FIELD LOCATION & MARKING OF NO-PASSING ZONES DUE TO VERTICAL ALIGNMENTS USING THE GLOBAL POSITIONING SYSTEM

A Thesis Proposal

By

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Submitted to the Office of Graduate Studies
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

February 2008

Major Subject: Civil Engineering
INTRODUCTION

Passing maneuvers on two-lane roadways are one of the most difficult movements that a driver may perform because their vehicle must enter the opposing traffic stream to complete the maneuver. Guidance on where passing maneuvers are prohibited is provided by a solid line, also known as a barrier line, as part of the centerline on the roadway surface, and supplemental signs. These pavement markings and signs indicate to drivers where there is insufficient sight distance to complete a passing maneuver. The locations delineated by these specific markings and signs are known as no-passing zones.

In 1999 two-lane roadways alone made up approximately 82 percent of the centerline miles in Texas (Fitzpatrick et al. 2001). Since such a large percentage of two-lane roadways exist, no-passing zones must be located and accurately marked on pavement surfaces to effectively assist drivers. However, locating no-passing zones can be a daunting and very time-consuming process under the current practices utilized by state transportation agencies. Additionally, many current practices require work crews to operate in the roadway, which may create potentially hazardous situations.

Due to these challenges, new alternatives need to be developed for the safe, accurate, and efficient location of no-passing zones on two-lane roadways. The use of GPS coordinates to evaluate sight distance provides one such alternative for an automated no-passing zone location system and is the subject of this research. This research proposal outlines the current problem, the background on this subject, the objectives of the research, the specific tasks that will be carried out to achieve the set objectives, and the potential benefits of developing an automated no-passing zone location and marking system.

PROBLEM STATEMENT

Many alternative methods for locating no-passing zones are available and range in cost, time, and accuracy. Despite the many alternatives, new methods that will efficiently locate no-passing zones, define the no-passing zones accurately, and do so safely are needed. GPS has the potential to meet these needs; however, processes for gathering roadway GPS data, smoothing
GPS data, mathematically locating no-passing zones from GPS data, and implementing the results in the field must be addressed. It is believed that a system enabling work crews to drive two-lane roadways with GPS units to automatically determine no-passing zones can be developed by focusing on these issues.

RESEARCH OBJECTIVES

The goal of the proposed research is to develop a system that utilizes GPS technology to locate no-passing zones associated with the vertical alignment of a roadway. Work crews should be able to more safely, efficiently, and accurately locate no-passing zones on two-lane roadways with the system. Several objectives have been identified to achieve this goal. They are:

- identify the processes necessary to smooth GPS data and geometrically model roadway surfaces,
- create an algorithm for locating no-passing zones from modeled roadway surfaces due to vertical sight obstructions,
- validate the system by comparing results to existing no-passing zone pavement markings, and
- provide guidelines for field implementation of the system.

BACKGROUND

The section provides some basic understanding and insight into the areas associated with developing a system for automatically locating no-passing zones using GPS. The American Association of State Highway Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (2004) and the *Manual on Uniform Traffic Control Devices* (2003) both cover the subject of passing sight distance as it relates to passing zones and no-passing zones. The contents of these documents are briefly covered below. Also provided is a brief list of current methods for locating and marking no-passing zones along with a quick introduction to GPS. Lastly, information on work that has been completed in the area of geometric roadway modeling and its application to the location of no-passing zones is summarized. These topics provide a basis for building the proposed research.
AASHTO: Passing Sight Distance for Two-Lane Highways

Sight distance is the ability of a driver to see the roadway ahead. More specifically, AASHTO defines passing sight distance as follows:

“The passing driver should be able to see a sufficient distance ahead, clear of traffic, to complete the passing maneuver without cutting off the passed vehicle before meeting an opposing vehicle that appears during the maneuver (AASHTO 2004).”

No-passing zones occur when available sight distance is less than a required minimum distance. When this sight deficiency arises, it indicates that attempting a passing maneuver may be hazardous. AASHTO (2004) outlines procedures for implementing safe passing sight distances in design and provides assumptions that are made concerning driver behaviors during passing maneuvers. AASHTO’s assumptions lead to what many consider to be very conservative passing sight distance requirements. These distances differ from the guidelines in the MUTCD for marking no-passing zones.

MUTCD: No-Passing Zone Marking Criteria

The 2003 MUTCD does not provide information concerning how the minimum passing sight distance guidelines presented in Part 3 of the MUTCD were developed (Hardwood et al. 2005). Hardwood et al. mention that numbers in the current MUTCD are identical to the 1940 American Association of State Highway Officials (AASHO) policy. Hardwood et al. conclude that the minimum sight guidelines presented by the 1940 AASHO policy are a compromise between distances required for a flying pass and those of a delayed pass. In a flying pass a passing driver approaches the vehicle to be overtaken and proceeds to the left lane and around the overtaken vehicle without having to slow down. In a delayed pass the passing vehicle approaches the vehicle to be overtaken, decelerates to follow the vehicle to be overtaken, and then accelerates to complete a pass.

