Developing a Prototype System for Establishing Passing and No-Passing Zones of Two-Lane Highways

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1 INTRODUCTION

Passing sight distance (PSD) is an essential component taken into account in the geometric design of two-lane two-way highways, simply termed two-lane highways similar to the one shown in Figure 1. Note that two-lane highways are very common in rural states like Wyoming. Establishing passing and no passing zones is essential in ensuring the safety of the driving public.

Figure 1: Two-lane highway.
Source: What is Meant by a "Two-Lane" Road (2018).

2 LITERATURE REVIEW

In two-lane highways, drivers would have to drive on the opposing traffic lane to pass a slow moving vehicle ahead before merging back into their original lane. Before executing the passing maneuver, the drivers should see no vehicles in the opposing traffic lane for an adequate distance such that they can pass the slow moving vehicle in front of them and retreat to their lane without cutting off the vehicle passed. In some instances, the driver attempting the pass initiates it by driving on the opposing traffic lane, sees an oncoming vehicle ahead and returns to his or her lane behind the slow moving vehicle. A schematic diagram of the distances traveled by the passing vehicle and the distance traveled by the oncoming vehicle in the opposing traffic lane is presented in Figure 2.

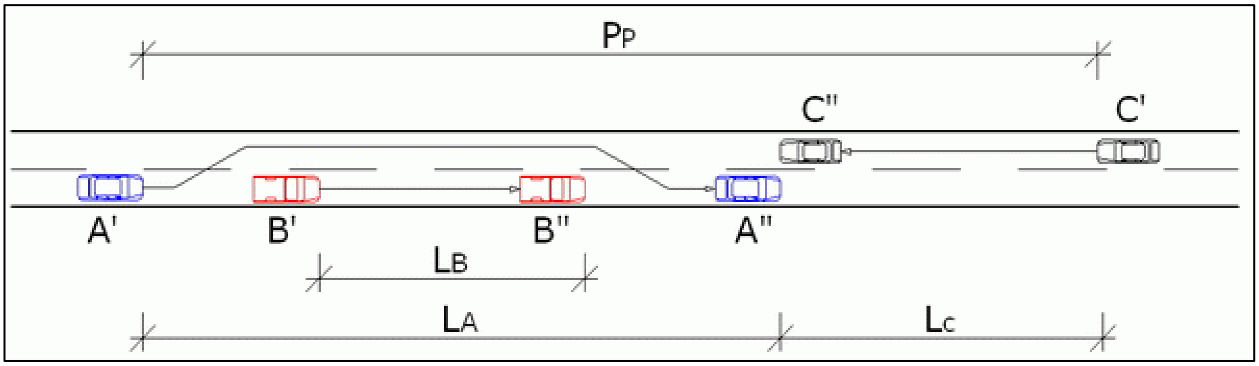


Figure 2: Distances traveled by the passing vehicle and the oncoming vehicle during the passing maneuver execution.
Source: Put Information Center (2007).

The PSD is measured from the driver's eye height, 3.5 ft relative to the pavement surface, to a point at a height of 3.5 ft as well. The PSD is obstructed at horizontal curves especially when there are objects blocking the driver's view and at crest vertical curves as shown in Figure 3.

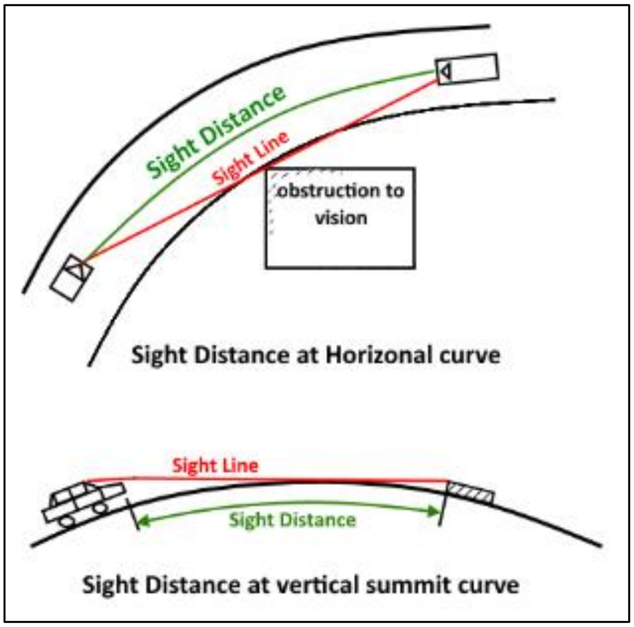
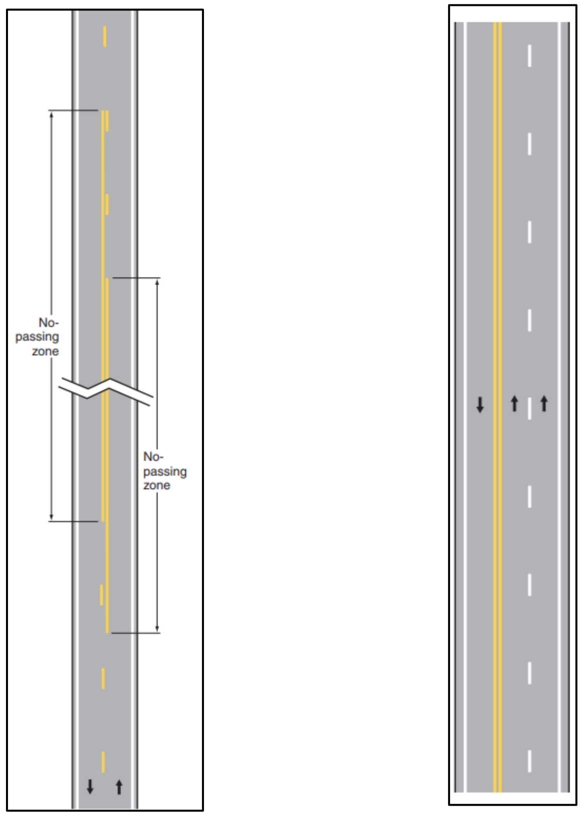


Figure 3: Passing sight distance limitations at horizontal curves and crest vertical curves.
Source: Sight Distance (2018).

