

NCHRP IDEA Program

CurvePortal for Automated Identification and Extraction of Horizontal Curve Information

Final Report for
NCHRP IDEA Project 185

Prepared by:
David Noyce
University of Wisconsin-Madison

March 2018

Innovations Deserving Exploratory Analysis (IDEA) Programs Managed by the Transportation Research Board

This IDEA project was funded by the NCHRP IDEA Program.

The TRB currently manages the following three IDEA programs:

- The NCHRP IDEA Program, which focuses on advances in the design, construction, and maintenance of highway systems, is funded by American Association of State Highway and Transportation Officials (AASHTO) as part of the National Cooperative Highway Research Program (NCHRP).
- The Safety IDEA Program currently focuses on innovative approaches for improving railroad safety or performance. The program is currently funded by the Federal Railroad Administration (FRA). The program was previously jointly funded by the Federal Motor Carrier Safety Administration (FMCSA) and the FRA.
- The Transit IDEA Program, which supports development and testing of innovative concepts and methods for advancing transit practice, is funded by the Federal Transit Administration (FTA) as part of the Transit Cooperative Research Program (TCRP).

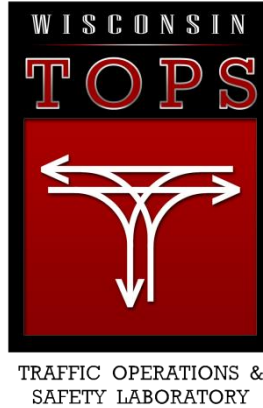
Management of the three IDEA programs is coordinated to promote the development and testing of innovative concepts, methods, and technologies.

For information on the IDEA programs, check the IDEA website (www.trb.org/idea). For questions, contact the IDEA programs office by telephone at (202) 334-3310.

IDEA Programs
Transportation Research Board
500 Fifth Street, NW
Washington, DC 20001

The project that is the subject of this contractor-authored report was a part of the Innovations Deserving Exploratory Analysis (IDEA) Programs, which are managed by the Transportation Research Board (TRB) with the approval of the National Academies of Sciences, Engineering, and Medicine. The members of the oversight committee that monitored the project and reviewed the report were chosen for their special competencies and with regard for appropriate balance. The views expressed in this report are those of the contractor who conducted the investigation documented in this report and do not necessarily reflect those of the Transportation Research Board; the National Academies of Sciences, Engineering, and Medicine; or the sponsors of the IDEA Programs.

The Transportation Research Board; the National Academies of Sciences, Engineering, and Medicine; and the organizations that sponsor the IDEA Programs do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of the investigation.



CurvePortal for Automated Identification and Extraction of Horizontal Curve Information

IDEA Program Final Report

Contract Number: NCHRP-185
Purchase Order Number: SUB0000673

Prepared for the IDEA Program
Transportation Research Board
The National Academies

Principal Investigator:
David A. Noyce
Traffic Operations and Safety Laboratory
Department of Civil and Environmental Engineering
University of Wisconsin-Madison

Authors:
Madhav V. Chitturi, Zhixia Li, Glenn Vorhes, David A. Noyce, and Andrea R. Bill

March 2018

ACKNOWLEDGMENTS

This research was partly supported by the National Academy of Science (NAS) through the Transportation Research Board's (TRB) NCHRP IDEA Program. We would like to the NCHRP IDEA panel for providing support for the project and for their valuable feedback. Special thanks are due to the advisory panel for the project for providing feedback and guidance during this project.

NCHRP IDEA PROGRAM COMMITTEE

CHAIR

DUANE BRAUTIGAM

Consultant

MEMBERS

AHMAD ABU HAWASH

Iowa DOT

FARHAD ANSARI

University of Illinois at Chicago

PAUL CARLSON

Road Infrastructure, Inc.

ALLISON HARDT

Maryland State Highway Administration

ERIC HARM

Consultant

JOE HORTON

California DOT

DENISE INDA

Nevada DOT

DAVID JARED

Georgia DOT

PATRICIA LEAVENWORTH

Massachusetts DOT

CATHERINE MCGHEE

Virginia DOT

MAGDY MIKHAIL

Texas DOT

J. MICHELLE OWENS

Alabama DOT

A. EMILY PARKANY

Virginia Agency of Transportation

JAMES SIME

Consultant

JOSEPH WARTMAN

University of Washington

FHWA LIAISON

DAVID KUEHN

Federal Highway Administration

TRB LIAISON

RICHARD CUNARD

Transportation Research Board

IDEA PROGRAMS STAFF

CHRISTOPHER HEDGES

Director, Cooperative Research Programs

LORI SUNDSTROM

Deputy Director, Cooperative Research Programs

INAM JAWED

Senior Program Officer

DEMISHA WILLIAMS

Senior Program Assistant

EXPERT REVIEW PANEL

ANNE ELLIS *Arizona DOT*

KOHINOOR KAR, *Arizona DOT*

REBECCA SZYMKOWSKI, *Wisconsin DOT*

MICHAEL PAWLOVICH, *South Dakota State University*

TABLE OF CONTENTS

Executive Summary.....	1
Introduction	2
Literature Review	4
CurveFinder	5
Algorithm Underlying CurveFinder	5
Software Implementation of the Algorithm	9
Incorporation of MIRE Compatibility	11
Application of CurveFinder	13
Curve Identification Accuracy	16
Impact of Low-Quality GIS Roadway Data	18
Improving CurveFinder Algorithm for Low-quality GIS Datasets.....	19
Pre-processing to Improve Low-quality Datasets	19
CurveFinder Steps	20
Application of Updated CurveFinder to Iowa Dataset	23
CurvePortal Interface	23
Conclusions	24
References	26

LIST OF FIGURES

FIGURE 1 The curve identification algorithm.	6
FIGURE 2 Illustration of the critical steps in curve identification and classification.	7
FIGURE 3 Illustration of the “CurveFinder” interface and curve identification results.	10
FIGURE 4 Curve types defined in MIRE (28).	11
FIGURE 5 Algorithm for MIRE Curve Type Classification.	13
FIGURE 6 Identified curves in two counties of Iowa.	14
FIGURE 7 Example of identified curves with different types.	15
FIGURE 8 Example of attributes of an extracted curve.	16
FIGURE 9 DIPCs for the Iowa, Wisconsin and New Jersey datasets.	18
FIGURE 10 Typical scenarios of low-quality GIS source data.	18
FIGURE 11 Smoothing Algorithms	19
FIGURE 12 Vertex density of original features vs smoothed by two algorithms	20
FIGURE 13 Curve identification process flowchart.....	22
FIGURE 14 Ground truth curve identification by percentage of curve identified.....	23
FIGURE 15 Snapshot of CurvePortal Webpage.....	24

LIST OF TABLES

TABLE 1 Example of a curve shapefile’s attributes in association with MIRE elements.....	12
TABLE 2 Evaluation results for curve identification accuracy.	17
TABLE 3 Example output table from calibration step.	21

EXECUTIVE SUMMARY

Twenty-seven percent of fatal crashes occur at horizontal curves, although they account for less than 10% of public roadway miles. Research has proved that knowing where horizontal curves are located and their geometric characteristics are key to successfully address curve safety issues. Curve information is also essential for accurate placement of warning signs as safety treatment especially where a curve has a history of crashes. In this context, the availability of curve information for all roads is vital. However, many states lack that information. The University of Wisconsin-Madison had developed and demonstrated CurveFinder that automatically identifies horizontal curves and extracts their geometric characteristics solely from GIS roadway maps. CurveFinder is unique because the method is automated and solely based on existing GIS roadway maps, thus eliminating the need for additional data collection, making the approach an easy and low-cost solution to implement. CurveFinder was applied on datasets from multiple states including Delaware, Iowa, New Jersey, and Wisconsin. The primary lesson learned was the need to improve the accuracy of CurveFinder for low-quality datasets that contain errors or do not represent the actual roadway alignment accurately. States also expressed the need to obtain curve information compatible with Federal Highway Administration's Model Inventory of Roadway Elements (MIRE). The goal of this Type 2 IDEA project is to:

1. Incorporate the ability in CurveFinder to extract curve-related MIRE elements;
2. Improve the accuracy of CurveFinder for low-quality GIS data sources;
3. Develop an online portal called CurvePortal where agencies can upload their GIS roadway maps for obtaining horizontal curve location and geometric information.

MIRE has a specific subcategory for horizontal curve data, and includes eight elements. The updated CurveFinder extracts all MIRE elements from GIS roadway maps except for Element 111 Superelevation, which can only be obtained from field surveys. For each curve extracted by CurveFinder, information on curve type, curve degree, curve radius, curve length, whether there is a presence of transition section, the deflection angle if the curve is a horizontal angle point, and the curve direction is included as attributes in the GIS shapefile.

Curve Finder preparation, calibration, and run for production of final results has been streamlined into a five step process contained within a ArcMap toolbox containing models which reference internally managed python scripts. This is an improvement from previous approaches as it creates an easy to follow process with reduced need for user documentation to have reproducible results. In addition, to improve the accuracy of CurveFinder for low-quality GIS datasets, two smoothing methods are used to preprocess the data before applying the CurveFinder algorithm. Calibration is performed within desktop GIS software by an iterative process by which the original road segments as well as smoothed road features by means of best fit and spline methods with a variety of offset and angle thresholds are passed to the curve finder algorithm. Two hundred thirty-one output curves versions are created during this step to identify the optimal parameters for CurveFinder. The application of the preprocessing and calibration steps resulted in better identification of the start and end points of curves as demonstrated by the increased coverage of identified curves as compared to ground truth curves.

CurvePortal, an online portal was developed and is hosted at www.curveportal.cee.wisc.edu. CurvePortal serves as an intuitive web interface by which users can upload spatial road features as well as optionally define an attribute field on which distinct road segments participating in a given roadway can be joined. This is commonly the road name or other identifier unique to a route. Additionally, the interface offers the option to upload ground truth features that can be used for calibration purposes and identification of optimal algorithm parameters prior to the final curve identification step.

Through this IDEA Type 2 Project, the University of Wisconsin-Madison team has made significant improvements to CurveFinder and developed the CurvePortal. During the course of this IDEA Type 2 project, the research team has reached out to several states for using CurvePortal and are currently in communicating with some states for contracting with the University of Wisconsin-Madison to use CurvePortal and extract curve information.

IDEA PRODUCT

The IDEA product developed in this project is CurvePortal. Building on the extensive experience with geographic information systems (GIS), data integration and safety analysis, the University of Wisconsin TOPS Lab developed CurveFinder, a tool to extract horizontal curve location and geometric information automatically from GIS roadway maps. CurveFinder was successfully used in Wisconsin and Iowa for extracting curve information. The CurveFinder algorithm needs to be improved to address accuracy issues with low-quality GIS maps, to incorporate compatibility with FHWA's Model Inventory of Roadway Elements (MIRE) curve elements, and make it available for public use. The objectives of this Type 2 project are to improve the CurveFinder algorithm and develop a prototype of CurvePortal which is a web interface for extracting horizontal curve location and geometric information automatically from GIS roadway maps. CurvePortal will provide curve data in GIS format for easy integration with existing asset management, roadway inventory, and crash datasets.

CONCEPT AND INNOVATION

According to Federal Highway Administration, 27% of fatal crashes occur at horizontal curves although they account for less than 10% of roadway miles. Research has proved that knowing where horizontal curves are located and their geometric characteristics are key to successfully address curve safety issues. Curve information is also essential for accurate placement of curve warning signs as safety treatment. Furthermore, Moving Ahead for Progress in the 21st Century (MAP-21), the federal highway authorization bill requires the safety performance measures to assess safety on all public roads including local roads in addition to the state highway systems. In this context, the availability of curve information for local roads is vital. However, many states lack that information.

Cost-effective data collection methods are paramount to building and managing a safe and efficient 21st century transportation network. Compared with traditional data sources, GIS roadway maps have the following advantages: no additional cost or requirement of data collection once being collected; availability of complete roadway network data; and less preprocessing requirement. Previous GIS-based methods are either manual or semi-automatic, or based on GPS data that require additional data collection.

The proposed approach is unique because the method is fully-automatic and solely based on existing GIS roadway maps, thus eliminating the need for additional data collection, making the approach an easy and low-cost solution to implement. A proven concept of the approach was developed by the research team and implemented as an ArcGIS® Add-In tool named: CurveFinder which was calibrated and validated and used to obtain curve information on County roads for several counties in Wisconsin. CurveFinder was also applied on datasets of county roads from other states such as Delaware, Iowa and New Jersey. The primary lesson learnt was the need to improve the accuracy of CurveFinder for low-quality datasets that contain errors or do not represent the actual roadway alignment accurately. States also expressed the need to obtain curve information compatible with MIRE. Therefore, the objectives of this Type 2 proposal are to:

1. Improve the accuracy of CurveFinder for low-quality GIS data sources;
2. Incorporate and validate the ability in CurveFinder to extract curve-related MIRE elements;
3. Implement a prototype of an online portal called CurvePortal. Agencies can upload their GIS roadway maps for obtaining horizontal curve location and geometric information.

In summary, the proposed innovation will provide horizontal curve data that will have the most direct effect on addressing curve safety issue, especially for local roads and help the nation advance towards the goal of zero deaths. Furthermore, curve information will contribute to a more complete roadway inventory data system as well as enable agencies to meet the MUTCD horizontal curve signing and MAP-21 requirements.

