

**Development of the ConnDOT  
Horizontal Curve Classification  
Software - Phase II**

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# Standard Conversions

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

\*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)

## Technical Documents Page

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16. Abstract Horizontal curves are an integral part of roadway design; they provide a transition between tangents on a roadway. While many types of horizontal curves can be used in the geometric design of a roadway, simple circular curves are typically used. Other curve types that can be used include compound and spiral curves. The development of a quick, reliable, and efficient method for identification of horizontal curves and extraction of their geometric parameters from road inventory data is of immense benefit to transportation agencies and traffic safety. Efficient and reliable identification of horizontal curves and extraction of geometric parameters like radius, degree of curvature, point of curvature, and point of tangency can be used by transportation agencies to set advisory speeds, perform design and safety audits, select placement of curve warning signs, and evaluate vehicle crashes that occur at or near horizontal curve locations on the roadway. Phase II of this project attempts to create a software package that can automate the process of identifying the Point of Curvature (PC) and Point of Tangency (PT) of every curve on the state transportation network in Connecticut. Using five designed curves and the reverse run of the same stretch of roadway a software package was developed. Each curve on the state system was identified and the roadway geometry for each curve was calculated.			
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## **1.0 INTRODUCTION**

### **1.1 Background**

Horizontal curves are an integral part of roadway design; they provide a transition between tangents on a roadway. While many types of horizontal curves can be used in the geometric design of a roadway, simple circular curves are typically used. Other curve types that can be used include compound and spiral curves. The development of a quick, reliable, and efficient method for identification of horizontal curves and extraction of their geometric parameters from road inventory data is of immense benefit to transportation agencies and traffic safety. Efficient and reliable identification of horizontal curves and extraction of geometric parameters like radius, degree of curvature, point of curvature, and point of tangency can be used by transportation agencies to set advisory speeds, perform design and safety audits, select placement of curve warning signs, and evaluate vehicle crashes that occur at or near horizontal curve locations on the roadway.

The Connecticut Department of Transportation (ConnDOT) realizes the benefits of and need for the ability to identify horizontal curves and extract their geometric characteristics from roadway inventory data, and has invested efforts in previous research towards such goals. An efficient and reliable method to identify horizontal curves and extract metrics, like the start and end points of curves, will enable ConnDOT to rapidly investigate crashes at curve locations on state maintained roads, audit the design of such horizontal curves, and post curve warning signs and advisory speed limits at the beginning of such horizontal curves. ConnDOT, like many transportation agencies in the US, collects and maintains a road inventory database, which

contains data from an annual photolog survey of all state maintained roadways, with supplemental data for Highway Performance Monitoring Sections (HPMS). This photolog data is collected using an Automatic Road Analyzer (ARAN) van. The ARAN van collects data on roadway characteristics including geometry and surface condition, and is equipped with GPS sensors and a gyroscope to collect location and vehicle attitude data, including heading and grade at four (4) meter intervals. This inventory contains a rich dataset for identifying and extracting roadway geometric information, including horizontal curves and their parameters.

In Phase I of the Development of ConnDOT's Horizontal Curve Classification Software, a simple method was developed to classify horizontal curves and grades using heading and grade data obtained from an ARAN van. A per point curve classification method was developed and used to categorize horizontal curves and grades into six classes. The classification scheme makes use of simple equations to determine radius and degree of horizontal curvature from the change in measured heading between adjacent points. The horizontal curve classification method and length extraction process were developed as two standalone executable applications, which can be deployed to obtain classification and length data for both curves and grades on routes.

The tool developed in Phase I uses equations to extract horizontal curve parameters such as radius and degree of curvature using the change in heading during the classification method. The curve data contained in the classification text files can be incorporated into safety research for identifying high risk locations for crashes. Lastly, this tool can be used to produce a rich database of existing curves and grades for each route where ARAN van inventory data are collected. These data can be useful to various state transportation agencies.

One of the limitations of the per-point method was that the Point of Curvature (PC) and Point of Tangency (PT) were not explicitly defined and located. This information would be of great value to the Traffic Division at ConnDOT. The per curve method proposed in Phase I of the project focused on classifying curves by separating data into tangents and curves and then identifying the PC and PT of the horizontal curves. Once the PC's and PT's of the curves were determined, data points within these boundaries are classified as a single curve based on the change in heading between the PC and PT. The second phase of the project seeks to update the Phase I custom software package to allow calculation of additional horizontal curvature metrics, for every curve on the state transportation system, using the per curve method.

## **1.2 Research Objectives**

The objective of the Phase 2 study is to further develop the per curve method to calculate the PC and PT, for each photologged route. Once the PC and PT are obtained, the length of curve ( $L$ ), radius ( $R$ ) and Degree ( $D$ ) for each curve identified can be calculated. This process will be more complicated than the per point method developed in Phase I, due to the need to accurately select the PC and PT of each curve, then calculate a uniform radius for the entire length of the curve. The resulting process would be automated and only need to be run once a year when a new Photolog file is finalized and created, for the year.

## **2.0 LITERATURE REVIEW**

Common horizontal curve identification techniques involve the use of GPS data, satellite imagery, laser scanning data, and AutoCAD digital maps. Pratt et al. (1) used GPS data collected by a test vehicle driven along the roadway to estimate radius and deflection angle of horizontal curves at 25 ft. increments. An electronic ball bank indicator was used to compute super



elevation rates. The curve data is recorded by Texas Roadway Analysis and Measurement Software (TRAMS) from which curve radius and super elevation rate are determined. These data were then post processed to a second software tool—the Texas Curve Advisory Speed (TCAS) software to calculate curve advisory speeds. Using ground truth data, their results showed that the method provides an accurate and precise measurement of curve radius. A 2006 study by Imran et al. (2) used a GPS based method that incorporated GIS applications to develop 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 (2), extracted horizontal curve characteristics including radius, length, and center coordinates of simple circular curves in the alignment, and spiral curve length by fitting straight lines to tangent sections and circular curves to curved sections. Their results showed that the GPS could be used to quickly, efficiently and accurately extract horizontal curve data. Hans et al (3) 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. GPS coordinate data collected at 10 meter intervals were manipulated to identify sites of possible curvature through a continuous refinement process involving line simplification, reduction of identified vertices and grouping of consecutive points in ArcGIS. The method uses circular regression, and chord equations to estimate radius and lengths of horizontal curves.

Researchers and state agencies have also used a combination of GPS data and GIS based applications to extract horizontal curve data from GIS roadway maps. These include tools like the Curvature Extension developed in ArcGIS by Florida Department of Transportation(FDOT) (4) for identifying and classifying horizontal curves, the curve calculator found in the Coordinate

geometry toolbar in ARCGIS by the Environmental Systems Research Institute (5) and Curve finder by the New Hampshire Department of Transportation(NHDOT) (6). Although these tools extract length and radius of horizontal curves, both the ESRI tool and the FDOT require manual identification of curve and tangents on the GIS maps by specifying start and end points of curves. The tool developed by NHDOT, although semi-automatic, still requires a manual selection of the curve features classes. Findley et al. (7) investigated an automated application of three available curve GIS based curve extraction tools: Curve finder; Curve extensions; and Curve calculator, for identifying and characterizing numerous horizontal curves in a large dataset.

Bogengreift et al. (8) developed a hybrid manual-computer method that uses a GIS-based procedure, GPS road data collected at 10 m intervals, circular regression, chord equations, and line simplification to identify and measure curves. The horizontal curve data extracted was validated with as built design plans by comparing estimated curve data to the as built curve data. Although the method was able to yield estimated curve length and radii that were close to as built curves, improvement in the method was recommended by authors (8) before incorporation in a safety performance evaluation.

Image based techniques have also been developed in literature for identifying horizontal curves and extracting their road inventory data. This has been accomplished using both automatic and semi-automatic approaches. Zhao et al. (9) developed a semi-automatic approach using a road mask defined by distinguishing road pixels from others using commercial remote sensing software. Easa et al. (10) 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 (10). Dong et al. (11) 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. (12) 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. Tsai et al. (13) extract horizontal curve data from roadway images. The algorithm proposed by Tsai et al. (13) extracts curve edges from images using image processing techniques, and then maps the edge positions from an image domain to a real-world domain, and lastly calculates the curve radius and center from curve points by using a curve fit. Research to extract horizontal curves using AutoCAD digital maps include Watters and O'Mahony (14) and Hashim and Bird (15) who successfully extracted roadway horizontal geometric information in Ireland and the United Kingdom, respectively, using digital maps in AutoCAD.

Other automatic and semi-automatic approaches have been developed using different algorithms that use 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. (16) 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 (16) 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, beyond which points were otherwise classified as curves and tangents. Once the data points were separated into curve and tangent sections, the radii 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<sup>th</sup> 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 (16). The algorithm was validated by applying it to 23 horizontal curves from four sections of roads and highways, and compared to that of the design drawings of these sections. Li et al. (17) 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 defines curves and tangent sections in a roadway layer using a threshold bearing angle 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 (17).

Othman et al. (18) extracted horizontal curves from field operational test data by identifying curved sections using heading values obtained by driving vehicles along the roadways. The approach used in (18) involved plotting field operational test roads from GPS data, identifying curved sections of the roadways and then estimating curve radius, lengths, and starts 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 (19) also developed an algorithm which 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 (19). 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.

