ArcGIS Horizontal Curve Recognition and Fitting Tool

Douglas Wright

In Brief:

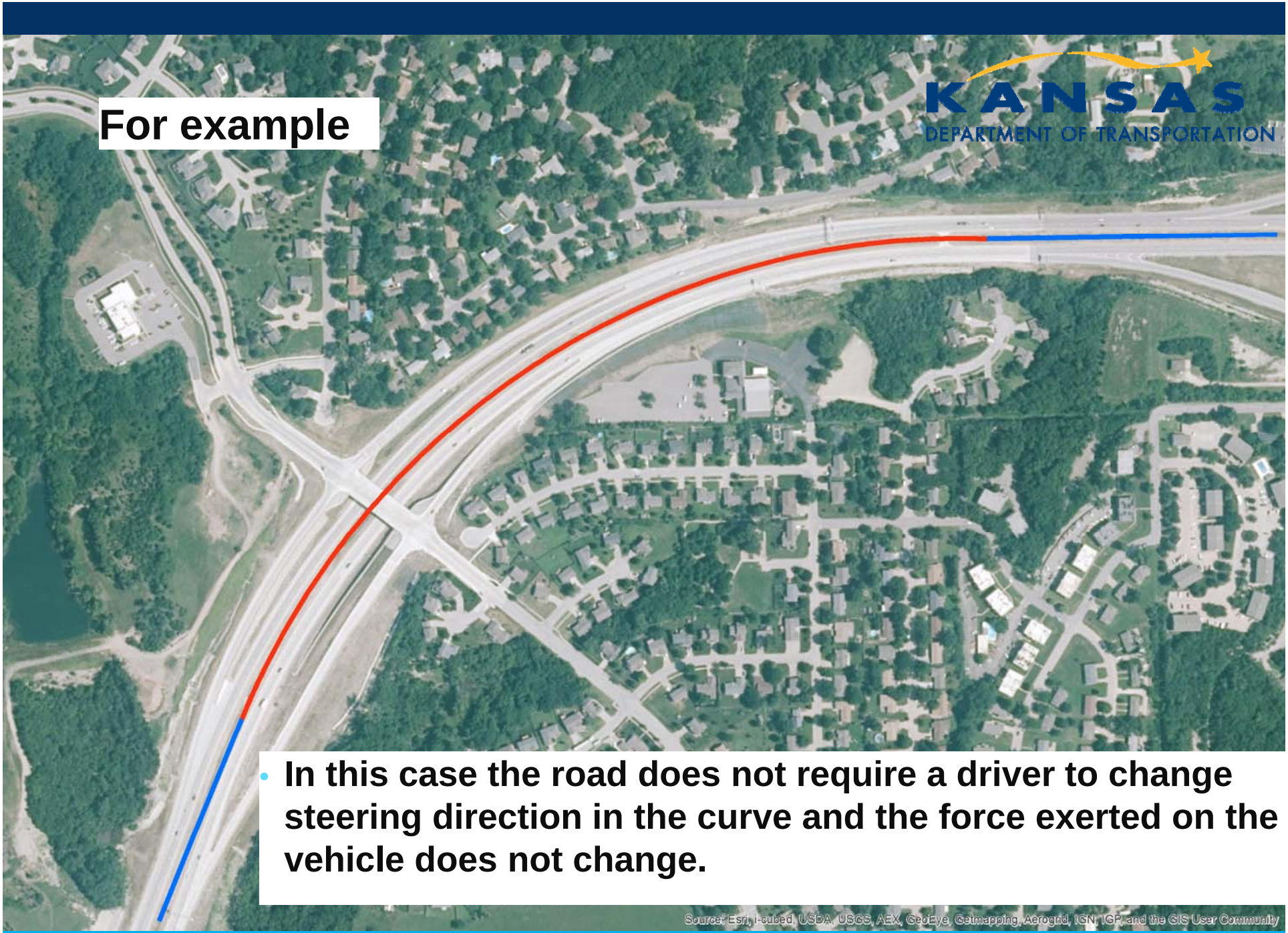
- Developed by AECOM in 2014
- Python tool in ArcGIS for horizontal curve detection and fitting of digitized curves in transportation safety analyses
- Generates an algebraic solution with negligible inbuilt bias
- Detects curves and generates best-fit parameters in minimal time for large road vector datasets

The Challenge

- The Kansas Department Of Transportation (KDOT) required a tool to generate best-fits for horizontal curves for their freeway system that must
  - Run in ArcGIS
  - Detect the start and end locations of all curves within digitized road polyline feature classes
  - Provide output feature classes comprising detected curves and the best-fit curve with associated statistics

Background

- Horizontal curves are circular curves, with a radius and center of curvature
- Road safety is best-served by circular curves because this allows the driver to negotiate the curve without having to change the tilt of the wheel while passing through
- Detection of locations where curves depart from circularity is necessary for safety evaluations, and remediation measures such as
  - Stopping distance
  - Passing distance



- **In this case the road does not require a driver to change steering direction in the curve and the force exerted on the vehicle does not change.**

In contrast,

- Curves of changing radius are intrinsically unsafe, such as this notorious case:

KANSAS
DEPARTMENT OF TRANSPORTATION

Literature Review

- No other similar applications were found in literature review as of 2014
- Existing research:
  - Zhixia, et all.
  - Ali Al-Sharadqah and Nikolai Chernov, 2009
- We incorporated the most promising techniques into our code

Algorithms

Programming Approaches

- **Regression Techniques using Iteration**
  - **Also called “Geometric”**
  - **Minimizes the function:**

$$\mathcal{F}(a, b, R) = \sum d_i^2,$$

where d_i stands for the distance from (x_i, y_i) to the circle, i.e.

$$d_i = r_i - R, \qquad r_i = \sqrt{(x_i - a)^2 + (y_i - b)^2},$$

where (a, b) denotes the center, and R the radius of the circle.

