Horizontal Curve Data Inventory on Local Roads

Contract # PS0548

Prepared for: Vermont Agency of Transportation

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This report is a summary of project activities and accomplishments related to the Horizontal Curve Data Inventory on Local Roads project for the Vermont Agency of Transportation (VTrans). The focus of this project has been in developing curve data on local rural roads to facilitate systemic safety planning. This project has involved extensive manual quality control review and edits of the Vermont centerline data, specifically on local rural roads. It has also involved calculation of horizontal curvature events on all roads throughout the state.

Calculation of horizontal curves have been performed using our ArcGIS Desktop extension called *Curve and Grade Tools for ArcGIS*. These curve tools have been developed to facilitate reporting of curve classification information originally required for HPMS – and to facilitate network screening as part of the safety planning process.

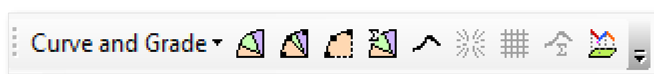

Figure 1 - the toolbar that appears in ArcMap

Specific tasks and objectives for this project were to:

1. Task 1a: Calculate horizontal curve data from VTrans agency centerlines.
2. Task 1b: Provide training to VTrans staff on methods to improve the road centerline geometry for better curve data calculation.
3. Task 2a: Perform quality control edits to centerline vertices to correct issues causing inaccurate curve results.
4. Task 2b: Assess the accuracy and completeness of final data.

This report describes the work performed, and accomplishments achieved, with each of these four tasks.

TASK 1a: CALCULATION OF HORIZONTAL CURVE DATA

Statewide calculation of curve classification took place immediately upon beginning work. This data was delivered to VTrans on January 8, 2017. Recalculation of the basic curve classification and radius information is easily performed using two tools in the Curve and Grade ArcGIS extension (Construct Horizontal Curves and Dissolve Horizontal Curves). These tools were used extensively during the Task 2a QC, and on final centerline data at the conclusion of this project.

This project delivers the MIRE data elements 107 through 114, excluding 111. Elements 107, 109, 110, 112, 114, and to a partial extent Element 108, are direct outputs from the tools. Element 112, and to a partial extent Element 108, require analysis of individual curves in relation to adjacent segments and were calculated through additional GIS routines following the initial output from the tools.

Table 1 : MIRE Curve Related Data Items:

MIRE #	MIRE Element
107	Curve Identifiers and Linkage Elements
108	Curve Feature Type
109	Horizontal Curve Degree AND Radius
110	Horizontal Curve Length
111	*Superelevation (Not deliverable from GIS centerline data)*
112	Horizontal Transition/Spiral Curve Presence
113	Horizontal Curve Intersection/Deflection Angle
114	Horizontal Curve Direction

Our final deliverable of the horizontal curve data includes a database file containing three critical files:

The first of these is a simple polyline geospatial feature class representing all independent, compound, and reverse horizontal curves along the VTrans centerline. This feature class contains as attributes the Curve Identifier, Linkage Elements, Feature Type, Curve Degree and Radius, Curve Length, Horizontal Transition, and Curve Direction. Segments which are too straight to be classified as curves are included as well, so every segment of every route in the centerline file will have these attributes.

The second database file is a point geospatial feature class representing all Horizontal Angle Points (one of the Curve Feature Types described in Element 108). This is a separate file because Horizontal Angle Points are better represented as points than lines. Points that have been included are those with a deflection angle greater than 30 degrees. The MIRE data requirements do not specify a minimum horizontal angle point, but 30 degrees has been deemed a reasonable minimum at an actual angle point curve. Some of the deflection angles in the deliverable represent poorly digitized turns in roads that were not edited by through this project, and have potential to highlight specific points where quality control editing to the centerline should perhaps take place in the future. The deflection angle is included as an attribute for each horizontal angle point.

The third file included is an Excel table containing all curve types together—Horizontal Angle Points, Independent Curves, Compound Curves, and Reverse Curves. It is not feasible to include both point and line data in a single geospatial feature class, but these different curve types can be combined in a tabular format to allow for inspection and summary of Horizontal Angle Points together with other types of curves.

TASK 1b: INSTRUCTION/FACILITATION

The *Curve and Grade Tools ArcGIS* extension has been installed on several VTrans workstations to facilitate calculation of curve classification by VTrans staff. It is anticipated that VTrans staff will use these tools in calculating curves on localized roadways where centerlines are being added or edited, and some staff have already begun editing their network, using the horizontal curve tools as an aid. VTrans may also, at any time, use the tools to recalculate curve classification on the entire network.

