =	54.25	Mean =	48.26
	Std. Dev =	7.59	Std. Dev =	7.27	Std. Dev =	5.56
	Median =	53	Median =	54	Median =	48
	85th % Speed =	60.00	85th % Speed =	61.00	85th % Speed =	53.00

Table A.4: Summary Statistics of McKenzie Westbound

	McKENZIE WESTBOUND (40 MPH ADVISORY SPEED)		
	All Vehicles (N = 479)	Passenger Cars (N = 396)	Heavy Vehicles (N =64)
Sensor 1	Mean = 57.82	Mean = 58.45	Mean = 54.20
	Std. Dev = 6.56	Std. Dev = 6.29	Std. Dev = 4.46
	Median = 58	Median = 58.5	Median = 54
	85th % Speed = 63.00	85th % Speed = 64.00	85th % Speed = 57.85
Sensor 2	Mean = 57.80	Mean = 58.52	Mean = 54.45
	Std. Dev = 6.50	Std. Dev = 6.39	Std. Dev = 5.80
	Median = 57	Median = 58	Median = 55
	85th % Speed = 65.00	85th % Speed = 65.00	85th % Speed = 60.00
Sensor 3	Mean = 55.03	Mean = 55.78	Mean = 51.26
	Std. Dev = 6.48	Std. Dev = 6.25	Std. Dev = 6.27
	Median = 55	Median = 55	Median = 50
	85th % Speed = 61.75	85th % Speed = 62.00	85th % Speed = 57.00
Sensor 4	Mean = 52.44	Mean = 53.14	Mean = 48.95
	Std. Dev = 6.06	Std. Dev = 5.40	Std. Dev = 6.92
	Median = 52	Median = 53	Median = 47.5
	85th % Speed = 59.00	85th % Speed = 59.00	85th % Speed = 53.85
All	Mean = 55.77	Mean = 56.47	Mean = 52.20
	Std. Dev = 6.78	Std. Dev = 6.49	Std. Dev = 6.28
	Median = 56	Median = 56	Median = 52
	85th % Speed = 62.00	85th % Speed = 63.00	85th % Speed = 58.00

Table A.5: Summary Statistics of North Umpqua Eastbound

	NORTH UMPQUA EASTBOUND (30 MPH ADVISORY SPEED)					
	All Vehicles (N = 185)		Passenger Cars (N = 145)		Heavy Vehicles (N = 27)	
Sensor 1	Mean =	53.71	Mean =	53.44	Mean =	54.81
	Std. Dev =	7.13	Std. Dev =	7.12	Std. Dev =	7.76
	Median =	53	Median =	53	Median =	53
	85th % Speed =	60.00	85th % Speed =	60.00	85th % Speed =	63.00
Sensor 2	Mean =	52.61	Mean =	53.37	Mean =	50.26
	Std. Dev =	10.21	Std. Dev =	10.96	Std. Dev =	6.59
	Median =	51	Median =	51	Median =	50
	85th % Speed =	61.00	85th % Speed =	61.40	85th % Speed =	54.00
Sensor 3	Mean =	46.63	Mean =	47.14	Mean =	45.00
	Std. Dev =	4.47	Std. Dev =	4.58	Std. Dev =	3.55
	Median =	46	Median =	47	Median =	45
	85th % Speed =	51.00	85th % Speed =	51.00	85th % Speed =	49.00
Sensor 4	Mean =	52.24	Mean =	52.70	Mean =	49.67
	Std. Dev =	5.27	Std. Dev =	5.16	Std. Dev =	4.41
	Median =	52	Median =	53	Median =	49
	85th % Speed =	58.00	85th % Speed =	58.00	85th % Speed =	53.20
All	Mean =	51.30	Mean =	51.66	Mean =	49.94
	Std. Dev =	7.62	Std. Dev =	7.82	Std. Dev =	6.72
	Median =	51	Median =	51	Median =	49
	85th % Speed =	58.00	85th % Speed =	58.15	85th % Speed =	54.00

Table A.6: Summary Statistics of North Umpqua Westbound

	NORTH UMPQUA WESTBOUND (30 MPH ADVISORY SPEED)					
	All Vehicles (N = 311)		Passenger Cars (N = 274)		Heavy Vehicles (N = 31)	
Sensor 1	Mean =	54.88	Mean =	55.21	Mean =	53.13
	Std. Dev =	6.79	Std. Dev =	6.76	Std. Dev =	6.77
	Median =	55	Median =	55	Median =	51
	85th % Speed =	61.00	85th % Speed =	62.00	85th % Speed =	60.00
Sensor 2	Mean =	46.96	Mean =	47.32	Mean =	44.71
	Std. Dev =	5.29	Std. Dev =	5.24	Std. Dev =	5.16
	Median =	47	Median =	47	Median =	43
	85th % Speed =	53.00	85th % Speed =	53.00	85th % Speed =	52.00
Sensor 3	Mean =	49.68	Mean =	50.04	Mean =	47.58
	Std. Dev =	6.08	Std. Dev =	6.11	Std. Dev =	5.38
	Median =	49	Median =	50	Median =	46
	85th % Speed =	55.00	85th % Speed =	55.00	85th % Speed =	53.00
Sensor 4	Mean =	56.20	Mean =	56.60	Mean =	53.23
	Std. Dev =	7.09	Std. Dev =	7.18	Std. Dev =	5.85
	Median =	56	Median =	56	Median =	51
	85th % Speed =	63.50	85th % Speed =	64.00	85th % Speed =	59.50
All	Mean =	51.93	Mean =	52.29	Mean =	49.66
	Std. Dev =	7.38	Std. Dev =	7.39	Std. Dev =	6.82
	Median =	51	Median =	52	Median =	49.5
	85th % Speed =	59.00	85th % Speed =	60.00	85th % Speed =	58.00