Solutions

Programming Approaches using Regression techniques

- **Advantages**
  - **Minimal error**
- **Disadvantages**
  - **Computationally intensive**
  - **May take many iterations to converge to a solution**
  - **Longer processing time**
  - **Some cases may never converge to a solution**

Solutions

Programming Approaches using Algebraic Methods

- **Algebraic**
  - **Non-iterative**
  - **Achieves result by solving for the minima in a system of linear equations**
  - **Advantages**
    - **Fast processing time**
  - **Disadvantages**
    - **Larger error than geometric methods**

Solutions

Programming Approaches

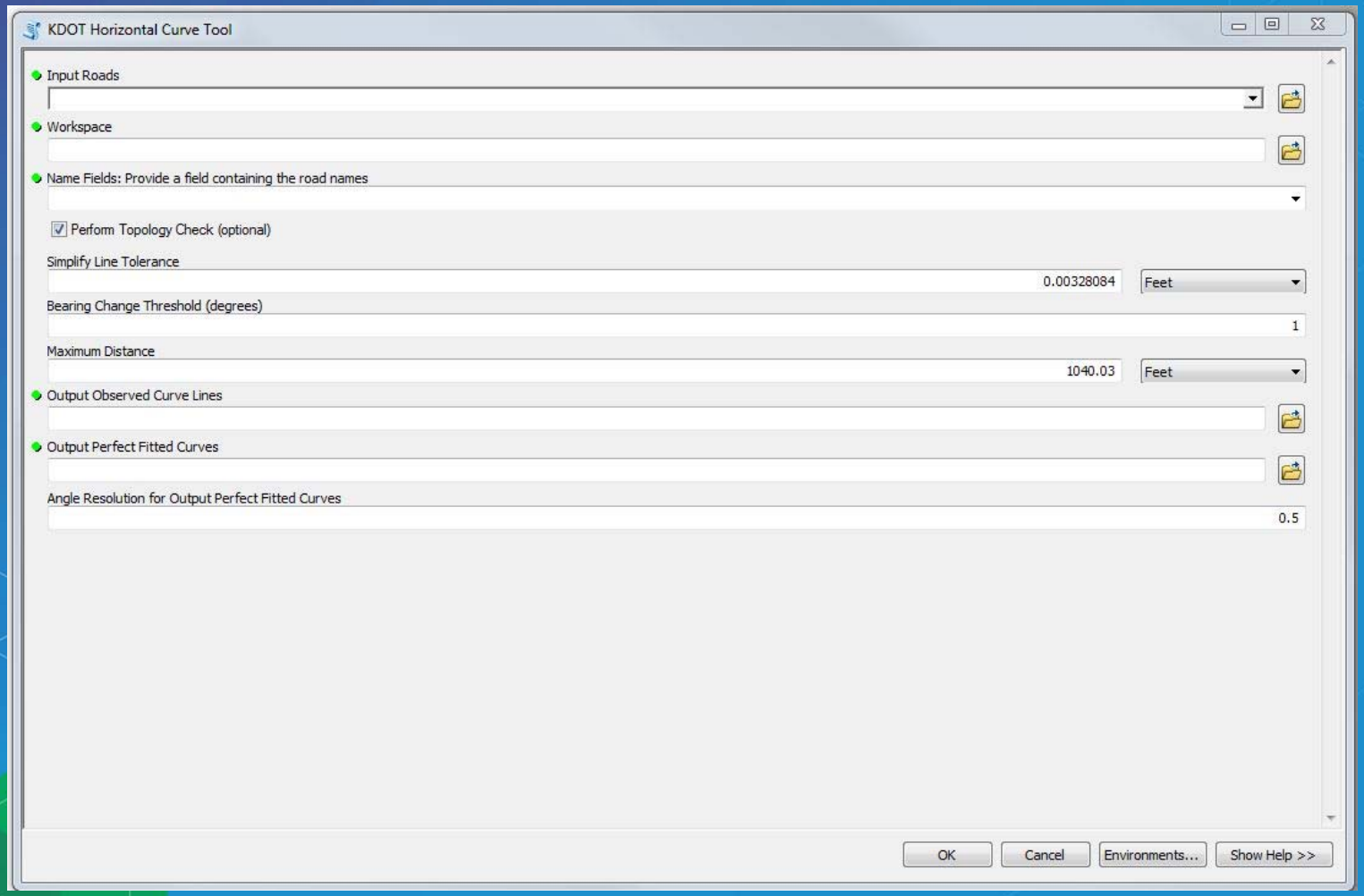
- **Algebraic “Hyperfit” Algorithm**
  - **Developed by Ali Al-Sharadqah and Nikolai Chernov, Department of Mathematics, University of Alabama at Birmingham, 2009**
  - **Has negligible inbuilt bias and error**
  - **Outperforms geometric fits in accuracy**
  - **Performs extremely fast**
  - **Python code publically available for commercial or private use**

Program Outline

In summary:

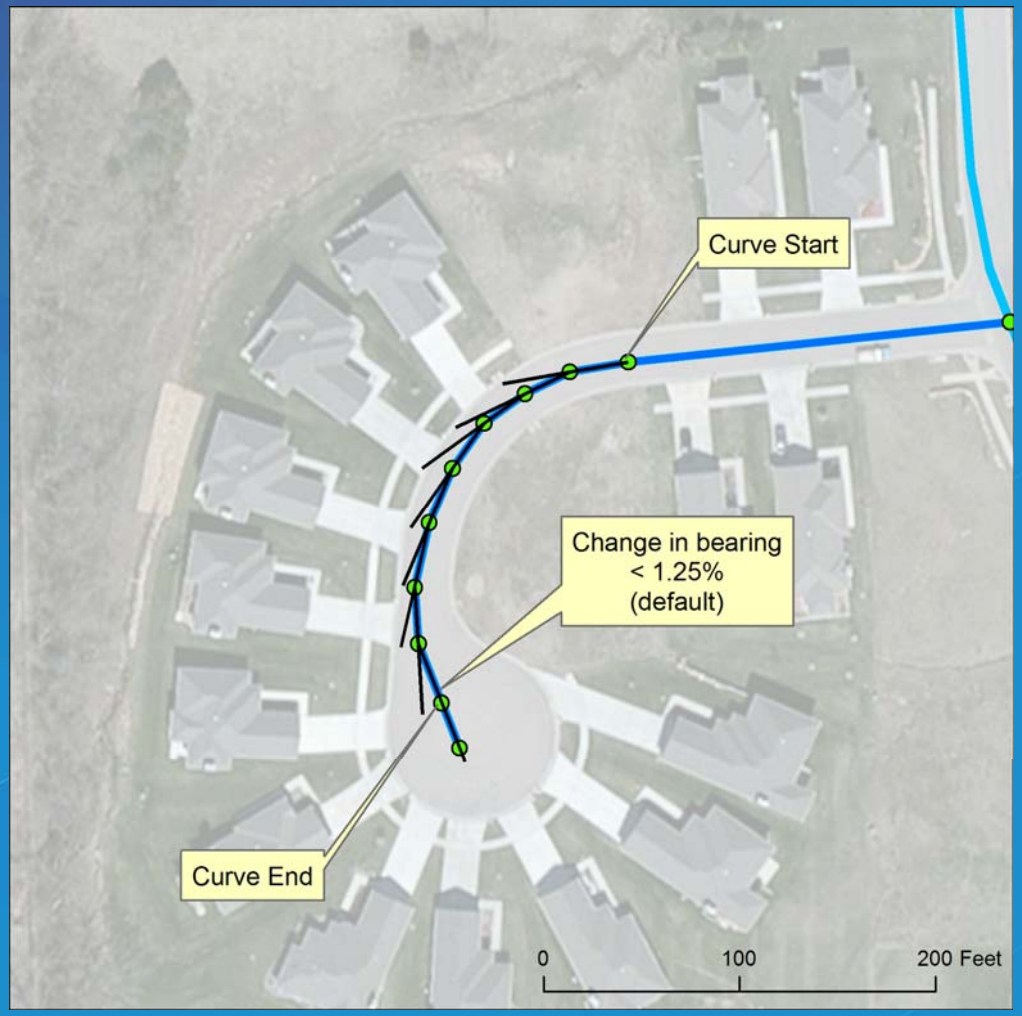
- Developed as a Toolbox employing Python code (v 2.7) and Numpy
- Filters input data with topological rules
- Requires user to specify input parameters
- Reduces input route lines into vertices for detection of curve starts and ends, and for use in Hyperfit algorithm
- Creates features classes for
  - Segments of input detected as curves
  - Generates output curve from Hyperfit solution using the associated Radius and Center of Curvature .
  - Generates R-squared ratings for curves