A Vermont-specific protocol document has been developed to provide step-by-step guidance in utilizing curve tools, and in performing quality control centerline edits to improve the accuracy of curve data. This guidance document has been posted to the following website: Curve and Grade Utilities Special Topics > Vermont.

Other documentation has also been provided to guide VTrans GIS staff in the centerline review and edit protocol. Web meetings took place with VTrans on February 17th and on March 28th where Works Consulting staff demonstrated use of Curve tools and instructed on the centerline review and edit process. A video recording of the March training has been shared with VTrans for reference and use in training others.

On April 11th, Michael Trunzo and Joe Breyer co-presented the basics of this project at the annual GIS-T Symposium in Phoenix, Arizona. The full slide deck for the presentation includes 31 slides. An amateur video of the presentation was also recorded—available upon request.

TASK 2a: QUALITY CONTROL EDITS

Curve classification information has been calculated from centerline geometry; the validity of the curve data is, therefore, limited to the accuracy of digitized roadway centerlines. VTrans centerlines have been derived from multiple original sources that often predated availability of highly accurate aerial imagery. This task has involved manual review of centerline data against aerial imagery and LiDaR visualizations—followed by the editing of vertices to allow more accurate calculation of curve classes. The extent of the centerline edits performed by our staff was limited to local rural roads deemed most relevant for safety planning efforts.

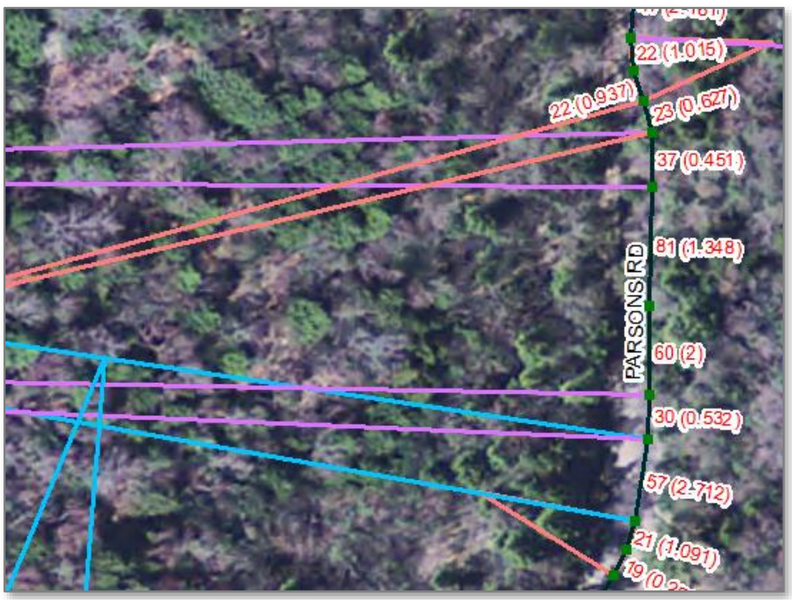

Figure 2 : Example of Curves Generate on data prior to curve calculation optimization. The different colors represent different curve steepness, and many short, varying curves are portrayed rather than dissolved, smooth curves which would represent reality.

