**Development of the ConnDOT Horizontal Curve Classification Software**

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Standard Conversions

| SI* (MODERN METRIC) CONVERSION FACTORS | | | | |
|---|---|---|---|---|
| **APPROXIMATE CONVERSIONS TO SI UNITS** | | | | |
| **Symbol** | **When You Know** | **Multiply By** | **To Find** | **Symbol** |
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yard | 0.836 | square meters | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ |
| | | NOTE: volumes greater than 1000 L shall be shown in $m^3$ | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact degrees)** | | |
| $^oF$ | Fahrenheit | 5 (F-32)/9<br>or (F-32)/1.8 | Celsius | $^oC$ |
| | | **ILLUMINATION** | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/$m^2$ | cd/$m^2$ |
| | | **FORCE and PRESSURE or STRESS** | | |
| lbf | poundforce | 4.45 | newtons | N |
| lbf/$in^2$ | poundforce per square inch | 6.89 | kilopascals | kPa |
| **APPROXIMATE CONVERSIONS FROM SI UNITS** | | | | |
| **Symbol** | **When You Know** | **Multiply By** | **To Find** | **Symbol** |
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yards | $yd^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | cubic meters | 35.314 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact degrees)** | | |
| $^oC$ | Celsius | 1.8C+32 | Fahrenheit | $^oF$ |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/$m^2$ | candela/$m^2$ | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lbf/$in^2$ |

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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16. Abstract
The Highway Performance Monitoring System (HPMS) is a national, highway information system that requires states to collect and submit data on the extent, condition, performance, use, and operating characteristics of the nation's highways. HPMS requirements include limited data on all public roads, with more detailed data for sample sections of the arterial and collector functional classes. One of the field inventory reviews that many states have a difficult time reporting efficiently is the required horizontal curve classification for each HPMS section. Connecticut has more than 2000 HPMS sites making manual updates to these sections very difficult and time consuming. Automated methods to create a batch reporting process could save significant time and effort while increasing the accuracy with which data are reported to FHWA. Connecticut is fortunate in that the department of transportation performs an annual photolog survey of all states roads and conducts supplemental data collection runs for HPMS sections. This report details the creation of an automated curve classification software kit to generate grade and horizontal curve classification files for HPMS reporting.

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# 1.0 INTRODUCTION

## 1.1 Background

Roadways typically consist of curves and straight sections with horizontal curves providing transition between straight segments of a roadway. Horizontal curves typically used in design include simple circular curves, compound and transition curves. There are several roadway inventory databases maintained by State Departments of Transportation that contain data on use, conditions, and performance of roadways, which can be used in a variety of planning and operational applications. The Connecticut Department of Transportation (ConnDOT) performs an annual photolog survey of all state maintained roadways with supplemental data for Highway Performance Monitoring Sections (HPMS). This photolog information is collected using an Automatic Road Analyzer (ARAN) van, which collects various data on roadway characteristics including geometry, and surface condition. The ARAN van is equipped with GPS sensors and a gyroscope that collects location data and vehicle attitude data including heading and grade at four (4) meter intervals. This inventory contains a wealthy dataset for identifying and extracting roadway geometric information including horizontal curves. Identification of the locations of and parameters for horizontal curves has potential benefits in accident safety research, and can be used in analyses for improvement in level of service.

There have been previous efforts by ConnDOT using ARAN photolog data to develop an algorithm for identification and extraction of horizontal curve information for the purposes of curve classification. An algorithm was developed as part of software called the Horizontal Curve Classification and Display System (PLV-HC) to process the ARAN horizontal alignment data. The algorithm, which consists of a curve finder, a curve fitter and segment patcher, is used in conjunction with the Photolog data to extract roadway geometric information.

The Highway Performance Monitoring System (HPMS) is a national highway information system that requires states to collect data on the extent, condition, performance, use, and operating characteristics of the nation's highways. HPMS reporting requirements typically include limited data on all public roads, with more detailed data also required for sample sections of the arterial and collector functional classifications of roads. Data required on state public roads include road mileage, vehicle miles travelled (VMT) and lane mileage data.

The Federal Highway Administration (FHWA) reviews this data annually to ensure its validity and suitability for the appropriation of Federal aid highway funds. Horizontal curve classification is one of the data requirements of HPMS sections that is reported to the FHWA. Horizontal curve classification is also one that most states have difficulty reporting efficiently. In addition, the state of Connecticut has over 2000 HPMS sites, which makes manual updates to these sections difficult and time consuming. There is, therefore, a need to develop a simple, user friendly, efficient, and accurate classification system that can extract geometric information for these HPMS sections, once the data is obtained from the ARAN van.

Developing a method to extract geometric information with batch reporting process capabilities will save significant time and increase the accuracy with which data is reported for the HPMS sections. This research sought to develop an efficient and simple method for extracting and classifying geometric data (specifically curve and grades within HPMS sections per HPMS reporting requirements) from ARAN vehicle data.

### 1.2 Research Objectives

The first objective of the study was to develop a method to classify geometric characteristics of data obtained from field collection. The aim was to use the method developed to extract horizontal curves and classify them into six curve classes; A, B, C, D, E, and F based on the degree of curvature. In the process of classifying curves and grades, characteristics of curves like radius and length would be produced as an additional benefit of the method developed.

The second objective was to automate the curve classification process to allow users to specify a section of the roadway and generate a curve classification report for that section. This would make the classification method developed user friendly and the data obtained from it easily accessible. Lastly, the research aimed to develop batch processing capability and a reporting structure that will allow users to add an input data file, and then extract and classify curve segments within the input data file. This will improve users' ability to enter data, and quickly and efficiently obtain a wealth of horizontal roadway knowledge from the data entered.

## 2.0 LITERATURE REVIEW

There is a body of research focused on the identification and extraction of horizontal curve information for both maintenance and safety performance purposes. The most common methods used to identify and extract horizontal curve data involve the use of Global Positioning Systems (GPS) data, satellite imagery, laser scanning data, and AutoCAD digital maps. GPS data has been used to estimate and evaluate horizontal curve characteristics like radius and degree of curve for operational and safety purposes. In this context, Imran et al. (*1*) used post processed GPS data in a Geographic Information System (GIS) application to develop a procedure and an algorithm for the extraction of horizontal alignment based on the path of a control vehicle. Using field data that was collected at 0.1s intervals under different speed conditions on a segment of a rural highway, Imran et al (*1*), extracted horizontal curve characteristics including radius, center coordinates of simple circular curves, and lengths of both simple circular and spiral curves by fitting straight lines to tangent sections and circular curves to curved sections. The authors (*1*) also asserted that the algorithm, which was developed as an extension in ArcGIS, was able to track vehicle lateral displacement along the alignment, and that the GPS method provided a low cost, accurate, and efficient method for obtaining horizontal curve data.

Hans et al (*2*) also used GPS data to develop a method to identify curve locations, and produced a statewide curve database for identifying high crash and problem horizontal curves in Iowa. The researchers (*2*) manipulated GPS coordinate data collected at ten (10)-meter intervals to identify sites of possible curvature through a continuous refinement process involving the creation and simplification of polylines, reduction of identified vertices, and grouping of consecutive points in ArcGIS. Horizontal curve characteristics, specifically radius and curve length, were estimated using a circular regression and chord equations. The focus of the research in (*2*) was the identification of curve sites and the allocation of crashes to such sites. In addition to GPS based techniques of identifying and extracting roadway geometric data, exclusively GIS based techniques have also been used. In this regard, different GIS based tools have been developed by state departments of transportation around the U.S. in an effort to define and classify horizontal curves. The Florida Department of Transportation (FDOT) (*3*), (Cited in Rasdorf et al. (*4*)), developed an add-in tool in ArcGIS called Curvature Extension for identifying and classifying horizontal curves. The FDOT tool requires the user to manually identify the curve by specifying start and end points, after which the length of the curve is calculated based on the selected endpoints along the route, and the radius is determined utilizing chord length, chord angle and curve length based on a circular arc (*3*). Other GIS tools include Curve finder by the New Hampshire Department of Transportation (*5*), and Curve calculator found in the Coordinate geometry toolbar in ArcGIS by the Environmental Systems Research Institute (*6*). Rasdorf et al. (*4*) compared and evaluated the accuracy and the performance of three GIS based curve tools; Curve Extension, Curve Finder and Curve Calculator, which were used in extraction and identification of horizontal curve information by comparing results obtained from these tools to precisely drawn curves in GIS, and field measured curves. Based on a sensitivity analysis, Rasdorf et al. (*4*) recommended the Curve Extension tool for individual curve analysis, while the Curve Finder and the Curve Calculator tools were recommended for route analysis and situations in which GIS data points were readily available, respectively, to ensure accuracy in results obtained. Findley et al. (*7*) investigated an automated application of the three aforementioned GIS based curve extraction tools (Curve Finder, Curve Extensions and Curve Calculator) for identifying and characterizing numerous horizontal curves in a large dataset.