Input Parameters



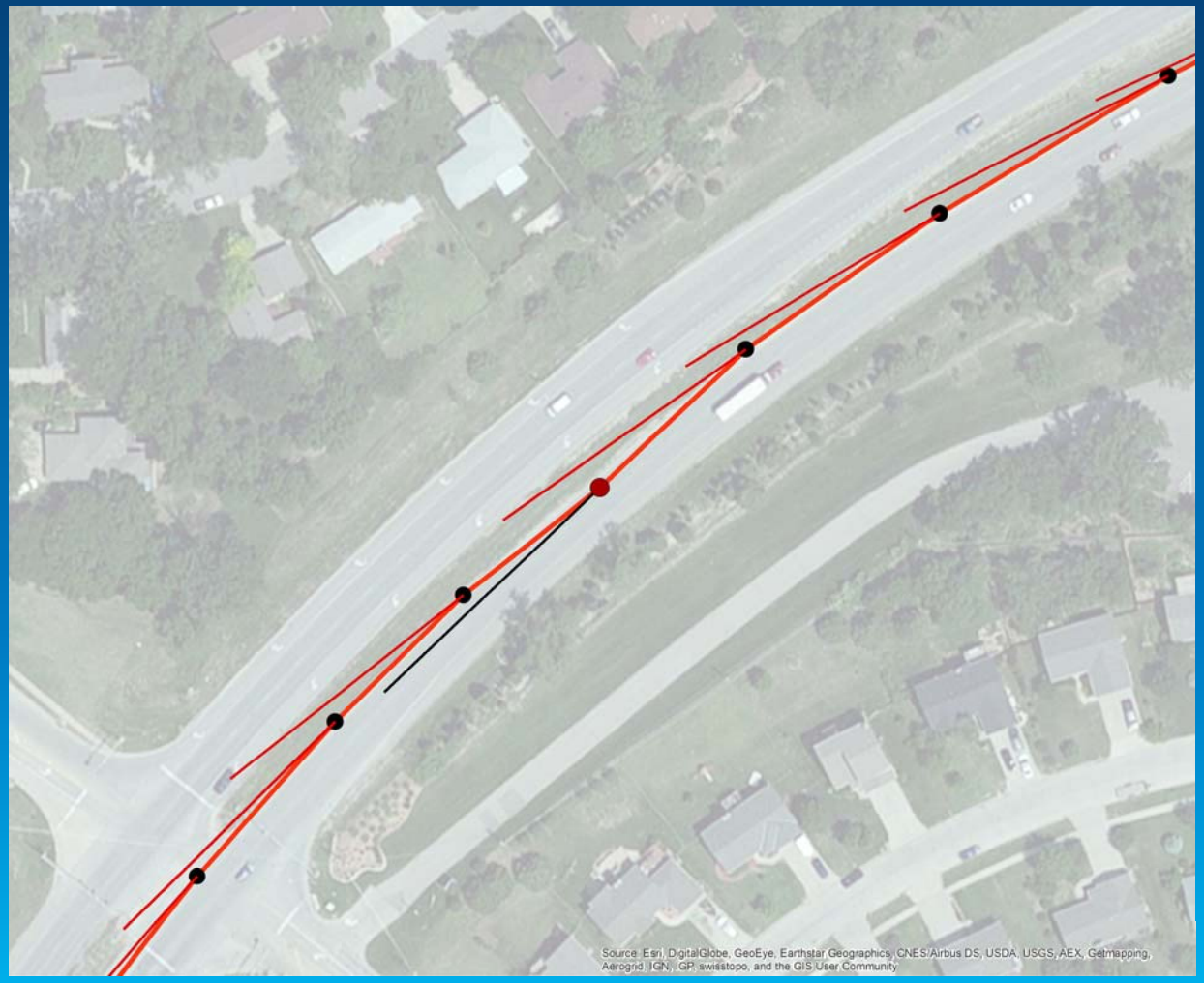
Considerations for Input

Recognizes start and end of curve by changes in bearing within input tolerance or if the bearing reverses direction (e.g., clockwise into anti-clockwise)



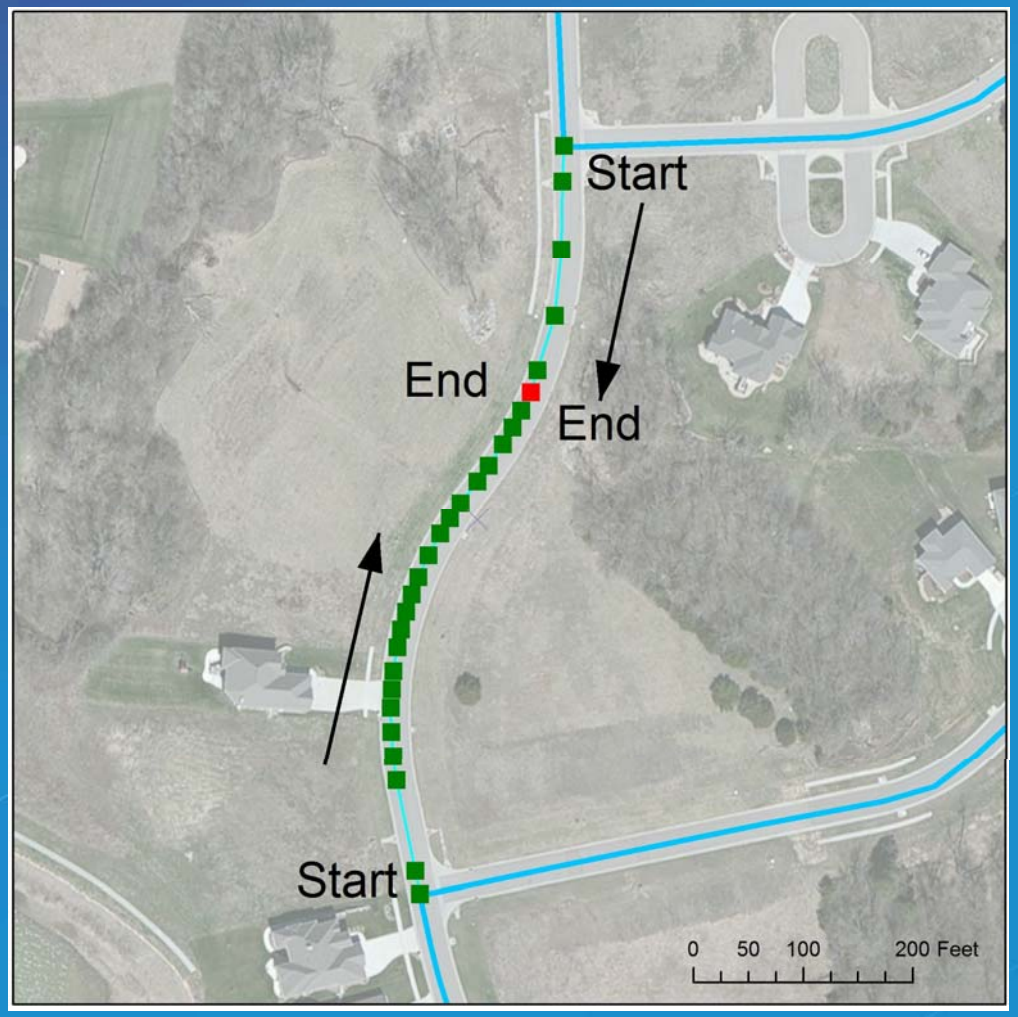
Considerations for Input

However, there may be data defects, where digitization errors create a reversal in direction that will prematurely end curve:



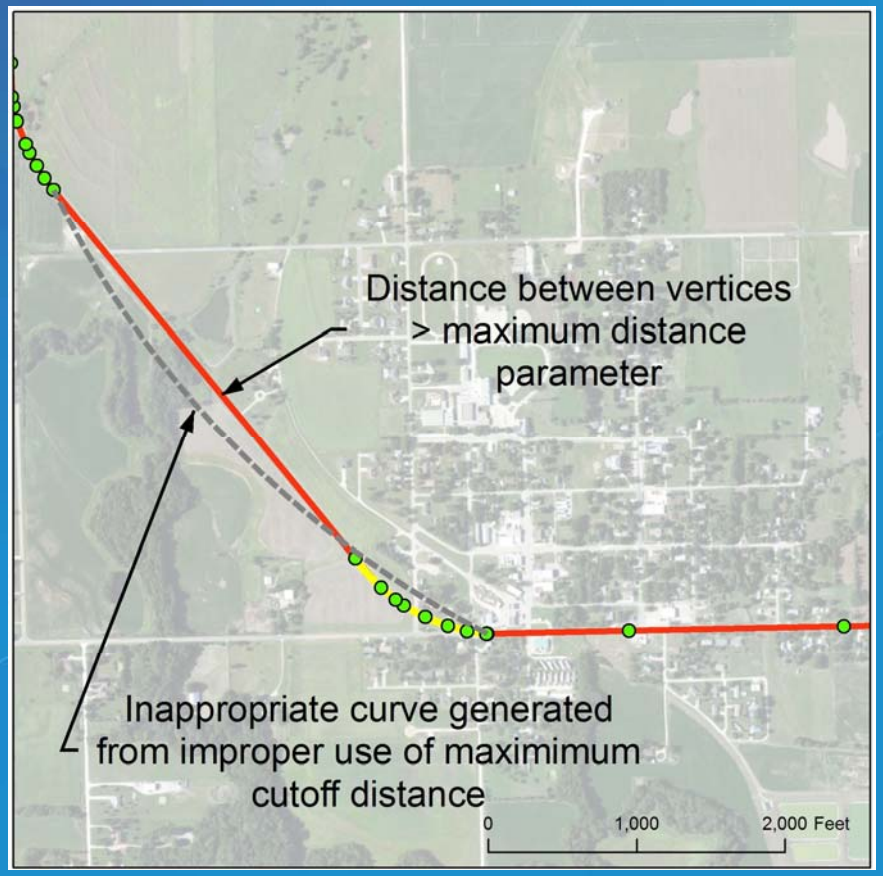
Considerations for Input

Data defects, where multipart route lines with the same name have opposing directions



Considerations for Input

Maximum distance: This is an input parameter of a maximum distance between two points in a curve to ensure the curve fitting process calculates a realistic result, and can be chosen based on a consideration of the straight-line distance required to stabilize a vehicle at the end of a horizontal curve when driving along the curve at full speed.