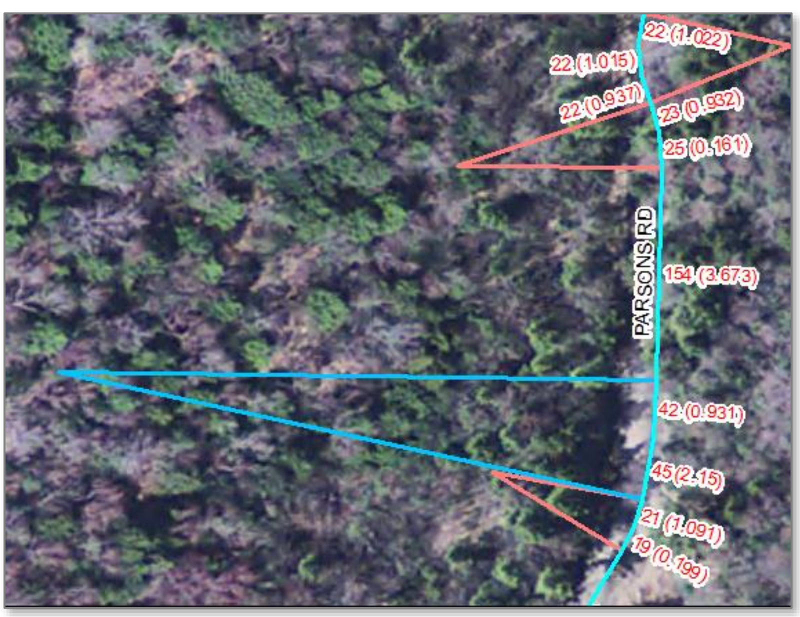

Figure 3 : The same road as pictured in the figure above, but after editing the vertices to optimize curve calculation. At the bottom a compound curve exists, where a very steep curve transitions into a less steep curve. At the top a reverse curve exists.

Editing Environment

The editing environment was initially established by remote connection into the VTrans network. It was decided that the long-term effort would be significantly more efficient by working with the data locally in Arizona. Daily disconnected editing sessions – using a downloaded copy of the centerline network – were established and provided virtually flawless performance. Works Consulting used these temporary versions of the data from VTrans ArcGIS Server Mapping Unit – and edits were uploaded and reconciled to the parent daily to ensure that edits did not conflict with edits by VTrans staff.

Prioritizing Routes for Edit

The daily edit rate has varied substantially depending on the true shape of each reviewed roadway, and the edits necessary to bring centerlines into conformity with areal imagery. Curve edits tended to progress faster on higher classification roadways (arterials and collectors) where centerlines are less likely to be out of conformity with aerial imagery. Early edit rates helped establish the target of 3,700 centerline miles that could be expected to be achieved within the budget allowed for this project. Because of this limit, it became necessary to prioritize which centerline miles received attention.

Arcs in the centerline file were queried by Functional Class and reviewed to determine which roads already had legacy curve events provided by VTrans. Table 2 summarizes the distribution of all VTrans roadways, and where legacy curve data already exists. In addition to local roads (i.e. the focus of this project) many of the collectors and some of the minor arterials were also identified as not yet having curve events. Future review and editing of arterial and collector roads could take place by VTrans staff, while the focus of Works Consulting remains on rural roads functionally classified as local.

Table 2 : Estimated Distribution of Legacy Curve Data by Functional Class

Functional Class	Total Miles	Legacy Complete (estimate)	Not Completed
1 (Interstates)	723	723	done
2 (Freeways)	48	48	done
3 (Principal Arterials)	485	485	done
4 (Minor Arterials)	891	649	242
5 (Major Collectors)	2,229	1,149	1080
6 (Minor Collectors)	869	41	828
7 (Local)	**9,208**	**0**	**9,208**
0 (Private)	5,600	0	na
Total (0-7)	**20,057**	**3095**	**11,358**

The prioritization of local rural centerlines was based on two criteria. First, VTrans provided Works Consulting with statewide crash locations for the past five years to identify routes and individual arcs which had at least two or more property damage crashes, one injury crash, or one fatal crash. Second, Works Consulting created a "curve index," which reflects the number and length of total curves relative to each route, giving the highest weight (6) to F-curves, with slightly less (5) to E-curves, and slightly less weight (4) than that to D-curves

urves, and so on, until there is no additional weight to A-curves. Prioritization was, therefore, on those routes with the highest concentration and severity of curves that also have some crash occurrence. The balance intended in the prioritization process was comprehensively scanning from one end of the state to the other, while attending to the most critical specific route sections as possible in between.