Andrasik et al. (20) proposed a method for the automatic identification of curves and straight sections based on the geometry of roads. This method preprocessed that data by simplifying line segments through geometric line generalization, then calculated the radius of an osculating circle and identified straight and curved sections based on the curve radius. Lastly, Ai and Tsai (21) use vehicle collected GPS data to identify different types of horizontal curves, measure their radius, and classify them as simple, compound and spiral curves. The method uses iterative circular fitting to separate the GPS data into delineated segments, clustering segments into curves, and automatically identifies curves based on their spatial distribution and adjacency. Delineated segments are classified as tangents or curves based on a threshold of  $5^\circ$  for their central angle. This threshold is set based on manual identification of tangent and curve sections in the roadway and the distribution of the central angle in these segments. Identified curve segments are then classified in simple, compound, spiral or reverse curves according to their adjacency patterns. The method is validated using a simulation test, which identified about 90

percent of curves in the dataset, and a field test, which compared estimated radius to digitized ground truth curves on three existing roadways.

While these methods proposed in literature have provided efficient ways of identifying horizontal curves and estimating geometric characteristics like radius, length and degree of curve, most of them require manual identification of PC's and PT's of the curves to obtain reliable results, whilst others do not explicitly identify the PC and PT milepost of the different horizontal curves extracted. The method proposed in this Phase 2 study will identify milepost for PC and PT from the roadway inventory data and then calculate geometric characteristic of the horizontal curves like length, radius and degree using vehicle collected data.

### **3.0 METHODOLOGY**

The methodology proposed to identify PC and PT from the road inventory data works by first separating delta heading data (i.e., the difference in heading between adjacent points), into curve and tangent using a specified threshold, and then identifying the PC and PT of each curve on the route. Once the PC and PT are identified, the length, radius and the degree of the curve is calculated. The method is implemented as an executable in MATLAB 2013b software (22).

#### **3.1 Data Sources and Preprocessing**

The data used for analysis was obtained from ConnDOT and is composed of roadway inventory data for state roads collected using an ARAN van. The ARAN van is equipped with gyroscopes for collecting both heading (or azimuth bearing) and GPS data as it is driven along the roadway. The dataset contains heading and grade collected at four (4) meter intervals. The collected gyroscope heading data has seven (7) columns, with the columns of interest to the research being the route, compass direction, the agency milepost and the heading.

To ensure accuracy in analysis, the data is cleaned to remove missing data points and negative mileposts in the heading data. Noise in the heading data is removed using either of the two smoothing techniques in MATLAB, which are offered to the user in the development of the per curve method. These smoothing techniques are a simple moving average and a Savitzky-Golay smoothing filter. The moving average technique smooths data by applying a low pass filter, which replaces each single data point with the average of the neighboring data points defined within the span (22). The requirement for this method is to specify an odd span such that each data point is at the center of the span. The data at the beginning and end of each roadway are not smoothed because the required number of neighboring data points on each side of the data point are not accommodated (22). The Savitzky-Golay filter works 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 (22).

Users are provided with the option of selecting which of the two smoothing techniques to be applied to the heading data and entering parameters of the selected smoothing method. If no smoothing is entered by the user during the execution of the program, the default smoothing technique used is the Savitzky Golay smoothing filter with polynomial degree between 3 and 5, depending on the length of the optimal span for each route. Using statistical techniques, the optimal span for the default smoothing technique is 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 are not greater than a tolerance level of 0.02.

### 3.2 Per Curve/ Per Tangent Method

This method of curve classification focuses on classifying curves by separating data into tangents and curves and then identifying the PC and PT of the horizontal curves. The lengths of curves are calculated as the difference in the agency mile posts between the PT and the PC of the horizontal curves identified.

In order to differentiate between tangent and curve sections, a threshold for delta heading is set, beyond which the sections are otherwise classified as curves and tangents. The threshold method is summarized in equation (1).

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

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

$\delta$  is the heading threshold.

The threshold heading for identifying a heading point as a PC or a PT is determined based on the functional classification of the route. In order to set these heading thresholds, the routes in the heading data are classified as CT state routes, US highways and Interstate highways. The distribution for headings within curve and tangent sections for each of these classifications is determined, upon which the heading threshold is specified as a range from a value of 0.25 to a value of 2.00 in 0.25 increments, with lower thresholds being used for interstate highways, with typically gentler curves, and higher thresholds specified for US routes and CT state routes.

For each functional classification, the heading data is separated by direction and the difference in heading between adjacent points, referred to as delta heading, is calculated. Delta headings with absolute magnitudes greater than  $270^\circ$  are then corrected using a simple rule, which is to reset these points to a value which is equal to the difference between the delta



heading value and  $360^\circ$ , for positive delta heading values that are 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 classification, and in each direction, the delta heading of the first point and the lowest milepost are set to zero. The data is then smoothed by applying the user selected smoothing technique or in the absence of that, the default smoothing, which is achieved by running Savitzky Golay filter pass on the delta heading data. The smoothed heading data points are then sorted in order of increasing agency mileposts.

The procedure then checks for the first milepost at which the delta heading exceeds the set delta heading threshold and identifies it as a PC, and then moves on from that milepost to identify the first milepost at which the smoothed delta heading values become lower than the set heading threshold and identifies it as a PT. Once the PC and PT are identified, that section of the route (PC to PT) is clipped out of the heading dataset and the entire process is repeated from the lowest milepost in the remaining dataset until no more PC's and PT's can be further identified based on the set delta heading threshold.

Once the PC and PT mileposts are identified, three parameters namely length, radius and degree of curvature are calculated for each identified horizontal curve. The length of curve is calculated as a difference between the identified PC milepost, and PT milepost. The radius and degree of curve ( $D$ ) are then calculated using the heading difference ( $\Delta H$ ) between the identified PC and PT and the length of curve, and is summarized in equation (2) and equation (3).

$$R = \frac{180^\circ \times L}{\pi \times \Delta H} = \frac{57.2958 \times L}{\Delta H} \quad (2)$$

$$D = \frac{5729.58}{R} \quad (3)$$

To validate the per curve PC and PT identification method, the results of the method were compared against that obtained from design drawings of existing curves. The results of the curve software are analyzed in the next Section 4.2.

## **4.0 RESULTS**

Using the per curve method, an executable was produced, which can be deployed on any computer without software installation, for identifying PC and PT mileposts from road inventory heading data. This executable and its flow during execution is described in the following sections.

### **4.1 Horizontal Curve PC and PT Identification Executable**

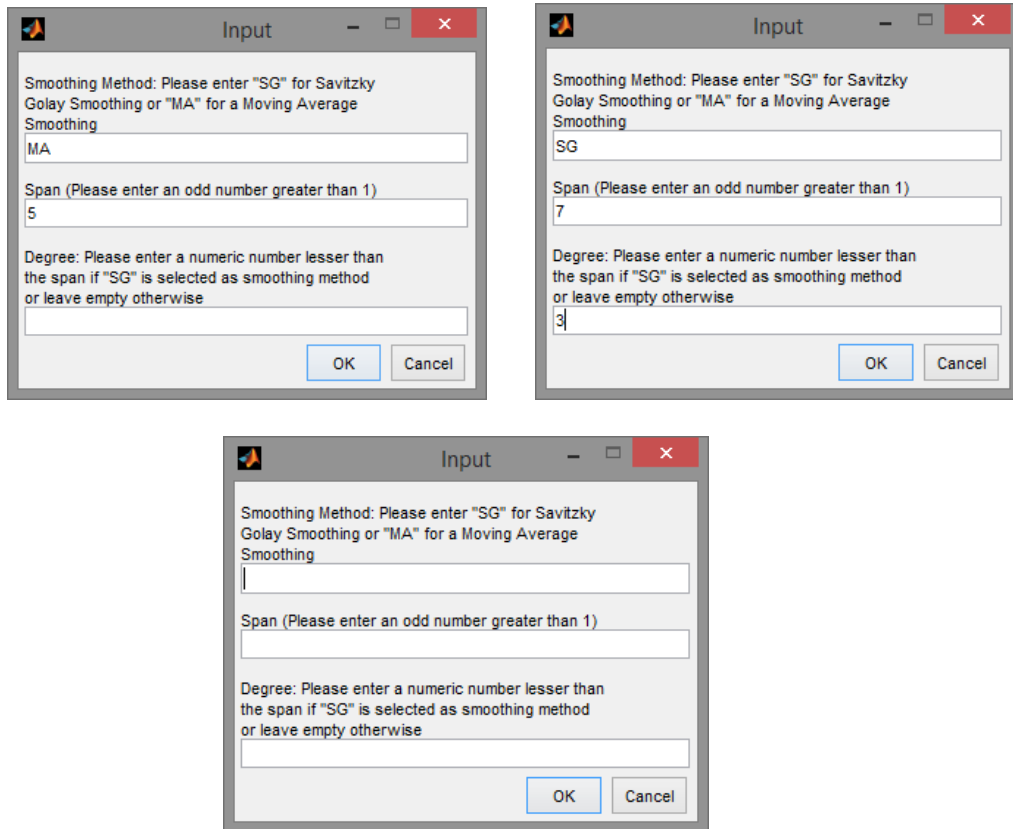
The Horizontal Curve PC and PT identification executable extracts the PC and PT mileposts using the per curve method. It takes as input, a gyro heading text file that users are allowed to select by navigating to the folder in which it is located during the execution of the application. The application is initialized by double clicking the executable, which produces a progress bar to show that the executable has been initialized. This is followed by a dialogue box prompting users to enter a year of analysis, which is followed by a file selection dialogue box that allows the user to select the input text file that contains the gyro heading and milepost data. The year of analysis value is appended to output files from the executable. The data is then read into the executable, followed by the functional classification of the routes in the dataset based on an existing route database file obtained from the Connecticut Transportation Safety Research Center's Crash Analysis System (CAS).