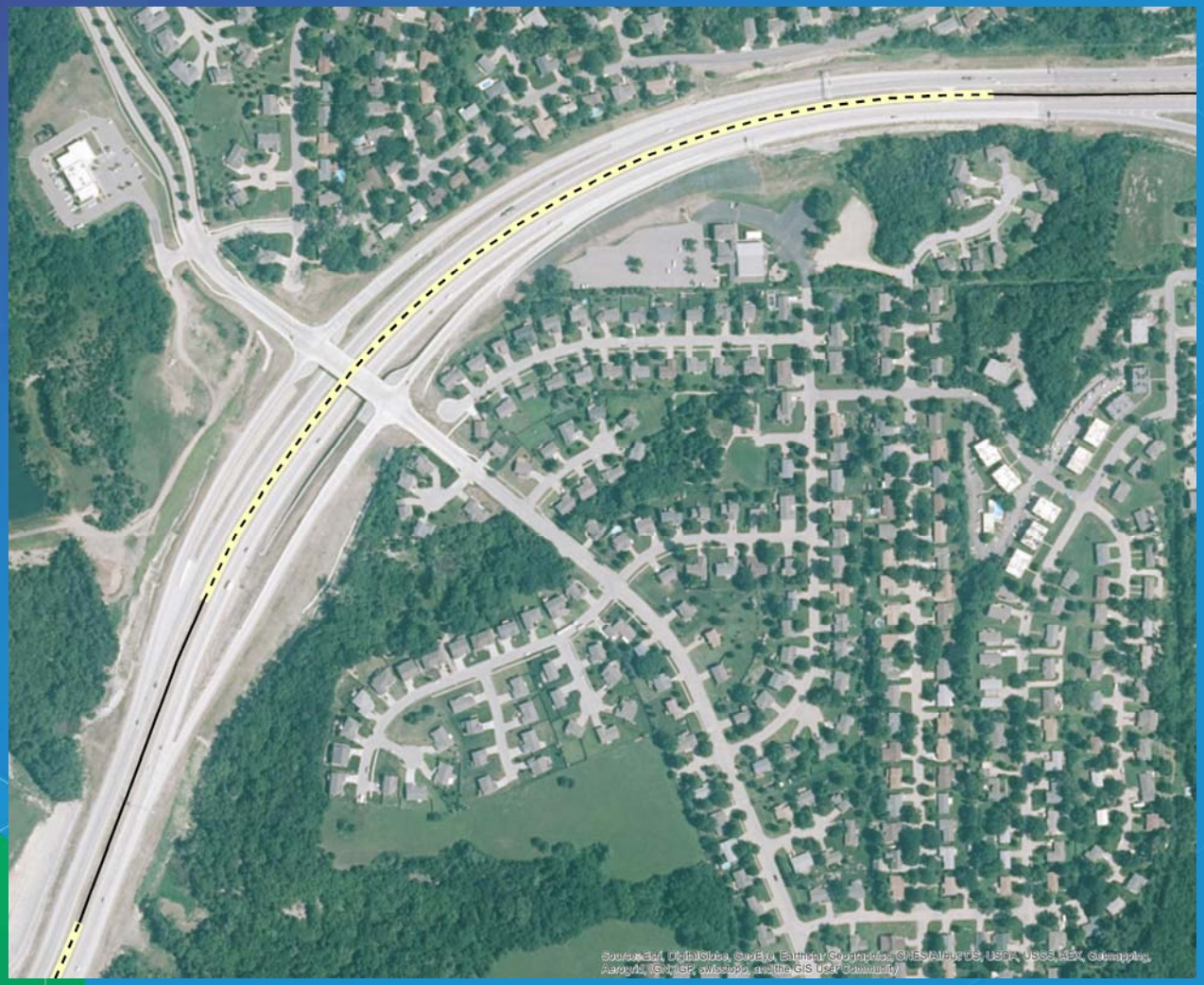


Data Treatment

- Removes divots by applying the “Simplify Line” tool with a specified input tolerance
- As an option, applies a topology rule to detect the presence of multipart lines and remove them from analysis
- Generates unique identifiers for each line in case there are duplicate road names

Considerations for Output

Exports each segment of recognized curves to a feature class



Considerations for Output

Generates a feature class with all solutions including output parameters and statistics, including R-squared ratings

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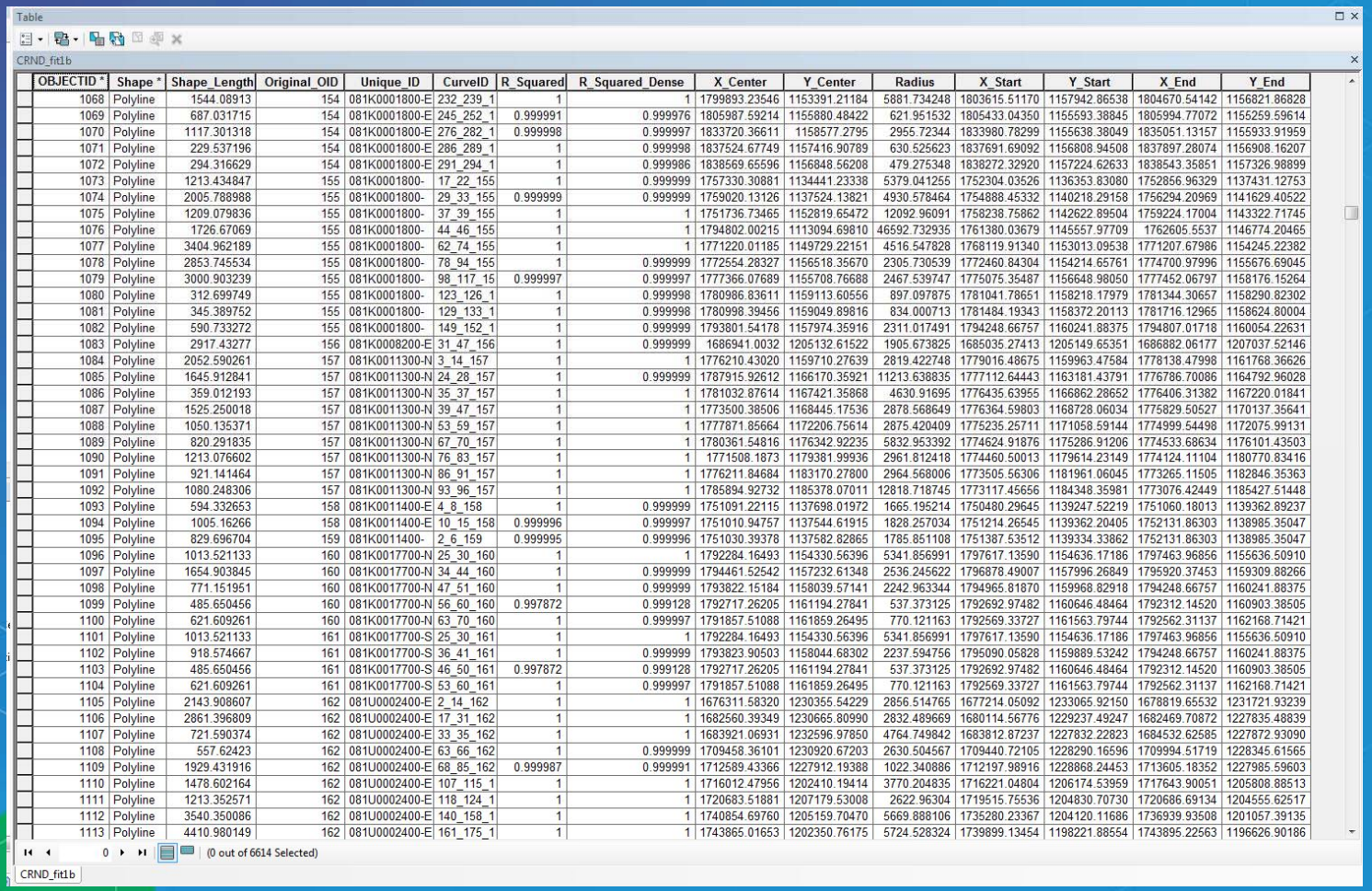