The Texas Manual on Uniform Traffic Control Devices (2006), which has exactly the same minimum passing sight distances as the 2003 MUTCD except for at the speed of 25 mph, states the following in reference to the accepted minimum passing sight distances:
“Distances shown are the minimum warrants based on AASHTO’s decision sight distances for a rural road avoidance maneuver (speed/path/direction change). The distances are derived for traffic operation-control needs and should not be confused with design passing sight distances which are based on different assumptions.”

This statement helps provide some clarification for the differences between AASHTO’s passing sight distance design guidelines and the MUTCD’s standards for minimum passing sight distances.

No-Passing Zone Location Methods

There are many possible existing methods for locating and marking no-passing zones. A few available options include the walking method, the eyeball method, the speed and distance method, single vehicle methods, and multi-vehicle methods (Traffic Control Devices Handbook 2001). The theory behind these methods is to identify locations where passing sight distance drops below minimum required passing sight distances. Passing sight distance is based upon a driver eye height of 3.5 feet and an object height, which would be an oncoming vehicle, of 3.5 feet. No one method is overwhelmingly used by state transportation agencies. Results from an informal survey conducted for a Texas Transportation Institute report show that agencies were using single or multi-vehicle methods that utilize some combination of distance measuring instruments and human sight to locate no-passing zones (Rose et al. 2004). These methods do get work crews out of the roadway, as compared to the traditional walking methods, but still rely on judgment in determining the beginning and ending of no-passing zones.

Global Position System (GPS)

GPS technology allows for any position on the earth to be determined. GPS was initially developed by the Department of Defense for military purposes in the 1970s and consists of three segments that are defined as space, control, and user. The space segment consists of 24 satellites that orbit the earth transmitting information. The control segment consists of ground bases that track satellite positions and the user segment is any receiver of GPS satellite signals. GPS operates on the premise that by receiving signals from any three satellites, a user can triangulate to find their position because distances to the satellites and satellites’ positions are known (El-
To obtain elevation data from GPS, a receiver must be processing signals from at least four satellites.

**Geometric Roadway Modeling**

The Kansas Department of Transportation (KDOT) has sponsored research at Kansas State University (KSU) in the area of geometric roadway modeling where a geometric roadway model based on B-Spline curves was developed (Ben-Arieh et al. 2004). The B-Spline model requires cleaning of GPS data to establish control points for use in the B-Spline method of developing a roadway model. Nehate and Rys (2006) took Ben-Arieh et al.’s geometric model and enhanced it to calculate stopping sight distances (SSD) on roadways. Namala and Rys (2006) built upon Nehate and Rys’ stopping sight distance model to include passing sight distance. No-passing zones were located on a roadway once passing sight distances were calculated. Namala and Rys included a minimum SSD in the passing sight distance model which is not usually done. The model was completed according to AASHTO design guidelines for passing sight distances and MUTCD criteria for marking no-passing zones. In practice, the MUTCD is the only field guide used for marking no-passing zones. KDOT used GPS data from previous roadway inventory logs obtained from data collection vehicles. The developed models were used to rate roads for consideration of improvements based on sight deficiencies found from the models. The developed models have not been used in the field for the marking of no-passing zones.

At KSU, further work looked into developing a different three-dimensional roadway model. This research addressed many of the errors associated with GPS data and methods for combining historically logged roadway data from KDOT (Young 2004). Although some description was given concerning the equipment used for GPS data collection, the specifically required GPS equipment was not described and the field implementation of locating no-passing zones was not addressed.

The work in Kansas has not been the only work in modeling roadway geometrics. Easa et al. (1998) developed analytical models for creating vertical profiles from field data. One analytical model consists of two steps. First, the model divides roadways into segments of tangents, crest curves, and sag curves based on trends in incremental slopes of field data points. Once roadway
segments are identified, the segments are fit according to whether they are tangents or curves. Tangents are fit by linear regression and vertical curves by splines. One problem with this method is that raw GPS data collected from a moving vehicle are not smooth. As a result, the determination of trends for tangents, crest curves, and sag curves is very difficult and not believed by the researcher to be feasible with current positional data produced by GPS systems.