The data is then separated by route direction into East, West, North, and South data. For each route in each classification, and for every direction, the change in heading between adjacent

points is computed and smoothed to remove noise. Errors in delta headings below or above 270 degrees are also corrected for, as previously explained. A dialogue box is generated during this stage of execution to provide the user with the option of selecting one of the two smoothing methods offered in the executable for removing noise in the delta heading data. The user has the option of entering the abbreviation “MA” or “SG” to select a Moving average or Savitzsky Golay smoothing technique respectively, and entering an odd number span and a polynomial degree less than the entered span for the case of the Savitzsky Golay smoothing. If the dialogue box for selecting a smoothing method is left empty, a default smoothing of a Savitzsky Golay with span specified as a percentage of the number heading data points and a degree between 3 and 5 depending on the calculated span, is used. The dialogue box for selecting a smoothing method during the execution of the application is shown in Figure 1. The PC and PT mileposts are then identified using the described per curve/ tangent method, with the length, radius and degree of the curve subsequently estimated.

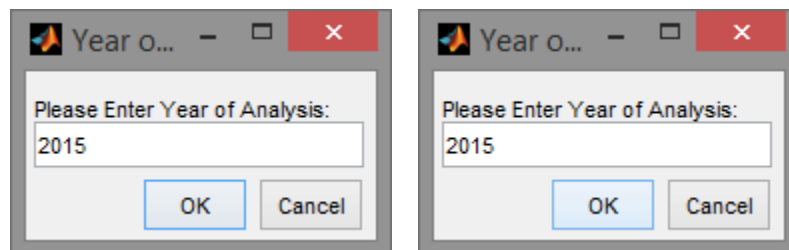
After successful completion of the program, an Excel<sup>®</sup> file and text file containing PC and PT mileposts, headings, length, radius and degree of curvature is populated and saved in a folder labeled “Horizontal Curve Data”. In addition to this, routes with non-numeric ID’s are replaced with standard generated route ID from 1000 in increments of 1 to a maximum increment of number of such routes in the gyro heading data. At the end of the execution, an additional text file is produced showing such routes that were replaced and their new corresponding route ID in the result dataset. It is worth mentioning that the folder containing the results of the execution of the program is deleted together with its contents each time the application is initialized. Users, therefore, have the option of copying results to a different folder

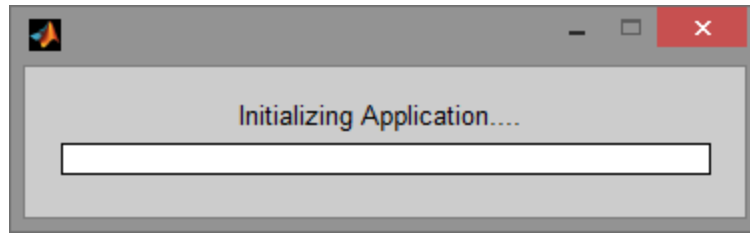
before subsequent execution of the application or running the executable in a different folder for the subsequent execution.



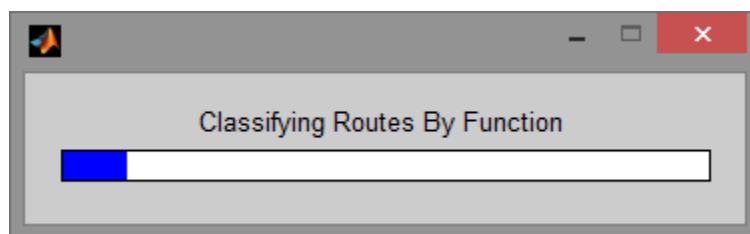
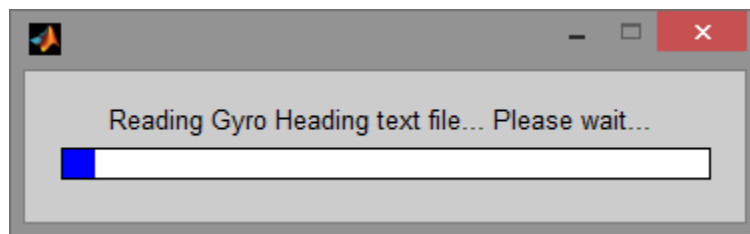
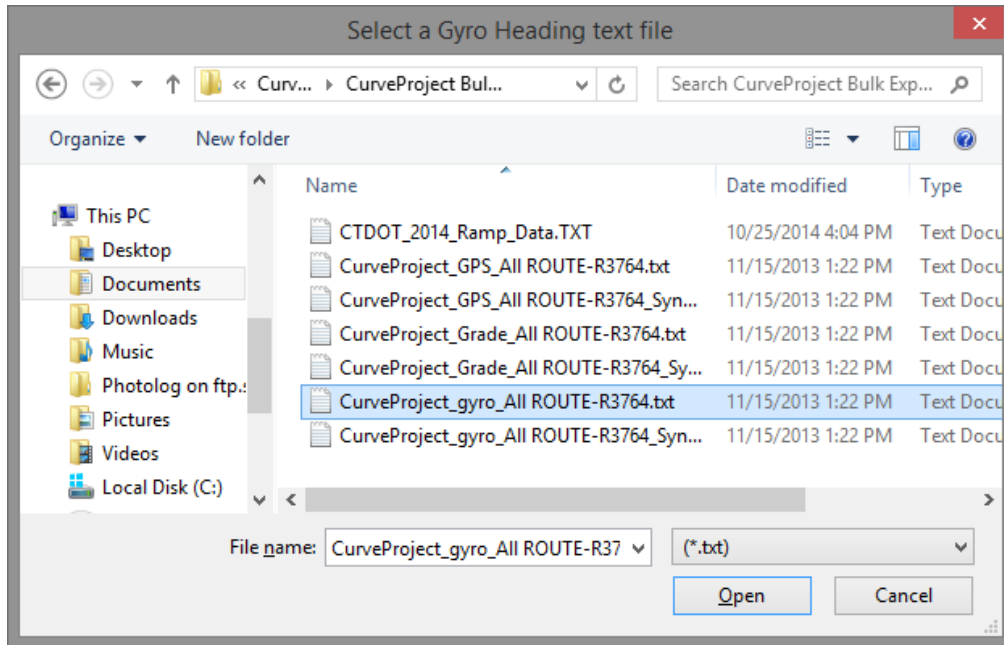
**Figure 1: Dialogue Box for Selecting Method of Smoothing during Execution of Application**

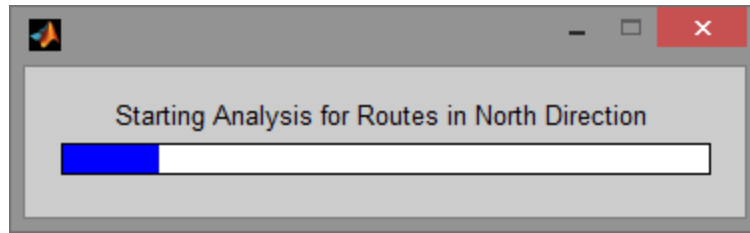
The interface of the executable including the progress bars that show the stage of execution is shown below in Figure 4:



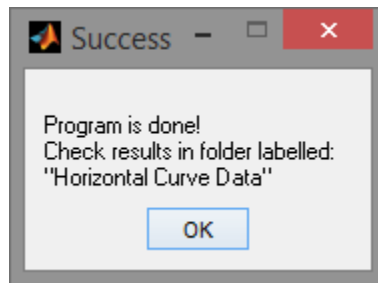
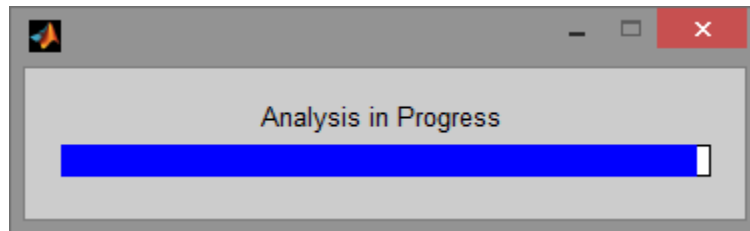
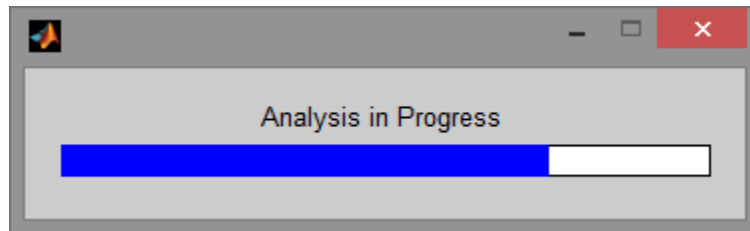


**Figure 2. Interface of Application during Execution**





**Figure 3. (Cont'd.) Interface of Application during Execution**



**Figure 4. (Cont'd.) Interface of Application during Execution**

## 4.2 Software Results Analysis

This analysis will focus on data output of two of the six (6) curves analyzed. The first curve analyzed was located on U.S. Route 44 between milepost 56.308 and 56.423. This curve was used to evaluate the software output versus the design drawings. The PC and PT of the

selected curve for testing were supplied as stations on the design drawing but were converted from stations to mileposts using the milepost of a known intersection on the routes. The per curve method software was then run to determine the PC and PT and geometric parameters for all curves along that route. The results were then compared to the calculated parameters from the design drawings. The geometric characteristics of the curves selected on Route 44 are summarized in Table .