INVESTIGATION

INTRODUCTION

Horizontal curves of suburban and rural highways have been long recognized as one of the critical locations with regard to roadway departure crashes (1). The National Highway Traffic Safety Administration (NHTSA) indicates horizontal alignment contributes to 76% of single vehicle crashes in the United States (U.S.) based on the 2007 Fatality Analysis Reporting System data (2). Previous research results also reported that crash rates on horizontal curves are 1.5 to four times higher than the crash rates on roadway tangents (3). Moreover, other researchers revealed that crash rates increase as the degree of the curvature increases, while a curvature of 15° or greater has a high probability of being hazardous (4, 5).

Nationwide, a research convention has been formed by research projects that have been and are being conducted to better understand the relationship between characteristics of horizontal curves and crashes, and explore effective countermeasures to prevent the crashes from happening on horizontal curves (6-8). A typical safety countermeasure resulted from these research projects is the installation of warning signs in advance of the curves. In most cases, warning signs have already been installed at critical curve locations. However, there is still a possibility that some locations of high crash rates or severe crash levels have inappropriate or improperly located signs though no predictive model has been established. Knowing where horizontal curves are located and what the geometric characteristics of the curves are is an essential and important task in the research framework of solving the curve safety issue. In the U.S., although many states have their state roadway inventory system that might include location and geometric information of horizontal curves on U.S. and state routes, most of these states do not have similar curve information for their county and local roads. And, it is costly and time-consuming to collect the curve information for county and local roads using traditional approaches. In this context, a high priority should be developing a novel approach that can identify location, radius, degree of curvature, and length for each horizontal curve in both state and county/local highway systems in an accurate, cost-effective, and time-efficient manner.

To date, satellite imagery, Global Position System (GPS) surveying data, laser scanning data, and AutoCAD® digital maps are four widely used sources by researchers to obtain horizontal curve data from. Successful applications based on these four sources are well documented in the literature (9-18). As Geographic Information System (GIS) roadway maps become more and more accessible and widely used by most government agencies and research institutions, they provide an alternative source for horizontal curve data extraction. Compared with the traditional data sources, GIS roadway maps potentially have the following advantages:

- Zero cost of data because of higher accessibility versus expensive commercial satellite imagery and rare AutoCAD® digital maps;
- Zero requirement and cost of data collection versus expensive and time-consuming GPS surveying and laser scanning;
- Availability of complete roadway network data versus a small amount of roadways where GPS surveying and laser scanning has been conducted; and,
- Less preprocessing requirement versus complicated image processing which causes longer data preparation time and possibly more error.

These facts demonstrate the need for a method that can effectively and efficiently detect horizontal curves and extract their information from GIS roadway maps. Recently, some researchers have started extracting horizontal curve data using ArcGIS® roadway shapefile under ArcMap® environment (19). ArcGIS® toolbar “Coordinate Geometry (COGO)” provides a similar function through a command “Curve Calculator” for manual extraction of curve data from GIS roadway maps (20). The methods in these applications required manual identification and construction of tangent points and chord lines on the ArcGIS® feature layers, which resulted in a large work load and lower efficiency. In fact, with the powerful programmable support provided by ArcGIS®, developing an automated curve data extraction tool that can be embedded in ArcGIS® is completely possible. So far, only one tool, which was developed by New Hampshire Department of Transportation, has been found in literature, featuring a semi-automatic approach. This method extracts roadway alignment information from geodatabase, and outputs curve data into a text file (21). Specifically, this method required a special roadway referencing system defined by mile posts, and a manual creation of curve feature classes and layers based on the output data. Besides this semi-automatic approach, no literature documenting a fully automatic method has been found.

The University of Wisconsin-Madison’s Traffic Operations and Safety Laboratory developed a fully automated method for horizontal curve identification and curve data extraction from GIS roadway maps (27). A specific tool “CurveFinder” was developed based on ArcGIS® programmable package: ArcObjects®. “CurveFinder”

can be loaded in ArcMap® as a customized GIS tool. The internal curve data extraction algorithm enables the tool to automatically locate simple circular curves and compound curves from a selected county highway layer, compute the length of each curve as well as the radius and curvature of each simple circular curve, and finally create a layer that contains all the identified curves features along with their geometric information. CurveFinder was calibrated and validated and used to obtain curve information on County roads for several counties in Wisconsin. CurveFinder was also applied on datasets of county roads from other states such as Delaware, Iowa and New Jersey. The primary lesson learned was the need to improve the accuracy of CurveFinder for low-quality datasets with sparse vertex density or do not represent the actual roadway alignment accurately. States also expressed the need to obtain curve information compatible with MIRE.

In this IDEA Type 2 project, the objectives of the University of Wisconsin-Madison team were to:

1. Incorporate and validate the ability in CurveFinder to extract curve-related MIRE elements;
2. Improve the accuracy of CurveFinder for low-quality GIS data sources;
3. Implement a prototype of an online portal called CurvePortal where agencies can upload their GIS roadway maps for obtaining horizontal curve location and geometric information.

Following the literature review, a description of CurveFinder, description of how the UW team achieved the three objectives are described.

LITERATURE REVIEW

High resolution satellite imagery is one of the most widely used sources for extracting elements of highway horizontal alignment. Various approaches using different techniques of image processing have been utilized by researchers to detect roadway geometry from satellite imagery (9, 10, 22-25). Specifically, researchers from Ryerson University conducted an insightful investigation for identifying horizontal curves from IKONOS® satellite images, and proved the feasibility of deriving geometric characteristics of simple, compound, and spiral curves using an approximate algorithm based on high resolution satellite images (9, 10). However, drawbacks of using satellite imagery are obvious: accuracy is reduced when roadway information is extracted from urban roadway images, because the variety of land cover can confuse the target and accuracy greatly relies on the image resolution while high-resolution commercial images are relatively expensive.

Dating back to early 2000s, GPS data has been used by researchers for extracting highway horizontal alignment information (11, 12). In those approaches, geographic coordinates were recorded by a GPS-equipped vehicle at short time intervals (e.g., 0.5 sec) along the roadway. The horizontal curves were then identified and the radii were computed using a customized GIS program based on the logged GPS data points along the curves. In another study of vehicle paths on horizontal curves in Canada, Imran et al. developed a method of incorporating GPS information into GIS for the calculation of the radius, length, and spiral length of horizontal curves (17). Hans et al. used GPS data to develop a statewide curve database for crash analysis in Iowa (18). In addition to GPS, Yun and Sung installed multiple sensors, including inertial measurement unit, distance measuring instrument, and cameras, on a surveying vehicle to acquire real world highway coordinates at a higher accuracy level (13). Other researchers equipped laser scanning technology on a surveying vehicle in addition to GPS to obtain three-dimensional characteristics of the horizontal curves (14). The high density three-dimensional information allows faster and easier extraction of cross section elements. In these methods, both GPS data and laser technology facilitated the collection of high accuracy of curve data. On the other hand, using these special surveying vehicles for data collection also limits the method from being applied to a larger number of roadways due to the high cost and long data collection time.

Compared with other data sources, digital map is a more economic and time saving data source. Researchers from the United Kingdom and Ireland succeeded in their attempts to extract highway geometry from digital maps under AutoCAD® environment (15, 16). Their methods used AutoCAD® commands to reconstruct the centerline of the roadway based on the digitized roadway map in AutoCAD® format. The reconstructed centerline facilitated locating the start and end points of simple curves. Curve radius, angle, and length were calculated using curve geometry equations. Recently, researchers considered the use of popular GIS digital roadway maps as the source of identifying horizontal curves, which is considered a step towards higher efficiency and wider applicability. Price introduced a method of manually locating the curves and calculating the turning radii on a digital GIS roadway map under ArcMap® environment (19). His method required manual identification and construction of tangent points and chord lines on the GIS feature layers. ESRI also provides a “Curve Calculator” function for computation of curve information through its toolbar “Coordinate Geometry (COGO)” (20). Similarly, Florida Department of Transportation developed a toolbar in ArcGIS®, named “Curvature Extension”, which is similar in both function and

operation as “Curve Calculator” (26). Although in these aforementioned applications, the radius and curve length calculation was performed by ArcMap®, fully manual identification and construction of tangents were required, which prevents these methods from achieving a higher efficiency and a lower cost. New Hampshire Department of Transportation developed a semi-automatic approach for curve data extraction (21). They developed an executable file which retrieves roadway coordinates from a geodatabase, and outputs curve’s starting and ending mileposts, radius, and number of segments to a text file. This method is specifically designed for GIS roadway map that has a special roadway referencing system defined by mile posts. A manual creation of curve feature classes and layers based on the output curve data is also needed.

CURVEFINDER

CurveFinder is an ArcMap® as an Add-In tool by programming using ArcObjects®. The underlying algorithm is presented first, followed by a discussion of the software implementation.

Algorithm Underlying CurveFinder

The objective of the algorithm is fourfold: (1) automatically detect all curves from each road in a selected roadway layer regardless of the type of curve; (2) automatically classify each curve into two categories: simple or compound; (3) automatically compute the radius and degree of curvature for each simple curve, as well as the curve length for both simple curves and compound curves; and (4) automatically create curve features and layer for all identified curves in GIS. Figure 1 presents a flow chart which explains the algorithm for identifying curves from a roadway polyline. The algorithm will be performed on each road in the selected roadway layer, so that all curves in the layer can be identified. A critical step in the curve identification algorithm is computing the bearing angle between two consecutive segments. Figure 2a gives an example that facilitates understanding the bearing angle.

In Figure 2a, the bearing angle α between Segment AB and Segment BC can be computed based on the geographic coordinates of Vertices A, B, and C using the following equations where each vertex has an x and y component.

$$\cos\left(\frac{\alpha \cdot \pi}{180}\right) = \frac{\overrightarrow{AB} \cdot \overrightarrow{BC}}{|\overrightarrow{AB}| \cdot |\overrightarrow{BC}|} = \frac{(x_B - x_A)(x_C - x_B) + (y_B - y_A)(y_C - y_B)}{\sqrt{(x_B - x_A)^2 + (y_B - y_A)^2} \times \sqrt{(x_C - x_B)^2 + (y_C - y_B)^2}} \quad (1)$$

$$\alpha = \cos^{-1}\left(\frac{(x_B - x_A)(x_C - x_B) + (y_B - y_A)(y_C - y_B)}{\sqrt{(x_B - x_A)^2 + (y_B - y_A)^2} \times \sqrt{(x_C - x_B)^2 + (y_C - y_B)^2}}\right) \times \frac{180}{\pi} \quad (2)$$

The only adjustable parameter of the curve identification algorithm is the threshold of the bearing angle. When the bearing angle between the current segment and the preceding segment is greater than the threshold, a new curve should begin or the existing curve should continue. On the contrary, when the bearing angle between the current segment and the preceding segment is equal to or less than the threshold, the segments are considered to be a part of a tangent section. Therefore, the selection of a reasonable threshold value is of great importance for accurate identification of curves.

Followed by the curve identification algorithm, a curve classification algorithm is designed to classify all identified curves into two types: simple or compound. A curve would be classified as a simple curve if the curve satisfies both of the following criteria: (1) same beginning and ending directions; and (2) difference between the computed curve length and the actual (measured from ground truth) curve length are within a certain percentage. If either condition is not met, the curve is classified as a compound curve.

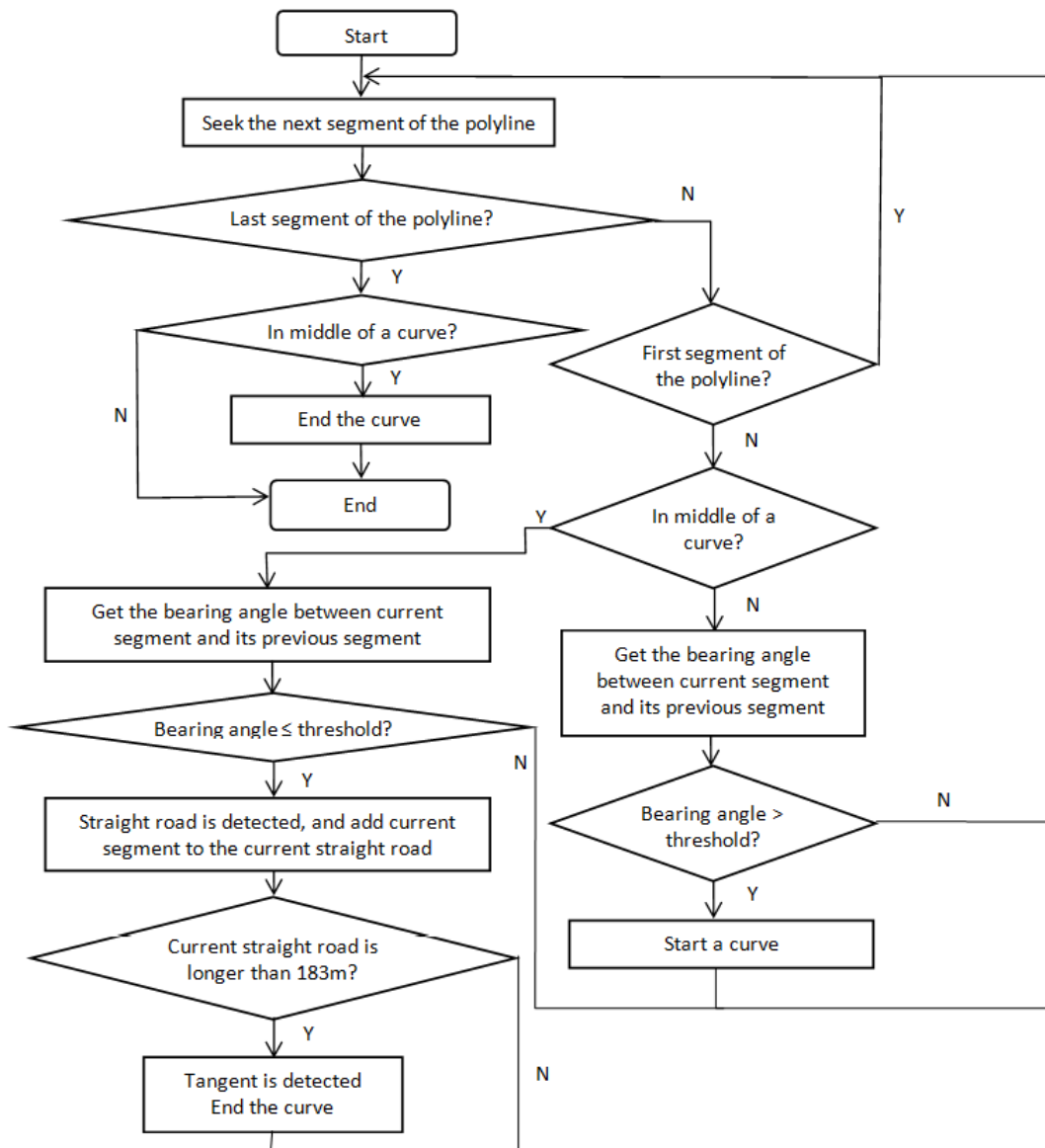


FIGURE 1 The curve identification algorithm.