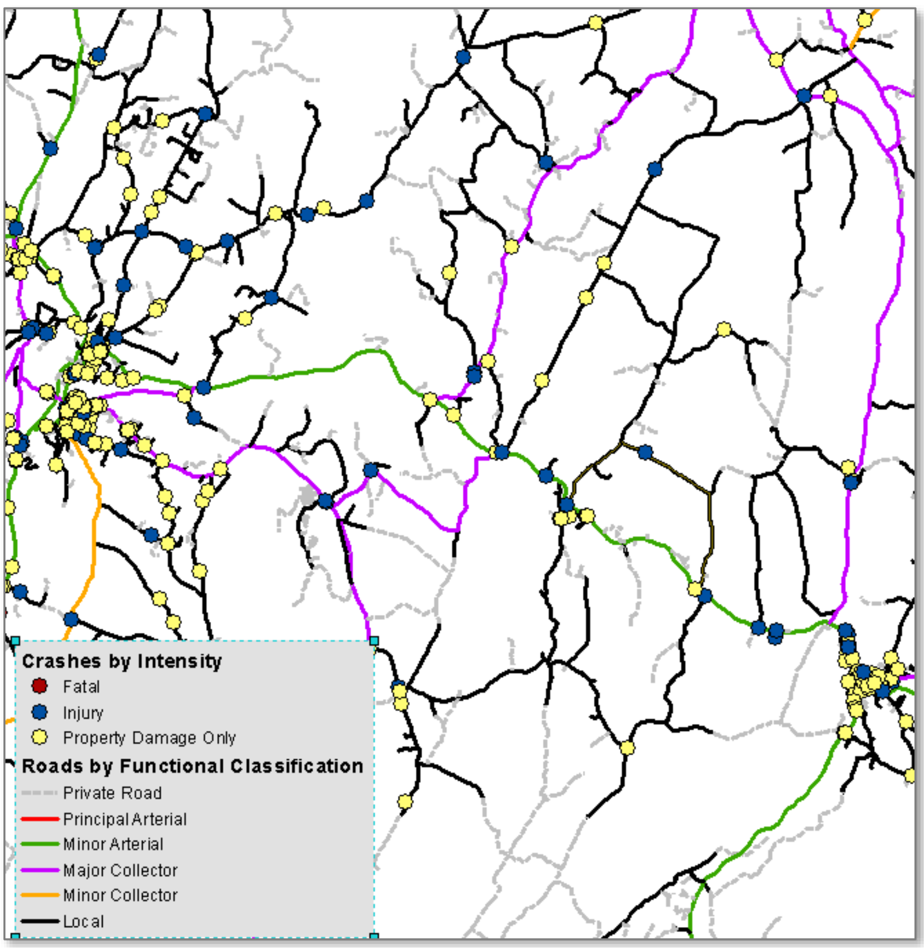

Figure 4 Example of an environment used to determine which road segments are prioritized for review/editing. This map shows crashes on the roads. Roads with a blue or red (injurious or fatal) crash, or three or more property damage crashes, was given priority. Many roads significantly exceeded this minimum.

