A white paper…

On Improving GIS Centerlines for Improved Curve Data

Overview

The emphasis of the Model Inventory of Roadway Elements (MIRE) on collection of roadway geometric characteristics in state highway agencies (SHAs) has created momentum toward improved knowledge of roadway curvature. Prior to MIRE standards being developed, the Highway Performance Monitoring System (HPMS) was the principal driving force for SHAs to consider keeping road curve databases. However, HPMS requires curve data only on sample panel sections which might only represent a fraction of a region's total mileage. With MIRE, there is value in achieving curvature data on the entire universe of roads to systemically relate crash histories, and to identify the extent of potential for crash reduction along roads with existing curves.

As SHAs tackle the generation of roadway curvature databases, SHA managers are curious whether the digitized shape of the GIS roadway centerline is adequate to accurately depict the roadway's true curvature. Some agencies are directing significant costs and effort at improving the digitized shape of the GIS roadway centerline.

This white paper shows how to assess the effect of cartographic improvement of the digitized GIS centerline in a statistical sense. It shows quantitative means for summarizing the difference between an un-edited centerline and one that has been reviewed and edited to better match aerial photo-imagery, GPS trace, or LIDAR representations of the roadway.

Curvature Classification

The "Construct Horizontal Curves" tool inside our *Curve and Grade Tools for ArcGIS* extension (http://lrstools.com/#/curve-grade-tools) generates curve wedges that are uniquely identifiable by RouteID, From-Measure, and To-Measure attributes. The measures are endowed onto each vertex of each roadway polyline as address-ranged, block-length polylines are amalgamated into measured routes. When a curvature output is generated, each straight chord segment between two vertices produces one curve calculation. Each of these curve calculations understands its RouteID, beginning and ending measures, and other attributes of the curve itself (Radius, CurveClass, and DeltaDistance along the curve). Curves which are within the same range of radius value, (i.e. in the same degree of curvature class, more on this below) are geospatially dissolved together to remove adjacent redundancy and assign all road segments into six curve classes (A through F) defined by the HPMS specifications. Outliers can be removed by "recipe" alterations available in the toolset – assuming the SHA wants to programmatically "smooth" the inherent errors in digitization without requiring technicians to manually correct the errors.

A-curves are the shallowest curves, and even include straight roads that do not curve and are technically a 0-degree (of curvature) curve, although A-curves with a radius greater than 1 miles are purposely not visualized as wedges. F-curves are the sharpest curves, and B through E curves lie in between on the degree of curvature scale. The degree of curvature is indirectly proportional to the curve's radius (high values of degree of curvature are associated with low values of radius). The following shows the HPMS-based groupings for degree of curvature and radius:

CurveClass
A - <3.5 degree or >1660 ft radius
B - <5.5 degree or >1053 ft radius
C - <8.5 degree or >675 ft radius
D - <14 degree or >413 ft radius
E - <28 degree or >200 ft radius
F - >=28 degree or <=200 ft radius

Figure 1 : Map Legend for the Construct Horizontal Curves tool results. A-curves with more than a mile of radius are normally not shown to prevent clutter on the map.

Curvature Class Change on an Edited Section of Road

In this section, we include examples which visually provide explanation as to how the curvature values along specific segments have been changed due to manual centerline quality edits. All curvatures are representable as arcs with a certain degree value, but they are also representable as 3-sided wedges. Final curve data is ultimately created into a polyline geospatial file, but they are most easily visualized as color coded wedges during the quality control review process—as shown in the following examples. Although technically every section of route is either an A-Curve or greater, we omit the A-Curves (curvatures of less than 3.5 degrees) since it would overwhelm the maps. Furthermore, more substantial A-Curves remain of the lowest priority for analysis.