The use of high resolution satellite images to extract road geometric information has also been proposed as a simple and efficient option to extract geometric road information in contrast to aerial imagery (*8-10*). This has been accomplished using both automatic and semi-automatic approaches. Zhao et al. (*8*) developed a semi-automatic approach using a road mask defined by distinguishing road pixels from others using commercial remote sensing software. The semi-automatic approach developed in (*8*) involved extracting a road mask by identifying road pixels, extracting road seeds by tracing edge line pixels from long edge lines with a slow change in direction and extracting road lines by matching road templates with road masks and road seeds. Easa et al. (*9*) also developed a method for extracting horizontal curves using Ikonos satellite imagery. The algorithm developed used a Hough transform to detect curve and tangent sections of horizontal curves from satellite imagery, and can be applied to extract both simple and reverse horizontal curves (*9*). Dong et al. (*10*) developed an approximate algorithm to extract spiraled horizontal curves from high resolution satellite imagery using automated extraction methods involving the application of a Hough transform to images.  Other methods of extracting horizontal curve information include the use of laser scanning data and AutoCAD digital maps. Kim et al. (*11*) used laser scanning technology to obtain three dimensional information from a highway, which allowed the efficient, fast , and automatic extraction of center line characteristics like tangent and curved sections, and other cross sectional elements like lateral profiles and super elevation. Research to extract horizontal curves using AutoCAD digital maps include Watters and O'Mahony (*12*) and Hashim and Bird (*13*) who successfully extracted roadway horizontal geometric information in Ireland and United Kingdom, respectively.

There have been other research efforts focused on developing different algorithms using GPS data, gyroscope data, and GIS techniques to classify horizontal curvature of roadways. The basic premise of most of these algorithms is to separate the data into tangent and curved sections using a set threshold, with some of the approaches being automated. Yun et al. (*14*) used attitude and positional data obtained from a survey vehicle to develop an algorithm that distinguishes between tangent and curved sections and extracted geometric parameters like circular curve center and radii, transition curve parameters, and horizontal curve lengths. The algorithm developed in (*14*) begins by separating data points into tangent and curved sections using heading differences between two adjacent points and a set threshold $0.01^{\circ}$ for heading change between adjacent points.  Once the data points were separated into curve and tangent sections, the radius within the curved sections were calculated from the change in heading between adjacent points and the radius of the horizontal curve was specified from the average of the radius of the 70$^{th}$ percentile of the data points. The algorithm further separated curved sections into circular and transition curves using the ratio of the radius of each heading data point and the average radius and a threshold ratio value of 1 (*14*).

The researchers (*14*) tested their algorithm by applying it to 23 horizontal curves from four sections of National roads and highways, and compared that to the design drawings of these sections. The researchers discovered an error rate of between 5% and 10% in extraction of curve geometric parameters like curve lengths and circular curve radii in the analysis results. Li et al. (*15*) developed a curve extraction algorithm, which was implemented as a custom add in tool in ArcMAP, that automatically identifies horizontal curves from GIS roadway maps in addition to calculating geometric curve parameters, including the length, the radius, and the central angle.

The algorithm developed detects all curves in a roadway layer using a bearing angle threshold, and automatically classifies identified curves as simple and compound. In addition, it computes the radius and degree of curvature for identified simple curves, and the lengths for both simple and compound curves, and creates curve layers for identified curves in GIS (*15*). Othman et al. (*16*) extracted horizontal curves from field operational test data (obtained by driving vehicles along the roadways), by identifying curved sections using heading values. The approach used in (*16*) involved plotting field operational test roads from GPS data, identifying curved sections of the roadways, and then estimating radii, lengths, and start and end points of curves using the change in heading, vehicle speed, and a threshold for change in heading when the vehicle enters and exits the curve, respectively. Drakopoulos and Ornek (*17*) also developed an algorithm that used vehicle collected field data to establish roadway geometry, and produced curve lengths, degree of curve, deflection angle, and maximum super-elevation. The algorithm developed detects the start and end points of curves as the points at which the vehicle heading starts changing and becomes constant again, respectively. The developed algorithm calculates the deflection angle and length of the curve as the difference in heading readings and the distance between the start and end points of the curve respectively (*17*). The researchers validated the algorithm by testing it on a two lane rural highway and comparing its results to as-built data, with information for both directions of travel.

Lastly, Souleyrette et al. (*18*) extracted horizontal alignment characteristics as part of an effort to identify high crash locations in Iowa, which utilized existing databases in georeferenced environments. Their methodology involved separating data into curved and tangent sections by examining changes in bearing angle between adjacent road line segments (100 m in length), and classifying anything 5° or greater as curves.

## 3.0 METHODOLOGY

Two methods were investigated in the research for classifying horizontal curves; the Per Point and the Per Curve/Tangent methods. Both methods involved using heading and grade data collected by the ARAN van and determining horizontal curve parameters using the HPMS classification scheme (*19*). In addition to classification of the horizontal curves and grades, the lengths of each curve and grade type within HPMS sections were extracted using tools and written routines in MATLAB (*20*)

### 3.1 Dataset Preprocessing and Cleaning

ConnDOT collects roadway inventory data on all state roads using the ARAN van. The ARAN van is equipped with gyroscopes for collecting heading, and GPS data as it is driven along the roadway. The heading and grade data used in analysis, which was supplied by ConnDOT, was obtained from the 2013 inventory collected on state maintained routes using the ARAN van. This data was collected at four (4)-meter intervals. The gyro heading data supplied had seven columns, but the columns of interest to the research were the route ID, compass direction, the agency milepost and the heading. The gyro grade data also had seven columns, with the columns of interest that were used in the analysis being the route ID, compass direction, the agency milepost and the grade.

It was essential to ensure that the data used in the classification methods was accurate and had enough quality to produce reasonable expected results. The data were therefore cleaned to remove missing data points and outliers in the heading data. The ARAN heading data were smoothed to remove noise and extremities in the data. Several smoothing techniques were investigated in MATLAB, and two smoothing techniques were selected based on efficiency in memory usage of the software; a simple moving average and a Savitzky-Golay smoothing filter.

The Moving average (MVA) and the Savitzky-Golay (SG) smoothing filter were applied to the heading data using an optimal span determined by using statistical linear regression techniques. The moving average smoothing technique in MATLAB (*20*) smooths data by applying a low pass filter that replaces each single data point with the average of the neighboring data points defined within the span. The requirement for this method of smoothing was that the span be specified as an odd number such that each data point was at the center of the span. The beginning and end points of the span in the moving average were not smoothed because the required number of neighbors on each side of the data point could not be accommodated (*20*). The Savitzky-Golay filter worked by performing an unweighted least squares fit to a polynomial of a specified degree to determine filter coefficients with the requirement of specifying an odd span and a polynomial degree lesser than the span (*20*). Using statistical linear regression techniques, the optimal span for both smoothing techniques was determined as a percentage of the number of data points for each route such that the difference between the smoothed values and the original data were not greater than a certain tolerance level of 0.02. A polynomial degree between 3 and 5 was specified for the Savitzky-Golay method, depending on the length of the optimal span for each route. In addition to smoothing, the data was also cleaned by removing rows with negative agency mile posts.