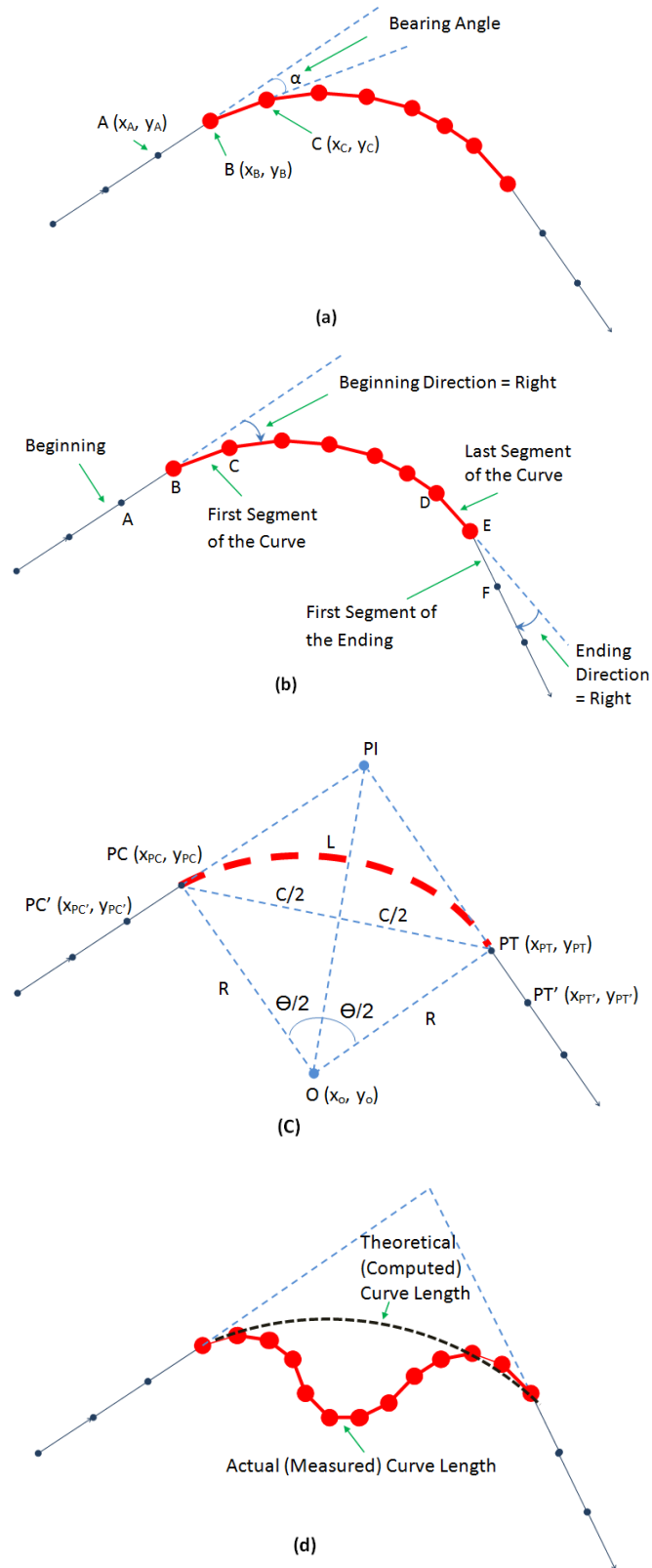


FIGURE 2 Illustration of the critical steps in curve identification and classification.

Figure 2b illustrates an example showing the curve's beginning and ending directions. The curve's beginning direction is defined as the bending direction of the first segment of the curve against the beginning tangent. On the other hand, the curve's ending direction is defined as the bending direction of the ending tangent against the last segment of the curve. In the case shown by Figure 4b, the beginning direction is the same as the ending direction, which indicates that the curve satisfies the first criterion for being classified as a simple circular curve.

In the second criterion, the difference between the computed and actual curve lengths should be no more than a certain threshold percentage. After a simple sensitivity analysis, 2.5% is used for the threshold for this paper. The computed curve length is the length of the ideal simple circular curve that can be estimated based on the detected tangents as shown in Figure 4c. According to Figure 2c, the computed curve length can be computed when the coordinates of PC , PC' , PT and PT' are known by using the following equations.

$$k_{O-PC} = \frac{x_{PC'} - x_{PC}}{y_{PC} - y_{PC'}} \quad (3)$$

$$b_{O-PC} = y_{PC} - x_{PC} \cdot \frac{x_{PC'} - x_{PC}}{y_{PC} - y_{PC'}} \quad (4)$$

$$k_{O-PT} = \frac{x_{PT'} - x_{PT}}{y_{PT} - y_{PT'}} \quad (5)$$

$$b_{O-PT} = y_{PT} - x_{PT} \cdot \frac{x_{PT'} - x_{PT}}{y_{PT} - y_{PT'}} \quad (6)$$

$$x_0 = \frac{b_{O-PT} - b_{O-PC}}{k_{O-PC} - k_{O-PT}} \quad (7)$$

$$y_0 = k_{O-PC} \cdot \frac{b_{O-PT} - b_{O-PC}}{k_{O-PC} - k_{O-PT}} + b_{O-PC} \quad (8)$$

$$R = \sqrt{(x_{PC} - x_0)^2 + (y_{PC} - y_0)^2} \quad (9)$$

$$C = \sqrt{(x_{PT} - x_{PC})^2 + (y_{PT} - y_{PC})^2} \quad (10)$$

$$\theta = 2 \times \sin^{-1}\left(\frac{C}{2R}\right) \times \frac{180}{\pi} \quad (11)$$

$$L = \frac{\theta \cdot \pi}{180} \times R \quad (12)$$

Where, k_{O-PC} = the slope of the line equation for Line O-PC;
 b_{O-PC} = the intercept of the line equation for Line O-PC;
 k_{O-PT} = the slope of the line equation for Line O-PT;
 b_{O-PT} = the intercept of the line equation for Line O-PT;
 x_0 = the x coordinate of curve's the center point;
 y_0 = the y coordinate of curve's the center point;
 R = the curve's radius in meters;
 C = the length of the curve's long chord in meters;
 θ = the curve's central angle measured in degrees; and,

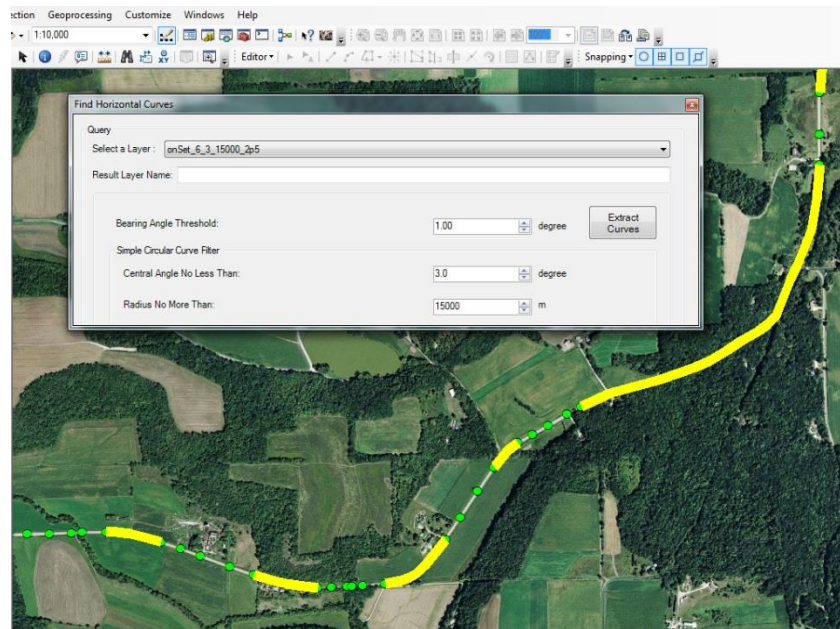
L = the computed length of the curve measured in meters.

On the other hand, the actual (measured) length of the curve can be simply measured by summing up the length of each segment of the curve. Figure 2d illustrates an example showing a curve that does not satisfy the second criterion of being classified as a simple curve. In Figure 4d, the difference between the computed curve length and the actual curve length is greater than the threshold of 2.5%, which indicates that the curve would not be classified as a simple curve, but as a compound curve.

Finally, the geometric information of each curve will also be automatically extracted after all curves are classified. The geometric information includes the actual length of each curve regardless of the type of curve, as well as the radius, central angle, and computed length of the simple curves. Specifically, the algorithm computes the radius, central angle, and computed curve length based on Equations 9, 11, and 12, respectively.

Software Implementation of the Algorithm

The curve data extraction algorithm was implemented in ArcMap® as a customized Add-In tool named as “CurveFinder”. The development of “CurveFinder” was based on the ArcGIS® programming package ArcObjects®. Microsoft Visual Studio® 2010 was selected as the software development interface while the programming language is C#. Figure 3a illustrates the user interface of “CurveFinder” as well as a snap shot of the identified curves, which is overlaid on a Bing® aerial map layer for a better presentation.



(a)

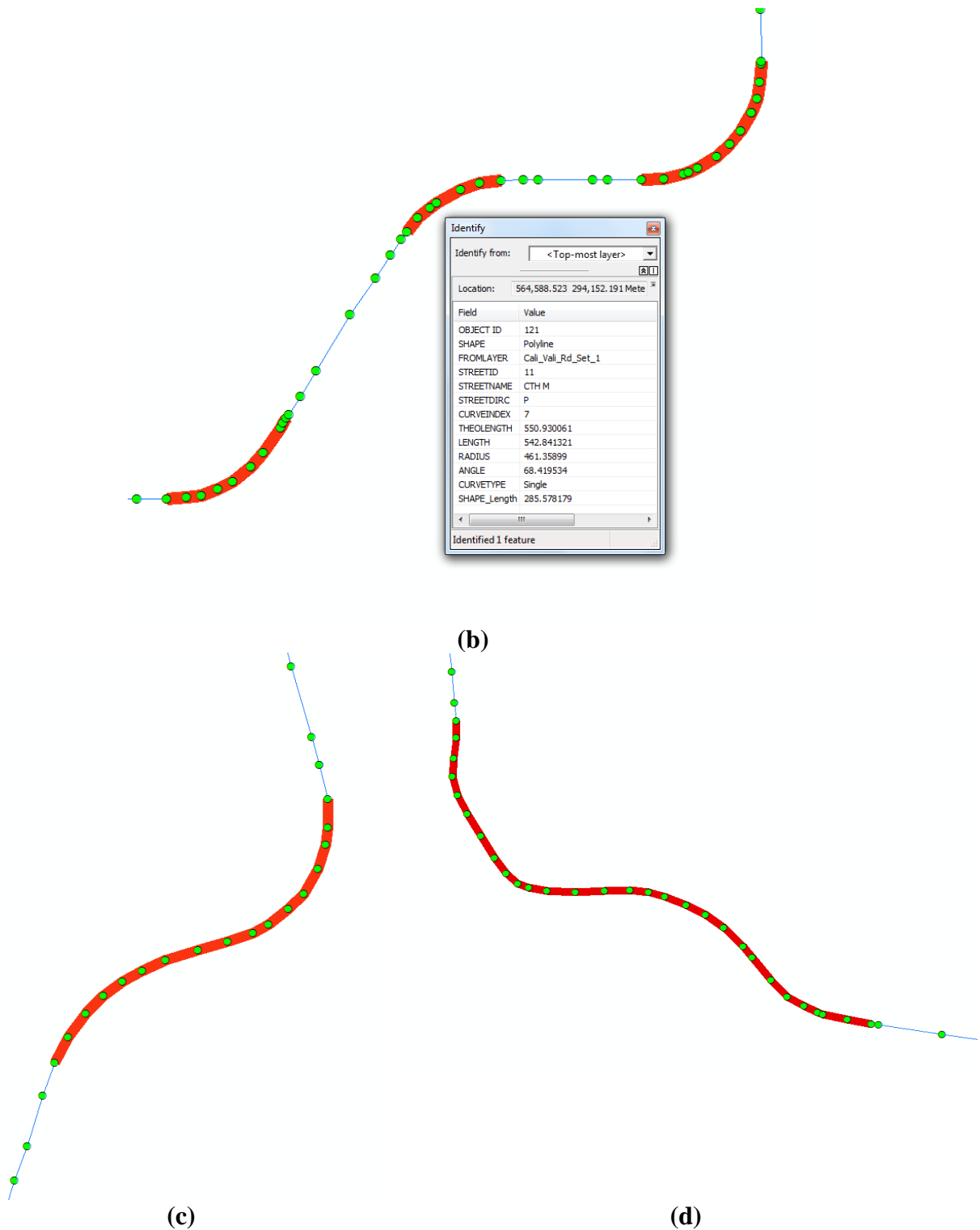


FIGURE 3 Illustration of the “CurveFinder” interface and curve identification results.