**Table 1 : Parameters of Curves on U.S.Route 44 Used in Validation**

<b>Curve A</b>		
	<b>Station</b>	<b>Milepost</b>
PC	4+98.70	56.184
PT	9+54.11	56.275
Known Intersection(Bidwell)	13+66	56.27
<b>Horizontal Curve Parameter</b>		
Length	455.41 ft	
Radius	470.00 ft	
Delta	55 ° 31' 00"	
Degree	12 ° 11' 26"	
<b>Curve B</b>		
	<b>Station</b>	<b>Milepost</b>
PC	11+53.66	56.23
PT	16+76.78	56.329
Known Intersection(Bidwell)	13+66	56.27
<b>Horizontal Curve Parameter</b>		
Length	523.12 ft	
Radius	470 ft	
Delta	63 ° 46' 17"	
Degree	12 ° 11' 26"	

When the calculated mileposts for the PC and PT for the curve on Route 44 are compared, Table 2, it becomes obvious that there are some differences. The closest mileposts in the output file to the design curves differ by approximately 0.025 miles (132 ft). This could be

attributed to the fact that the design drawings do not contain milepost information and the mileposts for PT and PC had to be estimated based on a known milepost at an intersection appearing in the drawing. Since it is unclear whether stationing at the intersection of Bidwell St on the drawings from Route 44 match exactly with the milepost found in the ConnDOT Highway Log, it is possible that this is the source of the error in mileposts assigned to PC and PT.

**Table 2: Curve Output for US Route 44**

<b>Curve A</b>			
	<b>Output</b>	<b>Design</b>	<b>Difference</b>
PC	56.163	56.184	0.021
PT	56.25	56.275	0.025
<b>Horizontal Curve Parameter</b>			
Length	459	455.41	-3.59
Radius	523	470	-53
Degree	10.95	12.1906	1.2406

<b>Curve B</b>			
	<b>Output</b>	<b>Design</b>	<b>Difference</b>
PC	56.294	56.23	-0.064
PT	56.404	56.329	-0.075
<b>Horizontal Curve Parameter</b>			
Length	580.8	523.12	-57.68
Radius	540.22	470	-70.22
Degree	10.61	12.1906	1.5806

There are also issues with the radius, length of curve and the degree of curve. Where the length of curve is off by 3.6 feet, the radius is off by 70 feet and the degree of curve is off by up to 1.6 degrees (11%). Curve A had the best fit with the design data but there are still inaccuracies in the dataset. ConnDOT will need to decide if these errors are acceptable or not.

To validate the per curve/tangent PC and PT identification method, the results of the method were compared against that obtained from design drawings of existing curves. A curve



on a section of Wolcott Road (Ct State Route 69) between milepost 23.26 and 23.50, is used in these tests by comparing the PC and PT mileposts obtained from the per curve/tangent method to those and their associated geometric parameters obtained manually from design drawing data. The PC and PT of the selected curve for testing were supplied as stations on the design drawing but were converted from stations to mileposts using the milepost of a known intersection on the routes. These calculations are shown in Appendix A of this report. The milepost at Long Swamp Road on Route 69 is used in the calculations. The per curve/tangent method is then run on Route 69 data in the heading dataset to determine the PC and PT and geometric parameters for all curves on that route, and compared to the calculated results from the design drawings. The geometric characteristics of the curve used on Route 69 and its known intersection milepost at Long Swamp Road are summarized in Table 3.

**Table 3 : Parameters of Route 69 Curve Used in Validation**

	<b>Output</b>	<b>Design</b>
PC	--	23.50
PT	--	23.26
Known Intersection (Long Swamp RD)	--	23.47
<b>Horizontal Curve Parameter</b>		
Length	--	1148.42 ft
Radius	--	1152 ft
Delta	--	57 ° 07' 02.94"
Degree	--	4.97

When the calculated mileposts for the PC and PT for the curve on Route 69 are compared to that obtained by the software, it was observed that the software was not able to detect this curve. This is due to the delta heading calculated for this curve, which did not exceed the threshold of 1 degree. All the changes in direction from point to point for this curve were less than 1 degree. The Route 44 example discussed previously works well because it has a very well

defined curve with a small radius (i.e. dramatic change in heading). The Route 69 example does not work at all because the radius is larger and the PC and PT threshold for rural roads and does not allow for detection of the curve. The software was designed to identify the road facility type (i.e State rural collector, US route, Interstate) and then use a threshold for PC and PT identification that is associated with the road facility type. Using a loop in the software the PC and PT selection threshold will vary from a 0.25 degrees change from one point to the next for interstates to a 1.0 degree change in heading for roads, where curves may have different design considerations. This method however has a few flaws. The first is that on the rural roads any smooth or gentle curves will not be captured if the threshold is too large. This can be seen in the data where there are 3 to 5 mile stretches of Route 44 with no curves detected. If the threshold for these sections of roadway is set to interstate threshold (0.25 degrees) they perform poorly when selecting PC and PT and the resulting curve data is inaccurate. An analysis that illustrates this was conducted and the results are shown below (Tables 4 and 5). Curves with a tendency to have lower radii were more important to safety and signage concerns, and therefore the threshold of 1.0 degree was used on these roads.

These inaccuracies may be attributed to trying to use a single bearing from PC and PT over a large distance to determine the curve geometrics. Slight errors in bearing propagate quickly when you are calculating curvature. Table 4 displays a sensitivity analysis to determine what happens when inaccuracies are introduced into the PC and PT headings. The first row contains the exact headings as calculated from the ARAN data for Route 44. Each row thereafter decreases (PC) and increases (PT) and in heading, by 0.3 degrees. Each 0.3 degrees increment causes a resultant 1 percent error in the radius and degree of curve.

**Table 4: Radius and Degree of Curve Sensitivity to Heading Changes**

RTE_ID	HEADING PC	HEADING PT	DELTA HEADING	LENGTH(ft)	RADIUS(ft)	DEGREE
44	75.7	23.9	-51.8	480.48	531.46	10.78
44	75.4	24.2	-51.2	480.48	537.69	10.66
44	75.1	24.5	-50.6	480.48	544.06	10.53
44	74.8	24.8	-50	480.48	550.59	10.41
44	74.5	25.1	-49.4	480.48	557.28	10.28

Furthermore, there could be a significant error in Radius and Degree of curvature caused by simply selecting an inaccurate PC or PT. It is possible that the PC occurred in the ARAN data point just prior to or just after the one selected as the PC or PT. This would allow an inaccurate bearing to be used, thus impacting the accuracy of the radius and then degree of curve. When looking at the raw data from the curve section the heading will change by as much as three (3) degrees from one data point to the next. The second and third row in Table 5 show what would happen to the radius calculations if the data point before and after the PC were chosen in place of the one actually desired. The last two rows in Table 5 show what would happen if the points prior to and after were used in the radius calculation for both PC and PT. Both of these errors could have a significant impact on the radius. By simply picking the PC data point just after the actual PC the radius changes by 24 feet. This is within the error value shown in Table 1 for the radius of Curve B. Once this error is introduced into both PC and PT a radius length error of upward of 70 feet is possible. This is within the error value shown in Table 1 for the radius of Curve A. Lastly the “Known” radius is simply the as designed radius. It is entirely possible that the true radius is somewhere between what is known as designed, as constructed, as striped, or even as driven. This is a common finding in literature, where the radius of a horizontal curve

from design plans is different from the travel path radius of the vehicle, which depends on the vehicle trajectory and measurement precision errors from instruments (16-18).

**Table 5: PC and PT Point Selection Error Analysis**

RTE_ID	HEADING PC	HEADING PT	DELTA HEADING	LENGTH(ft)	RADIUS(ft)	DEGREE
44	75.7	23.9	-51.8	480.48	531.46	10.78
44	73.5	23.9	-49.6	480.48	555.03	10.32
44	71.2	23.9	-47.3	480.48	582.02	9.84
44	73.5	21.2	-52.3	480.48	526.38	10.88
44	71.2	25.6	-45.6	480.48	603.72	9.49

The accurate selection of PC and PT is critical as this drives the rest of the equations and calculations. The selection of PC and PT is very difficult to do in an automated fashion. This is why many software packages will identify the curve section and then require the user to manually select the PC and PT. Once the user selects the curve start and end, the software is able to calculate the curve parameters. This project has produced a tool that will identify the PC and PT of curves but only for curves that have small radii, which will cause a change in heading of at least 1 degree every 13 feet (4 meters).