If the PSD is inadequate, dangerous passing maneuvers can result in wrong-way driving (WWD) crashes such as head-on and opposite-direction sideswipe crashes. When head-on crashes occur at two-lane highways with a speed limit of 55 mph, relative vehicle speeds are 110 mph resulting in instant fatalities let alone when head-on crashes occur on two-lane highways with higher speed limits. Opposite direction sideswipe crash impacts are lighter but such crashes are high severity crashes because of the large relative speeds. Preventing passing related crashes by establishing accurate passing and no-passing zone markings saves considerable amounts of comprehensive costs. The costs include but are not limited to emergency service costs, medical expenses, coroner's services, property damage costs, costs attributed to lost working days, insurance costs and court costs among others. Therefore, provision for adequate PSD is crucial for the design of two-lane highways. Otherwise, passing should be prohibited, as is the case of no-passing zones, or a passing lane should be provided. Examples of no-passing zones and a passing lane are presented in Figure 4.

Note that in Figure 4a, the right-hand-side solid yellow line indicates that passing is prohibited for drivers traveling in the northbound direction while the left-hand-side solid line indicates that passing is prohibited for the drivers traveling in the southbound direction. Likewise, dashed yellow lines indicate that passing is permitted. On the other hand, passing lanes, similar to the second to the rightmost lane shown in Figure 4b, are provided only for passing vehicles to overtake the slow moving vehicles. The rightmost lane, shown in Figure 4b, is referred to as a climbing lane for heavy vehicles on upgrades particularly steep ones.



a. No-passing zones. **b. Passing lane.**

Figure 4: No-passing zones and passing lane.
Source: FHWA (2009).

This research is focused on ascertaining the dimensions of passing zones and of no-passing zones on two-lane highways in Wyoming based on the PSD. The dimensions are the length and boundary points of the zones. Note that the PSD is a function of the design speed. Not only should the PSD be adequate but also the length of passing zones should be adequate.

There are multiple procedures for measuring the PSD in the field including the walking method, one-vehicle method and two-vehicle method among others. The walking method is time consuming and hazardous. It requires two inspectors walking on foot with range poles with markings at a height of 3.5 ft. One group member follows the other along the two-lane highway. Each member holds the end of a rope having a length equal to the PSD. The following member signals when he or she is no longer able to see the leading member's marking on the pole and hence signals the starting point of the no-passing zone. Similarly, when the leading member's marking on the pole comes back into view, the following member signals the end point of the no-passing zone. The one-vehicle method is another hazardous method that is less accurate than the walking method. However, it is less time-consuming. It requires an inspector in a car driving slowly through the highway. The inspector should exit the vehicle and mark the road every time he or she judges whether the PSD is adequate. The inspector is also equipped with a distance measuring device operable while driving to measure the distances between the markings (Brown and Hummer, 2000). The two-vehicle method is less hazardous and time consuming. Its accuracy depends on the quality of the equipment used. In the two-vehicle method, two vehicles equipped with the data collection apparatus maintain a specified gap distance equal to the PSD. Both vehicles are equipped with global positioning satellite (GPS) systems to record the locations of the vehicles at a specific frequency. Also, both vehicles communicate by radio. In addition to the aforementioned devices, the following vehicle is equipped with a switch, a laptop to record the data and a monitor to output the distance between both vehicles. The switch is operated when either the following vehicle driver is no longer able to see the leading vehicle, hence signaling the entrance to a no-passing zone, or vice versa. The following vehicle driver ought to pay close attention to the monitor to adjust speed to maintain the specified headway, ensure that all the equipment software programs are running smoothly, reset the software especially that of the GPS system if the GPS system stops recording data and operate the switch when necessary. Managing the driving task and the aforementioned tasks is cumbersome for the following vehicle driver especially at rounded and rugged terrain (Hutton and Cook, 2016). Other time consuming methods are the laser rangefinder method, optical rangefinder method and speed method (Brown and Hummer, 2000).

The method preferred and currently used by WYDOT to measure the PSD is the two-vehicle method because it is neither hazardous nor time consuming. The walking method is hazardous while the one-vehicle method is time consuming. Lane closures may be warranted for conducting the one-vehicle method as well. The laser rangefinder, optical rangefinder and speed methods are laborious. The apparatus which has been used by WYDOT personnel to implement the two-vehicle method, known as the Range Tracker System (The Hoosier Company Inc.) is obsolete and no longer functional. Furthermore, the system cannot be repaired and hence it is no longer available.

The goal of this research is develop a functional prototype of the two-vehicle method's apparatus because unfortunately the private sector is not developing a prototype. The apparatus ought to be tested for quality and accuracy as well. Designating passing and no-passing zones on the two-lane highways in the state needs to be carried out precisely. According to WYDOT, passing and no-passing zones are established in two-lanes highways representing more than 29,000 mi in the entire state. Around 6,000 miles of these roads are owned/maintained by WYDOT. Zone striping plans for these highways change over time due to changes in the two-lane highways' posted speed limits, which occurred in the past few years, crash occurrences, roadway re-alignments, placement of sight obstructions near horizontal curves and complaints from citizens among others. It is crucial that the proposed apparatus be used to evaluate whether the existing passing zone plans are safe. It is possible that a section of a two-lane highway is designated as a passing zone while the PSD is inadequate. On the other hand, it is necessary to evaluate whether existing zone striping designs are too conservative. A no-passing zone can be found to be longer than necessary. Furthermore, the apparatus ought to be used whenever a change to the striping plan is necessary to be made due to any of the previously mentioned reasons. Besides, passing related crashes such as head-on and opposite direction sideswipe crashes are either fatal or incapacitating injury crashes. Such crashes ought to be prevented at all costs. Another concern is that in cases where passing and no-passing zone pavement markings will have to be re-striped, signage relocation costs are expensive. An example of a no-passing zone with a sign is presented in Figure 5.