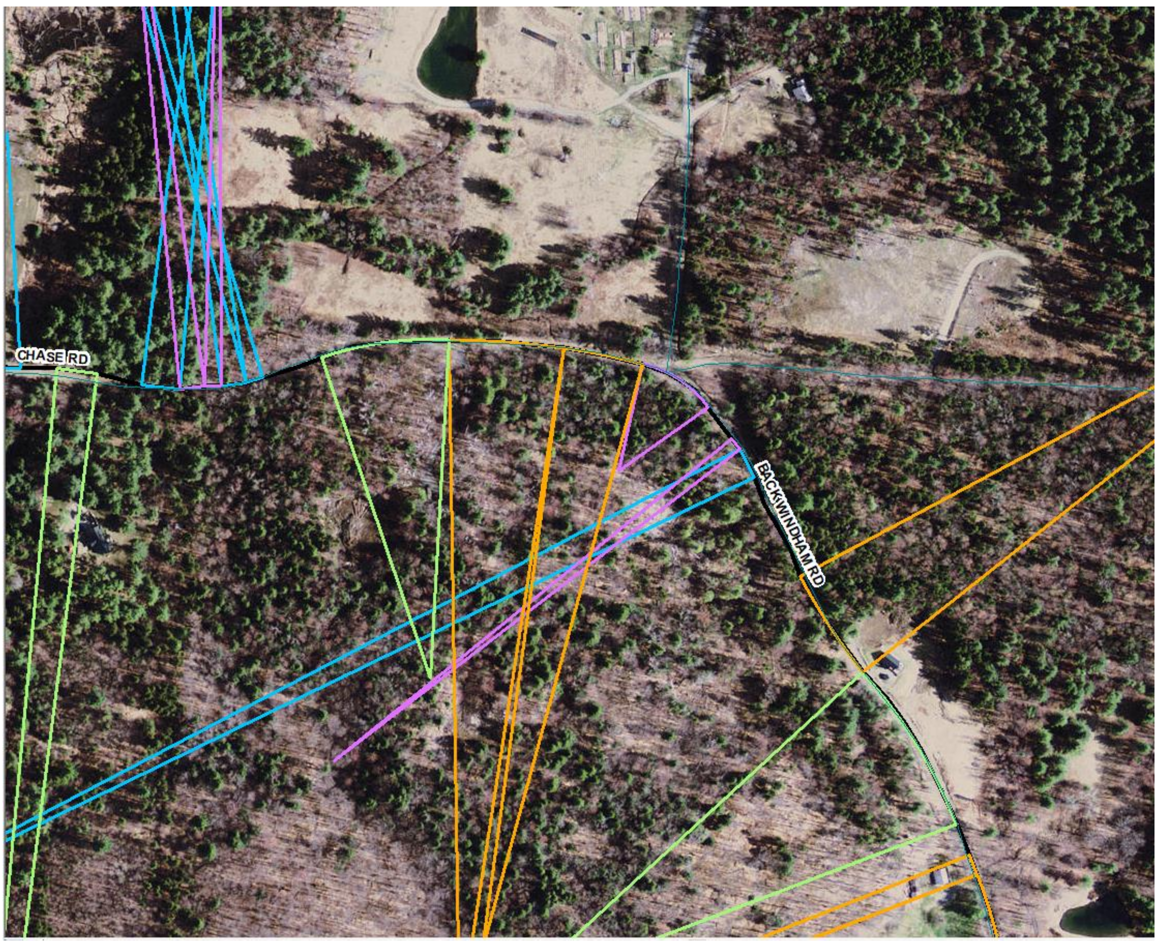

Figure 2: Curvature Calculations for Back Windham Rd, a local road in Vermont, prior to any centerline editing.