#### **4.2 Reverse Route Analysis**

The next type of analysis conducted was a reverse route analysis. This was simply looking at the curve results for both travel directions to determine if there is an agreement between directions, or if there are data quality issues with the raw data that would prevent the software from ever correctly identifying curves. Using both the Eastbound and Westbound data collection runs for the U.S. Route 44 section identified above (milepost 56.308 to 56.423), a comparison of the two runs is outlined in Table 6. In terms of milepost identification, the

difference between the east bound and west bound lanes is less than or equal to 0.025 miles (132 feet). This is the same magnitude of discrepancy seen in Table 1 when comparing designed vs. driven (i.e., ARAN) PC and PT. The difference in length and radius between these two runs is eight to 90 feet. Once again, these errors are of similar magnitude as the errors shown in Table 1. For this comparison on Route 44 the curves appear to align in the appropriate location and have very similar characteristics. As they should since this is not a divided highway.

**Table 6: Reverse Route Comparison US Route 44**

Route	DIRECTION	PC MILEPOST (mi)	PT MILEPOST (mi)	DELTA HEADING	LENGTH (ft)	RADIUS (ft)	DEGREE OF CURVE
CURVE A							
44	West	56.163	56.25	50.3	459.36	523.25	10.95
44	East	56.184	56.275	51.8	480.48	531.46	10.78
Difference		-0.021	-0.025	-1.5	-21.12	-8.21	0.17
CURVE B							
44	West	56.294	56.404	-61.6	580.8	540.22	10.61
44	East	56.319	56.412	-56.6	491.04	497.08	11.53
Difference		-0.025	-0.008	-5	89.76	43.14	-0.92

This multi-travel direction analysis was conducted for 12 other roadway sections (Routes US1, US5, US7, 39, 71, 20, 22, 42, 67, 69, 102, 215). Each section was 1 mile in length and chosen at random. Design drawings for these sections were not obtained. The analyses results (one of which can be seen in Table 7) are similar to previous discussions, where the mileposts of PC and PC are within the typical error of 0.025miles (134 ft) but the radius and degree of curve errors are relatively large (i.e. 30%). The example in Table 7 provides the results for Route 1. Four curves, in series over a one mile stretch were used to attempt to identify corresponding curves. Table 7 shows how runs in each direction compare. Looking at PC and PT mileposts, the last four rows of this table show the difference between each direction for assumed

corresponding curves. The mileposts align with a similar magnitude of error that was seen in all the previous analyses. However, there are major differences in the length, radius and degree of curve. The equations used to calculate the curvature are exactly the same. If these data are truly from the exact same section of roadway, just driven in different directions, it would appear that there 1) is a data quality limitation that prevents the software from selecting the correct PT and PC or 2) are issues with the bearing accuracy that prevent the accurate calculation of radius and degree of curve.

**Table 7: Reverse Route Comparison US Route 1**

Route	DIRECTION	PC MILEPOST (mi)	PT MILEPOST (mi)	LENGTH (ft)	RADIUS (ft)	DEGREE OF CURVE
1	South	48.303	48.311	42.24	654.10	8.76
1	South	48.433	48.440	36.96	516.50	11.09
1	South	48.545	48.560	79.20	487.94	11.74
1	South	49.022	49.032	52.8	593.18	9.66
1	North	48.244	48.286	221.76	155.33	36.89
1	North	48.451	48.467	84.480	744.67	7.69
1	North	48.573	48.592	100.32	756.30	7.58
1	North	49.035	49.102	353.76	579.11	9.89
Difference Between Directions		0.059	0.025	-179.52	498.77	-28.13
		-0.018	-0.027	-47.52	-228.17	3.40
		-0.028	-0.032	-21.12	-268.37	4.17
		-0.013	-0.07	-300.96	14.07	-0.23

## 5.0 SUMMARY AND CONCLUSIONS

A simple method was developed to identify horizontal curve PC and PT mileposts by first separating data into curve and tangent sections, and then using a range of set thresholds to identify points as PC and PT. In order to remove noise and outliers from the data, the data is

smoothed by applying either a user selected preference of either a moving average or Savitzky-Golay smoothing filter, or a default of a Savitzky-Golay smoothing filter with a calculated span.

The developed PC and PT identification method was attempted to be validated by using curves obtained from design drawings. The example shown in this report was of U.S. Route 44. Comparisons of horizontal curve PC and PT milepost and geometric characteristics of this curve from the design drawing of Route 44 with that obtained from using the developed method, did not show a close agreement. The discrepancies between the two were primarily attributed to the possibility of inaccuracies in PC and PT selection.

Once PC and PT mileposts are identified, the tool developed extracts horizontal curve parameters (like radius and degree of curvature) using the change in heading and simple circular curve equations. The outputted results can potentially be used as a network screening tool in safety and design audits for curves. However, the mileposts of curves of interest should be verified through the photolog imagery or field inspection. As determined in this study, there are data quality concerns and programmatic challenges that make automation of PC and PT difficult if not impossible. Similar to ConnDOT's current software, it is relatively easy for a person to manually identify the PC and PT on a curve-by-curve basis. But developing a computer program robust enough to identify the PC and PT of every type of curve in the transportation system may be an elusive task. The range and complexity of the curves that exist in the real (as-built) world may be too great to allow for automation of such a process. How we drive over a road, and how it was intended to be driven upon when designed or constructed may not coincide. The results from this study demonstrate that there are some instances where the software can be successful, but other situations were found where the software fails to deliver an expected result.

ConnDOT will need to decide if the methodology outputted can be of value for safety analysis, and/or if additional analysis or refinement is merited.



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## 7.0 APPENDIX

### APPENDIX A-1: CALCULATIONS FOR DETERMINING MILEPOST FOR CURVE ON ROUTE 69

#### Route 69 Curve Calculations

*Long Swamp Road Station at ROUTE 69 = 112 + 07 = 11207ft = 2.1225 mi*

*POB Station = 100 + 00 = 10000ft = 1.8939 mi*

*Long Swamp Road milepost = 23.47*

*POB milepost = 23.47 - (2.1225 - 1.8939) = 23.2414*

#### Route 69 Curve 1:

*PC Station = 101 + 22.82 = 10122.82ft = 1.9172 mi*

*PT Station = 113 + 71.24 = 11371.24 ft = 2.1536 mi*

*Length = 1248.042 ft = 0.2364 mi*

*Radius = 1152 ft = 0.2182 mi*

$\Delta = 57^\circ 07' 02.94'' = 57.12^\circ$

*PC milepost = 23.2414 + (1.9172 - 1.8939) = 23.26*

*PT mile Post = 23.2414 + (2.1536 - 1.8939) = 23.50*

**APPENDIX A-2: TABLES SHOWING RESULTS OF EXECUTABLE RUN FOR ROUTE 69**

RTE_ID	PC MILEPOST (mi)	HEADING_ AT_PC	PT MILEPOST (mi)	HEADING_ AT_PT	DELTA_ HEADING	LENGTH (ft)	RADIUS (ft)	DEGREE	DIRECTION
69	0.006	345.3	0.024	355.9	-10.6	95.04	513.7163049	11.15319865	N
69	0.468	338.8	0.473	335.8	3	26.4	504.20304	11.36363636	N
69	1.268	342.3	1.287	353	-10.7	100.32	537.1882856	10.66586922	N
69	1.645	5.5	1.658	359.8	5.7	68.64	689.9620547	8.304195804	N
69	1.854	3.8	1.859	5.8	-2	26.4	756.30456	7.575757576	N
69	8.374	9.3	8.381	6	3.3	36.96	641.71296	8.928571429	N
69	11.908	341.1	11.923	347.9	-6.8	79.2	667.3275529	8.585858586	N
69	12.121	349	12.129	345.9	3.1	42.24	780.7014813	7.339015152	N
69	14.689	317.7	14.699	321.9	-4.2	52.8	720.2900571	7.954545455	N
69	14.716	328.2	14.734	335.7	-7.5	95.04	726.0523776	7.891414141	N
69	14.744	339.4	14.761	347.7	-8.3	89.76	619.623013	9.24688057	N
69	14.884	346.1	14.899	339.3	6.8	79.2	667.3275529	8.585858586	N
69	14.914	333.5	14.936	324	9.5	116.16	700.5768556	8.178374656	N
69	14.949	319.5	14.974	305.7	13.8	132	548.0467826	10.45454545	N
69	15.193	278.9	15.206	273	5.9	68.64	666.5735105	8.595571096	N
69	15.281	275.4	15.311	290.7	-15.3	158.4	593.1800471	9.659090909	N
69	15.376	301.3	15.411	321.9	-20.6	184.8	513.9933903	11.14718615	N
69	15.554	321.8	15.559	319.8	2	26.4	756.30456	7.575757576	N
69	16.212	327.8	16.23	99.7	228.1	95.04	23.87283135	240.0042088	N
69	16.514	75.7	16.528	69	6.7	73.92	632.1351546	9.063852814	N
69	16.554	62.4	16.572	50.8	11.6	95.04	469.4304166	12.20538721	N
69	16.769	42.8	16.774	45	-2.2	26.4	687.5496	8.333333333	N
69	16.816	52.2	16.826	56.8	-4.6	52.8	657.6561391	8.712121212	N
69	16.927	70.6	16.941	77.3	-6.7	73.92	632.1351546	9.063852814	N
69	17.023	77.2	17.066	54	23.2	227.04	560.7085531	10.21846371	N