Table A.7: Summary Statistics of Mt. Hood (80) Northbound

	MT. HOOD (80) NORTHBOUND (45 MPH ADVISORY SPEED)					
	All Vehicles (N = 218)		Passenger Cars (N = 181)		Heavy Vehicles (N = 28)	
Sensor 1	Mean =	63.39	Mean =	64.41	Mean =	57.93
	Std. Dev =	9.78	Std. Dev =	9.24	Std. Dev =	8.94
	Median =	64	Median =	65	Median =	60
	85th % Speed =	72.00	85th % Speed =	73.00	85th % Speed =	65.00
Sensor 2	Mean =	57.11	Mean =	57.76	Mean =	53.61
	Std. Dev =	6.18	Std. Dev =	6.02	Std. Dev =	6.00
	Median =	57.5	Median =	58	Median =	53.5
	85th % Speed =	63.00	85th % Speed =	63.00	85th % Speed =	59.00
Sensor 3	Mean =	57.34	Mean =	58.12	Mean =	53.32
	Std. Dev =	6.36	Std. Dev =	6.28	Std. Dev =	5.48
	Median =	58	Median =	59	Median =	53
	85th % Speed =	63.00	85th % Speed =	64.00	85th % Speed =	58.95
Sensor 4	Mean =	56.59	Mean =	57.22	Mean =	52.07
	Std. Dev =	7.03	Std. Dev =	6.53	Std. Dev =	6.91
	Median =	56	Median =	57	Median =	51.5
	85th % Speed =	63.00	85th % Speed =	64.00	85th % Speed =	56.95
All	Mean =	58.61	Mean =	59.38	Mean =	54.23
	Std. Dev =	7.96	Std. Dev =	7.70	Std. Dev =	7.21
	Median =	58	Median =	59	Median =	54
	85th % Speed =	66.00	85th % Speed =	67.00	85th % Speed =	62.00

Table A.8: Summary Statistics of Mt. Hood (80) Southbound

	MT. HOOD (80) SOUTHBOUND (45 MPH ADVISORY SPEED)					
	All Vehicles (N = 262)		Passenger Cars (N = 206)		Heavy Vehicles (N = 34)	
Sensor 1	Mean =	55.03	Mean =	55.51	Mean =	51.74
	Std. Dev =	6.86	Std. Dev =	6.54	Std. Dev =	5.99
	Median =	55	Median =	55	Median =	51
	85th % Speed =	62.00	85th % Speed =	62.00	85th % Speed =	59.05
Sensor 2	Mean =	58.02	Mean =	57.81	Mean =	58.56
	Std. Dev =	6.83	Std. Dev =	6.98	Std. Dev =	6.08
	Median =	57.5	Median =	57	Median =	57
	85th % Speed =	65.00	85th % Speed =	65.00	85th % Speed =	64.00
Sensor 3	Mean =	54.44	Mean =	54.39	Mean =	53.65
	Std. Dev =	5.91	Std. Dev =	6.22	Std. Dev =	3.87
	Median =	54	Median =	54	Median =	53.5
	85th % Speed =	60.00	85th % Speed =	60.00	85th % Speed =	57.05
Sensor 4	Mean =	57.06	Mean =	57.00	Mean =	55.97
	Std. Dev =	7.10	Std. Dev =	6.93	Std. Dev =	5.66
	Median =	57	Median =	57	Median =	56
	85th % Speed =	64.00	85th % Speed =	64.00	85th % Speed =	61.15
All	Mean =	56.14	Mean =	56.18	Mean =	54.98
	Std. Dev =	6.84	Std. Dev =	6.79	Std. Dev =	5.99
	Median =	56	Median =	56	Median =	55
	85th % Speed =	63.00	85th % Speed =	63.00	85th % Speed =	60.00

Table A.9: Summary Statistics of Mt. Hood (62) Northbound

	MT. HOOD (62) NORTHBOUND (40 MPH ADVISORY SPEED)					
	All Vehicles (N = 245)		Passenger Cars (N = 179)		Heavy Vehicles (N = 50)	
Sensor 1	Mean =	49.78	Mean =	53.66	Mean =	38.72
	Std. Dev =	9.98	Std. Dev =	7.37	Std. Dev =	7.10
	Median =	51	Median =	54	Median =	38
	85th % Speed =	58.40	85th % Speed =	60.00	85th % Speed =	46.00
Sensor 2	Mean =	47.72	Mean =	51.08	Mean =	38.22
	Std. Dev =	8.19	Std. Dev =	5.01	Std. Dev =	7.38
	Median =	50	Median =	51	Median =	37.5
	85th % Speed =	54.00	85th % Speed =	56.00	85th % Speed =	46.00
Sensor 3	Mean =	45.99	Mean =	49.68	Mean =	35.16
	Std. Dev =	9.00	Std. Dev =	5.79	Std. Dev =	7.93
	Median =	47	Median =	49	Median =	34
	85th % Speed =	53.00	85th % Speed =	54.00	85th % Speed =	45.00
Sensor 4	Mean =	47.33	Mean =	51.75	Mean =	33.72
	Std. Dev =	10.33	Std. Dev =	5.51	Std. Dev =	8.09
	Median =	50	Median =	51	Median =	31
	85th % Speed =	56.00	85th % Speed =	57.00	85th % Speed =	42.65
All	Mean =	47.71	Mean =	51.54	Mean =	36.46
	Std. Dev =	9.50	Std. Dev =	6.14	Std. Dev =	7.86
	Median =	49	Median =	51	Median =	35.5
	85th % Speed =	56.00	85th % Speed =	57.00	85th % Speed =	46.00