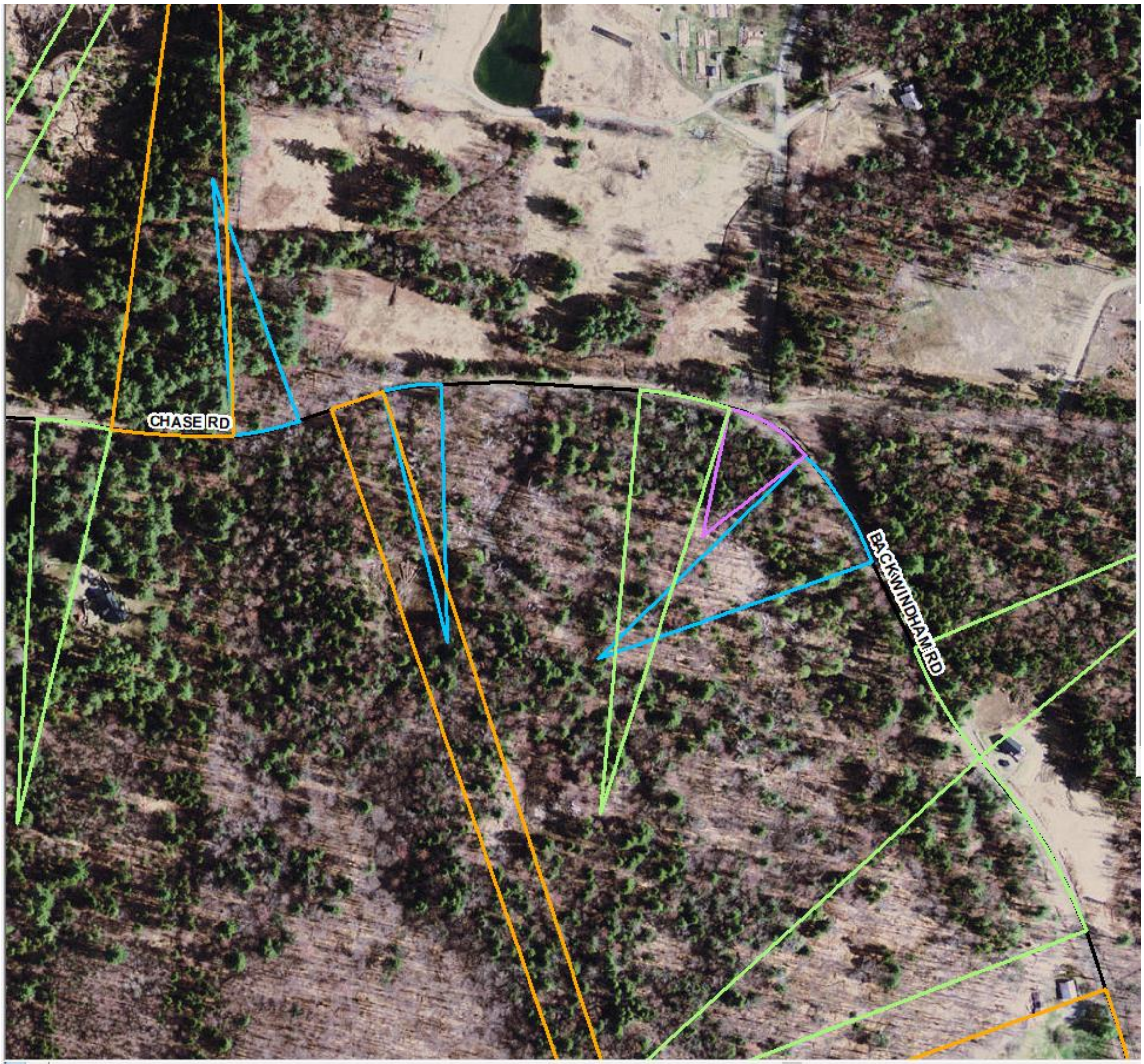

Figure 3 : The same segment of Back Windham Rd seen in Figure 2, with curvatures calculated after editing had been done.

Figure 2 and Figure 3 represent the curve data before and after quality control centerline edits. The later roadway centerline more accurately reflect the background aerial imagery, and the curve wedges are more accurate.