### 3.2 Curve and Grade Classification Categories

A total of five categories from A to F were used for classifying curves and grades based on the degree of curvature and percentage of the grade, respectively. These categories were obtained from the HPMS field manual and are summarized in table 1.1.

**Table 1.1: Curve and Grade Classification Criteria**

| **Curve Classification Criteria** | **Grade Classification Criteria** | **Classification Type** |
|---|---|---|
| **Degree of Curvature (D)** | **Percent Grade** | **Category** |
| Under 3.5 degrees | 0.0 – 0.4 | A |
| 3.5 – 5.4 degrees | 0.5 – 2.4 | B |
| 5.5 – 8.4 degrees | 2.5 – 4.4 | C |
| 8.5 – 13.9 degrees | 4.5 – 6.4 | D |
| 14.0 – 27.9 degrees | 6.5 – 8.4 | E |
| 28 degrees or more | 8.5 or greater | F |

### 3.3 Per Point Classification Method

The Per Point Classification was performed by classifying each data point for each route as a curve type. This method had the advantage that each data point was classified as a curve or grade type without jumps in one classification category to next. The classification was performed using the heading change between adjacent points. To begin this method of classification, the gyro heading data were first separated by direction. For each set of directional data the change in heading from one data point to the next, referred to as delta heading, was calculated as the difference between the adjacent data point and the current data point for each route. Delta headings with absolute magnitudes greater than $270^{\circ}$ were corrected using a simple rule which was to reset these points to a value equal to the difference between the delta heading value and $360^{\circ}$,for positive delta heading values that were greater than $270^{\circ}$, or a sum of the delta heading value and $360^{\circ}$, for negative delta heading values. For each route in each direction, the delta heading of the first point (the point corresponding to the lowest milepost) was set to zero. The data was then smoothed by applying the described smoothing techniques.

The next stage involved extracting the radius and degree of curvature for each delta heading point. This was achieved using mathematical relationships described by equation 1-1 (*21*) and equation 1-2 below.

$$R = \frac{180° \times L}{\pi \times \Delta H} = \frac{57.2958 \times L}{\Delta H} \qquad [1\text{-}1]$$

$$D = \frac{5729.58}{R} \qquad [1\text{-}2]$$

Where $L$ is the length of the curve selected; and $R$, $D$ and $\Delta H$ are the radius of curve, degree of curvature and delta heading, respectively at four (4)-meter intervals where the data were collected. Once the degree of curvature was determined, the data points were classified using the classification scheme summarized in Table 1.1 for curves.

The classification process for the grades followed a similar process using grade data from the ARAN van to classify the grades for each route.

### 3.4 Per Curve/Tangent Classification Method

This method of curve classification focused on classifying curves by separating data into tangents and curves and then identifying the point of curvature (PC) and point of tangent (PT) of the horizontal curves. Once the PC's and PT's of the curves were determined, data points within these points were classified as curve types based on the change in heading between the PC and

PT. The length of curves were calculated as the difference in the agency milepost at the PT and that at the PC of the horizontal curves identified.

In order to differentiate between tangent and curve sections for the different routes, a threshold for delta heading had to be set beyond which the sections were classified as curves, otherwise, they were classified as tangents. Based on similar work that had been done and the distribution of delta headings within tangent and curved sections, (*14,16-17*) this threshold was set to be a value of 1 and is summarized in equation 1-3 .

$$If \begin{cases} |h_{i+1} - h_i| \leq 1 \quad , classify\ as\ tangent \\ |h_{i+1} - h_i| > 1, classify\ as\ curve \end{cases} \quad \forall i \in heading\ data \qquad [1\text{-}3]$$

Where $h$ is the heading at milepost *i*.

The PC's and PT's of curves on each route were identified by first sorting data points in ascending order based on the agency milepost and starting from the smallest milepost, identifying the first data milepost at which the delta heading exceeded a value of 1 as a PC and moving on from that milepost, identifying the next milepost at which the delta heading drops to a value lesser than or equal to 1 as a PT. Once the PC and PT were identified, that section of the route was clipped out of the dataset and the entire process repeated from the smallest milepost in the remaining dataset until no more PC and PT's could be further identified based on the delta heading threshold set.

The approach was, however, not explored further, because it was discovered that precision of the gyroscope readings were such that thresholds of delta heading for separating the data into curved and tangent sections potentially depended on the functional classification of the routes. Curves on interstates for example were too gentle to be picked up by the precision of the gyroscope. The method for locating PC's and PT's was tested on Route 44 using MATLAB to plot sections of Route 44 and locate the PC and PT's. These plots are shown in appendix B.

## 3.5 Validation and Error Checking

A number of steps were taken in the development of the curve classification method to check for errors and validate the classification method developed. These steps are described in the following sections.

### *3.5.1. Validation*

To validate the Per Point Classification method, the results of classification were compared against design drawings of existing curves. Curves from sections of Route 44 and Route 20 were used to perform these checks. Two curves between Milepost 56.13 and 56.46 of Route 44 and one curve from Route 20 between Mileposts 25.04 and 25.17 were used. The PC and PT's were supplied on the design drawings as stations but were converted from stations to feet then to mileposts of known intersections on the routes. These calculations are shown in Appendix A. The mileposts of the PC's and PT's of the two curves on Route 44 were determined by using the milepost of its intersection with BIDWELL Street while that of the curve on Route 20 was determined by using the milepost of its intersection with HILLCREST Street. The first curve on Route 44 had its PC estimated to be at Milepost 56.18, and its PT at Milepost 56.27 with a degree of cuvature of $12^{\circ}\,11'\,26''$. The second curve on Route 44 had a degree of curvature of $12^{\circ}\,11'\,26''$ and its PC and PT at Mileposts 56.31 and 56.41, respectively. The curve on Route 20 had a degree of curvature of $2^{\circ}\,54'38''$ and its PC and PT estimated to be at Milepost 25.04 and 25.17, respectively from design drawings. Using the classification scheme in Table 1.1 and the degrees of curvature, both horizontal curves selected from design drawings of Route 44 were classified as Curve Type D while the that on Route 20 was classified as Curve Type A.

These sections on both routes were classified using the Per Point method and are shown in TABLES A-1 to A-6 in the appendix for both east and west directions. For Route 44, almost all the data points within the two sections for both horizontal curves were classified as Curve Type D with a few points classified as Curve Type C in the east and the west direction. On Route 20, most data points for the data were classified as Curve Type A with a few points classified as Curve Type B and C for both directions. This is a common finding in literature, where the designed radius of a horizontal curve from design plans is slightly different from the travel path radius of the vehicle, which depends on the vehicle trajectory, and measurement precision errors from instruments (*14*, *16-17*).

### *3.5.1 Lane Change Error*

In order to collect consistent data that accurately represents the roadway, the ARAN van drivers attempt to drive with the left wheel path of the vehicle 2 feet from the centerline of the roadway. Unavoidable lane changes and events that occur during the driving of the ARAN van have the potential to affect the data collected, by causing sudden changes in the heading data. The ARAN van data however, is collected in a manner such that these lane changes and events (like maneuvering around a billboard) are logged at the mileposts at which they occur.

To examine the effects of the lane changes and events, the classification was examined for sudden jumps in categories of curve classification between consecutive points within mileposts, where such events were logged. Any anomalies in classification were checked for by comparing the curve classification at these mileposts to the adjacent points and resetting the classification to that of adjacent data points of mileposts outside these sections if they were significantly different.