CurveFinder allows users to select a roadway layer from the dropdown list as the source layer for curve identification. Users can specify the bearing angle threshold before running the algorithm. CurveFinder also features a query-based

result filter for simple curves. Only those qualified simple curves that satisfy the user-designated minimum central angle and maximum radius will be extracted from the selected roadway layer. Clicking the button “Extract Curves” will trigger the algorithm, and a layer containing all identified curves will be created automatically. Figure 3b shows an example of the identified simple curves with their geometric information stored in the property table, while Figures 3c and 3d illustrate examples of different compound curves that are identified by the algorithm.

INCORPORATION OF MIRE COMPATIBILITY

The Federal Highway Administration (FHWA) developed Model Inventory of Roadway Elements (MIRE). MIRE provides a standard data model and guidance to transportation agencies on collecting consistently safety-related roadway and traffic data (28). Eight elements in MIRE that are related to horizontal curves include: curve identifiers and linkage elements, curve feature type, horizontal curve degree or radius, horizontal curve length, curve superelevation, horizontal transition/spiral curve presence, horizontal curve intersection/deflection angle and horizontal curve direction. Compatibility with MIRE can facilitate integration of the curve data extracted by CurveFinder into crash analysis.

In the original CurveFinder algorithm, only two curve types were considered, namely, independent circular curves and compound curves (i.e., all curves except for independent circular curves). Curve geometric information was extracted for independent circular curves only. As more states adopt MIRE, incorporation of MIRE compatibility into CurveFinder becomes essential. MIRE has different definitions of curve types than the original CurveFinder. Curves are defined to be one of the following types in MIRE (28):

- Horizontal angle point (i.e., joining of two tangents without a horizontal curve)
- Independent horizontal curve
- Component of compound curve (i.e., one curve in compound curve)
- Component of reverse curve (i.e., one curve in a reverse curve)

Figure 4 illustrates the curve types that are defined in MIRE.

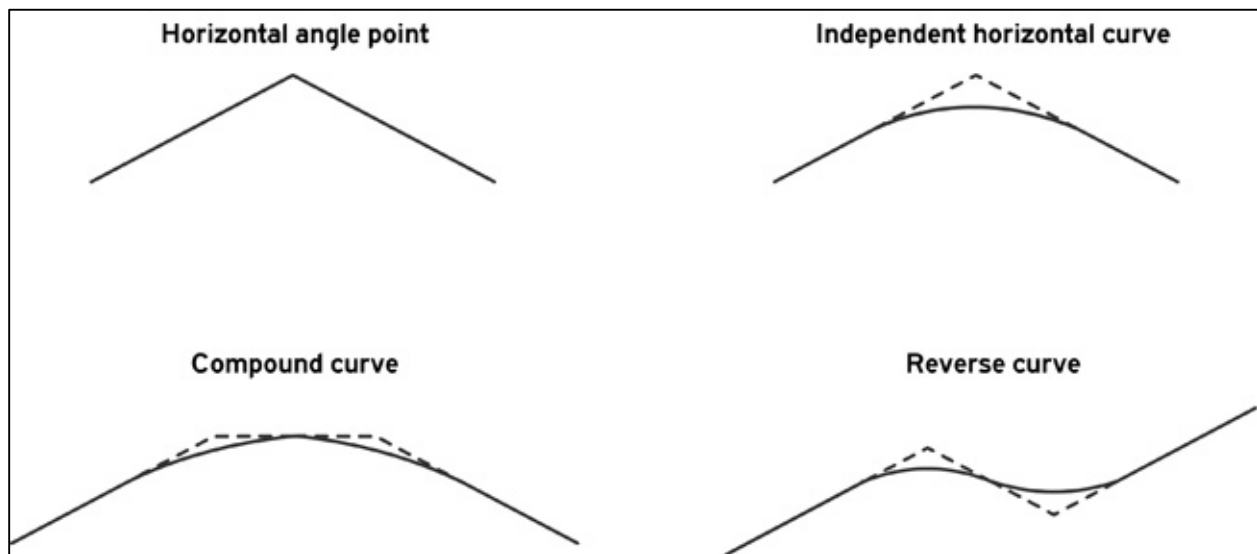


FIGURE 4 Curve types defined in MIRE (28).

MIRE has a specific subcategory for horizontal curve data, which includes the following MIRE elements (28).

- 107.Curve Identifiers and Linkage Elements
- 108.Curve Feature Type
- 109.Horizontal Curve Degree or Radius
- 110.Horizontal Curve Length
- 111.Curve Superelevation
- 112.Horizontal Transition/Spiral Curve Presence
- 113.Horizontal Curve Intersection/Deflection Angle
- 114.Horizontal Curve Direction

The updated CurveFinder was designed to extract all MIRE elements from GIS roadway maps except for Element 111 Superelevation, which can only be obtained from field surveys. For each curve extracted by CurveFinder, it includes information on curve type, curve degree, curve radius, curve length, whether there is a presence of transition section, the deflection angle if the curve is a horizontal angle point, and the curve direction. The attribute table of the extracted curve shapefile includes the MIRE elements' information. Table 1 illustrates an example of how attributes in a Curve GIS shapefile associate with the MIRE elements.

TABLE 1 Example of a curve shapefile's attributes in association with MIRE elements.

Curve Shapefile Attribute	Associated MIRE Element	Remarks
TASLINKID	107 Curve Identifiers and Linkage Elements	
TRNLINKID	107 Curve Identifiers and Linkage Elements	
TRNNODEF	107 Curve Identifiers and Linkage Elements	
TRNNODE_F	107 Curve Identifiers and Linkage Elements	
TRNNODE_T	107 Curve Identifiers and Linkage Elements	
CURV_TYPE	108 Curve Feature Type	<ul style="list-style-type: none"> • Horizontal Angle Point • Independent Horizontal Curve • Reverse Curve • Component of Compound • Transition
RADIUS	109 Horizontal Curve Degree or Radius	<ul style="list-style-type: none"> • Does not apply to Horizontal Angle Point and Transition • Measured in meter
DEGREE	109 Horizontal Curve Degree or Radius	<ul style="list-style-type: none"> • Does not apply to Horizontal Angle Point and Transition • Measured in meter
CURV_LENG	110 Horizontal Curve Length	<ul style="list-style-type: none"> • Measured in meter
HAS_TRANS	112. Horizontal Transition/Spiral Curve Presence	<ul style="list-style-type: none"> • Transition only
INTSC_ANGLE	113 Horizontal Curve Intersection Angle	<ul style="list-style-type: none"> • Only for Horizontal Angle Point • Measured in degree
CURVE_DIRE	114 Horizontal Curve Direction	<ul style="list-style-type: none"> • Left or right

The AASHTO Green Book defines independent horizontal curves as curves separated by a tangent of at least 183 meters or 600 feet (29). Therefore, CurveFinder tentatively uses the AASHTO definition. If two curves are separated by a tangent less than the minimum separation distance, these two curves are considered components of compound curves if curve directions are the same, or components of reverse curves if curve directions are different. If a reverse curve and another horizontal curve are located within 183 m, both curves are therefore considered to form a compound curve. This horizontal curve is accordingly considered as a compound curve. On the other hand, according to MIRE, if two segments intersect at an angle, the two segments are classified as a Horizontal Angle Point. CurveFinder assumes that a Horizontal Angle Point is always independent, which is never included in a compound

curve. Figure 5 illustrates the curve type classification algorithm implemented in the improved CurveFinder, based on which MIRE curve type is assigned to every identified curve.

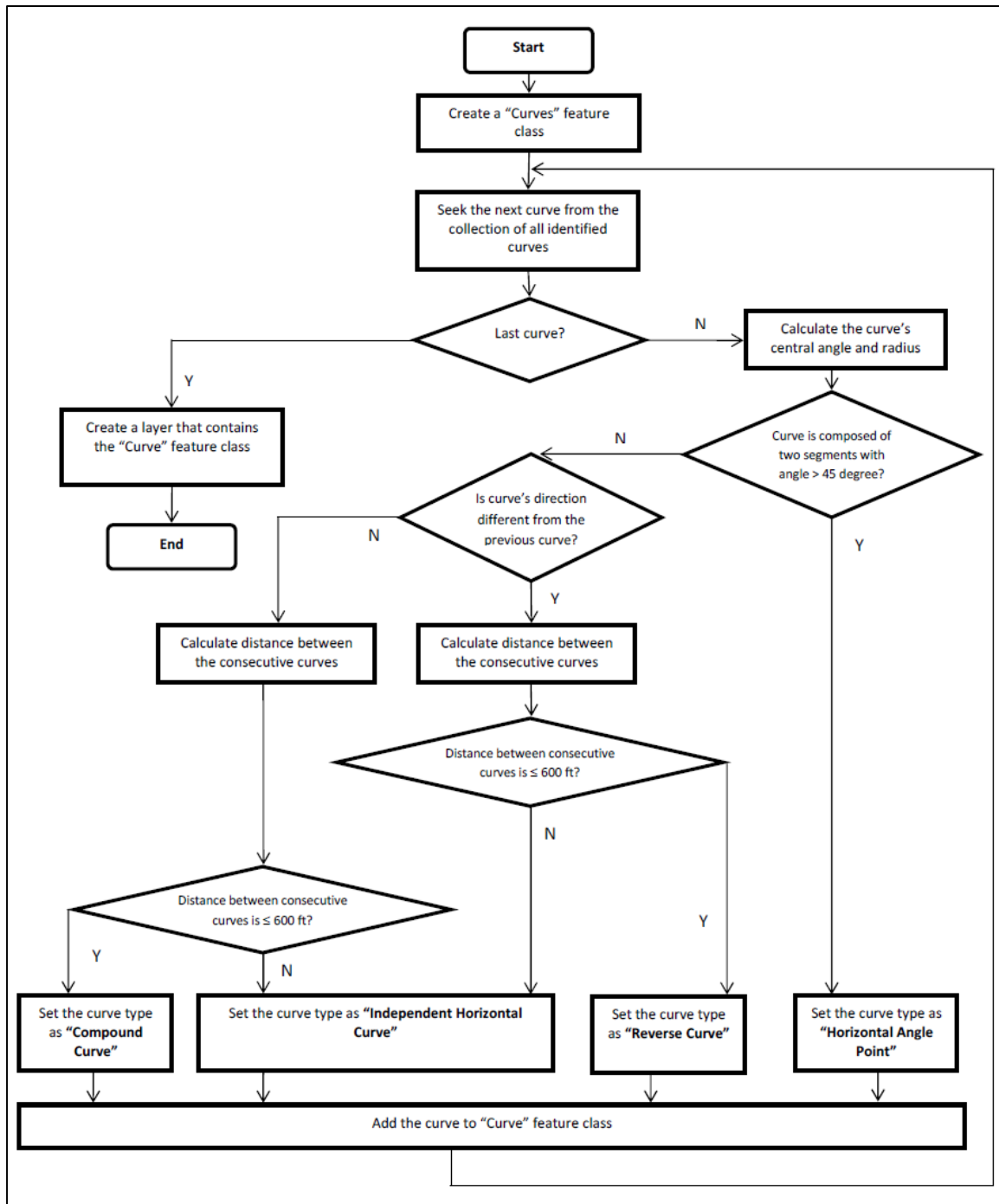


FIGURE 5 Algorithm for MIRE Curve Type Classification.

APPLICATION OF CURVEFINDER

Local roads in Iowa comprise the majority of the rural surface transportation system, or about 90,000 miles of roads, of which almost 80% are unpaved. Rural public roadway maps were used for curve data extraction. Figure 6 illustrates an overview of the identified curves from Counties of Adams and Taylor of Iowa.