Table A.10: Summary Statistics of Mt. Hood (60) Southbound

	MT. HOOD (62) SOUTHBOUND (40 MPH ADVISORY SPEED)					
	All Vehicles (N = 330)		Passenger Cars (N = 258)		Heavy Vehicles (N = 54)	
Sensor 1	Mean =	56.06	Mean =	56.38	Mean =	55.15
	Std. Dev =	6.67	Std. Dev =	5.69	Std. Dev =	8.67
	Median =	55	Median =	55.5	Median =	53.5
	85th % Speed =	62.65	85th % Speed =	62.45	85th % Speed =	62.00
Sensor 2	Mean =	50.64	Mean =	51.08	Mean =	49.37
	Std. Dev =	6.04	Std. Dev =	5.88	Std. Dev =	6.08
	Median =	50	Median =	50.5	Median =	48.5
	85th % Speed =	57.00	85th % Speed =	57.00	85th % Speed =	56.00
Sensor 3	Mean =	53.55	Mean =	53.84	Mean =	52.91
	Std. Dev =	6.40	Std. Dev =	5.94	Std. Dev =	6.32
	Median =	53	Median =	53	Median =	52
	85th % Speed =	59.00	85th % Speed =	59.00	85th % Speed =	58.00
Sensor 4	Mean =	58.83	Mean =	59.81	Mean =	55.70
	Std. Dev =	6.92	Std. Dev =	6.45	Std. Dev =	6.68
	Median =	58	Median =	59	Median =	55
	85th % Speed =	66.00	85th % Speed =	66.00	85th % Speed =	61.05
All	Mean =	54.77	Mean =	55.28	Mean =	53.28
	Std. Dev =	7.18	Std. Dev =	6.80	Std. Dev =	7.40
	Median =	55	Median =	55	Median =	52.5
	85th % Speed =	62.00	85th % Speed =	62.00	85th % Speed =	60.00

Table A.11: Summary Statistics of Santiam Eastbound

	SANTIAM EASTBOUND (35 MPH ADVISORY SPEED)		
	All Vehicles (N = 376)	Passenger Cars (N = 328)	Heavy Vehicles (N = 37)
Sensor 1	Mean = 38.76	Mean = 39.22	Mean = 35.16
	Std. Dev = 4.68	Std. Dev = 4.26	Std. Dev = 4.04
	Median = 39	Median = 39	Median = 35
	85th % Speed = 43.00	85th % Speed = 43.00	85th % Speed = 39.00
Sensor 2	Mean = 38.61	Mean = 38.81	Mean = 37.38
	Std. Dev = 4.36	Std. Dev = 4.19	Std. Dev = 5.31
	Median = 38	Median = 38.5	Median = 37
	85th % Speed = 43.00	85th % Speed = 43.00	85th % Speed = 40.00
Sensor 3	Mean = 39.92	Mean = 40.35	Mean = 36.86
	Std. Dev = 4.45	Std. Dev = 4.38	Std. Dev = 3.83
	Median = 40	Median = 40	Median = 37
	85th % Speed = 44.00	85th % Speed = 44.00	85th % Speed = 40.60
Sensor 4	Mean = 41.92	Mean = 42.43	Mean = 38.41
	Std. Dev = 5.82	Std. Dev = 5.70	Std. Dev = 3.75
	Median = 41	Median = 41	Median = 38
	85th % Speed = 47.00	85th % Speed = 47.00	85th % Speed = 42.00
All	Mean = 39.80	Mean = 40.20	Mean = 36.95
	Std. Dev = 5.03	Std. Dev = 4.88	Std. Dev = 4.40
	Median = 39	Median = 40	Median = 37
	85th % Speed = 44.00	85th % Speed = 45.00	85th % Speed = 41.00

Table A.12: Summary Statistics of Santiam Westbound

	SANTIAM WESTBOUND (35 MPH ADVISORY SPEED)					
	All Vehicles (N = 313)		Passenger Cars (N = 259)		Heavy Vehicles (N = 33)	
Sensor 1	Mean =	39.91	Mean =	40.79	Mean =	34.97
	Std. Dev =	6.30	Std. Dev =	6.06	Std. Dev =	5.15
	Median =	40	Median =	40	Median =	36
	85th % Speed =	46.00	85th % Speed =	46.30	85th % Speed =	40.20
Sensor 2	Mean =	38.85	Mean =	39.86	Mean =	33.15
	Std. Dev =	6.23	Std. Dev =	5.89	Std. Dev =	4.55
	Median =	39	Median =	40	Median =	34
	85th % Speed =	45.00	85th % Speed =	45.00	85th % Speed =	37.20
Sensor 3	Mean =	38.14	Mean =	38.81	Mean =	34.55
	Std. Dev =	6.11	Std. Dev =	5.92	Std. Dev =	5.06
	Median =	38	Median =	39	Median =	35
	85th % Speed =	43.20	85th % Speed =	44.00	85th % Speed =	38.20
Sensor 4	Mean =	40.79	Mean =	41.78	Mean =	35.00
	Std. Dev =	5.85	Std. Dev =	5.49	Std. Dev =	4.58
	Median =	40	Median =	41	Median =	34
	85th % Speed =	47.00	85th % Speed =	47.00	85th % Speed =	39.00
All	Mean =	39.42	Mean =	40.31	Mean =	34.42
	Std. Dev =	6.20	Std. Dev =	5.94	Std. Dev =	4.85
	Median =	39	Median =	40	Median =	35
	85th % Speed =	45.00	85th % Speed =	46.00	85th % Speed =	39.00

Table A.13: Summary Statistics of Umpqua Left Lane

	UMPQUA LEFT LANE (45 MPH ADVISORY SPEED)					
	All Vehicles (N = 22)		Passenger Cars (N = 20)		Heavy Vehicles (N = 1)	
Sensor 1	Mean =	69.18	Mean =	70.00	Mean =	55.00
	Std. Dev =	8.57	Std. Dev =	8.35	Std. Dev =	*n/a*
	Median =	67.5	Median =	68	Median =	55
	85th % Speed =	81.10	85th % Speed =	82.30	85th % Speed =	55.00
Sensor 2	Mean =	60.32	Mean =	61.00	Mean =	49.00
	Std. Dev =	6.24	Std. Dev =	5.96	Std. Dev =	*n/a*
	Median =	60.5	Median =	62.5	Median =	49
	85th % Speed =	66.00	85th % Speed =	66.15	85th % Speed =	49.00
Sensor 3	Mean =	61.05	Mean =	61.85	Mean =	55.00
	Std. Dev =	8.66	Std. Dev =	8.66	Std. Dev =	*n/a*
	Median =	59.5	Median =	60.5	Median =	55
	85th % Speed =	65.85	85th % Speed =	66.15	85th % Speed =	55.00
Sensor 4	Mean =	60.95	Mean =	61.40	Mean =	58.00
	Std. Dev =	5.30	Std. Dev =	5.34	Std. Dev =	*n/a*
	Median =	60.5	Median =	61	Median =	58
	85th % Speed =	63.00	85th % Speed =	63.15	85th % Speed =	58.00
All	Mean =	62.88	Mean =	63.56	Mean =	54.25
	Std. Dev =	8.09	Std. Dev =	8.02	Std. Dev =	3.77
	Median =	62	Median =	62	Median =	55
	85th % Speed =	68.00	85th % Speed =	69.00	85th % Speed =	56.65