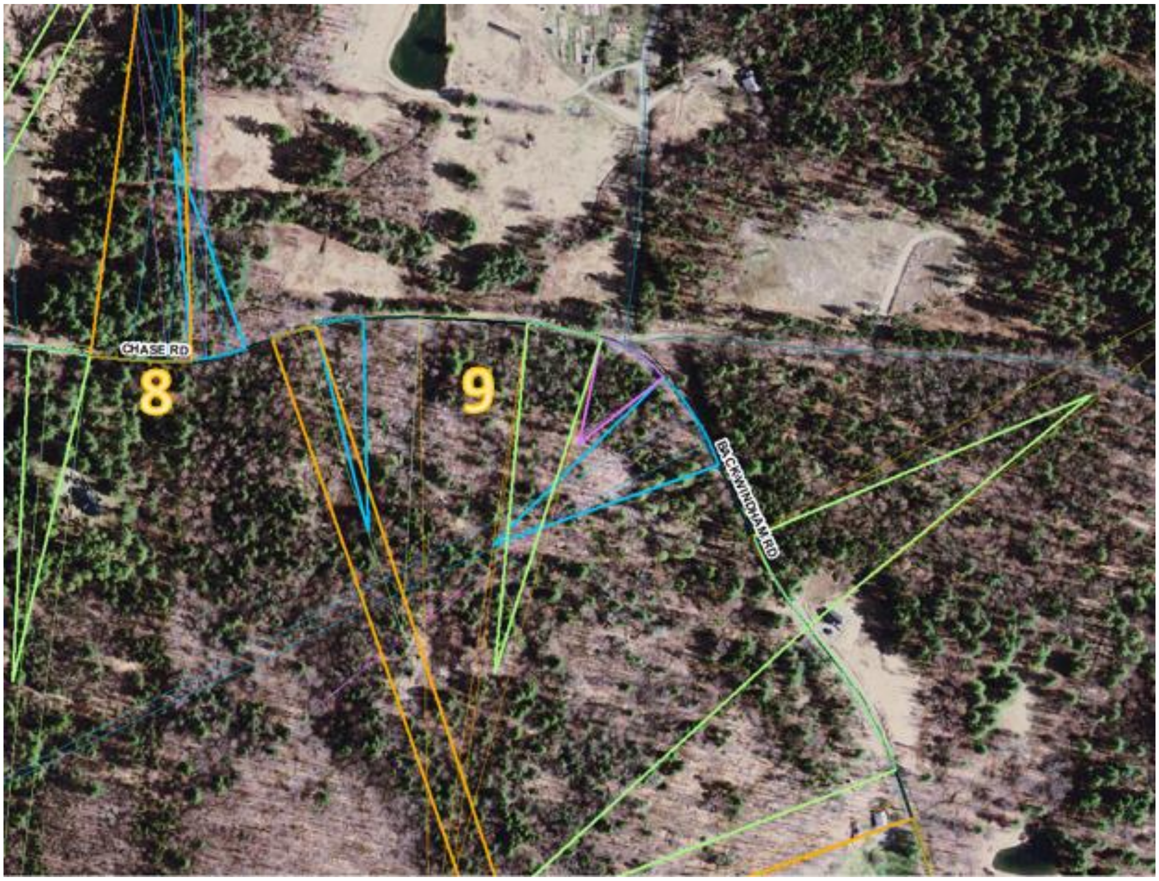

Figure 4: Backwindham Rd, with curvature calculations from Figure 3 overlaid on the curvature calculations from Figure 2.

Figure 4 shows the same roadway segment and previously, where curve wedges from Figure 3 (resulting from centerline quality control edits) are overlain with Figure 2 (the older before curve calculations). The older curve wedges are now more thinly and transparently underlain so some differences can be seen in the image. The number labels "8" and "9" highlight segments that will be analyzed in more depth in Figure 5 and Figure 6.