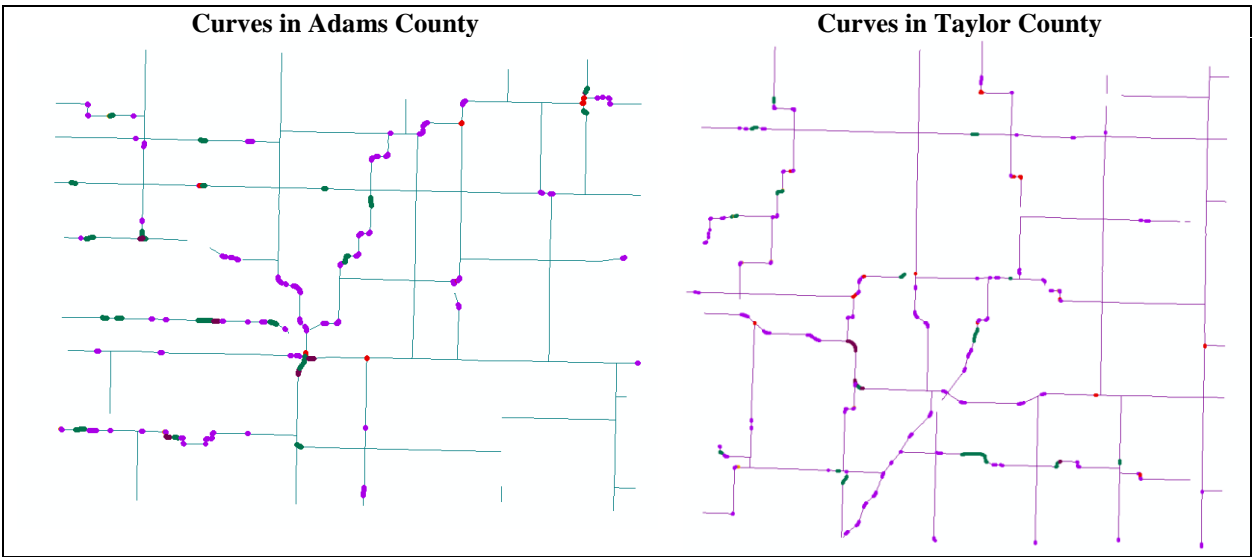
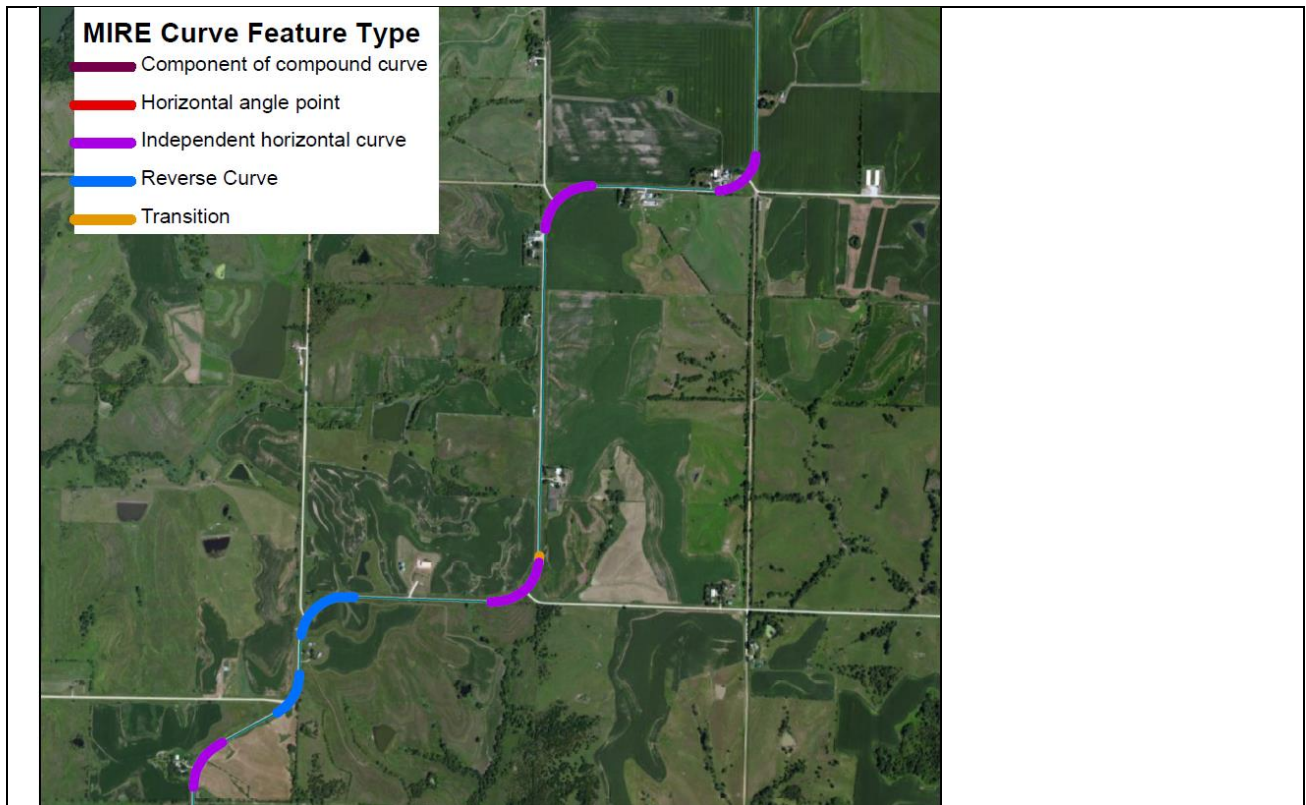


FIGURE 6 Identified curves in two counties of Iowa.

Figure 6 illustrates that all curves from the road network shown in the figure are identified by CurveFinder. Figure 7 provides a more detailed view of the identified curves with different curve types. Specifically, Figure 7a illustrates an example showing independent horizontal curves and reverse curves; Figure 7b demonstrates a compound curve with transition section; and Figure 7c shows an example of horizontal angle point. Figure 8 shows an example of the attributes of an extracted curve.



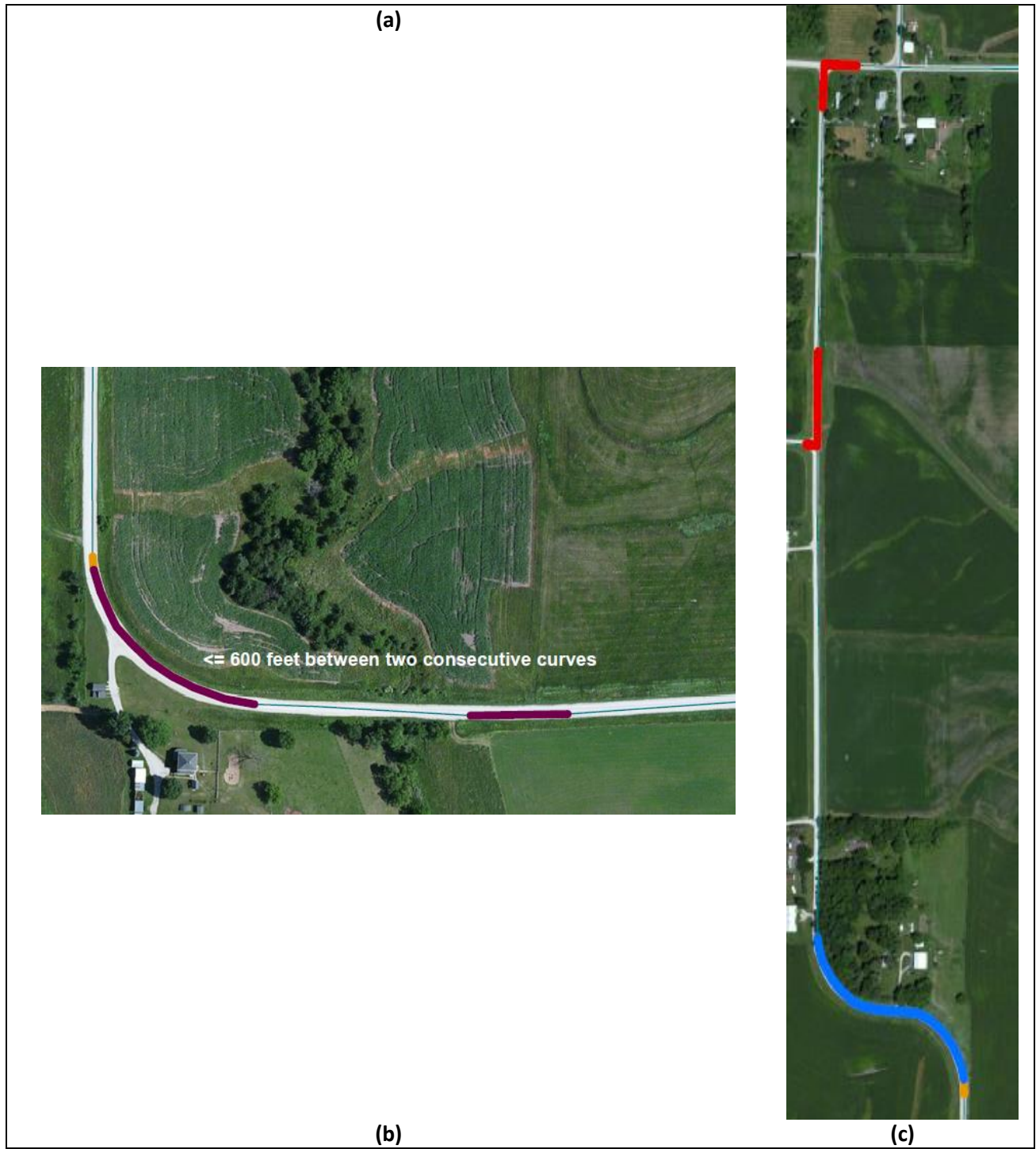


FIGURE 7 Example of identified curves with different types.

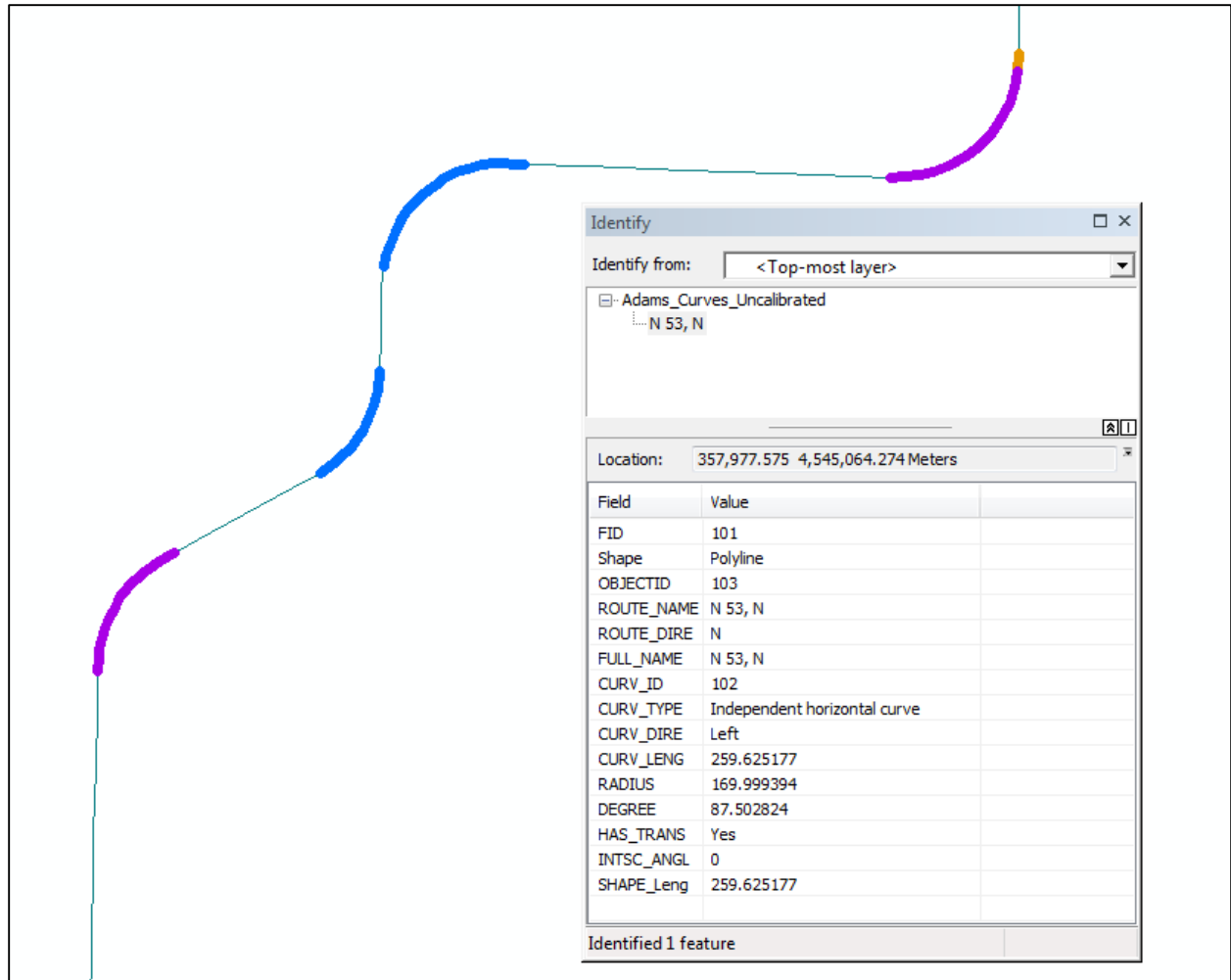


FIGURE 8 Example of attributes of an extracted curve.