#### *3.5.3 Checking Errors due to turns at the Begin and End Milepost of a Route*

An examination of the curve classification at the beginning and end mile post of different routes revealed them to be significantly different from that of points that were consecutive to and preceding these two mileposts, respectively. This error was attributed to the ARAN van turning at the beginning and end mileposts of a route. These points were registered as Curve Type F for most routes by the classification method because of the turning of the van at these points. To correct these errors, the curve type classification at the beginning mileposts was reset to the curve class of the subsequent mile post and the curve class at the end mile post of a route was reset to that of the preceding milepost.

### 3.6 Determining Lengths of Curves Types and Grade Types per Route

One of the objectives of the research project was to determine the lengths of each curve and grade type after classification, which are contained within the HPMS segments of the routes. In order to achieve this, HPMS segment data containing the beginning and end mile posts, and length of each HPMS section and the lengths of each curve and grade type contained in the section, for the different routes was supplied by ConnDOT.

Using the length, beginning and end mileposts of the HPMS sections for each route as input, the HPMS sections were clipped from the classified curve and grade data and the length of each curve (grade) type within the section was determined as a proportion of the HPMS segment length. This proportion was determined as a ratio of the number of curves (grades) of a particular type within the section to total number of curves (grades) within the section. The extracted lengths of curves (grade) types for each direction of travel were compared to their corresponding HPMS section data to determine how close the classification system matched that of the supplied HPMS data.

### 3.7 Developing HPMS Character Separated Out File

One of the requirements for reporting curve and grade length was to develop a character separated file that contained the curve and grade lengths for each HPMS section contained in the classified dataset. The file was to be formatted in the following manner:

Year_Record|State_Code|Route_ID|Begin_Point|End_Point|Data_Item|Section_Length|Value_Numeric|Value_Text|Value_Date|Comments.

This was achieved using MATLAB scripts to create tables of the extracted curve and grade type lengths and specifying a bar as a delimiter. This file was extracted for each driving direction of the ARAN van and a specified default (the log direction of east and north) direction and was outputted as a text file at the end of the run of the classification and length extraction algorithm.

## 4.0 RESULTS

Using the developed method of classification, two standalone executables for classifying curves and grades and extracting lengths of curves and grades, which can be deployed on any computer, were produced by the research team. The two standalone executable files are described in the following sections.

### 4.1 Horizontal Curve and Grade Classification Executable

The Horizontal Curve and Grade Classification executable classifies horizontal curve and grades using the per point classification method. It takes as input, a gyro heading text file, a gyro grade text file and lane event text file. Users are allowed to select input files by navigating to the folder in which the input files are located during the execution of the application. The application works by separating data into routes by their ID types. Two types of Route ID categories are used for separation of the data: Numeric ID types like Route 1 and Route 44; and String ID types like Route 2A, and Route 17A. At the beginning of the application, users are allowed to enter a year of analysis (which is appended to the filename of the output text file created after a successful execution of the application), followed by a file selection dialogue box that allows the user to select input text files. Input files are required to be selected in a particular order for successful execution of the application. The gyro heading file is selected first, followed by the selection of the gyro grade file and then the lane event text file. Users have the option of not selecting a text file by hitting the cancel button when the select file dialogue box opens. To successfully run the application and produce results for the classification, users have to select at least one of the gyro input text files.

After successful completion of the program, depending on the input data, text files for both horizontal curve and grade classification are produced. If both the gyro heading and gyro grade text files containing a mixture of route IDs are fed as input to the application during the file selection process, four text files are produced at the end of the analysis with classification data. Two of these text files are produced for horizontal curves and grades classified on routes with Numeric IDs, while another two are produced for horizontal curves and grades classified on routes with String IDs. If the input gyro and grade files contain routes with only one type of ID, two text files; one for horizontal curve and the other for grade classification are produced after successful execution of the application.

The output text file for horizontal curve classification contains 20 columns. The first ten columns contains information on route ID, direction, milepost, delta milepost, heading, delta heading, type of data (tangent or curve), radius, degree of curve, and horizontal curve class all based on delta headings. The next five columns in this output dataset contains data on MVA smoothed delta heading values, type of data point(tangent or curve), radius, degree of curve, and curve classification based on MVA smoothed delta headings. The last five columns in the output data dataset for horizontal curve classification contains information on SG smoothed delta heading values, type of data point (tangent or curve), radius, degree of curve, and curve classification based on SG smoothed delta headings. The output text file for grade classification contained five columns that provided information on the route ID, direction, milepost, grades and the class of grade.

### 4.2 Horizontal Curve and Grade Length Executable

The horizontal curve and grade length executable extracts the length of each curve and grade of each category found within HPMS sections in the data. It requires as input, grade and horizontal curve classification data obtained from running the Horizontal Curve and Grade Classification executable. Once the application is started, users are required to enter a year of analysis followed by the selection of file inputs. Five standard file inputs are required by prompts of the file selection dialogue box during the execution of the application.

The HPMS Microsoft (MS) Office excel file, is selected during the first file selection dialogue box prompt. The second and third file selection dialogue boxes that open during the execution of the application are for selecting the horizontal curve classification text files for routes with Numeric ID’s and routes with String ID’s , respectively. The fourth and fifth file selection dialogue prompts are for selecting the grade classification text files for routes with Numeric IDs and routes with String ID’s, respectively. During the file selection dialogue for classification text files, users have the option of hitting cancel if the classification text file kind (e.g. grade classification for routes with Numeric ID’s) is unavailable for selection. However, to successfully run and produce output of a character separated text file with horizontal curve and grade lengths, a minimum of one text file for curve classification and a corresponding grade classification text file is required.

After successful run of the application, text file outputs with all directions that were contained in the input files and a default log direction of east and north direction where available in the input dataset, are produced and stored in a folder labeled ‘Analysis Results’. In addition two MS Office excel files comparing the extracted horizontal curve and grade lengths to that contained in the input HPMS MS office excel file are also created and stored in the “Analysis Results” folder.

## 5.0 SUMMARY AND CONCLUSIONS

A simple method was developed to classify horizontal curves and grades using heading and grade data obtained from an ARAN van. In order to remove noise and outliers from the data, the data were smoothed by applying a moving average and a savitzky-golay smoothing filter. The per point curve classification method developed categorizes horizontal curves into six classes in a classification scheme outlined in the HPMS manual (*9*), by using the change in heading between adjacent points in simple equations to determine radius and degree of horizontal curves. Grades were also classified using the per point method according to the same scheme.

The developed classification method is validated using three curves obtained from design drawings of Connecticut State Routes 44 and 20. Comparisons of horizontal curve classification of the sections of the curves from the design drawings of both routes using the per point method showed close agreement with classification obtained from using design data. The minor discrepancies between the two were attributed to van trajectory and level of precision of the measuring instruments of the ARAN van. Different error corrections for lane change events, and the turning of the ARAN van at the beginning and end of the different routes were applied to horizontal curve classification to improve accuracy of classification.

In addition to the classification method developed, the length of each horizontal curve type and grade type found on HPMS sections were also extracted and used to create an HPMS character separated out file with length data. The horizontal curve classification method and length extraction process were developed as two standalone executable applications that can be deployed on different computers to obtain classification and length data for both curves and grades on different routes.

The tool developed extracts horizontal curve parameters like radius and degree of curvature using the change in heading in equations during the classification method, and is contained in the classification text files that can be incorporated in safety research for identifying high risk locations for crashes. Lastly, this tool can be used to produce a rich database for existing curve and grades for different routes using ARAN van inventory data, which can be maintained by different state transportation agencies.

## 5.1 POTENTIAL FOR FUTURE STUDIES

While this has been a good step in developing a method for classifying and extracting horizontal curves and grade data, there are ways in which the tool developed can be enhanced to improve the quality of classification, as well as its user friendliness. The incorporation of the ability to visualize horizontal curves by selecting sections and producing figures of horizontal curves for selected sections could further enhance user experience with the tool.

The inclusion of batch processing capabilities in the tool developed will increase efficiency and speed up the process of classifying horizontal curves and grades and extracting their parameters. This will improve user ability to enter data and quickly and efficiently obtain a wealth of horizontal roadway knowledge from the data entered.