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Figure 5: No-passing zone with sign.
Source: Hayworth (2013).

When jurisdictions such as local governments or the Wind River Indian Reservation request help, WYDOT personnel are unable to offer adequate help because their two-vehicle method's apparatus is no longer functional. Thus, it is imperative that a prototype of the apparatus of the two-vehicle system be developed, tested and provided to WYDOT. The goal is to ensure that it is of good quality, accurate, cost-effective, durable and convenient. Minimal training ought to be required for set-up, running and data processing. In the following sections, the objective, background literature, tasks of this research, timeline, budget and deliverables are discussed.

3 OBJECTIVE

The main objective of this study is to develop initially a quick and functional prototype of the two-vehicle method for measuring the PSD on Wyoming's two-lane highways. This first prototype will be developed in a year and a half. WYDOT will be able to put this first prototype into service quickly. Within a year after that, the research team will enhance the design of the developed system and incorporate all the advanced state-of-the-art intelligent transportation system (ITS) technologies into it. The first prototype will be then upgraded so that WYDOT will have two functional systems for establishing passing zones by the end of the study. The developed systems will make it possible for WYDOT to:

- Evaluate whether the existing striping plans of passing zones of Wyoming's two-lane highways are safe and whether the existing striping plans of no-passing zones are too conservative
- Continuously re-establish the boundaries of passing and no-passing zones of the state's two-lane highways. That is particularly needed in cases where changes in any features that affect the design criteria of passing and no-passing zones occur.
- Save costs related to placing no-passing zones signs after accurately establishing no passing zones.
- Minimize crashes involving passing, which are normally severe.
- Minimize WYDOT's liability in case of crashes.

4 BACKGROUND

This section is about the design criteria of passing and no-passing zones based on federal and state standards.

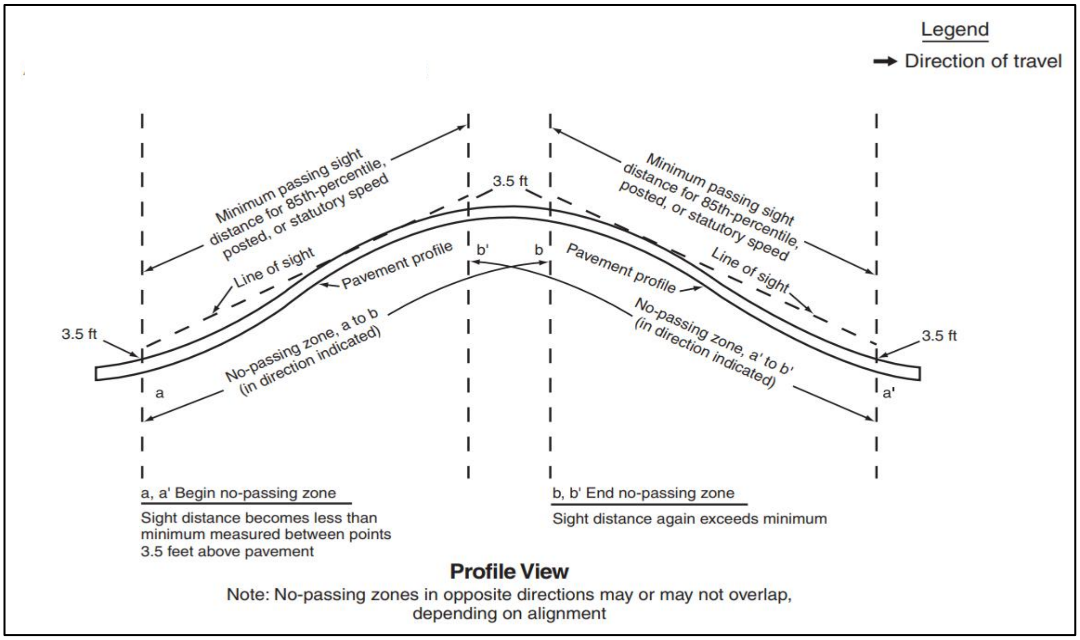
As previously mentioned, PSD is one of the utmost design elements of two-lane highways. The American Association of State Highway and Transportation Officials (AASHTO, 2011) recommend minimum PSD values based on the minimum sight distances suggested by the Manual on Uniform Traffic Control Devices (MUTCD) which is published by the Federal Highway Administration (FHWA, 2009). The minimum PSD design values used by WYDOT are the same as those of AASHTO (2011) except that the minimum PSD design value for a two-lane highway with a posted speed limit of 65 mph is 1,200 feet assuming that drivers drive above the speed limit (WYDOT Traffic Program, 2012). The PSD design values are presented in Table 1.

Table 1: Passing Sight Distance Design Values.