Table A.14: Summary Statistics of Umpqua Right Lane

	UMPQUA RIGHT LANE (45 MPH ADVISORY SPEED)					
	All Vehicles (N = 282)		Passenger Cars (N = 235)		Heavy Vehicles (N = 34)	
Sensor 1	Mean =	56.99	Mean =	57.98	Mean =	52.00
	Std. Dev =	7.14	Std. Dev =	6.61	Std. Dev =	8.11
	Median =	57	Median =	58	Median =	50.5
	85th % Speed =	63.00	85th % Speed =	64.00	85th % Speed =	57.05
Sensor 2	Mean =	53.72	Mean =	54.81	Mean =	47.85
	Std. Dev =	7.73	Std. Dev =	7.36	Std. Dev =	7.99
	Median =	54	Median =	55	Median =	47
	85th % Speed =	60.00	85th % Speed =	61.00	85th % Speed =	56.15
Sensor 3	Mean =	58.81	Mean =	60.20	Mean =	50.82
	Std. Dev =	8.18	Std. Dev =	7.39	Std. Dev =	8.39
	Median =	59	Median =	60	Median =	51
	85th % Speed =	66.00	85th % Speed =	66.00	85th % Speed =	59.05
Sensor 4	Mean =	60.29	Mean =	61.46	Mean =	52.35
	Std. Dev =	8.63	Std. Dev =	7.38	Std. Dev =	9.25
	Median =	61	Median =	62	Median =	50
	85th % Speed =	67.85	85th % Speed =	68.00	85th % Speed =	58.25
All	Mean =	57.45	Mean =	58.61	Mean =	50.76
	Std. Dev =	8.30	Std. Dev =	7.61	Std. Dev =	8.54
	Median =	57	Median =	58	Median =	50
	85th % Speed =	66.00	85th % Speed =	66.00	85th % Speed =	58.00

Table A.15: Summary Statistics of Elkton-Sutherlin Northbound

	ELKTON-SUTHERLIN NORTHBOUND (40 MPH ADVISORY SPEED)					
	All Vehicles (N = 295)		Passenger Cars (N = 256)		Heavy Vehicles (N = 28)	
Sensor 1	Mean =	57.56	Mean =	57.70	Mean =	54.11
	Std. Dev =	6.46	Std. Dev =	6.05	Std. Dev =	6.06
	Median =	58	Median =	58	Median =	54
	85th % Speed =	63.00	85th % Speed =	63.75	85th % Speed =	58.00
Sensor 2	Mean =	48.95	Mean =	49.50	Mean =	44.11
	Std. Dev =	5.83	Std. Dev =	5.56	Std. Dev =	6.68
	Median =	49	Median =	49	Median =	43
	85th % Speed =	54.00	85th % Speed =	54.75	85th % Speed =	49.85
Sensor 3	Mean =	51.22	Mean =	51.68	Mean =	47.18
	Std. Dev =	6.14	Std. Dev =	5.93	Std. Dev =	7.24
	Median =	51	Median =	52	Median =	46
	85th % Speed =	57.00	85th % Speed =	58.00	85th % Speed =	52.95
Sensor 4	Mean =	55.34	Mean =	56.02	Mean =	49.82
	Std. Dev =	6.54	Std. Dev =	6.34	Std. Dev =	6.23
	Median =	55	Median =	56	Median =	50
	85th % Speed =	62.00	85th % Speed =	62.00	85th % Speed =	55.95
All	Mean =	53.27	Mean =	53.73	Mean =	48.80
	Std. Dev =	7.10	Std. Dev =	6.81	Std. Dev =	7.45
	Median =	53	Median =	54	Median =	49
	85th % Speed =	60.00	85th % Speed =	61.00	85th % Speed =	56.00

Table A.16: Summary Statistics of Elkton-Sutherlin Southbound

	ELKTON-SUTHERLIN SOUTHBOUND (40 MPH ADVISORY SPEED)					
	All Vehicles (N = 377)		Passenger Cars (N = 280)		Heavy Vehicles (N = 80)	
Sensor 1	Mean =	58.02	Mean =	59.02	Mean =	53.94
	Std. Dev =	7.65	Std. Dev =	7.04	Std. Dev =	6.53
	Median =	58	Median =	59	Median =	53
	85th % Speed =	65.00	85th % Speed =	66.00	85th % Speed =	60.00
Sensor 2	Mean =	51.93	Mean =	53.20	Mean =	48.10
	Std. Dev =	7.20	Std. Dev =	7.12	Std. Dev =	6.06
	Median =	51	Median =	53	Median =	48
	85th % Speed =	58.00	85th % Speed =	59.00	85th % Speed =	53.00
Sensor 3	Mean =	49.24	Mean =	50.42	Mean =	45.89
	Std. Dev =	6.09	Std. Dev =	6.01	Std. Dev =	4.57
	Median =	49	Median =	50	Median =	46
	85th % Speed =	54.00	85th % Speed =	55.15	85th % Speed =	50.00
Sensor 4	Mean =	50.26	Mean =	51.08	Mean =	47.53
	Std. Dev =	6.08	Std. Dev =	5.78	Std. Dev =	5.67
	Median =	50	Median =	51	Median =	47
	85th % Speed =	56.00	85th % Speed =	57.00	85th % Speed =	52.00
All	Mean =	52.36	Mean =	53.43	Mean =	48.86
	Std. Dev =	7.59	Std. Dev =	7.34	Std. Dev =	6.49
	Median =	52	Median =	53	Median =	48
	85th % Speed =	59.00	85th % Speed =	61.00	85th % Speed =	55.00