Lastly, further exploring and developing the tool to identify the PC's and PT's of different curves on different routes and classifying curves between PC's and PT's will improve the functionality of the tool developed, provide an alternative method for classifying horizontal curves, and provide users with the option of selecting a preferred classification method.

## REFERENCES


1. Imran, M., Y. Hassan, and D. Patterson. GPS–GIS-Based Procedure for Tracking Vehicle Path on Horizontal Alignments. *Computer-Aided Civil and Infrastructure Engineering*. Vol. 21,No. 5,2006,pp. 383-94
2. Hans, Z., T. Jantscher, R. Souleyrette, and R. Larkin. *Horizontal Curve Identification and Evaluation*. InTrans Project 10-369, 2006, Center for Transportation Research and Education, Iowa State University, Ames, IA, 2012.
3. Florida Department of Transportation (FDOT). Geographic information system (GIS): Curvature extension for ArcMap 9.x.Transportation Statistics Office, Tallahassee, FL. URL: ⟨http://www.dot.state.fl.us/planning/statistics/gis/⟩ (Cited in Rasdorf et al.(*4*))
4. Rasdorf, W., D. J. Findley, C. V. Zegeer, C. A. Sundstrom, and J. E. Hummer. Evaluation of GIS Applications for Horizontal Curve Data Collection. Journal of Computing in Civil Engineering, Vol. 26,2012,pp.191-203
5. Harpring, J. NHDOT. Curve Finder FAQ for Version 2. Concord, NH: New Hampshire Department of Transportation, 2010.
6. Environmental Systems Research Institute. GIS for Highways. Redlands, CA: Author. ,2010, Retrieved from http://www.esri.com/industries/highways/index.html

7. Findley,D.J., C.V. Zegeer, C.A. Sundstrom, J.E. Hummer ,W. Rasdorf, and T, J. Fowler. Finding and Measuring Horizontal Curves in a Large Highway Network: A GIS Approach. *Public Works Management and Policy*. XX(X),pp.1-23
8. Zhao, H., Kumagai, J., Nakagawa, M., and Shibasaki, R.2002. Semiautomatic road extraction from high-resolution satellite image. International Archives of Photogrammetry and Remote Sensing, Vol. 34, No. 3B, pp. 406–411.
9. Easa, S.M, H. Dong and J. Li. Use of Satellite Imagery for Establishing Road Horizontal Alignments. In *Journal of Surveying Engineering*, Vol. 133, No. 1 , 2007,pp. 29-35
10. Dong, H., S.M, Easa and J. Li. Approximate Extraction of Spiralled Horizontal Curves from Satellite Imagery. In *Journal of Surveying Engineering*, Vol. 133, No. 1, 2007, pp. 36-40.
11. Kim, J. S., J. C. Lee, I. J. Kang, S. Y. Cha, H. Choi, and T. G. Lee. Extraction of Geometric Information on Highway Using Terrestrial Laser Scanning Technology. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.* Vol. XXXVII. Part B5, Beijing, China, 2008, pp. 539–544.
12. Watters, P., and M. O'Mahony. The Relationship between Geometric Design Consistency and Safety on Rural Single Carriageways in Ireland. *Proceedings of European Transport Conference,* Leiden, Netherlands, Association for European Transport, London, 2007.
13. Hashim I. H. and R. N. Bird. Exploring the Relationships between the Geometric Design Consistency and Safety in Rural Single Carriageways in the UK, *Proceedings of the 36th Annual Conference*, Universities' Transport Study Group, University of Newcastle upon Tyne, January, 2004.

14. Yun D. G, J.G. Sung and H.S. Kim. Development and Identification Algorithm for Horizontal Alignment using Attitude and Positional Data of Vehicle. *In Korean Society of Civil Engineers ,Journal of Civil Engineering*,Vol. 17,No.4,2013 ,pp.797-805.

15. Li, Z., M.V. Chitturi, A.R. Bill. and D. A. Noyce. Automated Identification and Extraction of Horizontal Curve Information from Geographic Information Maps. In *Transportation Research Record, Journal of the Transportation Research Board*, No. 2291, Washington DC. pp 80-92.

16. Othman, S., T. Thomson, and G. Lannér. Using Naturalistic Field Operational Test Data to Identify Horizontal Curves. In *Journal of Transportation Engineering*, Vol. 138, No. 9, 2012.

17. Drakopoulos, A. and E. Ornek. Use of Vehicle-Collected Data to Calculate Existing Roadway Geometry. Journal of Transportation Engineering, Vol. 126, No 2, 2000.

18. Souleyrette, R., A. Kamyab, Z. Hans, K.K. Knapp, A. Khattak, R. Basavaraju, and B. Storm. Systematic Identification of High Crash Locations. Iowa Department of Transportation. Iowa DOT Project TR-442., 2001, Ames, IA.

19. Highway Performance Monitoring System Field Manual, *Office of Highway Policy Information*, Federal Highway Administration, US Department of Transportation, 2012.

20. MATLAB and Curve Fitting Toolbox, Release 2013b, The Math Works, Inc., Natick, Massachusetts, United States.

21. Carlson, P. J., M. Burris, K. Black, and E. R. Rose. Comparison of Radius-Estimating Techniques for Horizontal Curves. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1918, Transportation Research Board of the National Academies, Washington,D.C., 2005, pp. 76–83