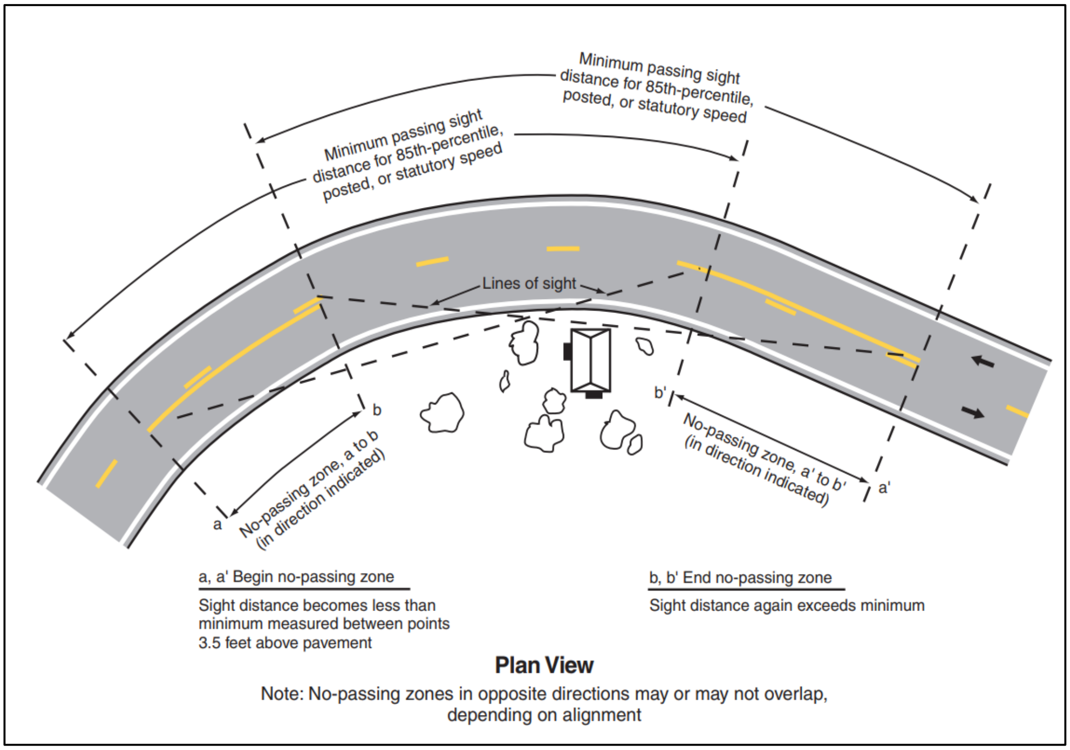
Design Speed (mph)	Assumed Speeds (mph)		PSD (ft)
	Passed Vehicle	Passing Vehicle	
20	8	20	400
25	13	25	450
30	18	30	500
35	23	35	550
40	28	40	600
45	33	45	700
50	38	50	800
55	43	55	900
60	48	60	1,000
65	53	65	1,100
70	58	70	1,200[1]
75	63	75	1,300
80	68	80	1,400

1: A PSD design value of 1,200 ft is used for two-lane highways with a 65 mph speed limit in Wyoming. Sources: AASHTO (2011) and WYDOT Traffic Program (2012).

The values, shown in the Table 1 are based on a variety of assumptions including those of vehicle kinematics and proximity to sight obstructions which depend on the highway's profile as shown in Figure 6.



a. Designation of no-passing zone at crest vertical curve.



b. Designation of no-passing zone at horizontal curve.

Figure 6: Designation of no-passing zones because of sight obstructions at crest vertical curves and horizontal curves.

Source: FHWA (2009).

Passing zones should have a minimum length depending on the speed to improve operational efficiency (Harwood et al., 2008). The minimum length is ascertained such that passing zones shorter than it do not negatively affect the operational efficiency of two-lane highways. The minimum passing zone lengths of AASHTO (2011) and WYDOT (WYDOT Traffic Program, 2012) are shown in Table 2. Note that the minimum passing zone lengths of WYDOT are more conservative than those of AASHTO except for two-lane highways with speed limits of 65 mph or higher.

Table 2: Minimum Passing Zone Lengths

85th Percentile Speed or Posted or Statutory Speed Limit (mph)	**AASHTO's Minimum Passing Zone Length (ft)**	**WYDOT's Minimum Passing Zone Length (ft)**
20	400	Not Specified
30	550	320
35	650	370
40	750	410
45	800	500
50	800	550
55	800	650
60	800	700
65	800	850
70	800	850

Sources: AASHTO (2011) and WYDOT Traffic Program (2012).

In this research, the two-vehicle method will be employed with a prototype of the apparatus to be developed. The prototype will be tested and calibrated such that zone striping plans satisfy WYDOT's design criteria.

5 STUDY TASKS

This research is composed of the following study tasks:

1. Literature Review
2. Prototype Instrumentation Development and Software Set-Up
3. Field Testing of the Prototype
4. Preparing the Report and Implementation Plan
5. Upgrading the First Prototype

5.1 Literature Review

A comprehensive literature review will be conducted regarding the design criteria for passing zones and no-passing zones of two-lane highways. The design criteria include WYDOT and federal design criteria. Also, a review of the past methods of measuring the PSD, documented in the literature, will be studied. Other related reference materials will be reviewed as well.

5.2 Prototype Instrumentation Development and Software Set-Up

The focus of the design and development of the prototype instrumentation and associated software is to replace and improve the two-vehicle PSD measuring apparatus known as Range Tracker Systems used currently by WYDOT. The Range Tracker System is no longer available and therefore another system is immediately needed. The features of the initial system (prototype 1) which will be delivered in 1.5 years will be then discussed in task 4.2.1 while the features of the ultimate system (prototype 2) will be described in task 4.2.1.

5.2.1 Prototype 1 Features

Prototype 1 will be developed and then delivered to WYDOT to sever the urgent need for a functional system within 1.5 years of starting the study. This prototype 1 will have the following functionalities implemented:

- V2V communication based on the IEEE 802.1p – Wireless Access in Vehicular Environments (WAVE) devices Locomate mini-2.
- GPS Data collection synchronized with manual detection of the lead vehicle using two-button operation.
- Graphical User Interface based Software for real-time GPS data display interfaced with maps, GPS and capability to store GPS and mile marker data.

5.2.2 Prototype 2 Features

The limitations of the Range Tracker System necessitates the design and development of an advanced ITS prototype satisfying the following technical objectives:

- GPS based Vehicular distance measurement with real-time Google Map display
- Autonomous Real-Time Detection of the Lead Vehicle
- Graphical user interface based software program with real-time visual display and capable of storing images and measured data.

The proposed prototype 2 of the two-vehicle system is composed of an integrated GPS based V2V communication systems in both the vehicles. In addition to the V2V communication system, the following vehicle will have high-resolution cameras, radar for redundant leading vehicle detection and distance measurement, and a laptop interfaced to the sensors providing a real-time graphical display to the driver as shown in In Figure 9.