Table A.17: Summary Statistics of Coos Bay-Roseburg Westbound

	COOS BAY-ROSEBURG WESTBOUND (45 MPH ADVISORY SPEED)					
	All Vehicles (N = 405)		Passenger Cars (N = 309)		Heavy Vehicles (N = 96)	
Sensor 1	Mean =	61.89	Mean =	63.03	Mean =	58.23
	Std. Dev =	6.03	Std. Dev =	5.91	Std. Dev =	4.86
	Median =	62	Median =	63	Median =	59
	85th % Speed =	68.00	85th % Speed =	68.00	85th % Speed =	63.00
Sensor 2	Mean =	63.26	Mean =	64.29	Mean =	59.95
	Std. Dev =	9.52	Std. Dev =	9.12	Std. Dev =	10.06
	Median =	63	Median =	64	Median =	57
	85th % Speed =	72.00	85th % Speed =	73.00	85th % Speed =	68.00
Sensor 3	Mean =	61.39	Mean =	62.27	Mean =	58.57
	Std. Dev =	7.83	Std. Dev =	7.83	Std. Dev =	7.14
	Median =	61	Median =	62	Median =	58
	85th % Speed =	67.00	85th % Speed =	68.80	85th % Speed =	64.00
Sensor 4	Mean =	61.89	Mean =	63.03	Mean =	58.23
	Std. Dev =	6.03	Std. Dev =	5.91	Std. Dev =	4.86
	Median =	62	Median =	63	Median =	59
	85th % Speed =	68.00	85th % Speed =	68.00	85th % Speed =	63.00
All	Mean =	62.11	Mean =	63.15	Mean =	58.74
	Std. Dev =	7.52	Std. Dev =	7.35	Std. Dev =	7.07
	Median =	62	Median =	63	Median =	58
	85th % Speed =	68.00	85th % Speed =	69.00	85th % Speed =	64.00

Table A.18: Summary Statistics of Woodburn-Estacada Northbound

	WOODBURN-ESTACADA NORTHBOUND (NO ADVISORY SPEED)					
	All Vehicles (N = 442)		Passenger Cars (N = 382)		Heavy Vehicles (N = 33)	
Sensor 1	Mean =	57.49	Mean =	57.57	Mean =	54.58
	Std. Dev =	8.23	Std. Dev =	7.99	Std. Dev =	8.57
	Median =	57	Median =	58	Median =	54
	85th % Speed =	65.00	85th % Speed =	64.85	85th % Speed =	59.20
Sensor 2	Mean =	50.77	Mean =	51.13	Mean =	47.24
	Std. Dev =	6.22	Std. Dev =	5.96	Std. Dev =	8.25
	Median =	50	Median =	51	Median =	46
	85th % Speed =	56.00	85th % Speed =	56.00	85th % Speed =	53.20
Sensor 3	Mean =	56.14	Mean =	56.66	Mean =	50.03
	Std. Dev =	6.55	Std. Dev =	6.25	Std. Dev =	5.86
	Median =	56	Median =	57	Median =	49
	85th % Speed =	62.85	85th % Speed =	63.00	85th % Speed =	56.00
Sensor 4	Mean =	52.50	Mean =	53.10	Mean =	46.79
	Std. Dev =	6.08	Std. Dev =	6.02	Std. Dev =	3.85
	Median =	52	Median =	52	Median =	47
	85th % Speed =	58.00	85th % Speed =	59.00	85th % Speed =	50.20
All	Mean =	54.23	Mean =	54.61	Mean =	49.66
	Std. Dev =	7.34	Std. Dev =	7.10	Std. Dev =	7.50
	Median =	54	Median =	54	Median =	48
	85th % Speed =	60.00	85th % Speed =	61.00	85th % Speed =	56.00

Table A.19: Summary Statistics of Woodburn-Estacada Southbound

	WOODBURN-ESTACADA SOUTHBOUND (NO ADVISORY SPEED)					
	All Vehicles		Passenger Cars		Heavy Vehicles	
	(N = 608)		(N = 541)		(N = 51)	
Sensor 1	Mean =	57.62	Mean =	58.61	Mean =	50.37
	Std. Dev =	7.78	Std. Dev =	6.90	Std. Dev =	9.44
	Median =	58	Median =	58	Median =	52
	85th % Speed =	65.00	85th % Speed =	65.00	85th % Speed =	60.50
Sensor 2	Mean =	58.30	Mean =	59.32	Mean =	50.67
	Std. Dev =	8.10	Std. Dev =	7.03	Std. Dev =	9.88
	Median =	58	Median =	59	Median =	52
	85th % Speed =	65.00	85th % Speed =	66.00	85th % Speed =	60.00
Sensor 3	Mean =	53.40	Mean =	54.28	Mean =	46.98
	Std. Dev =	7.50	Std. Dev =	6.72	Std. Dev =	9.50
	Median =	54	Median =	54	Median =	48
	85th % Speed =	60.00	85th % Speed =	60.00	85th % Speed =	56.00
Sensor 4	Mean =	55.16	Mean =	55.91	Mean =	49.02
	Std. Dev =	6.92	Std. Dev =	6.09	Std. Dev =	8.62
	Median =	55	Median =	56	Median =	51
	85th % Speed =	61.00	85th % Speed =	61.00	85th % Speed =	57.00
All	Mean =	56.12	Mean =	57.03	Mean =	49.26
	Std. Dev =	7.83	Std. Dev =	6.99	Std. Dev =	9.42
	Median =	56	Median =	57	Median =	51
	85th % Speed =	63.00	85th % Speed =	64.00	85th % Speed =	58.00