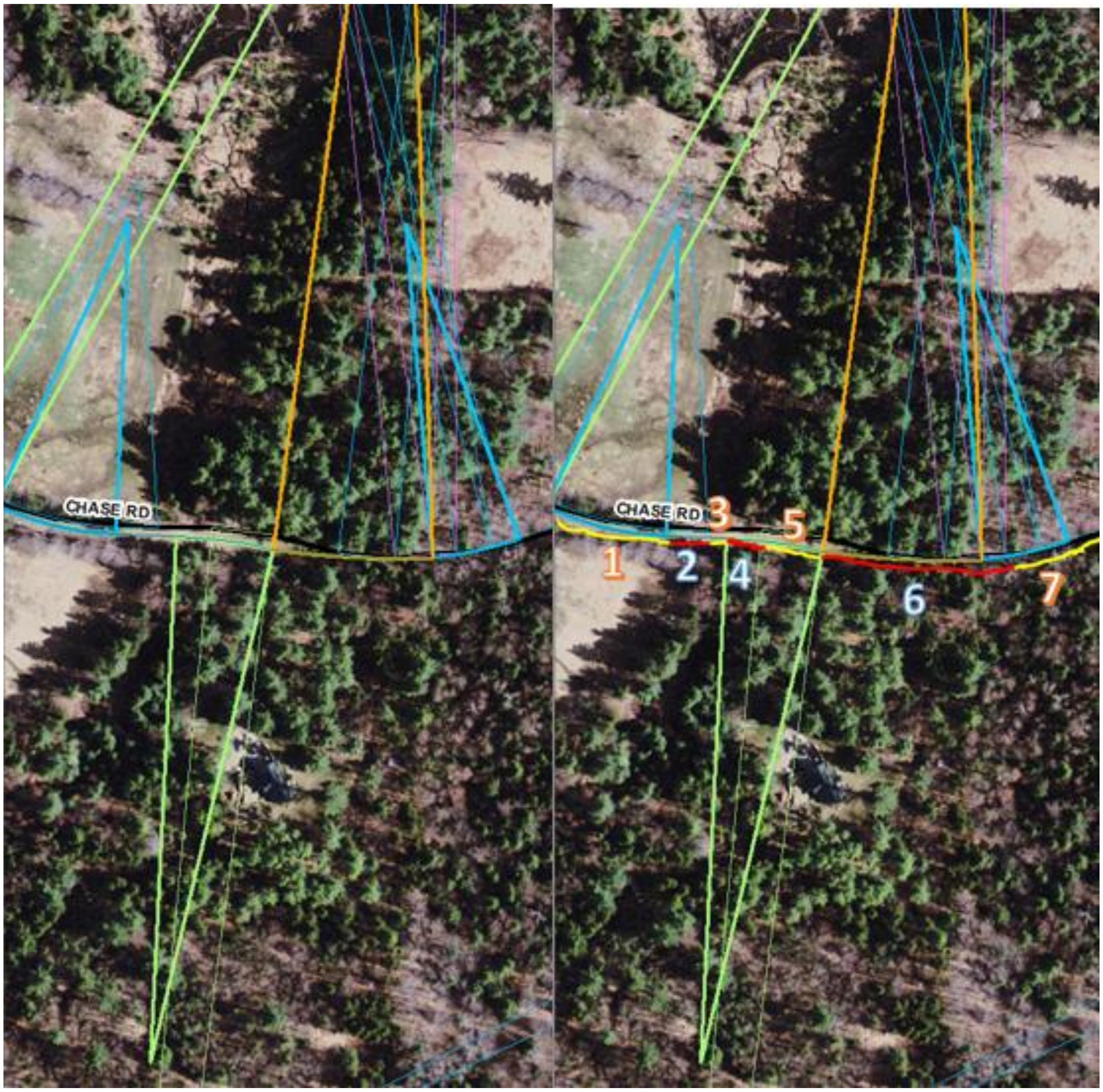

Figure 5 : The westernmost portion of Backwindham Rd., from earlier figures, showing where curve-class has changed after performing quality control edits to the centerline.

Figure 5 demonstrates the crux of this analysis—the Curve Class Change. Both the left and right images show this section of road with before and after curvature calculations. Thicker, non-transparent wedges represent the new curve calculations post-editing, while the thinner, slightly transparent wedges, represent the pre-edited data. The image on the right shows a corresponding alternating red/yellow line represents where the curvature remained the same on the route and where it has changed. Sections of change and no-change are labeled with numbers.