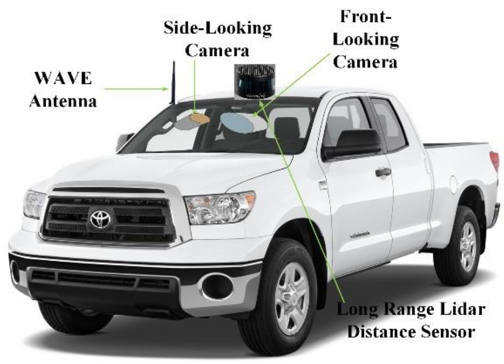


Figure 9: Prototype of the Following Vehicle.

The video from the front-looking camera with computer vision algorithms and neural networks will be used to detect the center lane markings, detect the lead vehicle and track. The position of the front looking camera in Figure 9 is for representation purpose only and the actual position of the front looking camera in the protoype will be at 3.5 ft from the pavement surface (typical height of a driver's eye). The rotating long-range lidar distance sensor from Velodyne along with GPS data will be used to measure the distance between the vehicles even when the vehicles are not in line-of-sight. We propose to use the long range rotating lidar sensor as a redundancy to the GPS based Vehicular distance measurement. The camera looking out of the passenger side of the follower vehicle can be used to track mile markers offline.

a) GPS based Vehicular distance measurement with real-time Google Map display

The IEEE 802.11 enabled WiFi devices used in laptops and smartphones are capable of establishing a point to point communication channel using standard authentication and protocols. However, devices using IEEE 802.11 radio transmitters and receivers are not suited for high speed moving V2V communication due to the communication environment changing rapidly and the need to complete data transactions in a short time interval. We propose to use the IEEE 802.11p - Wireless Access in Vehicular Environments (WAVE) device LocoMate mini-2 from ARADA Systems to implement the V2V communication between the leading and follower vehicle. The LocoMate mini-2 is a high powered Atheros wireless embedded device with an integrated GPS device. The LocoMate mini-2 is ideal for telematic applications by allowing vehicles on the road to talk to each other or another roadside unit. The mini-2 is fully compliant with Omni-Air's certification and currently deployed by the US Department of Transportation's Safety Pilot program, Ann Arbor, Michigan. The mini-2 is capable of acting as both "Passive" probe or "Active" probe. The mini-2 as a passive probe sends location information to another vehicle equipped with the mini-2 development board. In the following vehicle, a laptop and mini-2 development board with the built-in PCI interface are interfaced and using the software development kit (SDK) from ARADA Systems a software application will be developed. The software application will read the raw GPS data at the user requested interval and also when the lead vehicle goes in and out of view. The read GPS raw data is integrated with a suitable mapping system for real-time display on the laptop screen. The Locomate mini-2 supports multiple WAVE protocols, transmits at 5.85 GHz, and has an integrated GPS with an accuracy of less than 1 meter. The LocoMate mini-2 device and a depiction of the WAVE operation are shown in Figure 10.

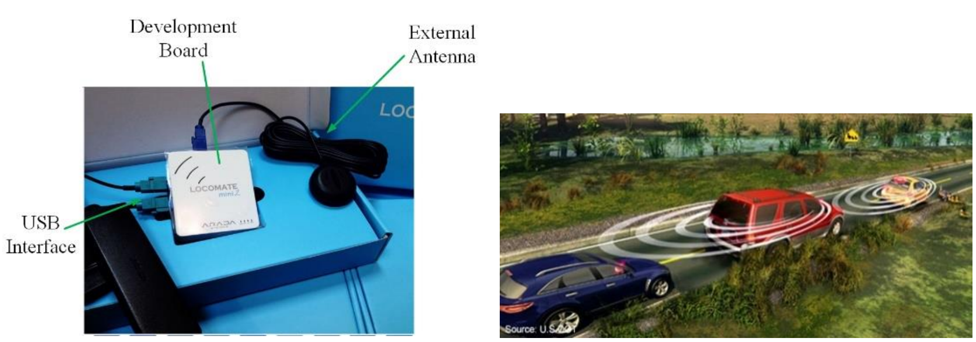


Figure 10: GPS Based Distance Measurement.

b) Autonomous Real-Time Detection of the Lead Vehicle

In the current two-vehicle approach of determining the PSD, the passenger in the following vehicle is tasked with detecting the lead vehicle going in and out of view visually by pressing two buttons and the software records the event of pressing the two buttons without the corresponding GPS coordinates. This approach worked well when the vehicles were driven at or less than 55 mph. However, at the highway speed of 70 mph with the PSD value of 1300 ft, this approach would result in the measured PSD being less accurate. We propose to implement a vision system capable of autonomously detecting and tracking the lead vehicle. The hardware component of the vision system consists of a commercially available high-resolution forward-looking video camera mounted inside the follower vehicle interfaced to the laptop as shown in Figure 9. The software of the vision system implemented on the laptop will comprise of computer vision and neural network based approaches. The input data to the vision system software consists of image sequences taken from the camera showing the lead vehicle, road, lane markings, other vehicles and areas next to the road. The vision system consists of two tasks, the lane detection, and the lead vehicle detection and tracking.

1. Lane Detection

   The input image sequences to the vision system consist of the lead vehicle and vehicles approaching the forward-facing camera on the other side of the road. The first task of the vision system is detecting the lane markers on the road to prevent detection of vehicles on the other side of the center lane as shown in Figure 11.

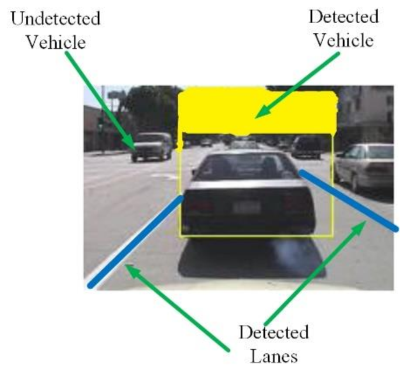


Figure 11: Detecting Lane Markers.

