Automated Extraction of Horizontal Curve Data From GIS Roadway Maps

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Highway horizontal curves at low-volume roads

- A large proportion of crashes on low-volume roads are roadway departure crashes.
- Roadway departure crashes are 1.5 to four times more likely at curves than on tangent sections.
- Importance of the curves’ location and geometric information:
  - Integration of highway inventory data; and
  - Proposing safety countermeasures.
• Background:
  • Traditional curve data collection
    • Satellite imagery;
    • GPS surveying data (PhotoLog/VideoLog)
    • Laser scanning data
What CurveFinder does?

- CurveFinder:
  - Automatically detect all curves from a selected roadway layer;
  - Automatically classify curves;
  - Automatically compute the radius and degree of curvature for each simple curve, and curve length for all curves;
  - Automatically create GIS curve features and layers for all identified curves.
What CurveFinder does?

- Improved CurveFinder
  - Compatible with MIRE
    - Automatically classifies curves into
      - Compound Curve
      - Horizontal Angle Point
      - Independent Curve
      - Reverse Curve
      - Simple Transition
    - Extracted curve include all other MIRE curve elements
What CurveFinder does?

- MIRE Curve Elements
  - 107. Curve Identifiers and Linkage Elements
  - 108. Curve Feature Type
  - 109. Horizontal Curve Degree or Radius
  - 110. Horizontal Curve Length
  - 111. Curve Superelevation (cannot be extracted from GIS)
  - 112. Horizontal Transition/Spiral Curve Presence
  - 113. Horizontal Curve Intersection/Deflection Angle
  - 114. Horizontal Curve Direction
What CurveFinder does?

- Curve shapefile includes the following MIRE elements

<table>
<thead>
<tr>
<th>Column</th>
<th>MIRE Element</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>TASLINKID</td>
<td>107 Curve Identifiers and Linkage Elements</td>
<td></td>
</tr>
<tr>
<td>TRNLINKID</td>
<td>107 Curve Identifiers and Linkage Elements</td>
<td></td>
</tr>
<tr>
<td>TRNNODEF</td>
<td>107 Curve Identifiers and Linkage Elements</td>
<td></td>
</tr>
<tr>
<td>TRNNODE_F</td>
<td>107 Curve Identifiers and Linkage Elements</td>
<td></td>
</tr>
<tr>
<td>TRNNODE_T</td>
<td>107 Curve Identifiers and Linkage Elements</td>
<td></td>
</tr>
<tr>
<td>CURV_TYPE</td>
<td>108 Curve Feature Type</td>
<td>Horizontal Angle Point, Independent Horizontal Curve, Reverse Curve, Component of Compound Transition</td>
</tr>
<tr>
<td>RADIUS</td>
<td>109 Horizontal Curve Degree or Radius</td>
<td>Horizontal Angle Point and Transition do not have a radius, Measured in meter</td>
</tr>
<tr>
<td>DEGREE</td>
<td>109 Horizontal Curve Degree or Radius</td>
<td>Horizontal Angle Point and Transition do not have a degree, Measured in degree</td>
</tr>
<tr>
<td>CURV_LENG</td>
<td>110 Horizontal Curve Length</td>
<td>Measured in meter</td>
</tr>
<tr>
<td>HAS_TRANS</td>
<td>112 Horizontal Transition/Spiral Curve Presence</td>
<td>GIS data is not good enough to identify spiral curve</td>
</tr>
<tr>
<td>INTSC_ANGLE</td>
<td>113 Horizontal Curve Intersection/Deflection Angle</td>
<td>Only for Horizontal Angle Point, Measured in degree</td>
</tr>
<tr>
<td>CURVE_DIRE</td>
<td>114 Horizontal Curve Direction</td>
<td>Left or right</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CURV_ID</th>
<th>CURV_TYPE</th>
<th>CURVE_DIRE</th>
<th>CURV_LENG</th>
<th>RADIUS</th>
<th>DEGREE</th>
<th>HAS_TRANS</th>
<th>INTSC_ANGLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Independent horizontal curve</td>
<td>Left</td>
<td>76.2</td>
<td>838.3</td>
<td>5.2</td>
<td>No</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Reverse Curve</td>
<td>Right</td>
<td>19.2</td>
<td>360.1</td>
<td>3.1</td>
<td>No</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Reverse Curve</td>
<td>Left</td>
<td>20</td>
<td>182.6</td>
<td>6.3</td>
<td>No</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>Reverse Curve</td>
<td>Right</td>
<td>211.5</td>
<td>620.8</td>
<td>19.5</td>
<td>No</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>Reverse Curve</td>
<td>Left</td>
<td>208.7</td>
<td>404.7</td>
<td>29.5</td>
<td>No</td>
<td>0</td>
</tr>
</tbody>
</table>
- Algorithms for curve identification, classification, & computation

**Curve Identification**: Curve starts and ends when the bearing angle between two consecutive segments is greater and less than the bearing angle threshold.