Table A.20: Summary Statistics of Jacksonville Eastbound

	JACKSONVILLE EASTBOUND (45 MPH ADVISORY SPEED)					
	All Vehicles (N = 313)		Passenger Cars (N = 296)		Heavy Vehicles (N = 8)	
Sensor 1	Mean =	57.79	Mean =	57.85	Mean =	54.63
	Std. Dev =	7.69	Std. Dev =	7.65	Std. Dev =	9.24
	Median =	57	Median =	57	Median =	54.5
	85th % Speed =	65.00	85th % Speed =	65.00	85th % Speed =	57.00
Sensor 2	Mean =	56.57	Mean =	56.58	Mean =	52.50
	Std. Dev =	13.51	Std. Dev =	13.76	Std. Dev =	7.58
	Median =	55	Median =	55	Median =	51
	85th % Speed =	63.00	85th % Speed =	62.00	85th % Speed =	60.60
Sensor 3	Mean =	54.01	Mean =	54.09	Mean =	50.13
	Std. Dev =	6.31	Std. Dev =	6.34	Std. Dev =	5.69
	Median =	54	Median =	54	Median =	48.5
	85th % Speed =	59.00	85th % Speed =	59.00	85th % Speed =	52.95
Sensor 4	Mean =	60.28	Mean =	60.32	Mean =	56.88
	Std. Dev =	6.80	Std. Dev =	6.62	Std. Dev =	8.66
	Median =	60	Median =	60	Median =	56
	85th % Speed =	67.00	85th % Speed =	67.00	85th % Speed =	60.85
All	Mean =	57.16	Mean =	57.21	Mean =	53.53
	Std. Dev =	9.32	Std. Dev =	9.37	Std. Dev =	7.94
	Median =	56.5	Median =	57	Median =	53
	85th % Speed =	64.00	85th % Speed =	64.00	85th % Speed =	61.00

Table A.21: Summary Statistics of Jacksonville Westbound

	JACKSONVILLE WESTBOUND (45 MPH ADVISORY SPEED)					
	All Vehicles (N = 306)		Passenger Cars (N = 294)		Heavy Vehicles (N = 11)	
Sensor 1	Mean =	57.15	Mean =	57.21	Mean =	56.18
	Std. Dev =	6.90	Std. Dev =	7.01	Std. Dev =	2.82
	Median =	57	Median =	57	Median =	56
	85th % Speed =	63.00	85th % Speed =	63.00	85th % Speed =	59.50
Sensor 2	Mean =	55.73	Mean =	55.84	Mean =	53.91
	Std. Dev =	7.48	Std. Dev =	7.51	Std. Dev =	6.22
	Median =	55	Median =	55	Median =	54
	85th % Speed =	63.00	85th % Speed =	63.00	85th % Speed =	60.00
Sensor 3	Mean =	57.60	Mean =	57.64	Mean =	57.45
	Std. Dev =	7.16	Std. Dev =	7.17	Std. Dev =	6.95
	Median =	57	Median =	57	Median =	57
	85th % Speed =	64.00	85th % Speed =	64.05	85th % Speed =	61.00
Sensor 4	Mean =	57.82	Mean =	57.95	Mean =	55.45
	Std. Dev =	6.84	Std. Dev =	6.80	Std. Dev =	7.06
	Median =	57	Median =	57	Median =	57
	85th % Speed =	64.25	85th % Speed =	65.00	85th % Speed =	62.50
All	Mean =	57.08	Mean =	57.16	Mean =	55.75
	Std. Dev =	7.14	Std. Dev =	7.16	Std. Dev =	5.95
	Median =	57	Median =	57	Median =	56
	85th % Speed =	64.00	85th % Speed =	64.00	85th % Speed =	61.00

Table A.22: Summary Statistics of Green Springs Eastbound

	GREEN SPRINGS EASTBOUND (NO ADVISORY SPEED)					
	All Vehicles (N = 56)		Passenger Cars (N = 53)		Heavy Vehicles (N = 2)	
Sensor 1	Mean =	48.38	Mean =	48.53	Mean =	47.50
	Std. Dev =	6.11	Std. Dev =	6.22	Std. Dev =	0.71
	Median =	48	Median =	48	Median =	47.5
	85th % Speed =	54.00	85th % Speed =	54.00	85th % Speed =	47.85
Sensor 2	Mean =	39.04	Mean =	39.06	Mean =	40.00
	Std. Dev =	6.59	Std. Dev =	6.75	Std. Dev =	2.83
	Median =	39	Median =	39	Median =	40
	85th % Speed =	44.75	85th % Speed =	45.00	85th % Speed =	41.40
Sensor 3	Mean =	38.54	Mean =	38.53	Mean =	41.00
	Std. Dev =	5.26	Std. Dev =	5.34	Std. Dev =	2.83
	Median =	38	Median =	38	Median =	41
	85th % Speed =	43.00	85th % Speed =	43.00	85th % Speed =	42.40
Sensor 4	Mean =	38.54	Mean =	38.74	Mean =	37.00
	Std. Dev =	4.60	Std. Dev =	4.60	Std. Dev =	0.00
	Median =	37	Median =	37	Median =	37
	85th % Speed =	42.75	85th % Speed =	43.20	85th % Speed =	37.00
All	Mean =	41.12	Mean =	41.21	Mean =	41.38
	Std. Dev =	7.04	Std. Dev =	7.14	Std. Dev =	4.37
	Median =	40	Median =	40	Median =	40.5
	85th % Speed =	49.00	85th % Speed =	49.00	85th % Speed =	46.80

Table A.23: Summary Statistics of Green Springs Westbound

	GREEN SPRINGS WESTBOUND (NO ADVISORY SPEED)					
	All Vehicles (N = 59)		Passenger Cars (N = 55)		Heavy Vehicles (N = 2)	
Sensor 1	Mean =	56.75	Mean =	56.44	Mean =	55.00
	Std. Dev =	6.93	Std. Dev =	6.55	Std. Dev =	2.83
	Median =	56	Median =	55	Median =	55
	85th % Speed =	64.00	85th % Speed =	64.00	85th % Speed =	56.40
Sensor 2	Mean =	47.03	Mean =	47.25	Mean =	48.50
	Std. Dev =	7.57	Std. Dev =	7.60	Std. Dev =	9.19
	Median =	45	Median =	46	Median =	48.5
	85th % Speed =	53.30	85th % Speed =	52.90	85th % Speed =	53.05
Sensor 3	Mean =	45.37	Mean =	45.29	Mean =	49.00
	Std. Dev =	6.58	Std. Dev =	6.62	Std. Dev =	9.90
	Median =	45	Median =	45	Median =	49
	85th % Speed =	51.00	85th % Speed =	50.90	85th % Speed =	53.90
Sensor 4	Mean =	48.34	Mean =	48.35	Mean =	45.00
	Std. Dev =	4.44	Std. Dev =	4.51	Std. Dev =	1.41
	Median =	48	Median =	48	Median =	45
	85th % Speed =	52.00	85th % Speed =	52.00	85th % Speed =	45.70
All	Mean =	49.37	Mean =	49.33	Mean =	49.38
	Std. Dev =	7.80	Std. Dev =	7.66	Std. Dev =	6.50
	Median =	47.5	Median =	47.5	Median =	49.5
	85th % Speed =	57.00	85th % Speed =	57.00	85th % Speed =	55.95