We propose to use the Deep learning method algorithm the Convolutional Neural Network (CNN) to perform the lane detection. The CNN is ideally suited to extract essential features in an image exploiting local spatial correlation. CNN operates by performing convolution of sequences of images and detect features that are learned through training. A CNN typically consists of multiple layers of neurons with the first layer detecting edges (lane) and subsequent layers learning to detect complex shapes. The training images from the Caltech Lanes Dataset, Road Marking Dataset, and Berkley Driving video database will be used to train the CNN to detect lanes. When the prototype device, collects the road images during its normal operation, the collected new images will be used to improve the training of the CNN. The block diagram of the lane detection task process is shown in Figure 12.

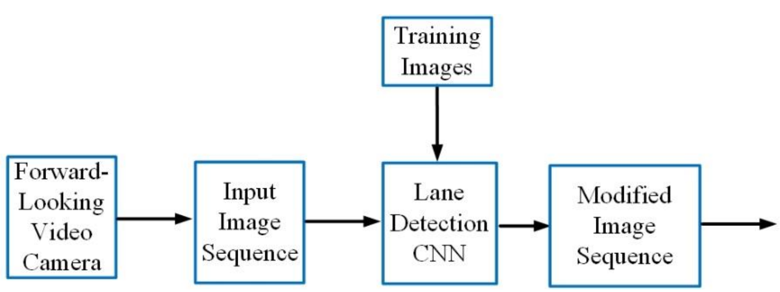


Figure 12: Lane Detection Task Flow.

2. Lead Vehicle Detection and Tracking

After completion of the first task, the image frames in the input image sequence will be tagged with an identified area of interest in which the lead vehicle has to be detected and tracked. One of the requirements of the two-vehicle PSD measurement apparatus is to maintain a constant distance between the lead and following vehicles resulting in very little relative motion between the lead car and the forward-looking camera. Therefore, the lead vehicle cannot be detected by merely differencing successive image frames. Furthermore, the 1300 feet distance between the lead vehicle and the forward-looking camera will result in the lead vehicle appearing as a rectangular object. Therefore, we will first use a feature-based method to detect and track the rectangular object by evaluating horizontal and vertical edges in the images since the edges along the top and the bottom of the rear of a vehicle are more pronounced. Next, we use a CNN trained with vehicle images from the GTI and KITTI Vision Vehicle Image database to track/identify/recognize the lead vehicle in the detected rectangular object as shown in Figure 13.

Figure 13: Lead Vehicle Detection and Tracking.

The prototype software will record the GPS coordinates when it cannot detect (the lead vehicle going off visually) the rectangular object in the modified image frame and on subsequent detection (the lead vehicle appearing visually back) of the rectangular object. The block diagram of the lead vehicle detection and tracking process is shown in Figure 14.

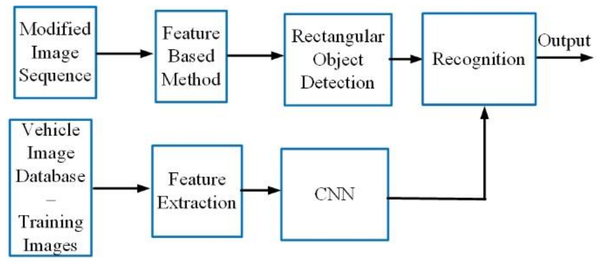


Figure 14: Lead Vehicle Detection and Tracking Task Flow.

c) Graphical user interface based software program

The software will be developed for execution in both Windows and Linux OS. The development in Linux OS will allow in future for execution on small footprint single board computers like Raspberry Pi, NVidia Jetsons, and Xavier. Depending on the real-time requirements, either Python or C language will be used for implementing the lane detection, detection/tracking/recognition of the lead vehicle, and data acquisition from various sensors. The library packages TensorFlow and Cognitive toolkit (CNTK) from Google and Microsoft respectively will be used for building the neural network software engines. The graphical user interface will be designed adhering to software development industry standards to allow both autonomous and manual operations of the appartus. Display windows showing the GPS data embedded into driving maps, the distance between the two vehicles, and front-looking camera video with lead vehicle detection will be provided. The apparatus will be powered by the vehicle's power supply by means of cords. Any devices that are found to receive insufficient power will require external batteries. Similar to the effort of Hutton and Cook (2016), a program into which the raw data are fed for processing will be developed. The program's intended function is to process the data and output the striping plans of the zones by type and direction of travel. The equipment and software are to be designed in such a way to be easy-to-use.

5.3 Field Testing of the Prototypes

Testing of the prototype is crucial. Once the apparatus is developed and the software is installed the advanced two-vehicle method will be tested. Both vehicles will be equipped with the apparatus and multiple runs will be conducted at a variety of locations at two-lane highways around the state. The locations will be those of passing and no-passing zones. Both vehicles should be positioned at a chosen gap distance from each other. The distance is computed in the software based on the difference of GPS coordinates of both vehicles. The GPS devices of both vehicles should record the vehicle positions at the same frequency. The GPS coordinate data of the lead vehicle is transmitted to the following vehicle by radio. All devices in the following vehicle store the data in the laptop which is also in the following vehicle. The software, installed in the laptop, updates the computed distance and the vehicle positions every time the GPS devices update the records of the vehicle positions. The laptop should alert the driver in the following vehicle to adjust his or her speed to maintain the pre-specified headway. Once the leading vehicle becomes invisible because of a horizontal or a vertical crest curve, the driver should operate the switch to indicate that the following vehicle is entering into a no-passing zone. On the other hand, once the leading vehicle comes back into view the driver should operate the switch to indicate that the following vehicle exited the no-passing zone. After the run is completed, the data will be processed using the developed program to output the striping plans of the test location. Selection of the test locations will be based on a statistical design of experiments. The zone striping plans of the field tests will be used to evaluate whether the existing zone markings of WYDOT are correctly designated according to the PSD design values.