The following explanations occur along the route from west to east (left to right on each image). In the right image, yellow represents where the curvature class calculation remained the same, and red represents where the curvature class calculation changed. Traveling from the west, section 1 represents where a blue curve (i.e. D-Curve) is calculated for the route both pre-editing and post-editing. However, the adjacent red section 2 of the new D-Curve is the portion where that curve had extended prior to editing, versus the new eastern ending of the curve which is further west. In short, this first red section represents the difference of that individual curvature change, but also a change of that section of route from an E-Curve to an A-Curve (represented as a Delta Class of E→A).

The next yellow section to the east, section 3, represents a short portion of road where there is a consistent A-Curve lying between the large blue curve (E-Curve) and green curve (C-Curve). In other words, there is no Delta Class Change since it was an A-Curve pre-editing and post-editing. Technically, we could have visualized an A-Curve here, but it was not necessary to do so, and A-Curves can be visually messy. The next red section, section 4, represents where only an A-Curve was calculated as the same A-Curve as section 3 pre-editing, but it is now part of a larger C-Curve post-editing. This is classified as a Delta Class change of A→C, since it was an A-Curve but is now a C-Curve. Section 5 represents where there is no Delta Class change, since it was both calculated as a C-Curve pre-editing and post-editing.

The sixth section in Figure 5 represents a longer stretch of road with several changes. In the pre-edited data, the western half of this section was an A-Curve (again, not depicted visually in Figure 2), and the eastern half was part D-Curve and part E-Curve. In our post-edited data, most of section 6 is now a B-Curve, and the far eastern end of it is part of a larger D-Curve. Therefore, this entire section consists of Delta Class changes of A→B, D→B, E→B, and E→D, when read from West to East. In this case, there were four total curve class changes over three curves. Finally, section 7 is another non-change zone which represents where we had calculated a D-Curve in both the before and after data.

Figure 6 : The eastern portion of Back Windham Road shown in earlier figures, again showing where curve-class has changed after performing quality control edits to the centerline.

Figure 6 illustrates more examples of changes to the curvature classes. In section 1, a lengthy section of road originally had one C-Curve before edits, which originally began just right of the visible area. In the post-editing version, this same section begins with a spiral curve (a curve with an increasing degree of curvature) which is dissolved into a B-Curve transitioning to an E-Curve. From west to east, this section would include Delta Class Changes of: A→B, C→B, C→D, C→A. This A-Curve extends all the way through section 2, along to the beginning of section 3.

Section 2 represents where there was a B-Curve in the pre-edited data, and an A-Curve in the post-edited data. However, when examined, this curve was only a relatively shallow B-Curve (almost shallow enough to be an A-Curve) in pre-editing, and a relatively steep A-Curve (almost a B-Curve) post-editing. There was a shallowing of the curve, and a delta class change. Therefore, despite the editing barely affecting this curve, it will still register as a Delta Class change of B→A.

Section 3 represents a similar change to section 2, where the starting and ending points of the curve are nearly identical, but there is a sharpening of a curve, from a B-Curve to a C-Curve. The wedge, similarly, is shorter and sharper.

In section 4, there is no change in curvature class change for the starting and ending point of this E-Curve. In this sense, there is no change. However, it is noticeable that there is a numerical change in the degree/radius of the curve. The wedge is not identical in shape, despite the same starting location, ending location, and curve class. This is because it's both slightly sharper and the road moves in slightly different directions away from the curve. This is an example where we do not register a change in the statistical analysis because it is not significant.

Sections 5 through 7 represent where there is now one D-Curve which has been more realistically depicted. Pre-edited centerline data had misrepresented this section as multiple D-Curves, E-Curves, and A-Curves.This means there are delta class changes of E→D, no change (D→D), and then D→A.