22. A Policy on Geometric Design of Highways and Streets. *AASHTO*, Washington, D.C., 2001.

# APPENDIX

## APPENDIX A: VALIDATION RESULTS

### Curve Calculations from Design Drawings

**Route 44 Curve Calculations**

$BIDWELL\ ST\ Station\ at\ US\ 44\ = 13 + 66\ = 1366ft\ = 0.26mi$

$BEGINNING\ OF\ PROJECT\ (BP)\ Station\ = 2 + 00\ = 200ft = 0.04mi$

$END\ OF\ PROJECT\ (EP)\ Station\ = 19 + 50 = 1950ft =\ 0.37mi$

$BIDWELL\ ST\ MILE\ POST\ = 56.35$

$BP\ Mile\ Post = 56.35 - (0.26 - 0.04) = 56.11$

$EP\ Mile\ Post = 56.35 + (0.37 - 0.26) = 56.46$

**Route 44 Curve 1:**

$PC1\ Station\ =\ 4\ +\ 98.70 = 498.70ft\ = 0.09mi$

$PT1\ Station\ =\ 9 + 54.11\ = 954.11ft\ = 0.18mi$

$PI1\ Station\ = PC + T = 4 + 98.70 + 2 + 47.37 = 7 + 46.07 = 746.07ft = 0.14mi$

$Length\ =\ 455.41ft\ =\ 0.086mi$

$Radius\ = 470\ ft\ = 0.089mi$

$T = 247.37\ ft = 0.047\ mi$

$\Delta = 55.31°$

$PC1\ Mile\ Post = 56.35 - (0.26 - 0.09) = 56.18$

$PT1\ Mile\ Post = 56.35 - (0.26 - 0.18) = 56.27$

$PI1\ \ Mile\ Post = 56.35 - (0.26 - 0.14) = 56.23$

**Route 44 Curve 2**

$PC2\ Station\ =\ 11+53.66=1153.66ft\ =0.22mi$

$PT2\ Station\ =\ 16+76.76\ =1676.76ft\ =0.32mi$

$PI2\ Station=11+53.66+2+92.39=14+46.05=1446.05=0.27mi$

$Length\ =523.12ft\ =\ 0.099mi$

$Radius\ =470\ ft\ =0.089mi$

$T=292.39ft=0.055\ mi$

$\Delta=63.46°$

$PC2\ Mile\ Post=56.35-(0.26-0.22)=56.31$

$PT2\ Mile\ Post=56.35+(0.32-0.26)=56.41$

$PI2\ \ Mile\ Post=56.35+(0.27-0.26)=56.36$

**Route 20 Curve Calculations**

$HILL\ CREST\ ST\ Station\ at\ RTE\ 20\ =123+40=12340ft\ =2.334mi$

$BP\ Station\ =122+00\ =12200ft=2.31mi$

$EP\ Station\ =133+00=13300ft=\ 2.519mi$

$HILLCREST\ ST\ MILE\ POST\ =25.045$

$BP\ Mile\ Post=25.045-(2.334-2.31)=25.021$

$EP\ Mile\ Post=25.045+(2.519-2.334)=25.23$

**TABLE A-1: Curve Classification for Curves for Route 44 East Section 1: MP: 56.18 to 56.27**

| ROUTE ID | MILEPOST | DEGREE OF CURVE | CURVE CLASSIFICATION |
|---|---|---|---|
| 44 | 56.181 | 6.86 | 'C' |
| 44 | 56.184 | 8.38 | 'C' |
| 44 | 56.186 | 9.91 | 'D' |
| 44 | 56.189 | 10.67 | 'D' |
| 44 | 56.191 | 11.43 | 'D' |
| 44 | 56.194 | 11.43 | 'D' |
| 44 | 56.197 | 10.67 | 'D' |
| 44 | 56.199 | 10.67 | 'D' |
| 44 | 56.202 | 10.67 | 'D' |
| 44 | 56.204 | 10.67 | 'D' |
| 44 | 56.207 | 10.67 | 'D' |
| 44 | 56.210 | 12.19 | 'D' |
| 44 | 56.212 | 11.43 | 'D' |
| 44 | 56.215 | 12.19 | 'D' |
| 44 | 56.217 | 13.72 | 'D' |
| 44 | 56.220 | 14.48 | 'D' |
| 44 | 56.223 | 13.72 | 'D' |
| 44 | 56.225 | 13.72 | 'D' |
| 44 | 56.228 | 12.95 | 'D' |
| 44 | 56.230 | 12.19 | 'D' |
| 44 | 56.233 | 11.43 | 'D' |
| 44 | 56.236 | 9.91 | 'D' |
| 44 | 56.238 | 9.91 | 'D' |
| 44 | 56.241 | 9.91 | 'D' |
| 44 | 56.243 | 11.43 | 'D' |
| 44 | 56.246 | 11.43 | 'D' |
| 44 | 56.249 | 11.43 | 'D' |
| 44 | 56.251 | 12.19 | 'D' |
| 44 | 56.254 | 12.95 | 'D' |
| 44 | 56.256 | 12.95 | 'D' |
| 44 | 56.259 | 12.19 | 'D' |
| 44 | 56.262 | 11.43 | 'D' |
| 44 | 56.264 | 9.91 | 'D' |
| 44 | 56.267 | 9.91 | 'D' |
| 44 | 56.269 | 9.91 | 'D' |

**TABLE A-2: Curve Classification for Curves for Route 44 West Section 1: MP : 56.18 to 56.27**

| ROUTE ID | MILEPOST | DEGREE OF CURVE | CURVE CLASSIFICATION |
|---|---|---|---|
| 44 | 56.182 | 12.95 | 'D' |
| 44 | 56.185 | 11.43 | 'D' |
| 44 | 56.188 | 12.19 | 'D' |
| 44 | 56.190 | 11.43 | 'D' |
| 44 | 56.193 | 11.43 | 'D' |
| 44 | 56.196 | 11.43 | 'D' |
| 44 | 56.198 | 11.43 | 'D' |
| 44 | 56.201 | 11.43 | 'D' |
| 44 | 56.204 | 11.43 | 'D' |
| 44 | 56.207 | 12.19 | 'D' |
| 44 | 56.209 | 12.19 | 'D' |
| 44 | 56.212 | 11.43 | 'D' |
| 44 | 56.215 | 12.19 | 'D' |
| 44 | 56.217 | 11.43 | 'D' |
| 44 | 56.220 | 12.19 | 'D' |
| 44 | 56.223 | 12.95 | 'D' |
| 44 | 56.226 | 13.72 | 'D' |
| 44 | 56.228 | 12.95 | 'D' |
| 44 | 56.231 | 13.72 | 'D' |
| 44 | 56.234 | 13.72 | 'D' |
| 44 | 56.236 | 13.72 | 'D' |
| 44 | 56.239 | 12.95 | 'D' |
| 44 | 56.242 | 12.19 | 'D' |
| 44 | 56.245 | 9.91 | 'D' |
| 44 | 56.247 | 9.14 | 'D' |
| 44 | 56.250 | 5.33 | 'B' |
| 44 | 56.253 | 3.81 | 'B' |
| 44 | 56.256 | 3.05 | 'A' |
| 44 | 56.258 | 2.29 | 'A' |
| 44 | 56.261 | 0.76 | 'A' |
| 44 | 56.264 | 0.76 | 'A' |
| 44 | 56.266 | 1.52 | 'A' |
| 44 | 56.269 | 0.76 | 'A' |

**TABLE A-3: Curve Classification for Curves for Route 44 East Section 2: MP : 56.31 to 56.41**

| ROUTE ID | MILEPOST | DEGREE OF CURVE | CURVE CLASSIFICATION |
|---|---|---|---|
| 44 | 56.31 | 3.81 | 'B' |
| 44 | 56.31 | 4.57 | 'B' |
| 44 | 56.32 | 4.86 | 'B' |
| 44 | 56.32 | 9.14 | 'D' |
| 44 | 56.32 | 10.67 | 'D' |
| 44 | 56.32 | 12.19 | 'D' |
| 44 | 56.33 | 12.95 | 'D' |
| 44 | 56.33 | 13.72 | 'D' |
| 44 | 56.33 | 14.48 | 'D' |
| 44 | 56.33 | 13.72 | 'D' |
| 44 | 56.34 | 12.95 | 'D' |
| 44 | 56.34 | 12.19 | 'D' |
| 44 | 56.34 | 12.19 | 'D' |
| 44 | 56.35 | 12.19 | 'D' |
| 44 | 56.35 | 12.19 | 'D' |
| 44 | 56.35 | 12.95 | 'D' |
| 44 | 56.35 | 12.19 | 'D' |
| 44 | 56.36 | 12.19 | 'D' |
| 44 | 56.36 | 12.95 | 'D' |
| 44 | 56.36 | 12.19 | 'D' |
| 44 | 56.36 | 12.95 | 'D' |
| 44 | 56.37 | 12.95 | 'D' |
| 44 | 56.37 | 12.19 | 'D' |
| 44 | 56.37 | 12.95 | 'D' |
| 44 | 56.37 | 12.95 | 'D' |
| 44 | 56.38 | 12.19 | 'D' |
| 44 | 56.38 | 12.19 | 'D' |
| 44 | 56.38 | 12.95 | 'D' |
| 44 | 56.38 | 12.19 | 'D' |
| 44 | 56.39 | 12.19 | 'D' |
| 44 | 56.39 | 11.43 | 'D' |
| 44 | 56.39 | 11.43 | 'D' |
| 44 | 56.39 | 11.43 | 'D' |
| 44 | 56.40 | 11.43 | 'D' |
| 44 | 56.40 | 12.19 | 'D' |
| 44 | 56.40 | 11.43 | 'D' |
| 44 | 56.41 | 10.67 | 'D' |
| 44 | 56.41 | 9.91 | 'D' |
| 44 | 56.41 | 8.38 | 'D' |