5.4 Preparing the Report and Implementation Plan

The literature review, development of the apparatus and field test results will be documented in a report, prepared in an appropriate format, to be submitted to WYDOT. Also, the research team will submit this research's findings for publications in various journals such as the Transportation Research Record (TRR).

5.5 Upgrading the First Prototype

At the conclusion of the study and after delivering the ultimate prototype to WYDOT, the research team will retrieve the first prototype from WYDOT and enhance it to include all the ITS features. This will provide WYDOT with two fully functional systems which can be used on the state highway system as well as roads owned by other agencies in the state.

5.6 Summary

As a recap, in the initial stage of this research, a comprehensive literature review about passing and no-passing zones of two-lane highways will be conducted. This pertains to design criteria, methods of measuring the PSD and any related topics. A basic apparatus of the two-vehicle system will be initially developed to fulfill the immediate needs of WYDOT. That system will be later enhanced and upgraded to include all ITS features. The developed prototypes will be tested in the field. The field test results will be compared to WYDOT's existing zone striping policies. The study tasks from the literature review to the testing of the prototype will be documented in a report to be submitted to WYDOT.

6 TIMELINE

This study is expected to be completed in 3 years. Assuming that the study will begin in January of 2019, Prototype 1 will be delivered to WYDOT by the end of July of 2020. Prototype

2 with all the advanced ITS features will be deliver to WYDOT at the end July of 2021. The upgraded Prototype 1 will be delivered to WYDOT by the end of January of 2022.

7 BUDGET

The tasks of this research require the contributions of a graduate student, two faculty members, an electrical engineer and a postdoc. Table 3 summarizes of the budget of this study. The WYDOT portion of this budget is only $171,899. It is estimated that around $85,000 will be spent on the equipment needed to build the two prototypes with all the advanced features. The research team has secured the commitment from MPC for the matching fund.

Table 3: Budget of the Project.

Categories	MPC	WYDOT	Total
Center Director Salary			
Faculty Salaries	$10,000	$19,000	$29,000
Engineer/ Post Doc	$10,500	$22,500	$33,000
Faculty/Engineer Fringe Benefits (43.3%)	$8,877	$17,970	$26,846
Student Salaries	$16,000	$20,000	$36,000
Student Fringe Benefits (3.9%)	$624	$780	$1,404
Total Personnel Salaries	$36,500	$61,500	$98,000
Total Fringe Benefits	$9,501	$18,750	$28,250
TOTAL Salaries & Fringe Benefits	**$46,001**	**$80,250**	**$126,250**
Travel	$500	$8,000	$8,500
Equipment	$40,000	$45,000	$85,000
Supplies	$500	$2,000	$2,500
Contractual			
Construction			
Other Direct Costs (Specify)*	$8,000	$8,000	$16,000
TOTAL Direct Costs	**$95,001**	**$143,250**	**$238,250**
F&A (Indirect) Costs	$20,915	$28,650	$49,565
TOTAL COSTS	**$115,916**	**$171,899**	**$287,815**

*Other Direct Cost includes Graduate Student Tuition, Fees and Insurance

8 DELIVERABLES

The deliverables of this research, to be provided to WYDOT are listed as follows:

1. Initial Prototype 1 with only basic features.
2. Prototype 2 fully developed with ITS technologies.
3. A manual describing how to set-up the advanced prototype, conduct field experiments and interpret results.
4. A report encompassing all previous study tasks from the literature review to the development of the prototype and its testing.
5. Prototype 1 will be upgraded to include the advanced ITS features by the end of the study.

All equipment purchased in this contract will be incorporated in the two prototypes and the prototypes will be delivered to WYDOT for their use.

9 PROPOSAL'S RELEVANCE TO WYDOT'S MISSION

9.1 Project Area

Various programs within WYDOT sponsor and advance research proposals to the Research Advisory Committee (RAC) of the department. This proposal is being submitted to the RAC from the WYDOT's traffic engineering program.

9.2 Strategic Intent

WYDOT has six strategic intent areas, one of which is the safety area. This research project is anticipated to enhance safety of motorists on two-lane highways. Therefore, it is classified under the safety area. This study is aimed at significantly cutting the number of severe crashes, particularly head-on and opposite direction sideswipe crashes, at two-lane highways in the state. The liability to WYDOT is extremely high if passing zones are not established correctly.

9.3 Project's Outcome

The outcome of this project is a set of products which are prototypes of the two-vehicle method to be used by WYDOT and other jurisdictions in the state. They are used to accurately establish passing and no-passing zones of two-lane highways. This product is essential for the day to day operation of the traffic program of WYDOT.

9.4 Benefit-Cost Ratio Estimation

The benefits and costs of the project are estimated to compute a benefit-cost ratio (BCR) in order to evaluate the project's feasibility. The costs includes: research costs of $287,815 and implementation/Maintenance costs of $40,000 comprising a total of $327,815. The benefits are crash reduction savings. The fact that the traffic branch of WYDOT cannot do its job without the equipment was not taken into consideration. The proportions of passing related crashes on two-lane highways by crash severity are presented in 4. They are estimated based on a study of three states. The crash severity levels are fatal injury (K), incapacitating injury (A), non-incapacitating injury (B), possible injury (C) and property damage only (PDO or O). Note that fatal and incapacitating injury crashes altogether are designated as KA.

Table 4: Estimated Proportions of Passing Related Crashes on Two-Lane Highways.

Crash Severity	Proportion of Passing Related Crashes (%)
KA	13.7
B	15.2
C	15.3
O	56.0

Source: FHWA (1994).

According to the CARE package database of crash records in Wyoming, the total count of two-lane highway crashes in the state between 2008 and 2017 is 68,754. Also, the fatal crashes represent 21.1% of KA crashes. Calculations are conducted to estimate the total costs of two-lane highway crashes in Wyoming that occurred in the ten-year period. The calculations are illustrated in 5. The comprehensive costs per crash are obtained from FHWA (2009).