**Curve Classification**: Curve starts and ends when the bearing angle between two consecutive segments is greater and less than the bearing angle threshold.
• Implementing the Algorithms Into An ArcGIS Tool
  • ArcMap® Add-In tool: CurveFinder;
  • Developed using the ArcGIS® programming package: ArcObjects®.
Methodology

Introduction & Background

What CurveFinder Does?

Calibration of Algorithm Parameter

Validation Results

Conclusions
Methodology

Introduction & Background

What CurveFinder Does?

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Curves in Adams County

Curves in Taylor County
• **Threshold of Bearing Angle**: only configurable parameter in the CurveFiner algorithm
  
  • Calibration is to find the optimal bearing angle threshold that can result in least curve identification error.

![Diagram of CurveFinder](attachment:image.png)

(a)
• Two Types of Identification Errors
  • Type I Error: failing to detect an existing curve part;
  • Type II Error: misidentifying a tangent section as part of a curve.

Example Scenarios of Type I Error

(f) 25% missed  
(g) 50% missed  
(h) 75% missed  
(i) Completely missed

Example Scenarios of Type II Error

Legend
- Identified Curve
- Ground Truth Curve
Calibration of Algorithm Parameter

- Two Measures of Effectiveness
  - Identification Rate (IR): percentage of curve segments that are successfully identified.
    - Less Type I errors, higher identification rate.
  - Type II Error Rate (TIIR): the number of Type II errors over the number of curve segments.
    - More Type II errors, higher Type II error rate.

IR, TIIR vs. Bearing Angle Threshold
Sample Results based on Wisconsin Roadway Maps
Calibration of Algorithm Parameter

• Performance Measure in the Calibration
  • Unified Error: a combination of Type I and Type II errors
    • \textit{Number of Unified Error} = \frac{2}{3} \times \text{Number of Type I Error} + \frac{1}{3} \times \text{Number of Type II Error}

\textbf{Iowa Calibration}

\textbf{Unified Error vs Bearing Angle Threshold}

Calibrated Angle: optimal
Iowa Calibration Accuracy

Ground Truth Curves (249 Curves) All Identified
Calibration of Algorithm Parameter

• **Wyoming Calibration**

![Composite Error vs. Bearing Angle Threshold](image)

- **Introduction & Background**
- **Methodology**
- **What CurveFinder Does?**
- **Validation Results**
- **Conclusions**
Calibration of Algorithm Parameter

- **Wyoming** Calibration Accuracy

Ground Truth Curves (118 Curves) All Identified (2 Exceptions)

Distribution of Percent of the GC Curves Being Identified

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% Id'ed</td>
<td>55</td>
</tr>
<tr>
<td>90-99% Id'ed</td>
<td>9</td>
</tr>
<tr>
<td>90-89% Id'ed</td>
<td>26</td>
</tr>
<tr>
<td>80-79% Id'ed</td>
<td>9</td>
</tr>
<tr>
<td>70-69% Id'ed</td>
<td>9</td>
</tr>
<tr>
<td>60-59% Id'ed</td>
<td>4</td>
</tr>
<tr>
<td>50-49% Id'ed</td>
<td>2</td>
</tr>
<tr>
<td>40-39% Id'ed</td>
<td>2</td>
</tr>
<tr>
<td>30-29% Id'ed</td>
<td>0</td>
</tr>
<tr>
<td>20-19% Id'ed</td>
<td>0</td>
</tr>
<tr>
<td>10-19% Id'ed</td>
<td>0</td>
</tr>
<tr>
<td>1-9% Id'ed</td>
<td>0</td>
</tr>
<tr>
<td>0% Id'ed</td>
<td>2</td>
</tr>
</tbody>
</table>
- Iowa Validation Results
  - Independent set of 83 ground truth curves were used in the validation.

**Ground Truth Curves (83 Curves) All Identified**
- **Wyoming Validation Results**
  - Independent set of 38 ground truth curves were used in the validation.

  **Ground Truth Curves (38 Curves) All Identified (1 Exception)**

  **Distribution of Percent of the GC Curves Being Identified**

  ![Bar chart showing the distribution of percent of the GC curves being identified.](chart.png)
• Validation of Curve Geometric Information

- The slopes of the regression lines are all close to one, and all $R^2$ are close to one.
Conclusions

- Provides a useful tool for curve safety project:
  - Facilitates MIRE curve data elements collection.
  - Facilitates system wide curve safety modeling.

- Fully automatic compared with exiting approaches:
  - Calibration is being made automated once ground truth curve data is ready.

- Beneficial to curve data collection on county and rural low-volume roads:
  - Only requires GIS roadway maps;
  - No need of further data collection
• Further Improvements for Low-Quality Maps (Ongoing)
  • Potential source of errors
    • Scenario 1: Roadway centerline transverse error, namely deviations of the GIS centerline from the actual alignment. This source data error may be due to the human error in the map digitizing phase.

Potential Solution: Artificial Intelligence
- Further Improvements for Low-Quality Maps (Ongoing)
- Potential source of errors
  - Scenario 2: Low vertex density (conservative estimation; CurveFinder still works well but not as great when the density) of the GIS roadway centerline to describe the actual alignment of the roadway.

Potential Solution:
Image processing of aerial maps to fix the centerline
Thank You!

QUESTIONS?