**TABLE A-4: Curve Classification for Curves for Route 44 West Section 2: MP : 56.31 to 56.41**

| ROUTE ID | MILEPOST | DEGREE OF CURVE | CURVE CLASSIFICATION |
|---|---|---|---|
| 44 | 56.310 | 12.19 | 'D' |
| 44 | 56.313 | 12.19 | 'D' |
| 44 | 56.315 | 12.19 | 'D' |
| 44 | 56.318 | 12.19 | 'D' |
| 44 | 56.321 | 12.19 | 'D' |
| 44 | 56.324 | 11.43 | 'D' |
| 44 | 56.326 | 10.67 | 'D' |
| 44 | 56.329 | 11.43 | 'D' |
| 44 | 56.332 | 11.43 | 'D' |
| 44 | 56.334 | 11.43 | 'D' |
| 44 | 56.337 | 12.95 | 'D' |
| 44 | 56.340 | 12.19 | 'D' |
| 44 | 56.343 | 13.72 | 'D' |
| 44 | 56.345 | 12.19 | 'D' |
| 44 | 56.348 | 12.95 | 'D' |
| 44 | 56.351 | 12.95 | 'D' |
| 44 | 56.354 | 11.43 | 'D' |
| 44 | 56.356 | 12.19 | 'D' |
| 44 | 56.359 | 11.43 | 'D' |
| 44 | 56.362 | 11.43 | 'D' |
| 44 | 56.365 | 12.19 | 'D' |
| 44 | 56.368 | 12.19 | 'D' |
| 44 | 56.371 | 12.19 | 'D' |
| 44 | 56.373 | 12.19 | 'D' |
| 44 | 56.376 | 11.43 | 'D' |
| 44 | 56.379 | 12.19 | 'D' |
| 44 | 56.382 | 11.43 | 'D' |
| 44 | 56.385 | 12.19 | 'D' |
| 44 | 56.387 | 11.43 | 'D' |
| 44 | 56.390 | 12.19 | 'D' |
| 44 | 56.393 | 12.19 | 'D' |
| 44 | 56.396 | 12.19 | 'D' |
| 44 | 56.399 | 10.67 | 'D' |
| 44 | 56.401 | 9.14 | 'D' |
| 44 | 56.404 | 7.62 | 'C' |
| 44 | 56.410 | 6.10 | 'C' |

**TABLE A-5: Curve Classification for Curves for Route 20 East MP : 25.044 to 25.171**

| ROUTE ID | MILEPOST | DEGREE OF CURVE | CURVE CLASSIFICATION |
|---|---|---|---|
| 20 | 25.044 | 3.05 | 'A' |
| 20 | 25.046 | 3.05 | 'A' |
| 20 | 25.049 | 2.29 | 'A' |
| 20 | 25.051 | 3.05 | 'A' |
| 20 | 25.054 | 2.29 | 'A' |
| 20 | 25.057 | 3.05 | 'A' |
| 20 | 25.059 | 2.29 | 'A' |
| 20 | 25.062 | 2.29 | 'A' |
| 20 | 25.064 | 2.29 | 'A' |
| 20 | 25.067 | 2.29 | 'A' |
| 20 | 25.069 | 3.05 | 'A' |
| 20 | 25.072 | 3.05 | 'A' |
| 20 | 25.074 | 4.57 | 'B' |
| 20 | 25.077 | 3.81 | 'B' |
| 20 | 25.08 | 3.81 | 'B' |
| 20 | 25.082 | 3.81 | 'B' |
| 20 | 25.085 | 3.05 | 'A' |
| 20 | 25.087 | 3.05 | 'A' |
| 20 | 25.09 | 2.29 | 'A' |
| 20 | 25.092 | 3.05 | 'A' |
| 20 | 25.095 | 2.29 | 'A' |
| 20 | 25.097 | 1.52 | 'A' |
| 20 | 25.1 | 0.76 | 'A' |
| 20 | 25.102 | 1.52 | 'A' |
| 20 | 25.104 | 0.76 | 'A' |
| 20 | 25.107 | 0.76 | 'A' |
| 20 | 25.11 | 2.29 | 'A' |
| 20 | 25.112 | 2.29 | 'A' |
| 20 | 25.115 | 2.29 | 'A' |
| 20 | 25.117 | 3.05 | 'A' |
| 20 | 25.12 | 2.29 | 'A' |
| 20 | 25.122 | 2.29 | 'A' |
| 20 | 25.125 | 3.05 | 'A' |
| 20 | 25.128 | 3.05 | 'A' |
| 20 | 25.13 | 3.05 | 'A' |
| 20 | 25.133 | 1.52 | 'A' |
| 20 | 25.135 | 3.05 | 'A' |
| 20 | 25.138 | 2.29 | 'A' |
| 20 | 25.14 | 3.05 | 'A' |
| 20 | 25.143 | 2.29 | 'A' |

| ROUTE ID | MILEPOST | DEGREE OF CURVE | CURVE CLASSIFICATION |
|---|---|---|---|
| 20 | 25.145 | 1.52 | 'A' |
| 20 | 25.148 | 2.29 | 'A' |
| 20 | 25.15 | 1.52 | 'A' |
| 20 | 25.153 | 2.29 | 'A' |
| 20 | 25.155 | 1.52 | 'A' |
| 20 | 25.158 | 0.76 | 'A' |
| 20 | 25.16 | 1.52 | 'A' |
| 20 | 25.163 | 0.76 | 'A' |
| 20 | 25.165 | 0.76 | 'A' |
| 20 | 25.168 | 0.76 | 'A' |
| 20 | 25.17 | 0 | 'A' |

**TABLE A-6: Curve Classification for Curves for Route 20 West MP : 25.044 to 25.171**

| ROUTE ID | MILEPOST | DEGREE OF CURVE | CURVE CLASSIFICATION |
|---|---|---|---|
| 20 | 25.04 | 3.050 | 'A' |
| 20 | 25.05 | 3.810 | 'B' |
| 20 | 25.05 | 3.810 | 'B' |
| 20 | 25.05 | 3.050 | 'A' |
| 20 | 25.05 | 3.050 | 'A' |
| 20 | 25.06 | 3.050 | 'A' |
| 20 | 25.06 | 3.050 | 'A' |
| 20 | 25.06 | 3.810 | 'B' |
| 20 | 25.07 | 3.810 | 'B' |
| 20 | 25.07 | 3.050 | 'A' |
| 20 | 25.07 | 3.810 | 'A' |
| 20 | 25.07 | 3.050 | 'A' |
| 20 | 25.07 | 1.520 | 'A' |
| 20 | 25.08 | 2.290 | 'A' |
| 20 | 25.08 | 2.290 | 'A' |
| 20 | 25.08 | 2.290 | 'A' |
| 20 | 25.09 | 0.760 | 'A' |
| 20 | 25.09 | 0.760 | 'A' |
| 20 | 25.09 | 0.760 | 'A' |
| 20 | 25.09 | 1.520 | 'A' |
| 20 | 25.10 | 1.520 | 'A' |
| 20 | 25.10 | 3.050 | 'A' |
| 20 | 25.10 | 3.050 | 'A' |
| 20 | 25.10 | 3.050 | 'A' |
| 20 | 25.10 | 5.330 | 'C' |
| 20 | 25.11 | 6.100 | 'C' |
| 20 | 25.11 | 6.860 | 'C' |
| 20 | 25.11 | 6.100 | 'C' |
| 20 | 25.11 | 5.330 | 'B' |
| 20 | 25.12 | 3.810 | 'B' |
| 20 | 25.12 | 3.050 | 'A' |
| 20 | 25.12 | 2.290 | 'A' |
| 20 | 25.12 | 0.760 | 'A' |
| 20 | 25.13 | 1.520 | 'A' |
| 20 | 25.13 | 0.760 | 'A' |
| 20 | 25.13 | 0.760 | 'A' |
| 20 | 25.13 | 0.760 | 'A' |
| 20 | 25.14 | 0.760 | 'A' |
| 20 | 25.14 | 0.760 | 'A' |
| 20 | 25.14 | 0.000 | 'A' |
| 20 | 25.14 | 0.000 | 'A' |
| 20 | 25.15 | 0.000 | 'A' |

| ROUTE ID | MILEPOST | DEGREE OF CURVE | CURVE CLASSIFICATION |
|---|---|---|---|
| 20 | 25.15 | 0.000 | 'A' |
| 20 | 25.15 | 0.000 | 'A' |
| 20 | 25.15 | 0.760 | 'A' |
| 20 | 25.16 | 0.000 | 'A' |
| 20 | 25.16 | 0.760 | 'A' |
| 20 | 25.16 | 0.760 | 'A' |
| 20 | 25.16 | 0.000 | 'A' |
| 20 | 25.17 | 0.760 | 'A' |
| 20 | 25.17 | 0.000 | 'A' |
| 20 | 25.17 | 0.000 | 'A' |