Table

CRND_fit1b

OBJECTID *	Shape *	Shape_Length	Original_OID	Unique_ID	CurveID	R_Squared	R_Squared_Dense	X_Center	Y_Center	Radius	X_Start	Y_Start	X_End	Y_End
1068	Polyline	1544.08913	154	081K0001800-E	232_239_1	1	1	1799893.23546	1153391.21184	5881.734248	1803615.51170	1157942.86538	1804670.54142	1156821.86828
1069	Polyline	687.031715	154	081K0001800-E	245_252_1	0.999991	0.999976	1805987.59214	1155880.48422	621.951532	1805433.04350	1155593.38845	1805994.77072	1155259.59614
1070	Polyline	1117.301318	154	081K0001800-E	276_282_1	0.999998	0.999997	1833720.36611	1158577.2795	2955.72344	1833980.78299	1155638.38049	1835051.13157	1155933.91959
1071	Polyline	229.537196	154	081K0001800-E	286_289_1	1	0.999998	1837524.67749	1157416.90789	630.525623	1837691.69092	1156808.94508	1837897.28074	1156908.16207
1072	Polyline	294.316629	154	081K0001800-E	291_294_1	1	0.999986	1838569.65596	1156848.56208	479.275348	1838272.32920	1157224.62633	1838543.35851	1157326.98899
1073	Polyline	1213.434847	155	081K0001800-	17_22_155	1	0.999999	1757330.30881	1134441.23338	5379.041255	1752304.03526	1136353.83080	1752856.96329	1137431.12753
1074	Polyline	2005.788988	155	081K0001800-	29_33_155	0.999999	0.999999	1759020.13126	1137524.13821	4930.578464	1754888.45332	1140218.29158	1756294.20969	1141629.40522
1075	Polyline	1209.079836	155	081K0001800-	37_39_155	1	1	1751736.73465	1152819.65472	12092.96091	1758238.75862	1142622.89504	1759224.17004	1143322.71745
1076	Polyline	1726.67069	155	081K0001800-	44_46_155	1	1	1794802.00215	1113094.69810	46592.732935	1761380.03679	1145557.97709	1762605.5537	1146774.20465
1077	Polyline	3404.962189	155	081K0001800-	62_74_155	1	1	1771220.01185	1149729.22151	4516.547828	1768119.91340	1153013.09538	1771207.67986	1154245.22382
1078	Polyline	2853.745534	155	081K0001800-	78_94_155	1	0.999999	1772554.28327	1156518.35670	2305.730539	1772460.84304	1154214.65761	1774700.97996	1155676.69045
1079	Polyline	3000.903239	155	081K0001800-	98_117_15	0.999997	0.999997	1777366.07689	1155708.76688	2467.539747	1775075.35487	1156648.98050	1777452.06797	1158176.15264
1080	Polyline	312.699749	155	081K0001800-	123_126_1	1	0.999998	1780986.83611	1159113.60556	897.097875	1781041.78651	1158218.17979	1781344.30657	1158290.82302
1081	Polyline	345.389752	155	081K0001800-	129_133_1	1	0.999998	1780998.39456	1159049.89816	834.000713	1781484.19343	1158372.20113	1781716.12965	1158624.80004
1082	Polyline	590.733272	155	081K0001800-	149_152_1	1	0.999999	1793801.54178	1157974.35916	2311.017491	1794248.66757	1160241.88375	1794807.01718	1160054.22631
1083	Polyline	2917.43277	156	081K0008200-E	31_47_156	1	0.999999	1686941.0032	1205132.61522	1905.673825	1685035.27413	1205149.65351	1686882.06177	1207037.52146
1084	Polyline	2052.590261	157	081K0011300-N	3_14_157	1	1	1776210.43020	1159710.27639	2819.422748	1779016.48675	1159963.47584	1778138.47998	1161768.36626
1085	Polyline	1645.912841	157	081K0011300-N	24_28_157	1	0.999999	1787915.92612	1166170.35921	11213.638835	1777112.64443	1163181.43791	1776786.70086	1164792.96028
1086	Polyline	359.012193	157	081K0011300-N	35_37_157	1	1	1781032.87614	1167421.35868	4630.91695	1776435.63955	1166862.28652	1776406.31382	1167220.01841
1087	Polyline	1525.250018	157	081K0011300-N	39_47_157	1	1	1773500.38506	1168445.17536	2878.568649	1776364.59803	1168728.06034	1775829.50527	1170137.35641
1088	Polyline	1050.135371	157	081K0011300-N	53_59_157	1	1	1777871.85664	1172206.75614	2875.420409	1775235.25711	1171058.59144	1774999.54498	1172075.99131
1089	Polyline	820.291835	157	081K0011300-N	67_70_157	1	1	1780361.54816	1176342.92235	5832.953392	1774624.91876	1175286.91206	1774533.68634	1176101.43503
1090	Polyline	1213.076602	157	081K0011300-N	76_83_157	1	1	1771508.1873	1179381.99936	2961.812418	1774460.50013	1179614.23149	1774124.11104	1180770.83416
1091	Polyline	921.141464	157	081K0011300-N	86_91_157	1	1	1776211.84684	1183170.27800	2964.568006	1773505.56306	1181961.06045	1773265.11505	1182846.35363