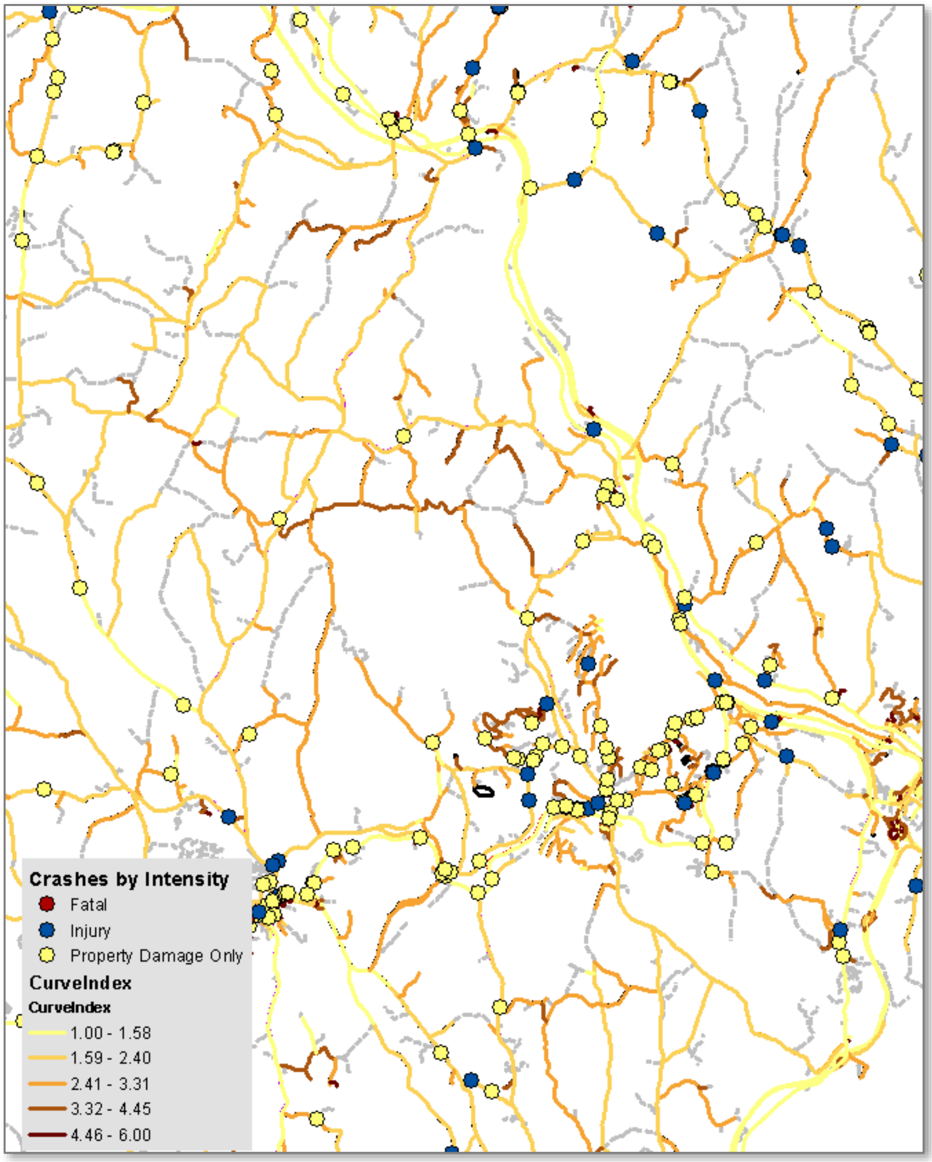

Figure 5 Map showing the editing environment with crashes, and roads visualized by Curve Index. Darker roads have more curves and/or sharper curves per mile, while yellow roads have the least curvature.

Production Edits

A sweep of the entire state has been performed where review and edits took place on local roads having a moderate to high curve index, and/or at least three property-damage-only crashes or one injury-related crash. With exception of early edits on select collectors and arterials, the focus has been on rural local-classified roads exclusively.

Table 3 summarizes final centerline miles edited through to the end of this project. The mileage listed has been calculated in ArcMap using summarizations of the records reviewed and edited by Works Consulting staff.

Table 3 : Total Rural Centerline Miles Edited and Not Edited

Functional Class	Total Miles	Rural Miles (TH-2 and TH-3)	Rural Legacy Complete (estimate)	Rural Edited Miles	Not Completed
1 (Interstates)	723	na	na	na	na
2 (Freeways)	48	na	na	na	na
3 (Principal Arterials)	485	na	na	na	na
4 (Minor Arterials)	891	26	576	na	230
5 (Major Collectors)	2,229	879	1,095	169	878
6 (Minor Collectors)	869	845	38	196	632
7 (Local)	**9,208**	**8,352**	**0**	**3,747**	**4,605**
0 (Private)	5,600	4,955	0	152	na
Total (0-7)	**20,057**	**18,160**	**2,320**	**4,264**	**6,345**

TASK 2b: STATISTICAL ANALYSIS

This project required assessment of the accuracy and completeness of the data. Statistical analysis of curve class changes may also be performed to indicate how quality control edits affected the resultant curve output.

Because the curve tools can be run on the entire network in less than a full day, the completeness of data extracted is regarded as 100%. The curve classification results are only limited in quality by poorly digitized centerline data. The only way around this problem is to improve centerline accuracy to match ortho-rectified imagery of the actual roadways. The accuracy of the calculated curve attribute data has been estimated using various methods.

Sampling the Change in Curve Endpoints – Before and After QC Edits

The initial methodology to satisfy the project proposal involved setting up observations to determine distances of the migration of curve start points and end points – calculated before edits and compared to the same curve after centerline edits improved the curvature result. Table 4 reports the percent of 848 sample observations within certain error ranges representing the distance between existing and revised transition points encasing the curves. These results were calculated from the collector and arterial roads observed early in the centerline improvement process. Because original centerline digitization is generally less refined on local roads than on higher functionally classified roads, we expect a local road statistical summary would be quite different than the summary for collectors and arterials shown below.

Table 4 Statistical Summary on Edited Collectors and Arterials

Range of Error	% of Observations
< 1 ft	42.4%
< 10 ft	54.7%
< 20 ft	61.7%
< 34 ft	68.2% (σ)
< 133 ft	95.5% (2σ)
< 321 ft	99.7% (3σ)
20 routes	848 observation points

This method generally allows analysts to gauge the probability that unreviewed roadway centerlines are demonstrated to give accurate curve class results to the given distance the stated percentage of total observations. For example, if a crash at milepost X on route A occurs and the analyst wants to assign a roadway curvature attribute to the crash location – the curvature class transition point (tangent-to-curve/PC or curve-to-tangent/PT) would be accurate within 10 feet of the true location for 54.7% of the observations. The 2nd standard deviation of error in distance would suggest that the maximum error could be as large as 133 feet to encompass 95.5% of all observations. This table is intended to help safety program managers in deciding whether the error distances are tolerable in unreviewed data. This could assist in determining whether the remainder of the network should be reviewed and improved.