RTE_ID	PC MILEPOST (mi)	HEADING_ AT_PC	PT MILEPOST (mi)	HEADING_ AT_PT	DELTA_ HEADING	LENGTH (ft)	RADIUS (ft)	DEGREE	DIRECTION
69	17.182	47.6	17.186	45.7	1.9	21.12	636.8880505	8.996212121	N
69	17.213	41.2	17.218	39.1	2.1	26.4	720.2900571	7.954545455	N
69	17.369	36.2	17.392	19	17.2	121.44	404.5349972	14.16337286	N
69	17.469	11.4	17.476	7.5	3.9	36.96	542.9878892	10.55194805	N
69	17.726	4.2	17.759	346.9	17.3	174.24	577.064751	9.928833792	N
69	17.87	346	17.89	319.6	26.4	105.6	229.1832	25	N
69	18.218	335.4	18.24	26.4	-51	116.16	130.4996104	43.90495868	N
69	18.599	23.5	18.609	17.9	5.6	52.8	540.2175429	10.60606061	N
69	18.614	20.6	18.624	27	-6.4	52.8	472.69035	12.12121212	N
69	19.288	37.6	19.298	42.2	-4.6	52.8	657.6561391	8.712121212	N
69	19.411	40.2	19.413	39.2	1	10.56	605.043648	9.46969697	N
69	19.442	30.7	19.455	25.4	5.3	68.64	742.0346626	7.721445221	N
69	21.097	347.6	21.112	354.1	-6.5	79.2	698.1272862	8.207070707	N
69	25.643	44.7	25.648	46.8	-2.1	26.4	720.2900571	7.954545455	N
69	26.432	76.5	26.509	4.8	71.7	406.56	324.8839672	17.63577332	N
69	26.734	4.1	26.747	358.1	6	68.64	655.463952	8.741258741	N
69	26.785	350.6	26.805	337.5	13.1	105.6	461.8653802	12.40530303	N
69	26.866	344.8	26.875	349.3	-4.5	47.52	605.043648	9.46969697	N
69	27.112	342	27.126	323.7	18.3	73.92	231.437461	24.75649351	N
69	27.13	325.5	27.154	349	-23.5	126.72	308.9584586	18.54482323	N
69	27.571	0.5	27.586	8.9	-8.4	79.2	540.2175429	10.60606061	N
69	27.655	16.3	27.682	45.8	-29.5	142.56	276.8843813	20.69304153	N
69	27.716	42.5	27.755	11.6	30.9	205.92	381.8236614	15.00582751	N
69	27.816	9.8	27.841	99.5	-89.7	132	84.31488963	67.95454545	N
69	27.922	94.6	27.926	92.6	2	21.12	605.043648	9.46969697	N
69	28.068	88.8	28.12	54.9	33.9	274.56	464.0452758	12.34702797	N
69	28.13	51.5	28.142	45.2	6.3	63.36	576.2320457	9.943181818	N

RTE_ID	PC MILEPOST (mi)	HEADING_ AT_PC	PT MILEPOST (mi)	HEADING_ AT_PT	DELTA_ HEADING	LENGTH (ft)	RADIUS (ft)	DEGREE	DIRECTION
69	28.198	44.2	28.221	347.3	56.9	121.44	122.2847443	46.8544137	N
69	28.547	353.9	28.562	344.7	9.2	79.2	493.2421043	11.61616162	N
69	29.479	336.7	29.484	334.7	2	26.4	756.30456	7.575757576	N
69	29.489	332.7	29.496	329.5	3.2	36.96	661.76649	8.658008658	N
69	30.062	356.2	30.084	26.8	-30.6	116.16	217.4993506	26.34297521	N
69	30.271	18.9	30.318	349.8	29.1	248.16	488.6091315	11.72630561	N
69	30.473	338.4	30.475	337.4	1	10.56	605.043648	9.46969697	N
69	31.206	343.9	31.223	336.1	7.8	89.76	659.3424369	8.689839572	N
69	31.262	338.3	31.299	358.9	-20.6	195.36	543.3644412	10.54463554	N
69	31.532	332.3	31.552	321.8	10.5	105.6	576.2320457	9.943181818	N
69	31.613	331	31.618	333	-2	26.4	756.30456	7.575757576	N
69	31.718	346.8	31.753	326.1	20.7	184.8	511.5103304	11.2012987	N
69	31.846	331.2	31.876	311.6	19.6	158.4	463.0436082	12.37373737	N
69	32.092	304.6	32.114	288	16.6	116.16	400.9325378	14.29063361	N
69	32.283	297.5	32.336	321.3	-23.8	279.84	673.6830534	8.50485992	N
69	32.703	298.5	32.718	291.3	7.2	79.2	630.2538	9.090909091	N
69	32.937	282.3	32.991	308.9	-26.6	285.12	614.1420487	9.329405163	N
69	33.003	313.6	33.015	319	-5.4	63.36	672.27072	8.522727273	N
69	33.03	324.6	33.059	337.9	-13.3	153.12	659.6340523	8.68599791	N
69	34.421	5.7	34.431	10.2	-4.5	52.8	672.27072	8.522727273	N
69	34.718	45.5	34.74	35.3	10.2	116.16	652.4980518	8.780991736	N
69	34.775	23.5	34.799	10.6	12.9	126.72	562.8313005	10.17992424	N
69	35.118	2.3	35.136	13.6	-11.3	95.04	481.893171	11.88973064	N
69	35.145	15.8	35.159	29.5	-13.7	73.92	309.1463895	18.53354978	N



ROUTE ID	PC MILEPOST (mi)	HEADING AT PC	PT MILEPOST (mi)	HEADING AT PT	DELTA HEADING	SAVITZSKY GOLAY DH	LENGTH (ft)	RADIUS (ft)	DEGREE	DIRECTION
69	15.328	297.2	15.331	298.1	-0.9	-10.05	15.84	90.27	63.47	N
69	15.376	301.3	15.411	321.9	-20.6	-8.84	184.80	1197.77	4.78	N
69	15.554	321.8	15.559	319.8	2	-25.81	26.40	58.62	97.75	N
69	15.651	317.9	15.654	318.7	-0.8	79.56	15.84	11.41	502.25	N
69	16.212	327.8	16.229	100.1	227.7	111.59	89.76	46.09	124.32	N
69	16.514	75.7	16.528	69	6.7	85.01	73.92	49.82	115.00	N
69	16.557	60.8	16.572	50.8	10	-13.02	79.20	348.45	16.44	N
69	16.769	42.8	16.774	45	-2.2	1.80	26.40	839.01	6.83	N
69	16.779	46.8	16.782	47.9	-1.1	-3.15	15.84	288.25	19.88	N
69	16.816	52.2	16.826	56.8	-4.6	-6.71	52.80	450.95	12.71	N
69	16.927	70.6	16.941	77.3	-6.7	3.05	73.92	1386.68	4.13	N
69	17.023	77.2	17.066	54	23.2	9.84	227.04	1322.38	4.33	N
69	17.182	47.6	17.186	45.7	1.9	8.77	21.12	137.91	41.54	N
69	17.213	41.2	17.218	39.1	2.1	4.94	26.40	306.37	18.70	N
69	17.369	36.2	17.390	19.9	16.3	8.33	110.88	762.79	7.51	N
69	17.469	11.4	17.476	7.5	3.9	10.97	36.96	193.02	29.68	N
69	17.726	4.2	17.759	346.9	17.3	21.77	174.24	458.67	12.49	N
69	17.870	346	17.890	319.6	26.4	0.45	105.60	13318.57	0.43	N
69	18.218	335.4	18.240	26.4	-51	-14.78	116.16	450.39	12.72	N