Curve Identification Accuracy

The curve identification accuracy was evaluated by three performance measures: Identification Rate (IR), False Identification Rate (FIR), and curve end point accuracy. The evaluation was conducted by comparing the identified curves with the ground truth control curves. If there is no overlapping portion between a ground truth curve and any identified curve, the curve is considered 100% missed. Otherwise, the ratio between the overlapped length and the ground truth curve length is calculated and recorded as Identified Portion per Curve (IPC). The IR is the ratio between number of curves that are not 100% missed and number of ground truth curves. The FIR is the ratio between number of tangent sections identified as curves and number of ground truth curves. The higher the IR is and the lower the FIR is, the more accurate the curve identification is. The following two equations define how IR and FIR are computed:

$$IR = \frac{m}{n} \quad (10)$$

$$FIR = \frac{l}{n} \quad (11)$$

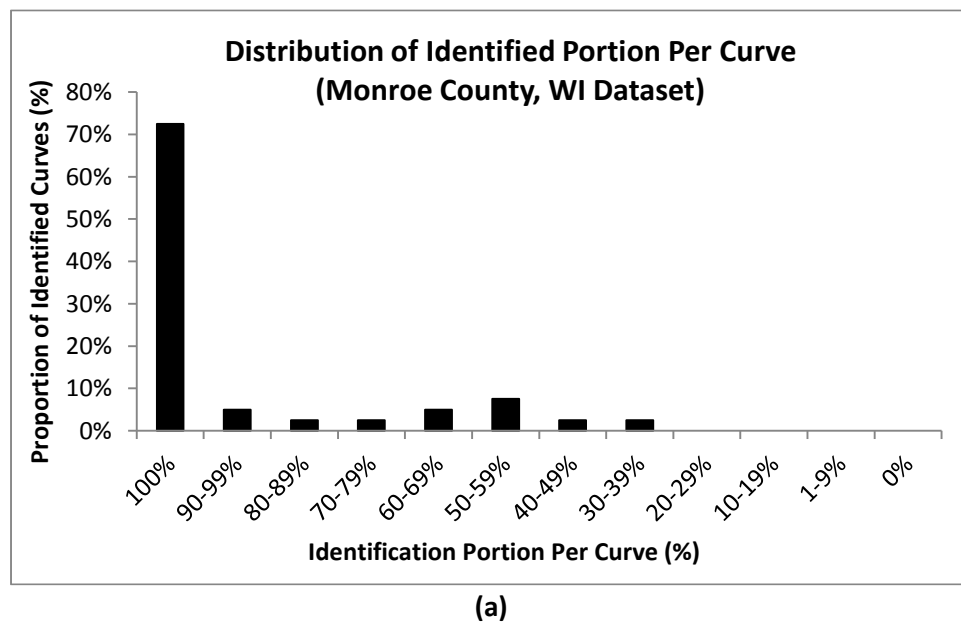
Where, IR = identification rate (%);
 FIR = false identification rate (%);
 n = number of ground truth curves;
 m = number of ground truth curves that are not 100% missed; and
 l = number of tangent sections identified as curves;

CurveFinder was also applied to data from Monroe County in WI and Morris County in New Jersey. The results (shown in Table 2) reveal that none of the control curves were missed by CurveFinder while there are a small number of false identifications by mistakenly recognizing tangent sections as curves.

TABLE 2 Evaluation results for curve identification accuracy.

	Number of Ground Truth Curves	IR	FIR
Iowa	249	100%	15%
Monroe County, WI Data	40	100%	6%
Morris County, NJ Data	48	100%	10%

On the other hand, another performance measure termed as Distribution of Identified Portions per Curve (DIPC) is introduced to evaluate how completely the curves are identified. DIPC is a distribution of completeness of curves identification into 12 completeness levels (i.e., 0% identified, 1-9% identified, 10-19% identified, ..., 90-99% identified, and 100% identified). Figures 9a and 9b illustrate the DIPC for the Monroe County, WI dataset and the Morris County, NJ dataset, respectively.



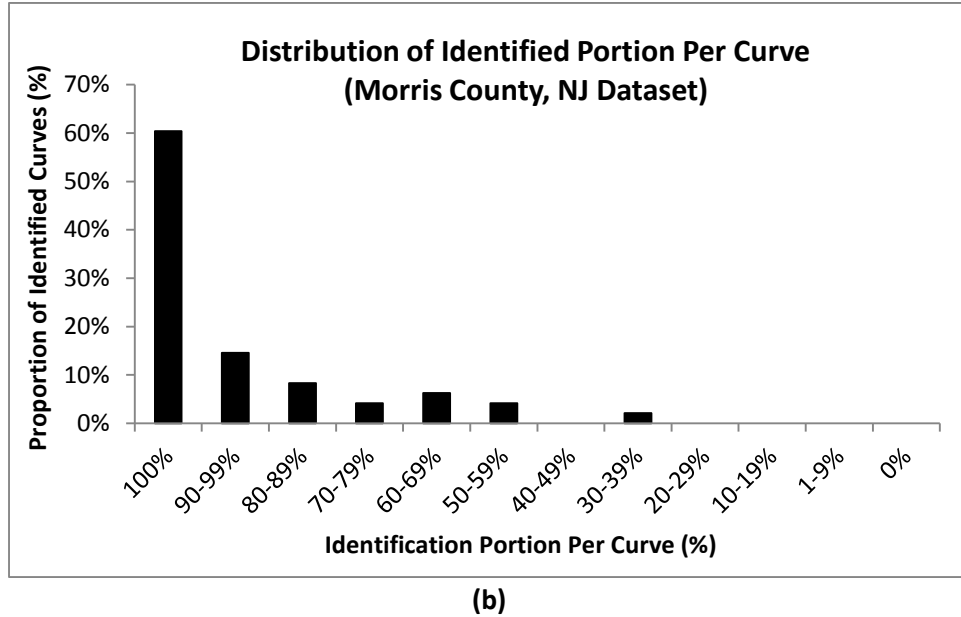


FIGURE 9 DIPCs for the Iowa, Wisconsin and New Jersey datasets.

According to Figure 9, the DIPCs for all the three datasets show a similar pattern that the majority of the curves are 100% identified. Identification completeness of the remaining curves is almost evenly distributed within the range between 30-39% and 90-99%. None of the curves is completely missed.

Impact of Low-Quality GIS Roadway Data

During the investigation of the curve identification errors, special attention has been paid to analyzing the reasons that caused the missing portions in the identified curves as well as the false identification of tangent sections as curves. Low-quality GIS maps as representations of roadway segments is a major cause of the curve identification errors. There are two typical scenarios involved with the low quality data.

- Scenario 1 is the roadway centerline transverse error, namely deviation of the GIS centerline from the actual alignment. This source data error may be due to the human error in the map digitizing phase. An example of Scenario 1 is shown in Figure 10a.
- Scenario 2 is the low vertex resolution of the GIS roadway centerline to describe the actual alignment of the roadway. Figure 10b shows an example.



FIGURE 10 Typical scenarios of low-quality GIS source data.

Both low-quality scenarios can be common in the GIS shapefiles due to digitizing errors. Particularly, Scenario 1 is more likely to occur on low-volume roads while the chance for Scenario 2 to occur is similar on low-volume roads and other roads. To improve the accuracy of curve data extraction for low-quality GIS data, solutions were investigated and are described in the following section.

IMPROVING CURVEFINDER ALGORITHM FOR LOW-QUALITY GIS DATASETS

Curve Finder preparation, calibration, and run for production of final results has been streamlined into a five-step process contained within an ArcMap toolbox containing models which reference internally managed python scripts. This is an improvement from previous approaches as it creates an easy to follow process with reduced need for user documentation to have reproducible results. The five step-process is described after describing the two methods used to improve the data quality of low-quality GIS datasets.

Pre-processing to Improve Low-quality Datasets

As described above, the CurveFinder algorithm is sensitive to the vertex density in order to accurately define the start and end points of curves. Simply adding vertices to the line at regular intervals is not sufficient and would result in identified curves that are shorter or longer than the actual curves. Therefore, the following two smoothing algorithms were used to prepare the data before applying CurveFinder algorithm:

1. Polynomial Approximation with Exponential Kernel (PAEK): This smoothing algorithm can be interpreted as a best fit of the vertices of the input line as shown in Figure 11a. A tolerance is specified for how closely the path of the output features must pass to the vertices defining the input features. The process described below creates lines using tolerances of 2, 4, 6, 8, 10, 12, 14, and 16 meters to create new geometries that are subsequently passed to the CurveFinder and calibration steps. An example of the change in vertex density is shown in Figure 12a.
2. Bezier Interpolation: This algorithm can be best thought of as a spline where by the output line passes through all vertices of those in the input features as shown in Figure 11b. The features created are not spatial lines in the traditional sense with vertices but are rather defined as true curves. In order to create geometries with vertices for use with the curve finder algorithm, a subsequent step generates vertices given a deviation tolerance. The current approach creates geometries using deviations of 0.1 to 1.0 meters at 0.1 meter intervals. An example of the vertex density change is shown in Figure 12b.

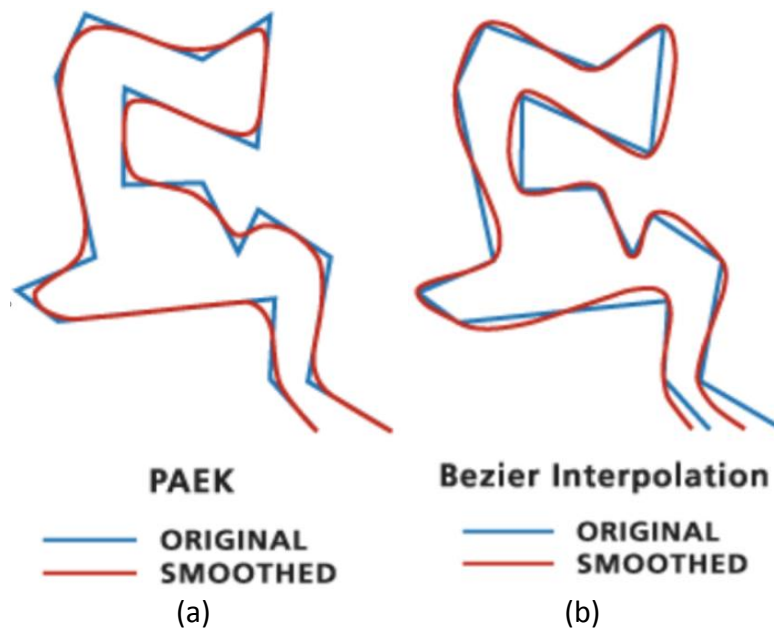


FIGURE 11 Smoothing Algorithms

An example output of the two smoothing processes is given below. Note that the output line is displayed as offset from the original line for display purposes but the true output follows the path of the inputs. The pre-processing step creates 20 new datasets; 10 for each of the smoothing algorithms applied with various tolerance and deviation values.

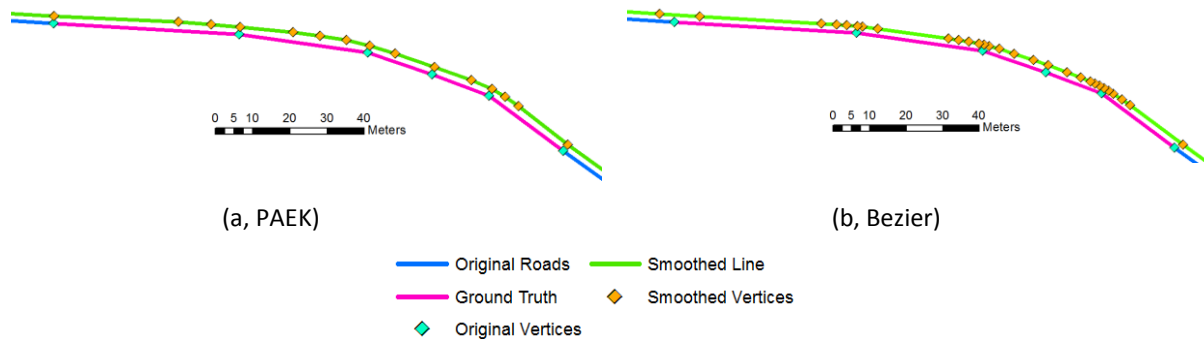


FIGURE 12 Vertex density of original features vs smoothed by two algorithms

CurveFinder Steps

As part of improving CurveFinder algorithm for addressing low-quality datasets, the process has been revamped to the following five steps:

1. Dissolve Roads based on user provided road identifier field. This step was previously the initial step and while easy to do, some intricacies with the dissolving process could create multipart features that do not work well with the curve finder algorithm. In addition to the out of the box dissolve tool, an additional step assures that only single part features are present in the output.
2. Select Intersecting Roads. Given user provided ground truth information or features visually identified as curves by the analyst, roads in the user provided dataset are selected. The subsequent calibration step is quite processing intensive and it speeds up the process to only include the subset of road features for which ground truth or identified curves are present.
3. Prepare Ground Truth. The ground truth information is prepared with appropriate columns. Most importantly, a unique identifier column corresponding to the segment id of the road features is appended to the ground truth feature. This allows for an attribute match of curves identified during the calibration process to the original ground truth feature as well as the input segment on which it was found.
4. Run Calibration. This is an iterative process by which the original road segments as well as smoothed road features by means of best fit and spline methods with a variety of offset and angle thresholds are passed to the curve finder algorithm which itself is run with a variety of angle thresholds from 0.5 to 2 degrees. 231 output curves versions are created during this intermediate step. The final step of the process is to rank the performance by comparing the number of curves identified on a per segment basis with the number of ground truth features for the respective segment with results provided in a table, an example of which is shown in Table 3. The lowest sum of under and over-identified curves (score, shown in Table 3) is considered to be the best. In addition to a ranking of the input parameters by difference in identified feature counts, the output table also provides metrics comparing the length differences and endpoint offsets of geometries of ground truth features compared to the nearest identified curve. For the sake of visual comparison, the output path of the identified curves is also provided. The information in the table lets the user make an informed determination of which smoothing approach to use if any as well as the best angle threshold for curve identification. An example of the output is given in the table below. Regardless of this step, it is important to keep in mind that the quality of outputs is heavily dependent on the quality of inputs. As shown in the example below, poor quality inputs cannot be improved by means of the methods described above to create an accurate determination of curves.