While the ability to calculate curves along a centerline file is certainly useful, the comparison of curve-class on individual segments before and after centerline edits lends confidence to the editing process and provides feedback to help analysts performing centerline edit to do so properly. Works Consulting is developing the method to automate the calculation of these changes into a tool called Wedge Class Change Evaluation. We expect that this tool would eventually exist as part of the Curve and Grade extension.

Summary of the Curve Compare Evaluation

After generating horizontal curves for all routes from two temporally different versions of the same centerline (or route) feature class, we use these separate outputs as the inputs for a tool called the Curve Compare Evaluation. A comparative curvature overlay initially details every instance where the curvature class has changed by overlaying route events using linear referencing on the same LRS datum – normally that of the improved arcs. Every section of compared routes with the same curve class is discarded. (For instance, it would be a stretch to say that a curve which changes from 4.0 degrees to 4.2 degrees is a “significant” change. Both would still be a B-curve, so the actual change is obfuscated by the HPMS-based groupings.) From this summarization of curve class change, each route can be further summarized for its corresponding relatively short segments of curve class change.

Three Summary Tables

Three tables are produced from the Curve-Class Compare Evaluation tool:

(A) Curve Comparison by Route and Delta-Class-Category
(B) Curve Comparison by Route
(C) Curve Comparison by Delta-Class-Category

To convey the effects that centerline edits have on the curve data, we compared the outputs of the unedited data with the most recently edited data. We employ our “Construct Horizontal Curves” tool to give us both outputs using the same “recipe” on different time versions of the same arc centerlines. After editing, the later-timed version is assumed to have improved digitization over the earlier-timed version. Visual comparisons can always be made by overlaying a curvature calculation from the older version of the centerline data with the same curvature calculation done on a newer version of data. The change evaluation analysis accomplishing the assessment of quality improvement on the entire network by automated and quantitative means.

Table A: Curve Comparison by Route and Delta-Class-Category

Overlay of the two curve event feature class files in GIS results in a combined before and after table. The first summary table is essentially a pivot table roll up of the raw overlay table with statistics summarized by individual routes and the category of curve class change, or delta-class-category. There are 30 possible combinations of curve-class change (six times five curve-class categories with class categories A-F). Delta Classes which do not exist on the route are not summarized in this table. The unique identification of each row is the combination of RouteID with Delta Class. For instance, in Table 2, the third row represents RouteID of ‘A ST’, and curve class change A→B. The following table is a sample of the first several records only, showing little more than summary of the first complete route.

Table A: Example summary of curve-class changes by Route and by Delta-Class-Category

RouteID	DeltaClass Category	Frequency of Class Change	Sum of Delta Distances (meters)
-	A-->B	15	28.29
-	C-->A	14	5.42
A ST	A-->B	2	33.88
A ST	A-->E	2	19.68
A ST	A-->F	2	0.32
A ST	B-->A	4	54.94
A ST	C-->A	3	33.95
A ST	C-->E	1	10.93
A ST	D-->A	1	17.63
A ST	D-->B	1	5.04
A ST	D-->E	1	19.05
A ST	D-->F	1	12.51
A ST	E-->A	4	26.44
A ST	E-->D	1	13.90
A ST	E-->F	2	16.82
A ST	F-->A	6	13.73
ABBOTT RD	A-->B	12	99.17
ABBOTT RD	A-->C	10	17.93

Route ID: the route name on which the delta-class changes occur. In this table, Route ID is not unique, but the combination of Route ID and Delta-Class-Category is unique.

Delta-Class-Category: the before and after curve-class change. For instance, A→B signifies that the curvature class was originally an A-curve in the pre-edited before data, but is a B-curve in the edited data.

Frequency of Class Change: the number of times that the category of curve class change occurs on the route. In Table A, the third row represents the class change of A to B (A→B) on 'A ST'. The Frequency of Class Change is 2, meaning there are two separate segments where this change occurs. The fourth row represents the same RouteID's A→E change, which has a frequency of 2, meaning that there are 2 locations on 'A ST' where the curvature of the route changed from an A-curve to a E-curve.