# APPENDIX B: FIGURES

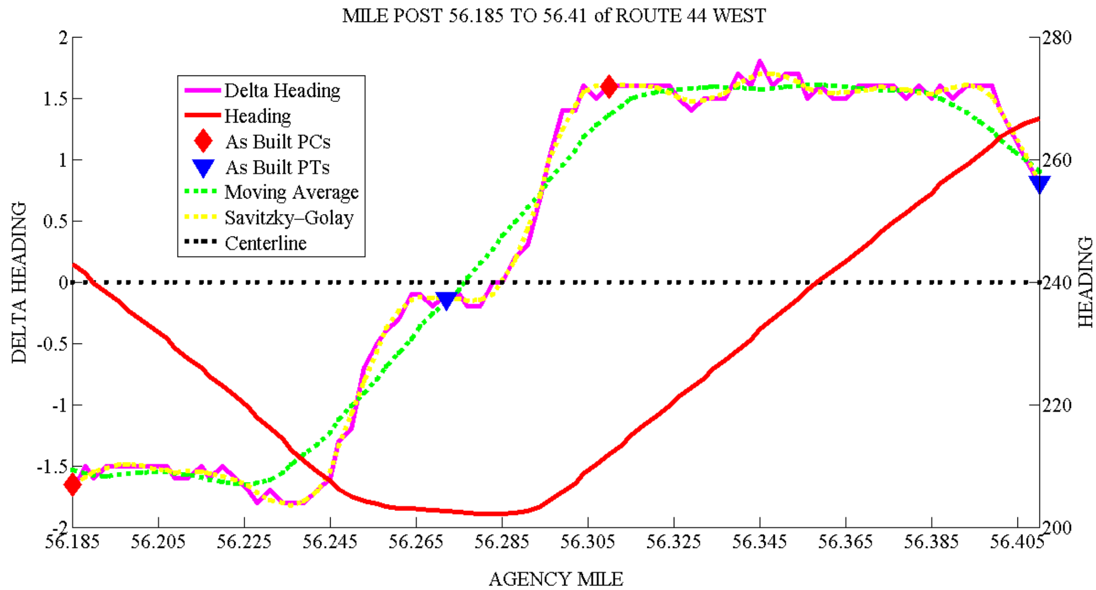


**Figure B-1: PC and PT Location of Route 44 West Milepost 56.185 to 56.41**

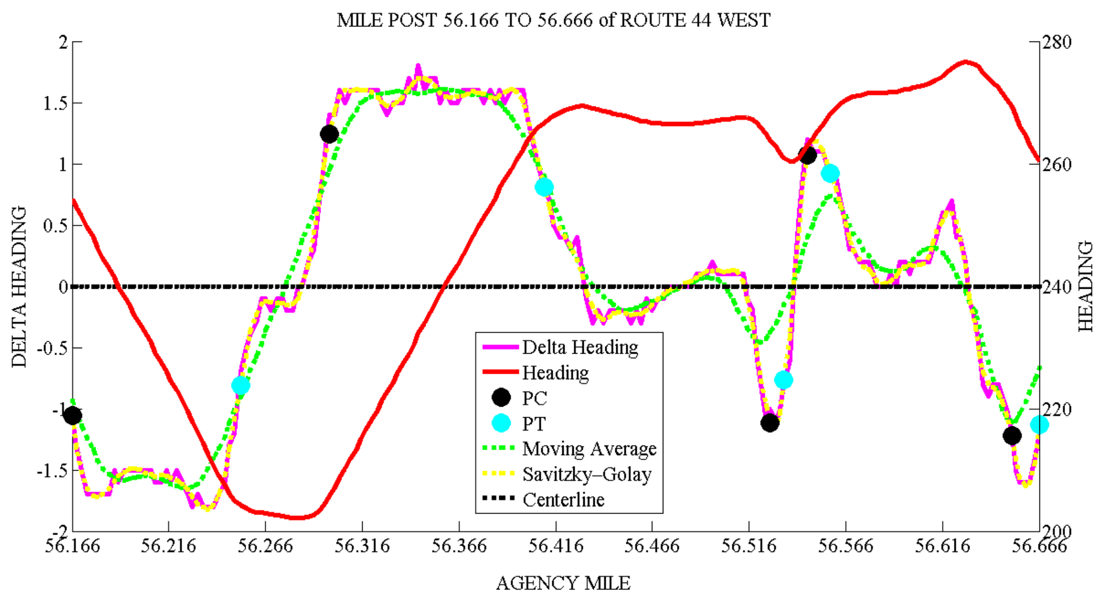


**Figure B-2: PC and PT Location of Route 44 West Milepost 56.166 to 56.666**

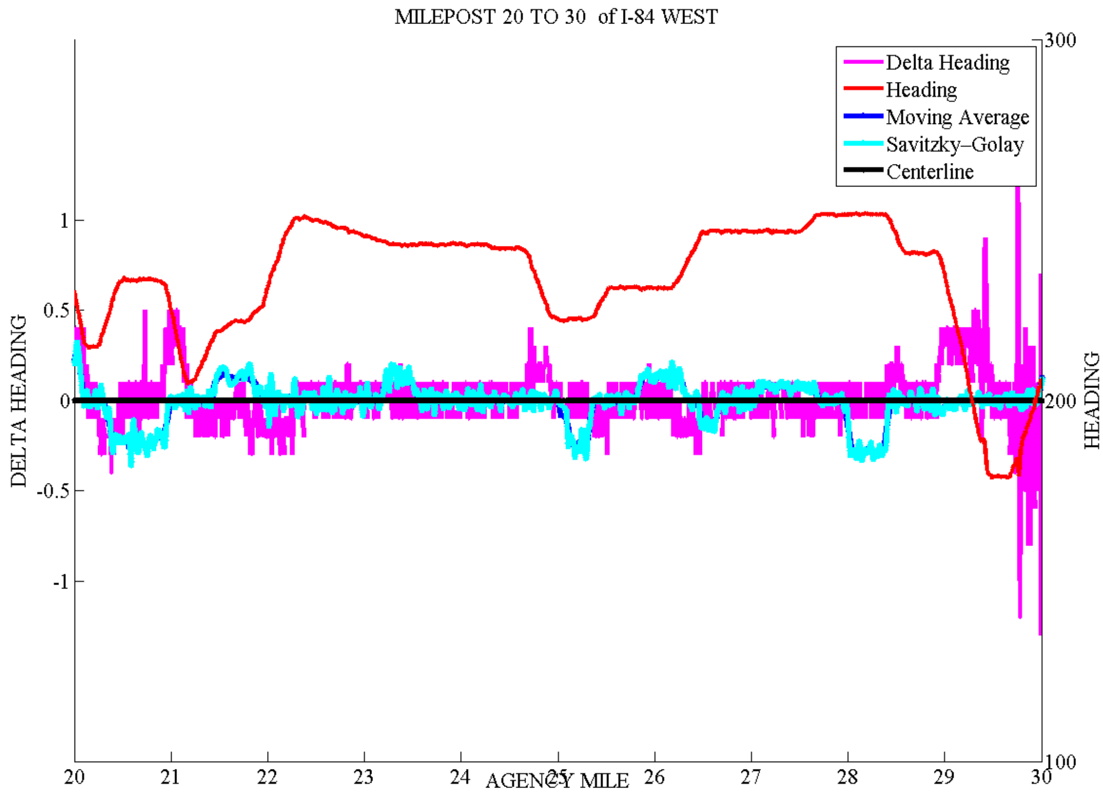


**Figure B-3: I-84 West Milepost of 20 to 30 Showing Smoothing Techniques Applied to Data**