This method is limited in that it does not effectively reflect improvements to "Bulges" and "Gaps" (between these start- and end-points) that are especially prevalent on poorly-digitized local functionally-classified roads. Another method of quantitatively determining the quality of the results has, therefore, been devised.

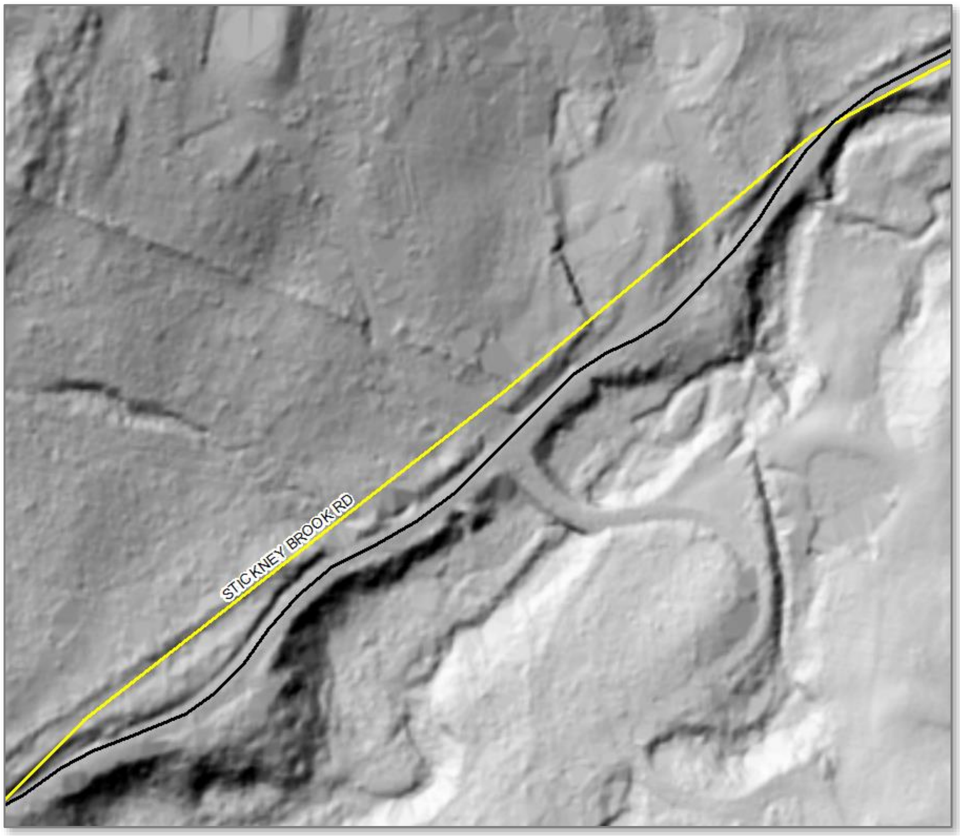

Figure 6 : The new centerline digitized on top of the road from the LIDAR imagery. Yellow is original digitization, and the black is latest centerline with edited vertices. You can see with the naked eye that the curve wedges on the un-edited yellow line will be much fewer than on the edited black line. The discussion that follows will show how we quantify the changes.

Curve Comparison Evaluating – Before and After QC Edits

During this project, a method was utilized that measures the actual change in curve classification before and after centerline edits. That evaluation takes place by overlaying two editions of the calculated curves, identifying each centerline fragment where curve-class has changed, and then summarizing length, the class change, and frequency statistics for each route. In this sense, the analysis is an absolute measure of change between two versions of the roadway centerline.

Evaluation results are summarized in three tables. Table 5 is a system level summary of the total frequency and length of curve-class changes since the project began in December. These totals reflect changes due to edits made by both Works Consulting and VTrans staff. Extremely small changes on some routes can are attributed to rounding error between the two versions of the event file, and not necessarily a real change to the data. Meaningful changes are attributed to the quality control edits of this project, or perhaps other ongoing centerline edits by VTrans staff during the project.