ROUTE ID	PC MILEPOST (mi)	HEADING AT PC	PT MILEPOST (mi)	HEADING AT PT	DELTA HEADING	SAVITZSKY GOLAY DH	LENGTH (ft)	RADIUS (ft)	DEGREE	DIRECTION
69	18.614	20.6	18.621	26.5	-5.9	3.38	36.96	626.00	9.15	N
69	19.283	35.6	19.286	36.6	-1	-4.35	15.84	208.57	27.47	N
69	19.291	38.7	19.298	42.2	-3.5	-1.34	36.96	1580.34	3.63	N
69	19.411	40.2	19.416	38.3	1.9	2.26	26.40	669.30	8.56	N
69	19.442	30.7	19.455	25.4	5.3	1.16	68.64	3390.33	1.69	N
69	21.097	347.6	21.115	355	-7.4	-2.45	95.04	2218.73	2.58	N
69	25.270	1.5	25.275	3.5	-2	-4.47	26.40	338.50	16.93	N
69	25.351	27.3	25.356	29.3	-2	-7.89	26.40	191.75	29.88	N
69	25.643	44.7	25.648	46.8	-2.1	22.53	26.40	67.12	85.36	N
69	26.432	76.5	26.509	4.8	71.7	35.10	406.56	663.65	8.63	N
69	26.734	4.1	26.747	358.1	6	33.00	68.64	119.18	48.08	N
69	26.782	351.9	26.805	337.5	14.4	-0.21	121.44	33823.62	0.17	N
69	26.866	344.8	26.875	349.3	-4.5	10.53	47.52	258.67	22.15	N
69	27.112	342	27.126	323.7	18.3	-1.23	73.92	3455.38	1.66	N
69	27.130	325.5	27.154	349	-23.5	-5.11	126.72	1422.04	4.03	N
69	27.571	0.5	27.586	8.9	-8.4	-26.47	79.20	171.44	33.42	N
69	27.655	16.3	27.682	45.8	-29.5	2.87	142.56	2850.28	2.01	N
69	27.716	42.5	27.755	11.6	30.9	-24.31	205.92	485.36	11.80	N
69	27.819	12.4	27.841	99.5	-87.1	-29.21	116.16	227.86	25.15	N

ROUTE ID	PC MILEPOST (mi)	HEADING AT PC	PT MILEPOST (mi)	HEADING AT PT	DELTA HEADING	SAVITZSKY GOLAY DH	LENGTH (ft)	RADIUS (ft)	DEGREE	DIRECTION
69	27.919	95.7	27.926	92.6	3.1	20.29	36.96	104.35	54.91	N
69	28.068	88.8	28.120	54.9	33.9	14.94	274.56	1052.95	5.44	N
69	28.130	51.5	28.142	45.2	6.3	33.09	63.36	109.72	52.22	N
69	28.200	42	28.221	347.3	54.7	25.38	110.88	250.34	22.89	N
69	28.532	359.2	28.535	358.2	1	21.58	15.84	42.06	136.24	N
69	28.547	353.9	28.562	344.7	9.2	0.87	79.20	5224.47	1.10	N
69	29.476	337.9	29.484	334.7	3.2	8.76	42.24	276.19	20.75	N
69	29.489	332.7	29.498	328.6	4.1	-11.13	47.52	244.60	23.42	N
69	30.061	354.9	30.084	26.8	-31.9	-4.47	121.44	1556.10	3.68	N
69	30.271	18.9	30.318	349.8	29.1	2.93	248.16	4850.37	1.18	N
69	30.323	347.8	30.326	346.8	1	13.49	15.84	67.28	85.16	N
69	30.470	339.5	30.477	336.5	3	4.02	36.96	526.78	10.88	N
69	31.206	343.9	31.226	335.3	8.6	-2.03	105.60	2982.61	1.92	N
69	31.262	338.3	31.299	358.9	-20.6	-7.87	195.36	1422.02	4.03	N
69	31.407	344.9	31.409	343.9	1	-3.54	10.56	170.78	33.55	N
69	31.532	332.3	31.552	321.8	10.5	6.61	105.60	915.54	6.26	N
69	31.613	331	31.618	333	-2	0.43	26.40	3553.11	1.61	N
69	31.648	341.9	31.650	342.9	-1	3.35	10.56	180.84	31.68	N
69	31.718	346.8	31.753	326.1	20.7	15.18	184.80	697.51	8.21	N
69	31.846	331.2	31.876	311.6	19.6	24.43	158.40	371.43	15.43	N

ROUTE ID	PC MILEPOST (mi)	HEADING AT PC	PT MILEPOST (mi)	HEADING AT PT	DELTA HEADING	SAVITZSKY GOLAY DH	LENGTH (ft)	RADIUS (ft)	DEGREE	DIRECTION
69	32.283	297.5	32.336	321.3	-23.8	-2.31	279.84	6936.69	0.83	N
69	32.701	299.7	32.718	291.3	8.4	-14.37	89.76	357.78	16.01	N
69	32.937	282.3	32.993	309.8	-27.5	-9.53	295.68	1778.47	3.22	N
69	33.000	312.5	33.015	319	-6.5	-17.78	79.20	255.22	22.45	N
69	33.030	324.6	33.059	337.9	-13.3	-6.29	153.12	1395.09	4.11	N
69	33.899	351.3	33.902	352.3	-1	-5.70	15.84	159.30	35.97	N
69	34.421	5.7	34.431	10.2	-4.5	-2.65	52.80	1142.21	5.02	N
69	34.517	36.9	34.527	40.8	-3.9	-3.75	52.80	807.65	7.09	N
69	34.572	54.9	34.574	55.8	-0.9	-2.01	10.56	300.38	19.07	N
69	34.700	51.9	34.703	50.9	1	3.28	15.84	276.70	20.71	N
69	34.715	46.6	34.740	35.3	11.3	11.30	132.00	669.30	8.56	N
69	34.775	23.5	34.799	10.6	12.9	7.22	126.72	1006.01	5.70	N
69	35.118	2.3	35.136	13.6	-11.3	-7.51	95.04	724.95	7.90	N
69	35.148	17.4	35.159	29.5	-12.1	-13.05	58.08	255.06	22.46	N
69	0.278	165.8	0.283	163.6	2.2	0.83	26.40	1819.29	3.15	S
69	1.241	158.7	1.266	169.8	-11.1	-5.63	132.00	1344.37	4.26	S
69	1.615	190.5	1.632	182.8	7.7	-0.51	89.76	10055.89	0.57	S
69	1.825	180.6	1.828	181.6	-1	2.93	15.84	309.30	18.52	S
69	1.839	184.5	1.841	185.5	-1	-2.73	10.56	221.51	25.87	S
69	4.882	182.6	4.887	184.6	-2	0.91	26.40	1670.07	3.43	S

<b>ROUTE ID</b>	<b>PC MILEPOST (mi)</b>	<b>HEADING AT PC</b>	<b>PT MILEPOST (mi)</b>	<b>HEADING AT PT</b>	<b>DELTA HEADING</b>	<b>SAVITZSKY GOLAY DH</b>	<b>LENGTH (ft)</b>	<b>RADIUS (ft)</b>	<b>DEGREE</b>	<b>DIRECTION</b>
69	6.281	165.3	6.284	164.2	1.1	3.05	15.84	297.98	19.23	S
69	6.311	158.2	6.313	157.1	1.1	1.33	10.56	454.43	12.61	S
69	7.330	202.1	7.337	199	3.1	1.95	36.96	1085.18	5.28	S
69	7.342	197	7.345	196	1	2.09	15.84	434.54	13.19	S
69	8.371	190.3	8.376	188.2	2.1	1.90	26.40	794.91	7.21	S
69	8.378	187.2	8.381	186.2	1	-0.47	15.84	1913.54	2.99	S
69	11.881	158.8	11.893	164.2	-5.4	-3.57	63.36	1015.66	5.64	S
69	11.916	170.6	11.923	173.6	-3	-3.23	36.96	655.33	8.74	S
69	12.123	167.6	12.126	166.6	1	0.73	15.84	1250.58	4.58	S
69	12.128	165.6	12.133	163.5	2.1	1.54	26.40	980.39	5.84	S
69	14.666	135.8	14.669	136.8	-1	-0.83	15.84	1095.34	5.23	S
69	14.671	137.8	14.678	140.9	-3.1	-1.51	36.96	1406.41	4.07	S
69	14.707	151.2	14.710	152.2	-1	-4.75	15.84	190.89	30.01	S
69	14.712	153.2	14.737	163.3	-10.1	-5.58	132.00	1354.69	4.23	S
69	14.740	164.3	14.746	166.3	-2	-5.36	31.68	338.64	16.92	S
69	14.748	167.3	14.751	168.3	-1	2.20	15.84	413.07	13.87	S
69	14.874	165.5	14.890	157.7	7.8	2.86	84.48	1690.74	3.39	S
69	14.907	151.4	14.911	149.4	2	8.80	21.12	137.55	41.65	S
69	14.929	142.9	14.960	126.1	16.8	11.13	163.68	842.28	6.80	S
69	15.174	98.2	15.190	90.1	8.1	10.21	84.48	474.15	12.08	S