Easa (1999) did additional work in identifying the vertical profiles of roadways from field data. Easa developed algorithms for determining optimum vertical alignments from field data based on optimization methods. Easa used knowledge that vertical profiles consist of linear tangent sections and parabolic curves. Using the roadway design equations for these two mathematical representations, Easa created linear optimization methods that found optimum values for incoming and outgoing slopes, as well as optimum elevations for given vertical points of curvature and tangency. Easa did suggest the problem could be taken a step further by creating a non-linear optimization problem by varying station location of vertical points of curvature and tangency instead of fixing the points in place. This process can be very time consuming because it is an iterative process and on roadways with multiple vertical curves, this process can become even more difficult.

**RESEARCH STUDY DESIGN**

Specific tasks have been identified for developing a system that locates no-passing zones associated with the vertical geometry of a roadway via GPS. One task is a literature review to aid in understanding the previous work and topics associated with the research. This background information will aid the researcher throughout the entire process. A second task is identifying methods for collecting and formatting GPS roadway data for input into the smoothing process. After collecting and formatting data, a third task involves smoothing and processing data for input into a no-passing zone algorithm. The fourth task is developing the no-passing zone algorithm which should provide a systematic approach for analyzing smoothed data to locate no-passing zones. The fifth task is calibration and sensitivity determination of the system. Once these tasks are complete, system validation in the field will be the sixth test. The seventh and final task will be to write guidelines for system operation and implementation. These tasks
should aid in achieving the goal of developing an automated no-passing zone location system.
The tasks are explored below.

**Task 1: Literature Review**
The initial step in this study is a thorough literature review on the subject. Background on GPS
technology, the history of no-passing zones, and how no-passing zones are currently located will be
explored. The history of no-passing zones should include a review of the *MUTCD* criteria for
marking no-passing zones and the AASHTO passing zone design standards. The literature
review should cover previous work in geometric modeling of roadways with GPS data and in
automated location of no-passing zones. After reading the literature review a person unfamiliar
with the subject should have a general understanding of the basis for the current research.

**Task 2: GPS Data Collection & Formatting**
The focus of the current research is on smoothing and analyzing GPS data for locating no-
passing zones. However, GPS data must be collected and placed in a format for use in the
smoothing process and no-passing zone algorithm. There are many GPS technologies available
today but it is not in the scope of this research to analyze and evaluate each option. Instead, GPS
equipment that is easily accessible to the researchers will be used. The Center for Transportation
Safety at the Texas Transportation Institute has an instrumented vehicle equipped with a Trimble
DSM 232 Differential Global Positioning System (DGPS) that uses commercial satellite
differential correction services provided by Omnistar. This GPS system uses VBS correction
service, this is the lowest grade correction service provided by Omnistar. This GPS system and
the Omnistar correction service will be used for initial testing. Once the data is collected it will
probably be in the format of longitudes, latitudes, and elevations. The longitude and latitude
coordinates must be converted into northing and easting coordinates. The equations necessary to
accomplish this will be found and applied to the data.

**Task 3: Data Smoothing**
The accuracy of GPS data, especially when collected from a moving vehicle, can vary drastically
with selected GPS units. Smooth vertical profiles cannot be taken directly from a single GPS
data collection run on a roadway due to inaccuracies associated with GPS. Jumps and
irregularities are seen in the data, especially at locations where GPS satellites are added or dropped. An example of a roadway profile obtained from raw GPS data is seen in Figure 1.

![Figure 1. FM 912 Eastbound Run 2 Raw Data.](image)

The GPS data needs to be corrected, cleaned, and/or smoothed to achieve a true representation of a roadway’s vertical alignment. Vertical roadway profiles are special because they cannot be modeled as one continuous mathematical function. Over the course of several miles a roadway may include multiple tangents and vertical curves. Because of this characteristic, multiple functions must be used to represent the profile. Therefore, it is hypothesized to try localized regression techniques. These approaches may allow for local trends of a roadway to be modeled.

One such technique that may prove promising is Loess regression. Loess regression is a locally weighted nonparametric regression method. Weights are provided to a span of points on either side of a test point. Data points closer to the test point have heavier weights than points near the edge of the span. A new value for the test point is calculated using surrounding weighted points and regression analysis. Linear or quadratic fitting can be used in Loess regression. The researcher believes quadratic fitting will be the best choice for this application because of the use of parabolic curves in geometric design of vertical roadway profiles. Because Loess is a
localized method, only small segments of a roadway are evaluated at a single time. This segmented method should allow a roadway’s vertical profile shape to remain intact (Cleveland 1993).

After smoothing GPS data, it is further theorized that cubic splines will allow for the creation of a continuous smoothed representation of the roadway. Cubic splines are piecewise functions and are similar to B-spline approaches others have used to model geometrics of roadways. Cubic splines should enable creation of evenly spaced points along a roadway’s surface that can efficiently be used in the no-passing zone algorithm. However, cubic splines are only one method; there may be more useful methods available.