Table 5: Crash Cost Calculations

Crash Severity	Number of Passing Related Crashes in Wyoming (2008-2017)	Comprehensive Cost Per Crash ($)	Comprehensive Cost ($)
K	40	4,008,900	159,364,559
A	149	216,000	32,158,992
B	209	79,000	16,539,933
C	211	44,900	9,462,594
O	773	7,400	5,721,710
		Grand Total	223,247,788

Preventing passing related crashes on two-lane highways especially severe ones yields significant benefits as can be observed from Table 5. An assumption is made that accurate passing and no-passing zone striping plans which are developed with the aid of the prototype proposed will cut crashes by a third. Hence, $74,400,000 will be saved over the course of ten years. With the benefits and costs estimated, the BCR is equal to 227 as shown in Figure 15. It is important to emphasis that in addition to the high BCR of the study, the traffic branch of WYDOT cannot fulfill its mission without the proposed device.

Template to Calculate Benefits-to-Cost Ratio (BCR) for Strategic Intent "*Safety*"

Project Title:	Developing a Prototype System for Ascertaining Limits of Passing and No-Passing Zones of Two-Lane Highways
Name:	Ahmed Farid, Khaled Ksaibati, Suresh Muknahallipatna & Victor Bershinsky
Organization:	University of Wyoming
Date:	October 2018

Costs Input Table	
Research Costs:	
Estimated Split Among Types:	
Salaries and Benefits	$126,250
Direct Costs	$112,000
Indirect Costs	$49,565
Other	
Implementation Costs:	
Estimated Split Among Types:	
Initial Costs	
Operation and Maintenance	$40,000
Technology Transfer	
Other	
GRAND TOTAL:	$327,815

Benefits Input Table	
Total Savings:	
Estimated Savings Split Among Following:	
Crash Reduction	$74,400,000
Travel Time	
Vehicle operating Costs	
Employment generation	
Other	
GRAND TOTAL:	$74,400,000

$$\textit{Overall Benefits-to-Costs Ratio (BCR)} = \frac{74{,}400{,}000}{328{,}815} = 227$$

Figure 15: Benefit-cost ratio for preventing crashes over the course of ten years.

10 REFERENCES

AASHTO, 2011. A Policy on Geometric Design of Highways and Streets. AASHTO, Washington, D.C.

Betke, M., Haritaoglu, E., Davis, L., 2000. Real-Time Multiple Vehicle Detection and Tracking from a Moving Vehicle. Machine Vision and Applications, 69 – 83.

Brown, R., Hummer, E., 2000. Determining the Best Method for Measuring No-Passing Zones. Transportation Research Record 1701, 1-67.

FHWA, 2009. Manual on Uniform Traffic Control Devices. FHWA, U.S. Department of Transportation, Washington, D.C.

FHWA, 2009. Highway Safety Improvement Program Manual. FHWA Report FHWA-SA-09-029. U.S. Department of Transportation, Washington D.C.

FHWA, 1994. The Magnitude and Severity of Passing Accidents on Two-Lane Rural Roads. FHWA, U.S. Department of Transportation, Washington D.C. https://www.fhwa.dot.gov/publications/research/safety/humanfac/94068.cfm. Accessed October 4, 2018.

GTI Vehicle Image Database, 2012. http://www.gti.ssr.upm.es/data/Vehicle_database.html.

Gurghian, A., Koduri, T., Bailur, S., Carey, K., Murali, V., 2016. DeepLanes: End-To-End Lane Position Estimation using Deep Neural Networks. IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPRW), 38 – 45.

Harwood, D., Gilmore, D., Richard, K., Dunn, J., Sun, C., 2008. National Cooperative Highway Research Program Report 605: Passing Sight Distance Criteria. Transportation Research Board of the National Research Council, Washington, D.C.

Hayworth, 2013. What's the Most Missed Question on Iowa Driver's License Test. Sioux City Journal, Sioux City, Iowa. https://siouxcityjournal.com/news/local/a1/what-s-the-most-missed-question-on-iowa-driver-s/article_71822ebe-343c-5b4e-adeb-877a7b901d12.html. Accessed September 26, 2018.

High Bandwidth Application Over WI-FI Connection with IEEE 802.11P, and IEEE P1609 (WAVE) Protocols, White Paper, ARADA Systems.

Hutton, J., Cook, D., 2016. Developing a System to Identify Passing and No Passing Zone Boundaries on Rural Two-Lane Highways. Report No. cmr 16-017 Submitted to the Missouri Department of Transportation. Contract No. 110906. Missouri Department of Transportation, Kansas City, Missouri.

IEEE P1609.4/D08, IEEE P1609.4 Trial-use Standard for Wireless Access in Vehicular Environments (WAVE) - Multi-Channel Operation, Jul 2006

KITTI Vision Benchmark Suite, 2012 http://www.cvlibs.net/datasets/kitti/.

Put Information Center, 2007. Autodesk, San Rafael, California. http://www.putic.com/. Accessed September 25, 2018.

Sight Distance, 2018. Engineer Babu Lal. https://engineerbabulal.blogspot.com/2018/02/sight-distance.html. Accessed September 25, 2018.

Stanford Vehicle Data Set, 2018. http://ai.stanford.edu/~jkrause/cars/car_dataset.

The Hoosier Company Inc. The Range Tracker System. The Hoosier Company Inc., Indianapolis, Indiana. http://www.hoosierco.com/2e384292ad43b698645a108066d54bca.html. Accessed September 25, 2018.

TRB, 2018. Highway Capacity Manual. Transportation Research Board of the National Research Council, Washington, D.C.

What is Meant by a "Two-Lane" Road, 2018. English Language and Usage. Stack Exchange Inc., New York City, New York. https://english.stackexchange.com/questions/270607/what-is-meant-by-a-two-lane-road. Accessed September 25, 2018.

WYDOT Traffic Program, 2012. Pavement Marking Manual. Wyoming Department of Transportation, Cheyenne, Wyoming.