1092	Polyline	1080.248306	157	081K0011300-N	93_96_157	1	1	1785894.92732	1185378.07011	12818.718745	1773117.45656	1184348.35981	1773076.42449	1185427.51448
1093	Polyline	594.332653	158	081K0011400-E	4_8_158	1	0.999999	1751091.22115	1137698.01972	1665.195214	1750480.29645	1139247.52219	1751060.18013	1139362.89237
1094	Polyline	1005.16266	158	081K0011400-E	10_15_158	0.999996	0.999997	1751010.94757	1137544.61915	1828.257034	1751214.26545	1139362.20405	1752131.86303	1138985.35047
1095	Polyline	829.696704	159	081K0011400-	2_6_159	0.999995	0.999996	1751030.39378	1137582.82865	1785.851108	1751387.53512	1139334.33862	1752131.86303	1138985.35047
1096	Polyline	1013.521133	160	081K0017700-N	25_30_160	1	1	1792284.16493	1154330.56396	5341.856991	1797617.13590	1154636.17186	1797463.96856	1155636.50910
1097	Polyline	1654.903845	160	081K0017700-N	34_44_160	1	0.999999	1794461.52542	1157232.61348	2536.245622	1796878.49007	1157996.26849	1795920.37453	1159309.88266
1098	Polyline	771.151951	160	081K0017700-N	47_51_160	1	0.999999	1793822.15184	1158039.57141	2242.963344	1794965.81870	1159968.82918	1794248.66757	1160241.88375
1099	Polyline	485.650456	160	081K0017700-N	56_60_160	0.997872	0.999128	1792717.26205	1161194.27841	537.373125	1792692.97482	1160646.48464	1792312.14520	1160903.38505
1100	Polyline	621.609261	160	081K0017700-N	63_70_160	1	0.999997	1791857.51088	1161859.26495	770.121163	1792569.33727	1161563.79744	1792562.31137	1162168.71421
1101	Polyline	1013.521133	161	081K0017700-S	25_30_161	1	1	1792284.16493	1154330.56396	5341.856991	1797617.13590	1154636.17186	1797463.96856	1155636.50910
1102	Polyline	918.574667	161	081K0017700-S	36_41_161	1	0.999999	1793823.90503	1158044.68302	2237.594756	1795090.05828	1159889.53242	1794248.66757	1160241.88375
1103	Polyline	485.650456	161	081K0017700-S	46_50_161	0.997872	0.999128	1792717.26205	1161194.27841	537.373125	1792692.97482	1160646.48464	1792312.14520	1160903.38505
1104	Polyline	621.609261	161	081K0017700-S	53_60_161	1	0.999997	1791857.51088	1161859.26495	770.121163	1792569.33727	1161563.79744	1792562.31137	1162168.71421
1105	Polyline	2143.908607	162	081U0002400-E	2_14_162	1	1	1676311.58320	1230355.54229	2856.514765	1677214.05092	1233065.92150	1678819.65532	1231721.93239
1106	Polyline	2861.396809	162	081U0002400-E	17_31_162	1	1	1682560.39349	1230665.80990	2832.489669	1680114.56776	1229237.49247	1682469.70872	1227835.48839
1107	Polyline	721.590374	162	081U0002400-E	33_35_162	1	1	1683921.06931	1232596.97850	4764.749842	1683812.87237	1227832.22823	1684532.62585	1227872.93090
1108	Polyline	557.62423	162	081U0002400-E	63_66_162	1	0.999999	1709458.36101	1230920.67203	2630.504567	1709440.72105	1228290.16596	1709994.51719	1228345.61565
1109	Polyline	1929.431916	162	081U0002400-E	68_85_162	0.999987	0.999991	1712589.43366	1227912.19388	1022.340886	1712197.98916	1228868.24453	1713605.18352	1227985.59603
1110	Polyline	1478.602164	162	081U0002400-E	107_115_1	1	1	1716012.47956	1202410.19414	3770.204835	1716221.04804	1206174.53959	1717643.90051	1205808.88513
1111	Polyline	1213.352571	162	081U0002400-E	118_124_1	1	1	1720683.51881	1207179.53008	2622.96304	1719515.75536	1204830.70730	1720686.69134	1204555.62517
1112	Polyline	3540.350086	162	081U0002400-E	140_158_1	1	1	1740854.69760	1205159.70470	5669.888106	1735280.23367	1204120.11686	1736939.93508	1201057.39135
1113	Polyline	4410.980149	162	081U0002400-E	161_175_1	1	1	1743865.01653	1202350.76175	5724.528324	1739899.13454	1198221.88554	1743895.22563	1196626.90186

0 (0 out of 6614 Selected)

CRND_fit1b

Conclusions

- Alternative technique using unique algebraic method superior to regression techniques
- Expands the range of GIS applications for transportation safety
- Effective, fast tool that runs totally in GIS for combined curve recognition and fitting
  - Analyzed the entire Kansas state highway system in 15 minutes

Questions and Answers