APPENDIX B: 85S2 and 85MSR Tables for Passenger Cars and Heavy Vehicles

Table B.1:Maximum Difference of 85th Percentile Speeds and 85th Percentile of Maximum Reduction in Speeds for Passenger Cars

Site	Maximum Difference of 85th Percentile Speeds (mph)	85th Percentile of Maximum Reduction in Speeds (mph)
Kings Valley NB	0	7
Kings Valley SB	9	13.25
McKenzie EB	0	12
McKenzie WB	2	9
North Umpqua EB	9	13
North Umpqua WB	9	13
Mt. Hood (80) NB	10	14
Mt. Hood (80) SB	2	6
Mt. Hood (62) NB	6	12
Mt. Hood (62) SB	5.45	11.65
Santiam EB	0	5
Santiam WB	2.3	7
Umpqua LL	16.15	15
Umpqua RL	3	11
Elkton-Sutherlin NB	9	15
Elkton-Sutherlin SB	10.85	14
Coos Bay-Roseburg WB		11
Woodburn-Estacada NB	8.85	14.9
Woodburn-Estacada SB	5	9
Jacksonville EB	6	10
Jacksonville WB	0	9
Green Springs EB	11	18.2
Green Springs WB	13.1	16

Table B.2: Maximum Difference of 85th Percentile Speeds and 85th Percentile of Maximum Reduction in Speeds for Heavy Vehicles

Site	Maximum Difference of 85th Percentile Speeds (mph)	85th Percentile of Maximum Reduction in Speeds (mph)
Kings Valley NB	2.05	12.45
Kings Valley SB	14.35	14.45
McKenzie EB	6	10
McKenzie WB	1	7
North Umpqua EB	14	16.25
North Umpqua WB	8	12
Mt. Hood (80) NB	6.05	10
Mt. Hood (80) SB	2	5.1
Mt. Hood (62) NB	1	7
Mt. Hood (62) SB	6	11.9
Santiam EB		2.3
Santiam WB	3	5
Umpqua LL	6	6
Umpqua RL	0.9	9.65
Elkton-Sutherlin NB	8.15	17.1
Elkton-Sutherlin SB	10	12.3
Coos Bay-Roseburg WB		10
Woodburn-Estacada NB	6	12.5
Woodburn-Estacada SB	4.5	7
Jacksonville EB	4.05	7.5
Jacksonville WB		7
Green Springs EB	6.45	8.55
Green Springs WB	3.35	9.65

APPENDIX C: Detailed Speed Reduction Statistics

Table C.1: Detailed Speed Reduction Statistics for All Vehicle Types

	N	Average Speed Reduction (mph)		Std. Dev. (mph)		Estimated	p-value	95% Confidene		
		Point 1-2	Point 1-3	Point 1-2	Point 1-3	Difference		Interval		
Kings Valley NB	171	1.21	-0.16	7.51	6.26	1.36	0.01	0.31	to	2.42
Kings Valley SB	131	8.51	3.03	5.15	7.62	5.48	1.40E-15	4.29	to	6.67
McKenzie EB	262	-2.26	-3.02	9.79	9.16	0.77	0.01	0.16	to	1.37
McKenzie WB	479	0.01	2.77	6.36	6.37	-2.76	< 2.20E-16	-3.21	to	-2.31
North Umpqua EB	185	1.10	7.09	11.21	6.21	-5.98	4.07E-16	-7.30	to	-4.66
North Umpqua WB	311	7.92	5.20	5.22	6.26	2.72	2.20E-16	2.25	to	3.19
Mt. Hood (80) NB	218	6.28	6.05	6.82	6.89	0.23	0.47	-0.40	to	0.86
Mt. Hood (80) SB	262	-2.99	0.59	5.78	5.12	-3.58	< 2.20E-16	-4.14	to	-3.01
Mt. Hood (62) NB	245	2.06	3.78	5.80	7.26	-1.73	6.08E-06	-2.46	to	-0.99
Mt. Hood (62) SB	330	5.42	2.51	6.15	7.08	2.91	2.20E-16	2.29	to	3.53
Santiam EB	376	0.16	-1.17	4.14	4.17	1.33	1.288E-09	0.91	to	1.75
Santiam WB	313	1.06	1.77	4.53	4.99	-0.71	0.02	-1.29	to	-0.13
Umpqua LL	22	8.86	8.14	5.76	6.89	0.73	0.62	-2.32	to	3.78
Umpqua RL	282	3.27	-1.82	7.33	7.84	5.09	< 2.20E-16	4.26	to	5.93
Elkton-Sutherlin NB	295	8.61	6.34	6.48	6.98	2.27	1.28E-14	1.72	to	2.82
Elkton-Sutherlin SB	377	6.08	8.78	7.11	6.36	-2.69	< 2.20E-16	-3.24	to	-2.15
Coos Bay-Roseburge WB	405	-1.38	0.50	8.90	8.19	-1.87	1.27E-04	-2.82	to	-0.92
Woodburn-Estacada NB	442	6.72	1.35	8.53	8.58	5.37	< 2.20E-16	4.79	to	5.96
Woodburn-Estacada SB	608	-0.68	4.22	5.30	5.51	-4.90	< 2.20E-16	-5.29	to	-4.50
Jacksonville EB	312	1.81	3.76	8.42	7.06	-1.95	5.09E-06	-2.77	to	-1.12
Jacksonville WB	306	1.42	-0.45	7.68	6.46	1.87	6.27E-07	1.15	to	2.60
Green Springs EB	56	9.34	9.84	6.73	5.85	-0.50	0.57	-2.27	to	1.27
Green Springs WB	59	9.71	11.37	6.61	6.53	-1.66	0.03	-3.18	to	-0.14