TABLE 3 Example output table from calibration step.

OBJECTID *	method	deviation	tolerance	angle	cnt_unde	cnt_over	len_under	len_over	srt_offset	end_offse	score	path
1	No Smooth	<Null>	<Null>	1.5	0	73	3250.173	147353	72324.52	67231.24	73	C:\tmp\original_curves.gdb\monroe_sub_1p5
2	No Smooth	<Null>	<Null>	1.4	0	78	4007.16	148014.6	73876.91	68639.8	78	C:\tmp\original_curves.gdb\monroe_sub_1p4
3	No Smooth	<Null>	<Null>	1.3	0	80	4007.16	148149.6	74047.19	68595.91	80	C:\tmp\original_curves.gdb\monroe_sub_1p3
4	No Smooth	<Null>	<Null>	1.2	0	89	4083.176	151819.4	76893.25	71048.63	89	C:\tmp\original_curves.gdb\monroe_sub_1p2
5	No Smooth	<Null>	<Null>	1.1	0	92	4083.176	157056.2	78696.23	72853.91	92	C:\tmp\original_curves.gdb\monroe_sub_1p1
6	No Smooth	<Null>	<Null>	0.9	0	94	5063.764	160002.1	82962.59	75282.66	94	C:\tmp\original_curves.gdb\monroe_sub_0p9
7	No Smooth	<Null>	<Null>	1	0	94	4083.176	158170.7	80100.62	74506.26	94	C:\tmp\original_curves.gdb\monroe_sub_1p0
8	No Smooth	<Null>	<Null>	0.8	0	95	5514.921	160751	84393.88	77478.1	95	C:\tmp\original_curves.gdb\monroe_sub_0p8
9	No Smooth	<Null>	<Null>	0.7	0	100	5514.921	163830.8	86044.23	79427.13	100	C:\tmp\original_curves.gdb\monroe_sub_0p7
10	No Smooth	<Null>	<Null>	0.6	0	104	6256.252	165450.5	87989.1	82037.65	104	C:\tmp\original_curves.gdb\monroe_sub_0p6
11	No Smooth	<Null>	<Null>	0.5	0	107	7629.875	167951	87577.36	87348.23	107	C:\tmp\original_curves.gdb\monroe_sub_0p5
12	Bezier	1.0 Meters	<Null>	1.5	0	148	6788.198	195302.1	106609.8	102778.7	148	C:\tmp\smoothed_curves.gdb\monroe_sub_bezier_01_0_1p5
13	Bezier	0.9 Meters	<Null>	1.5	0	151	6277.193	200897.6	108135.7	104579.6	151	C:\tmp\smoothed_curves.gdb\monroe_sub_bezier_00_9_1p5
14	Bezier	1.0 Meters	<Null>	1.3	0	152	8022.868	197462.5	110591.3	104674.5	152	C:\tmp\smoothed_curves.gdb\monroe_sub_bezier_01_0_1p3
15	Bezier	1.0 Meters	<Null>	1.4	0	153	7230.19	199252.5	110806.3	105697	153	C:\tmp\smoothed_curves.gdb\monroe_sub_bezier_01_0_1p4
16	Bezier	0.9 Meters	<Null>	1.3	0	154	8051.872	203104.9	112063	105791.1	154	C:\tmp\smoothed_curves.gdb\monroe_sub_bezier_00_9_1p3
17	Bezier	0.9 Meters	<Null>	1.4	0	155	7259.194	204978.3	112312.2	106858.3	155	C:\tmp\smoothed_curves.gdb\monroe_sub_bezier_00_9_1p4
18	Bezier	1.0 Meters	<Null>	1.2	0	158	8336.927	201320	113195.7	108340.7	158	C:\tmp\smoothed_curves.gdb\monroe_sub_bezier_01_0_1p2

5. Run Final. Given the optimum parameters identified in the previous step, the whole input dataset is run. Visual and numeric inspection of the identified curves is then completed by the analyst.

Figure 13 shows a graphical representation of the curve identification process.

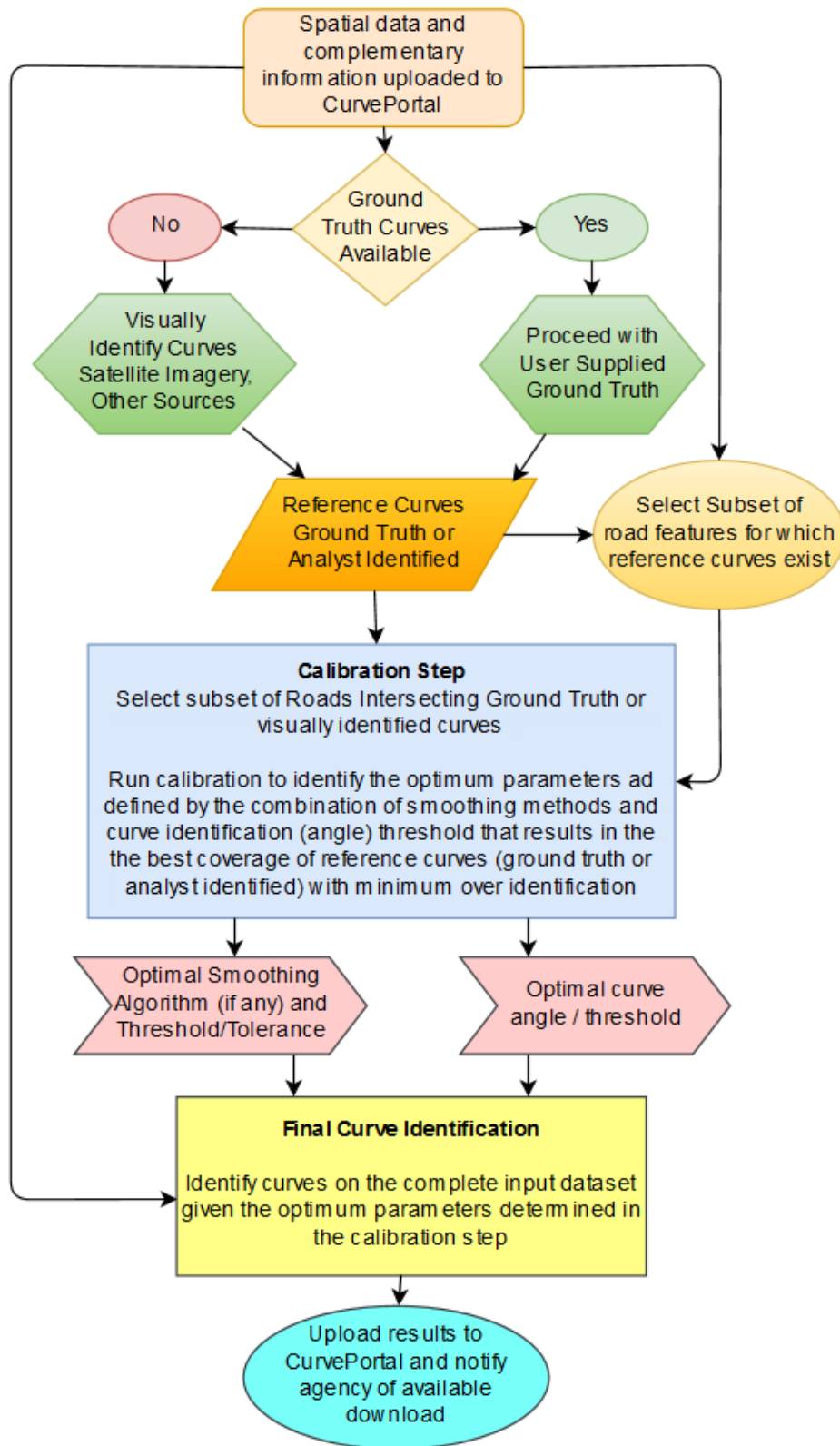


FIGURE 13 Curve identification process flowchart

APPLICATION OF UPDATED CURVEFINDER TO IOWA DATASET

The previous preprocessing and calibration steps were applied to the Iowa primary network dataset for which ground truth was available and was previously used for algorithm calibration. This made it a suitable candidate for an evaluation of improvements provided by the preprocessing steps. For the sake of processing efficiency, only road segments intersecting ground truth segments were considered. The segments were dissolved based on common road identifier attributes. The ground truth segments were spatially joined with the dissolved roads subset to add an identifier for the input road segment for calibration purposes. The ranked list of smoothing algorithms with relevant parameters and angle thresholds for curve identification as well as visual inspection suggested that the best approach was the Bezier smoothing algorithm with a two meter deviation and an angle threshold of 0.7 degrees. Spatial joins and manual calculation were used to generate Figure 14 which shows the improvement by using the preprocessing steps and optimal angle threshold compared with previous curve identification attempts. The figure shows the percentage of curves identified within each 10% range coverage bin. The preprocessing step resulted in substantially more identified curves covering 100% of the respective ground truth features.

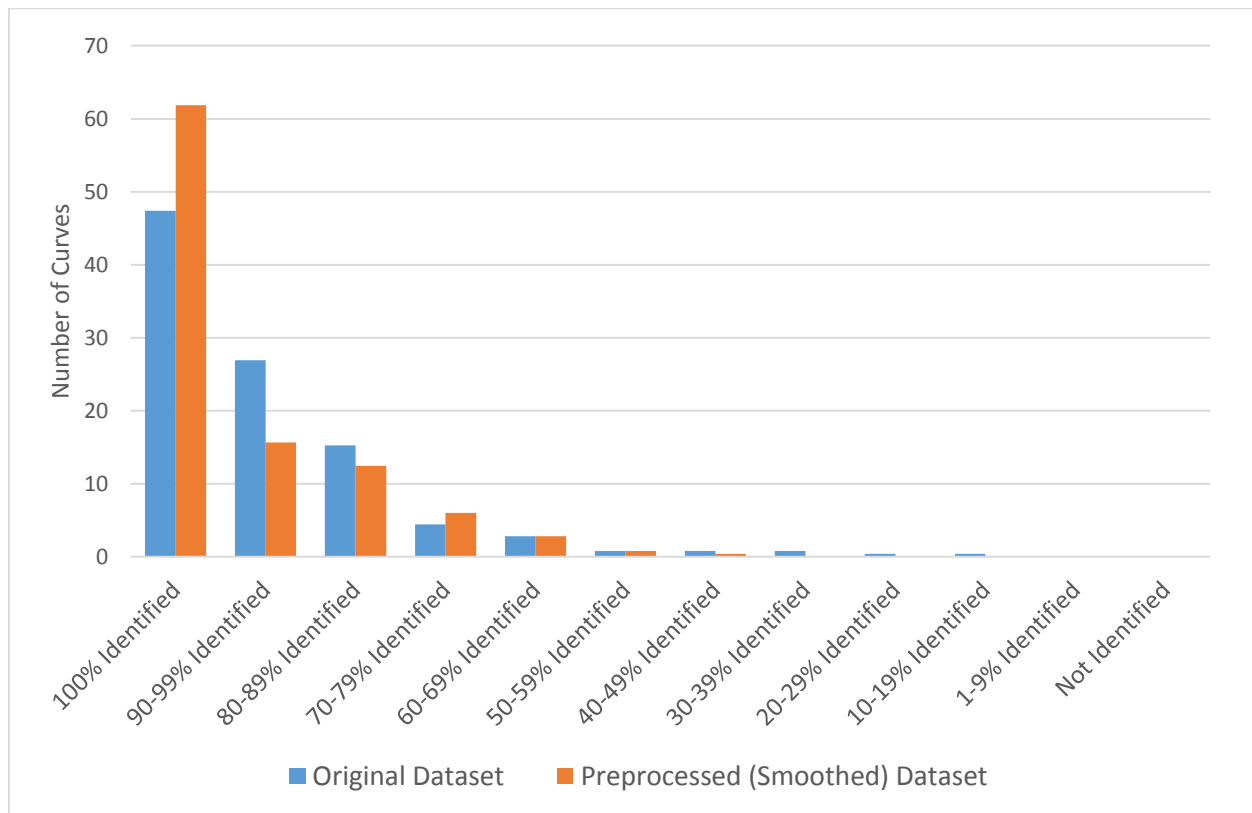


FIGURE 14 Ground truth curve identification by percentage of curve identified

CURVEPORTAL INTERFACE

The research team developed a CurvePortal interface that can be accessed by interested transportation agencies to upload their GIS roadway shapefiles for curve data extraction. The CurvePortal is available at: <http://curveportal.cce.wisc.edu/> and the webpage is shown in Figure 15.