Table 5 Summary of Before/After Evaluation by Delta Class Category

Delta-Class-Category	Number of Routes	Total Delta-Class Count	Sum of Delta Distances (meters)	Sum of Delta Distances (Miles)
A-->B	2,192	22,471	295,250	183.46
A-->C	2,042	18,211	179,305	111.42
A-->D	1,857	14,175	109,200	67.85
A-->E	1,705	10,377	61,663	38.32
A-->F	1,114	3,768	17,506	10.88
B-->A	2,255	21,968	244,687	152.04
B-->C	1,448	5,334	111,384	69.21
B-->D	1,228	4,176	54,674	33.97
B-->E	1,130	3,328	28,216	17.53
B-->F	570	1,172	7,013	4.36
C-->A	1,972	16,454	134,402	83.51
C-->B	1,311	4,549	92,014	57.18
C-->D	1,504	5,500	106,177	65.98
C-->E	1,303	4,245	44,329	27.55
C-->F	659	1,588	8,539	5.31
D-->A	1,774	12,337	80,181	49.82
D-->B	1,008	3,010	35,649	22.15
D-->C	1,347	4,595	82,853	51.48
D-->E	1,535	6,057	86,842	53.96
D-->F	918	2,382	15,643	9.72
E-->A	1,487	8,159	37,795	23.48
E-->B	692	1,929	13,215	8.21
E-->C	921	2,793	23,481	14.59
E-->D	1,402	4,937	62,164	38.63
E-->F	1,390	4,927	41,142	25.56
F-->A	757	2,472	8,597	5.34
F-->B	303	672	3,295	2.05
F-->C	364	814	3,926	2.44
F-->D	564	1,471	7,570	4.70
F-->E	1,198	3,996	30,151	18.74
Sum	**37,950**	**197,867**	**2,026,864**	**1,259**

Some significant differences exist between this final table and the intermediate results delivered mid-project where linear referencing systems (LRS) incompatibilities were still being encountered in the route files with the relation to LRS overlaps caused by bifurcations and loops. Using this evaluation method, minor limitations in reading the Delta-Class-Category change only exist when non-curve-related edits are made, such as in changing the name of the road, or the lengthening and shortening of routes.

The other two curve comparison summary tables (not shown here) are similar, but summaries are by individual route, and the more granular summary by route and each delta-class-category change.

A draft white paper was submitted mid-project on Temporal Comparison of Curvature by Classification, and contains explanation and examples of the evaluation process and results. That previous draft white paper has been updated to reflect final before/after evaluation of curve classification changes, and has been provided with final before/after evaluation results.

Curve Comparison Evaluation – VTrans Legacy Curves vs. Latest Calculated Curves

Curves calculated from the curve tools have also been compared against the VTrans legacy curve data to evaluate the extent to which extracted data elements agree with existing known values. No quality control edits have taken place on routes with legacy curve data – as these are higher order routes than were reviewed by Works Consulting technicians. The evaluation, therefore, only represents the difference in curve-class results due to analytical methodologies. The following table shows the total differences between the legacy and calculated curve event files, summarized by the 30 curve delta-class-categories.

Table 6 Summary of Curve Comparison Evaluation between Legacy and Calculated Data

Delta-Class-Category	Number of Routes	Total Delta-Class Count	Sum of Delta Distances (meters)	Sum of Delta Distances (Miles)
A-->D	49	68	1,669.01	1.04
A-->E	20	24	475.85	0.30
A-->F	6	7	196.71	0.12
B-->A	408	4999	147,692.72	91.77
B-->C	230	687	24,742.76	15.37
B-->D	109	199	4,538.15	2.82
B-->E	35	50	860.82	0.53
B-->F	10	20	239.19	0.15
C-->A	405	3707	90,648.46	56.33
C-->B	330	1560	67,544.53	41.97
C-->D	232	575	17,426.56	10.83
C-->E	87	129	2,506.94	1.56
C-->F	17	21	236.08	0.15
D-->A	329	1843	40,558.89	25.20
D-->B	230	566	13,929.54	8.66
D-->C	279	991	38,181.88	23.73
D-->E	150	301	6,980.53	4.34
D-->F	32	39	551.15	0.34
E-->A	211	629	11,708.50	7.28
E-->B	114	220	4,396.63	2.73
E-->C	153	310	7,705.10	4.79
E-->D	184	482	15,350.16	9.54
E-->F	69	117	1,583.68	0.98
F-->A	91	183	2,958.17	1.84
F-->B	42	52	1,028.94	0.64
F-->C	43	67	1,032.42	0.64
F-->D	41	68	1,435.92	0.89
F-->E	82	181	3,316.76	2.06
Sum	**4,306**	**18,986**	**548,891**	**341**