Table C.2: Detailed Speed Reduction Statistics for Passenger Cars

	N	Average Speed Reduction (mph)		Std. Dev. (mph)		Estimated Difference	p-value	95% Confidene Interval
		Point 1-2	Point 1-3	Point 1-2	Point 1-3			
Kings Valley NB	144	1.15	-0.42	7.56	5.88	1.58	0.01	0.426 to 2.73
Kings Valley SB	107	8.47	2.79	4.68	7.66	5.68	1.60E-12	4.275 to 7.09
McKenzie EB	198	-3.14	-3.86	9.49	8.84	0.72	0.05	5E-04 to 1.44
McKenzie WB	396	-0.07	2.68	6.38	6.32	-2.74	2.20E-16	-3.26 to -2.22
North Umpqua EB	145	0.07	6.30	11.67	5.70	-6.23	6.17E-12	-7.88 to -4.59
North Umpqua WB	274	7.89	5.16	5.30	6.31	2.72	2.20E-16	2.216 to 3.23
Mt. Hood (80) NB	181	6.65	6.29	6.65	6.57	0.36	0.32	-0.36 to 1.08
Mt. Hood (80) SB	206	-2.30	1.13	4.83	4.73	-3.42	2.20E-16	-4.02 to -2.83
Mt. Hood (62) NB	179	2.58	3.98	6.39	8.08	-1.40	3.35E-03	-2.33 to -0.47
Mt. Hood (62) SB	258	5.30	2.54	5.94	5.88	2.76	3.99E-15	2.11 to 3.41
Santiam EB	328	0.41	-1.13	3.85	4.06	1.54	1.95E-11	1.106 to 1.98
Santiam WB	259	0.92	1.98	4.70	5.21	-1.06	1.56E-03	-1.71 to -0.41
Umpqua LL	20	9.00	8.15	6.02	6.76	0.85	0.59	-2.38 to 4.08
Umpqua RL	235	3.17	-2.22	7.49	8.01	5.39	2.20E-16	4.485 to 6.30
Elkton-Sutherlin NB	256	8.20	6.02	6.14	6.65	2.18	1.30E-11	1.577 to 2.79
Elkton-Sutherlin SB	280	5.82	8.60	6.92	5.84	-2.78	9.78E-14	-3.48 to -2.08
Coos Bay-Roseburg WB	309	-1.27	0.76	8.70	8.58	-2.03	4.48E-04	-3.15 to -0.90
Woodburn-Estacada NB	382	6.43	0.91	8.52	8.43	5.52	2.20E-16	4.914 to 6.13
Woodburn-Estacada SB	541	-0.72	4.33	5.40	5.68	-5.04	2.20E-16	-5.46 to -4.63
Jacksonville EB	295	1.90	3.74	8.59	7.18	-1.84	3.53E-05	-2.7 to -0.98
Jacksonville WB	294	1.37	-0.44	7.75	6.50	1.81	2.61E-06	1.065 to 2.55
Green Springs EB	53	9.47	10.00	6.89	5.96	-0.53	0.57	-2.4 to 1.34
Green Springs WB	55	9.18	11.15	5.52	5.62	-1.96	0.02	-3.54 to -0.38

Table C.3: Detailed Speed Reduction Statistics for Heavy Vehicles

	N	Average Speed Reduction (mph)		Std. Dev. (mph)		Estimated Difference	p-value	95% Confidene Interval
		Point 1-2	Point 1-3	Point 1-2	Point 1-3			
Kings Valley NB	20	1.10	1.90	8.29	9.11	-0.80	0.653	-4.47 to 2.87
Kings Valley SB	18	8.89	4.33	6.82	8.06	4.56E+00	0.0006843	2.234 to 6.88
McKenzie EB	41	0.29	-0.32	6.07	5.22	0.61	0.1789	-0.29 to 1.51
McKenzie WB	65	-0.26	2.72	4.18	4.41	-2.98E+00	3.061E-08	-3.93 to -2.04
North Umpqua EB	27	4.56	9.81	9.34	7.85	-5.26E+00	3.716E-06	-7.11 to -3.41
North Umpqua WB	31	8.42	5.55	5.01	6.40	2.87E+00	0.0005211	1.362 to 4.38
Mt. Hood (80) NB	28	4.32	4.61	4.97	6.08	-0.29	0.6568	-1.59 to 1.02
Mt. Hood (80) SB	34	-6.82	-1.91	7.20	5.02	-4.91E+00	0.0001171	-7.2 to -2.62
Mt. Hood (62) NB	50	0.50	3.56	2.48	3.39	-3.06E+00	4.515E-06	-4.25 to -1.87
Mt. Hood (62) SB	54	5.78	2.24	6.55	8.25	3.54E+00	9.082E-07	2.26 to 4.81
Santiam EB	37	-2.22	-1.70	4.86	2.97	-5.14E-01	0.5035	-2.05 to 1.03
Santiam WB	33	1.82	0.42	4.03	3.31	1.39E+00	0.03634	0.094 to 2.69
Umpqua LL	1	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Umpqua RL	34	4.15	1.18	6.64	6.55	2.97E+00	0.006834	0.876 to 5.06
Elkton-Sutherlin NB	28	10.00	6.93	6.32	6.99	3.07E+00	0.0005451	1.464 to 4.68
Elkton-Sutherlin SB	80	5.84	8.05	5.07	4.73	-2.21E+00	5.814E-08	-2.95 to -1.48
Coos Bay-Roseburg WB	96	-1.72	-0.34	9.54	6.75	-1.38E+00	0.1258	-3.14 to 0.39
Woodburn-Estacada NB	33	7.33	4.55	6.27	7.47	2.79E+00	0.04015	0.133 to 5.44
Woodburn-Estacada SB	51	-0.29	3.39	2.85	3.45	-3.69E+00	1.479E-10	-4.61 to -2.76
Jacksonville EB	8	2.13	4.50	3.68	4.11	-2.38E+00	0.06153	-4.9 to 0.15
Jacksonville WB	11	2.27	-1.27	6.13	5.64	3.55E+00	0.08084	-0.52 to 7.61
Green Springs EB	2	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
Green Springs WB	2	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*