HOME

Building on the extensive experience with geographic information systems (GIS), data integration and safety analysis, the University of Wisconsin TOPS Lab developed CurveFinder, a tool to extract horizontal curve location and geometric information automatically from GIS roadway maps. CurveFinder was successfully used in Wisconsin and Iowa. CurveFinder incorporates compatibility with FHWA's Model Inventory of Roadway Elements (MIRE) curve elements. The CurvePortal is a web interface for extracting horizontal curve location and geometric information automatically from GIS roadway maps. CurvePortal will provide curve data in GIS format for easy integration with existing asset management, roadway inventory, and crash datasets.



FIGURE 15 Snapshot of CurvePortal Webpage

PLANS FOR IMPLEMENTATION

The research team has reached out to several state departments of transportation across the United States for using CurvePortal. Some of the states include Delaware, Indiana, Michigan, Minnesota, New Jersey, Washington. Currently, discussions are ongoing with some of the states for using CurvePortal. Research team is also exploring possibility of using CurvePortal as part of the Data-Driven Safety Analysis topic under the Every Day Counts initiative of FHWA.

CONCLUSIONS

The University of Wisconsin-Madison had developed and demonstrated CurveFinder that automatically identifies horizontal curves and extracts their geometric characteristics solely from GIS roadway maps. Through this Type 2 IDEA project, the research team set out to:

1. Incorporate the ability in CurveFinder to extract curve-related MIRE elements;
2. Improve the accuracy of CurveFinder for low-quality GIS data sources;
3. Develop an online portal called CurvePortal where agencies can upload their GIS roadway maps for obtaining horizontal curve location and geometric information.

The updated CurveFinder extracts all MIRE elements from GIS roadway maps except for Element 111 Superelevation, which can only be obtained from field surveys. For each curve extracted by CurveFinder, information on curve type, curve degree, curve radius, curve length, whether there is a presence of transition section, the deflection angle if the curve is a horizontal angle point, and the curve direction is included as attributes in the GIS shapefile.

In addition, to improve the accuracy of CurveFinder for low-quality GIS datasets, two smoothing methods are used to preprocess the data before applying the CurveFinder algorithm. Calibration is performed by an iterative process by which the original road segments as well as smoothed road features by means of best fit and spline methods with a variety of offset and angle thresholds are passed to the curve finder algorithm. The application of preprocessing steps can result in better identification of the start and end points of curves as demonstrated by the increase in percentage of curves identified. This is especially true in cases of low quality input datasets with sparse vertex density.

CurvePortal, an online portal was developed and is hosted at www.curveportal.cee.wisc.edu. Through this IDEA Type 2 project, the University of Wisconsin-Madison team has made significant improvements to CurveFinder and developed the CurvePortal.

REFERENCES

1. NHTSA Traffic Facts, 2007, Rural/Urban Comparison - DOT HS 810 996.
2. Statistics of National Highway Safety Administration, 2007, <http://www-fars.nhtsa.dot.gov/Crashes/>
3. Zegger, C.V., Stewart, J.R., Council, F.M., Reinfurt, D.W., and Hamilton, E. (1992). "Safety Effects of Geometric Improvements on Horizontal Curves." *Transportation Research Record* 1356, Transportation Research Board, National Research Council, Washington, D.C., 1992, pp. 11-19.
4. Lamm, R., Choueiri, E.M., Hayward, J.C., and Paluri, A. (1988). "Possible Design Procedure to Promote Design Consistency in Highway Geometric Design on Two-Lane Rural Roads." *Transportation Research Record* 1195, Transportation Research Board, National Research Council, Washington, D.C., 1988, pp. 111-122.
5. Lin, F.B. (1990) "Flattening of Horizontal Curves on Rural Two-Lane Highways." *Journal of Transportation Engineering*, 116(2), pp. 181-193.
6. Federal Highway Administration. (2004). NCHRP Report 500 Volume 7: A guide for Reducing Collisions on Horizontal Curves.
7. Schneider, W., Zimmerman, K., Van Boxel, D., and Vavilikolanu, S. (2009). "Bayesian Analysis of the Effect of Horizontal Curvature on Truck Crashes Using Training and Validation Data Sets." *Transportation Research Record* No. 2096, TRB, National Research Council, Washington, Dc., 2009, pp. 41-46.
8. Schneider, W., Zimmerman, K., Savolainen, P., and Moore, D. (2010). "Effects of Horizontal Curvature on Single-Vehicle Motorcycle Crashes along Rural Two-Lane Highways." *Transportation Research Record* No. 2194, TRB, National Research Council, Washington, D.C., 2010, pp. 91-98.
9. Dong, H., Easa, S.M., and Li, J. (2007). "Approximate Extraction of Spiralled Horizontal Curves from Satellite Imagery." *Journal of Surveying Engineering*, 133(1), pp. 36-40.
10. Easa, S. M., Dong, H., and Li, J. (2007). "Use of satellite imagery for establishing road horizontal alignments." *Journal of Surveying Engineering*, 133(1), pp. 29-35.
11. Breyer, J P (2000). "Tools to Identify Safety Issues for a Corridor Safety-Improvement Program." *Transportation Research Record* 1717, pp. 19-27.
12. Souleyrette, R., Kamyab, A., Hans, Z., and Khattak, A. (2002). "Systematic Identification of High Crash Locations", *Transportation Research Board 81st Annual Meeting CD-ROM*, Washington D.C, 2002.
13. Yun, D. and Sung J. (2005). "Development of Highway Horizontal Alignment Analysis Algorithm Applicable to the Road Safety Survey and Analysis Vehicle, ROSSAV." *Proceedings of the Eastern Asia Society for Transportation Studies*, 5, pp. 1909 – 1922.
14. Kim, J.S., Lee, J.C., Kang, I.J., Cha S.Y., Choi, H., and Lee, T.G. (2008). "Extraction of Geometric Information on Highway using Terrestrial Laser Scanning Technology." *ISPRS Congress. ISPRS*, 2008. pp. 539-544.
15. Hashim, I.H. and Bird, R.N. (2004). "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.
16. Watters, P. and O'Mahony, M. (2007) "The relationship between geometric design consistency and safety on rural single carriageways in Ireland", *Proceedings of the European Transport Conference*, Leiden, The Netherlands, October 2007.
17. Imran, M., Hassan, Y., and Patterson, D. (2006). "GPS-GIS-Based Procedure for Tracking Vehicle Path on Horizontal Alignments." *Computer-Aided Civil and Infrastructure Engineering*, 21(5), pp. 383-394.
18. Hans, Z., Jantscher, T., Souleyrette, R., and Larkin, R. (2009). "Development of a Statewide Horizontal Curve Database for Crash Analysis." *Proceedings of Mid-Continent Transportation Research Symposium*. Iowa State University. Ames, IA.
19. Price, M. (2010). "Under Construction - Building and calculating turn radii" *ArcUser*, Winter 2010, pp. 50-56.
20. Environmental Systems Research Institute (ESRI) Inc (2009). *ArcGIS Desktop 9.3.1*. Redlands, CA.
21. Rasdorf, W., Findley, D. J., Zegeer, C.V., Sundstrom, C. A., Hummer, J. E. (2011) "Evaluation of GIS Applications for Horizontal Curve Data Collection" *ASCE Journal of Computing in Civil Engineering*, doi:10.1061/(ASCE)CP.1943-5487.0000127.
22. Dial, G., Gibson, L., and Poulsen, R. (2001). "IKONOS satellite imagery and its use in automated road extraction." *Automatic extraction of manmade objects from aerial and space images (III)*, E. P. Baltsavias, A. Grün, and L. V. Gool, eds., Balkema, Lisse, pp. 357-367.
23. 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*, 34 (Part 3B), pp. 406-411.

24. Anil, P.N. and Natarajan, S. (2010) "Automatic Road Extraction from High Resolution Imagery Based On Statistical Region Merging and Skeletonization." *International Journal of Engineering Science and Technology*, 2(3), pp. 165-171.
25. Keaton, T. and Brokish, J. (2003) "Evolving roads in IKONOS multispectral imagery." *Proceedings of International Conference on Image Processing (ICIP 2003)*, pp. 1001-1004.
26. Florida Department of Transportation (FDOT) (2010). "Geographic Information System (GIS): Curvature Extension for ArcMap 9.x." Transportation Statistics Office, FDOT. Tallahassee, FL.
27. Li, Z., Chitturi, M., Bill, A., & Noyce, D. (2012). Automated identification and extraction of horizontal curve information from geographic information system roadway maps. *Transportation Research Record: Journal of the Transportation Research Board*, (2291), 80-92.
28. Lefler, N., Council, F., Harkey, D., Carter, D., McGee, H., & Daul, M. 2010. "Model Inventory of Roadway Elements-MIRE, Version 1.0", *FHWA-SA-10-018*.
29. A Policy on Geometric Design of Highways and Streets, 6th Edition, American Association of State Highway & Transportation Officials, 2011.

RESEARCH RESULTS

NCHRP IDEA Program Committee

March 2018

Title: CurvePortal for Automated Identification and Extraction of Horizontal Curve Information

Project Number: NCHRP-185
Duration: July 2015 – June 2017

Product Category: Safety Data

Principal Investigator:
David A. Noyce
Professor, University of Wisconsin-Madison
608 265 1882
danoyce@wisc.edu

CurvePortal for Automated Identification and Extraction of Horizontal Curve Information

Developed an algorithm and a web interface for extracting horizontal curve location and geometric information automatically from GIS roadway maps.

WHAT WAS THE NEED?

Twenty-seven percent of fatal crashes occur at horizontal curves. The 2009 Manual on Uniform Traffic Control Devices (MUTCD) states that on roadways with more than 1,000 AADT that are functionally classified as arterials or collectors, horizontal alignment warning signs shall be used. Having a complete horizontal curve database covering all roads, including county and local roads is essential to reach the Towards Zero Deaths goal and meet the MUTCD requirements. Many states do not have horizontal curve data for all of their roads, especially county and

local roads.

Existing methods for horizontal curve data extraction are usually expensive or require cumbersome data processing. Under the current economic climate, cost-effective and innovative methods are required to extract horizontal curve information for other roadways. GIS roadway maps which are already available at most transportation agencies are an alternative source for low-cost extraction of curve data for the entire roadway system. Previous GIS-based methods are either manual or semi-automatic or based on GPS data that requires additional data collection. Therefore, there is a need to develop methods that would automatically obtain curve information from existing data sources such as GIS roadway maps.

WHAT WAS OUR GOAL?

The goal was to improve the performance of the previously developed CurveFinder algorithm on low-quality datasets as well as incorporate Model Inventory of Roadway Elements (MIRE) compatibility. Following this, develop CurvePortal, a web interface for extracting horizontal curve location and geometric information

WHAT DID WE DO?

To improve the accuracy of CurveFinder for low-quality GIS datasets, two smoothing methods are used to preprocess the data before applying the CurveFinder algorithm. Calibration is performed within desktop GIS software by an iterative process by which the original road segments as well as smoothed road features by means of best fit and spline methods with a variety of offset and angle thresholds are passed to the curve finder algorithm. The various curve outputs obtained during this step are compared to ground truth data to identify the optimal parameters for CurveFinder. The application of the preprocessing and calibration steps resulted in better identification of the start and end points of curves. In addition, MIRE compatibility was incorporated. For each curve extracted by CurveFinder, information on curve type, curve degree, curve radius, curve length, whether there is a presence of transition section, the deflection angle if the curve is a horizontal angle point, and the curve direction is included as attributes in the GIS shapefile. Finally, CurvePortal, an online portal was developed and is hosted at www.curveportal.cee.wisc.edu. CurvePortal serves as an intuitive web interface by which users can upload spatial road features as well as ground truth data, if available.

WHAT WAS THE OUTCOME?

CurveFinder has been improved and CurvePortal interface is fully functional. Transportation agencies can use the CurvePortal in collaboration with the University of Wisconsin-Madison to obtain curve information from existing GIS roadway maps.



WHAT IS THE BENEFIT?

The chief benefit would be from long-term curve safety improvement from the availability of the horizontal curve data. Horizontal curves are a major contributor to the single-vehicle ROR crashes, and the horizontal curve location and geometric information is essential for placing curve warning and advisory speed signs. With the availability of system wide horizontal curve information, data driven decisions can be made to address curve safety and save lives. These benefits are usually prominent for rural county roads where roadway departure crashes typically occur and the horizontal curve data are usually unavailable.

Another benefit of this innovation from an economic viewpoint is that the proposed method is solely based on existing GIS roadway maps. Therefore, there is no need for additional data collection. The proposed innovation is software-based and uses readily available GIS roadway maps as the data source. With additional data collection not being required, the cost for obtaining horizontal curve data for an entire state using CurvePortal will be orders of magnitude lower than using the traditional methods.

LEARN MORE

To view the complete report:

<http://curveportal.cee.wisc.edu/>