The legacy curve data exists on 641 routes that total 4,588 miles in length. Along these routes, the Construct Horizontal Curves tool classified 2,543 miles of route centerline as having curves B-curve or sharper. On these routes, curves data exists on only 812 miles of road, with obvious gaps where legacy curve information is just missing. The total number of legacy curve events is 9,166.

To perform a meaningful evaluation of accuracy, the curve comparison has been limited to the 812 miles with existing legacy curve data. In all, 18,986 individual segments have been found to disagree between the two event files. This is roughly two disagreements per curve event, which is probably expected so long as curves fail to start and end in the same exact locations to a precision of several decimal places. A better measure is the total combined length of these segments, which is 341 miles where the legacy curves events have reported a different curve classification. By this measure, the latest calculated curve data is only 58% matching (1-341/812) to the existing legacy curve data.

There are several explanations for the measured change between legacy and calculated curve classifications. One issue is that there are some substantial differences in locations where the start and endpoints change. In most of these cases, the legacy curve data appears to be in error using the painted events and the naked eye – perhaps due to outdated measures after periodic changes to the route network.

Another issue, is simple differences in precision. The degree of curvature in the legacy data is reported in integer values in some places, and more precisely to two decimal places in others. Two curves that in-fact have nearly the same degree of curvature, may end up with different curve classifications.

Figure 7 is an example showing both issues. The legacy curve data calculated a 6-degree curve (C-Curve), whereas the Construct Horizontal Curves tool calculated a 4.8-degree curve (B-Curve) at the same general location. The curve start and end locations are slightly earlier on latest calculated data, so there will be a change from a no curve to a 4.8-degree curve, and vice-versa for the end of the curve where latest calculations shows the curve end earlier. Both are seemingly small changes, but they do contribute to the delta distance. The other important difference in this example is that this entire curve will change from C-curve in the legacy data to B-curve in the recently calculated data. Much of the legacy data is rounded to integers measures, whereas latest data is estimated to over five decimal places in units of miles (though we choose to only visualize and analyze to as much as 2 decimal places). Thus, six-degrees was likely only rounded to the nearest integer, and could have been as low as 5.5 degrees. The calculation of 4.8 degrees is quite close to the lower 6-degree possibility of higher precision, and yet it is represented in a different curve class (5.5 degrees is the breaking point between an B-curve and a C-curve).

Figure 7 : Example Curve Comparison between VTrans legacy data and latest calculated values using Curve and Grade Tools for ArcGIS by Works Consulting. The orange wedge represents the latest calculated B-curve – whereas the black line is shown offset from the centerline on the inside of the curve to see how it starts and ends at different locations compared to the orange wedge.

Generation of the best calculated curve information is based wholly on the centerline geometry provided. The accuracy of the vertex placements on the centerline of the road – AND the defining intra-vertex spacing of each geospatial centerline representation is critical to accurate calculation of the true curve data. Where legacy curve data is generated from other sources like extraction from paper construction plans or electronic CAD files – significant differences could be expected, and were indeed observed.

SUMMARY

This project advanced the knowledge of curvature conditions on ALL roads in Vermont. It was demonstrated that the entire road network can be calculated routinely – and that MIRE elements can be generated swiftly on a regular basis. The quality review and editing effort – since the initial curvature calculation in January – improved the accuracy of GIS centerlines on many of the local roadways AND generated MIRE elements for the first time on ALL Vermont roadways. VTrans GIS staff have also arrived at a better understanding of the GIS techniques that yield digitized centerlines that are extremely effective for statewide safety evaluations and network screenings. VTrans consequently has improved the higher order centerlines in parallel to the separate – but joint – work on local roads. The project accomplishments have the added benefit of more accurate and complete HPMS reporting of curvatures.

The Works Consulting project team hopes that VTrans has been pleased with these outcomes. We recognize that there is more that can be accomplished to bring all public roads in Vermont up to the same accuracy for MIRE and HPMS data – and offer our continued technical services toward the continuation this project.