**Task 4: No-Passing Zone Algorithm**

After smoothing GPS data and finalizing a vertical profile, a no-passing zone algorithm must be applied to the roadway model to pinpoint locations of no-passing zones due to vertical curves. No-passing zones occur when obstructions block a driver’s view of the roadway. The no-passing algorithm should test whether a driver has sufficient unobstructed sight distance. The unobstructed sight distance, also known as the required minimum sight distance, is defined according to criteria set in the *MUTCD*. For example, at a roadway design speed of 70 mph, a driver should be able to identify an oncoming vehicle at least 1200 feet from their present position.

Since no-passing zones associated with the vertical dimensions on roadways are being considered, a sight obstruction will occur when a roadway’s surface elevation is greater than the driver’s required line of sight. The driver’s required line of sight will be referred to as the theoretical sight distance. At a given location, the algorithm should test incrementally out to the *MUTCD*’s required minimum sight distance. If the roadway surface is greater than the theoretical sight line in any of the incremental tests, a no-passing zone should be at the test location. The two points that will define the theoretical sight line are the driver’s eye height and height of a possible oncoming vehicle. According to the *MUTCD* (2003), both of these heights are assumed to be 3.5 feet above the pavement surface. After testing for sight restrictions at one
location on the roadway, the algorithm should move to a position further along the road and test again for sight restrictions.

The input to the algorithm should be station and elevation data produced from the smoothing process. The output of the algorithm should be starting and ending stations of no-passing zones on a roadway. The station values should be measured from an identifiable reference point.

It is proposed to use Matlab to smooth GPS data and for developing the no-passing zone location algorithm. Matlab has the ability to manage large data sets and is a relatively easy environment for programming mathematical algorithms. After system development, Matlab has the potential to compile the system into a separate executable file for use on laptops in the field.

**Task 5: System Calibration & Sensitivity Determination**

After developing the smoothing process and no-passing zone algorithm, the roadway model and no-passing zone algorithm must be calibrated and sensitivity analyses run. Calibration will include the adjustment of input variables to ensure accurate geometric roadway models are being produced along with accurate location of no-passing zones. Some variables that need to be considered are the required number of GPS data collection runs (if more than one run is needed), the approximate spacing between collected GPS data points, and smoothing parameters such as the number of points used in local regression analysis.

As for system sensitivities, there are several considerations. One is how the roadway stations are calculated. In the creation of roadway plan and profile sets stations are determined in the horizontal plane. It is proposed to use the same practice in this research; however, the problem that is being addressed is not just in the two-dimensional horizontal plane but has a three-dimensional aspect. Therefore, the effect of using horizontal station distances calculated from northing and easting coordinates must be compared against station distances that are a function of northing, easting, and elevation coordinates. Furthermore, the no-passing zone algorithm intervals for testing line of sight obstructions will need to be examined. These intervals must be evaluated in order to determine how sensitive locations of no-passing zones are to interval selections. As the test intervals increase, the algorithm calculations will decrease.
This would produce a more efficient system; however, an optimum value needs to be found for accuracy and efficiency.

**Task 6: System Validation**

The developed vertical no-passing zone location system must be validated on several roadways and requires having appropriate roadway test locations. To locate these sites, contact will be made with local TxDOT offices. Engineers in these offices have local knowledge of roadways near Bryan-College Station, where the research is being conducted, and can give recommendations on roads that have no-passing zones associated with vertical curves only. Plan and profile sheets are not essential in this process as long as currently marked no-passing zones can be identified and compared to the locations identified by the developed no-passing zone location system. Field collected GPS data will be needed for input into the no-passing zone location system. Tests can then be run to compare the current field markings to the proposed field markings.

**Task 7: Implementation Guidelines**

The purpose of this research is to provide a more accurate, efficient, and safer method by which work crews can locate and mark no-passing zones in the field. In order for the research to be beneficial, guidelines for field implementation must be established. Guidelines and procedures must include steps for setting up the system, beginning data collection, ending data collection, and processing data. A description of the GPS unit should be included along with the collection rate of the GPS unit and driving speed of the data collection vehicle. These are variables that should be refined during the calibration and validation stage. Nonetheless, these variables must be documented in the implementation guidelines for work crews. After the guidelines have been written, they should be tested to see how well someone who is unfamiliar with the system can perform with the given guidelines.

**Potential Benefits of Study**

If this study is successful in creating and calibrating a system that accurately locates no-passing zones, field crews will be able to more efficiently locate no-passing zones and thus the striping patterns on two-lane roadways. More importantly, this system development will provide a safer method by which field crews can determine the location of two-lane roadway pavement.
markings. In the end, the time saved and safety gained by field crews should be well worth the effort of this endeavor.

REFERENCES