ROUTE ID	PC MILEPOST (mi)	HEADING AT PC	PT MILEPOST (mi)	HEADING AT PT	DELTA HEADING	SAVITZSKY GOLAY DH	LENGTH (ft)	RADIUS (ft)	DEGREE	DIRECTION
69	15.246	89.1	15.250	91.2	-2.1	-4.01	21.12	301.66	18.99	S
69	15.264	94.5	15.280	110.9	-16.4	-14.85	84.48	325.98	17.58	S
69	15.363	127.6	15.391	142.7	-15.1	-10.99	147.84	770.46	7.44	S
69	15.526	145.2	15.534	141.8	3.4	6.50	42.24	372.17	15.40	S
69	15.699	146	15.714	153.2	-7.2	-45.85	79.20	98.97	57.89	S
69	16.058	145.8	16.102	275.2	-129.4	-63.18	232.32	210.69	27.19	S
69	16.113	273.4	16.121	268.2	5.2	-44.83	42.24	53.98	106.14	S
69	16.123	267.9	16.133	275.5	-7.6	13.99	52.80	216.22	26.50	S
69	16.548	242.8	16.569	231.1	11.7	-1.13	110.88	5614.99	1.02	S
69	16.581	230.8	16.593	240.1	-9.3	2.54	63.36	1430.85	4.00	S
69	16.595	239.1	16.602	232.4	6.7	-1.23	36.96	1723.67	3.32	S
69	16.775	224.6	16.778	225.7	-1.1	3.04	15.84	298.54	19.19	S
69	16.794	231	16.797	232	-1	-6.46	15.84	140.49	40.78	S
69	16.910	246.9	16.926	256.5	-9.6	1.82	84.48	2663.71	2.15	S
69	17.013	256.8	17.046	236.6	20.2	6.54	174.24	1527.15	3.75	S
69	17.202	223.3	17.208	221	2.3	11.88	31.68	152.75	37.51	S
69	17.362	213	17.377	203	10	5.38	79.20	843.46	6.79	S
69	17.385	200.6	17.395	195.8	4.8	6.00	52.80	504.20	11.36	S
69	17.492	184.1	17.497	182	2.1	3.02	26.40	501.34	11.43	S
69	17.564	173.1	17.571	169.8	3.3	1.69	36.96	1254.11	4.57	S
69	17.616	172.5	17.618	173.4	-0.9	-1.06	10.56	569.26	10.06	S

ROUTE ID	PC MILEPOST (mi)	HEADING AT PC	PT MILEPOST (mi)	HEADING AT PT	DELTA HEADING	SAVITZSKY GOLAY DH	LENGTH (ft)	RADIUS (ft)	DEGREE	DIRECTION
69	17.718	181.5	17.745	167.1	14.4	18.21	142.56	448.66	12.77	S
69	17.837	162.8	17.864	142.1	20.7	-3.25	142.56	2514.36	2.28	S
69	18.195	154.3	18.220	205.4	-51.1	-15.15	132.00	499.16	11.48	S
69	18.271	203.8	18.279	194.4	9.4	-16.45	42.24	147.11	38.95	S
69	18.281	195.4	18.291	202.2	-6.8	1.95	52.80	1550.26	3.70	S
69	19.282	213.2	19.296	220.3	-7.1	-6.84	73.92	618.94	9.26	S
69	19.299	221.3	19.301	222.3	-1	-2.95	10.56	205.40	27.90	S
69	19.304	223.3	19.306	224.3	-1	0.66	10.56	912.78	6.28	S
69	19.421	215.6	19.429	212.5	3.1	2.14	42.24	1130.92	5.07	S
69	19.448	206.9	19.453	204.8	2.1	1.11	26.40	1357.47	4.22	S
69	21.091	170.4	21.096	172.4	-2	-5.13	26.40	294.94	19.43	S
69	23.300	210.4	23.310	206.1	4.3	25.27	52.80	119.74	47.85	S
69	26.415	257.4	26.494	186.4	71	36.34	417.12	657.71	8.71	S
69	26.722	185.6	26.729	182.1	3.5	28.42	36.96	74.52	76.89	S
69	26.774	170.8	26.791	159.2	11.6	7.19	89.76	714.85	8.02	S
69	27.095	158.1	27.107	143.7	14.4	5.01	63.36	723.98	7.91	S
69	27.109	143.4	27.119	161	-17.6	-6.28	52.80	481.94	11.89	S
69	27.121	161.5	27.124	165.9	-4.4	-8.54	15.84	106.27	53.91	S
69	27.125	166.5	27.127	164.6	1.9	0.25	10.56	2379.39	2.41	S

ROUTE ID	PC MILEPOST (mi)	HEADING AT PC	PT MILEPOST (mi)	HEADING AT PT	DELTA HEADING	SAVITZSKY GOLAY DH	LENGTH (ft)	RADIUS (ft)	DEGREE	DIRECTION
69	27.128	164.4	27.131	166.9	-2.5	0.10	15.84	9342.59	0.61	S
69	27.133	167.8	27.136	170	-2.2	-3.55	15.84	255.96	22.38	S
69	27.553	177.5	27.576	189.6	-12.1	-19.84	121.44	350.71	16.34	S
69	27.636	194.5	27.661	225.9	-31.4	-0.80	132.00	9453.81	0.61	S
69	27.696	222.5	27.736	191.5	31	-26.07	211.20	464.19	12.34	S
69	27.800	189.5	27.827	280.3	-90.8	-32.93	142.56	248.08	23.10	S
69	27.912	275.7	27.920	272.6	3.1	-24.27	42.24	99.72	57.45	S
69	28.065	269.4	28.125	232	37.4	45.67	316.80	397.43	14.42	S
69	28.193	223.7	28.216	167.6	56.1	42.02	121.44	165.60	34.60	S
69	28.541	173.2	28.553	166.5	6.7	19.54	63.36	185.79	30.84	S
69	29.446	164.9	29.448	163.9	1	-1.41	10.56	429.54	13.34	S
69	29.464	157.6	29.467	156.6	1	1.40	15.84	646.94	8.86	S
69	29.925	172.9	29.933	176.1	-3.2	-13.12	42.24	184.50	31.05	S
69	29.940	178.8	29.971	205	-26.2	-2.38	163.68	3940.41	1.45	S
69	30.256	200.5	30.308	167.4	33.1	5.99	274.56	2626.86	2.18	S
69	30.698	163.4	30.703	165.5	-2.1	17.10	26.40	88.46	64.77	S
69	31.187	164	31.204	156.3	7.7	-7.83	89.76	656.70	8.72	S
69	31.248	158.3	31.288	180.3	-22	-6.97	211.20	1737.20	3.30	S
69	31.380	168.9	31.390	163.4	5.5	-1.22	52.80	2479.69	2.31	S
69	31.510	155	31.530	143.5	11.5	6.19	105.60	976.78	5.87	S



ROUTE ID	PC MILEPOST (mi)	HEADING AT PC	PT MILEPOST (mi)	HEADING AT PT	DELTA HEADING	SAVITZSKY GOLAY DH	LENGTH (ft)	RADIUS (ft)	DEGREE	DIRECTION
69	31.605	151.5	31.616	155.8	-4.3	6.39	58.08	520.89	11.00	S
69	31.708	166.2	31.738	146.5	19.7	14.28	158.40	635.42	9.02	S
69	31.833	152.1	31.863	131.7	20.4	14.85	158.40	610.98	9.38	S
69	31.930	133.2	31.935	135.3	-2.1	11.97	26.40	126.41	45.32	S
69	32.080	126.1	32.102	109.1	17	-1.70	116.16	3908.42	1.47	S
69	32.274	116.5	32.319	138.1	-21.6	-4.23	237.60	3215.06	1.78	S
69	32.638	138.5	32.641	137.5	1	-8.67	15.84	104.70	54.73	S
69	32.648	134.7	32.651	133.6	1.1	5.84	15.84	155.41	36.87	S
69	32.686	122.9	32.701	115.1	7.8	4.22	79.20	1076.04	5.32	S
69	32.924	102	32.936	107.1	-5.1	-6.99	63.36	519.03	11.04	S
69	32.939	108.2	32.982	130.2	-22	-14.71	227.04	884.58	6.48	S
69	32.999	136.4	33.011	141.6	-5.2	-9.90	63.36	366.80	15.62	S
69	33.021	145.4	33.026	147.5	-2.1	-2.63	26.40	574.82	9.97	S
69	33.033	150.4	33.046	155.7	-5.3	-3.08	68.64	1276.88	4.49	S
69	33.055	158.4	33.058	159.6	-1.2	-2.45	15.84	370.22	15.48	S
69	33.888	171.2	33.893	173.3	-2.1	-2.57	26.40	588.24	9.74	S
69	34.407	185.3	34.419	191	-5.7	-4.29	63.36	847.06	6.76	S
69	34.442	196.2	34.452	200.4	-4.2	-5.89	52.80	513.74	11.15	S
69	34.484	208.8	34.499	215.1	-6.3	-5.42	79.20	837.68	6.84	S
69	34.501	216.1	34.504	217.1	-1	1.79	15.84	508.24	11.27	S
69	34.696	231	34.721	218.6	12.4	6.85	132.00	1103.40	5.19	S
69	34.746	210.7	34.751	208.6	2.1	4.81	26.40	314.57	18.21	S
69	34.756	206.6	34.759	205.6	1	3.07	15.84	296.04	19.35	S
69	34.766	202.8	34.786	192.4	10.4	10.35	105.60	584.66	9.80	S
69	34.796	188.8	34.814	181.3	7.5	-1.78	95.04	3054.31	1.88	S
RTE_ID	PC MILEPOST	HEADING_ AT_PC	PT MILEPOST	HEADING_ AT_PT	DELTA_ HEADING	LENGTH (ft)	RADIUS (ft)	DEGREE	DIRECTION	S

	(mi)		(mi)							
69	35.151	200.5	35.155	216.2	-15.7	-23.75	21.12	50.95	112.46	S