Sum of Delta Distance: the total distance of the Delta Class change on the RouteID for that class change category. In this example, units are in meters. For instance, the 'A ST' A→B on row three shows a total distance of 33.88 meters where the curvature changed from class A-curve to B-curve on 'A-ST'. The units are always expressed in the Map Units of the base data.

Table B: Curve Comparison by Route

Table B is a further summarization of Table A. In this table, RouteID is a unique ID in and of itself. Each row represents the attributes of curvature change summarized along each route—a twist on Table A. Routes with no curvature changes would not appear.

Table B: Example of the further summarization of the Route-Class summary table with DeltaClass dissolved. Each row signifies a route where at least one delta class change has occurred.

RouteID	Delta-Class-Category Count	Total Delta-Class Count	Sum of Delta Distances (meters)	Route Length (meters)	Deltas Per Mile	Deltas By Percent of Route
-	2	29	33.7	18,861	2.5	0.2
A ST	14	31	278.8	1,494	33.4	18.7
ABBOTT RD	19	118	690.5	7,774	24.4	8.9
ABENAKI ACRES	3	4	53.8	194	33.2	27.7
ABENAKI LOOP	2	3	48.1	461	10.5	10.4
ABIJAH PRINCE RD	19	48	501.5	1,641	47.1	30.5
ABROAD RD	3	7	73.9	305	36.9	24.2
ACADEMY AVE	1	3	30.1	225	21.5	13.4
ACADEMY HL	3	5	175.8	728	11.1	24.1
ACADEMY RD	4	39	111.4	6,681	9.4	1.7
ACADEMY ST	6	10	100.7	1,749	9.2	5.8
ACCESS RD	3	10	16.2	3,937	4.1	0.4
ACER RD	6	14	123.8	646	34.9	19.2
ACME ST	1	1	7.1	58	27.8	12.3
ACORN ST	4	10	129.7	371	43.3	34.9
ACTON HILL RD	4	11	45.5	1,971	9.0	2.3
AD BROOKS RD	3	6	114.1	625	15.4	18.2
ADAMANT RD	17	49	681.8	2,463	32.0	27.7

Route ID: the route name on which at least one delta class change occurs.

Delta-Class-Category Count: the number of *specific types* of delta class changes along the route. This is summarization of Table A's Delta Class Changes per route. The maximum possible number is 30, since there are only six curve-class categories and each category can only change to five other classes (6 times 5 = 30). For instance, 'A ST' has 14 types of classification changes.

Total Delta-Class Count: the total number of curvature changes along the route. This is simply the summation of the Frequency of Class Change column from Table A for each route. 'A ST' has 31 total changes in the route, which would include every segment where there is a curve class change, no matter how small. Despite there being 118 total changes, they only add up to 690.5 meters, so it's possible that many individual changes could be as small as less than a meter.

Sum of Delta Distances: the total distance, in meters, of the route that has changed curve classes. For instance, 'A ST' has 278.8 meters of the total Shape_Length of the route that has had its curve class made more accurate.

Route Length: the total distance of the route in map units, for use in the next 2 items. In this case, Route Length is in meters.

Deltas Per Mile: the average number of delta class changes per mile. For 'A ST', there are 33.4 changes per mile on road approximately 1,494 meters (0.93 miles) long.

Deltas By Percent: the percentage of the route length that has changed curve class. This is simply the Sum of Delta Distances divided by Shape Length expressed as a percentage. In short, this number demonstrates what percentage of the road has changed curve class. In example, 'A ST' is 18.9 percent changed from before it was edited.

Table C: Curve Comparison by Delta-Class-Category

Table C is another summarization of Table A, this time by Delta-Class alone. This table disregards individual routes and instead sums the number of routes affected by each of the 30 possible delta-class changes, the total occurrences for each distinct delta change, and the composite distances for each delta change. This is the most concise snapshot of the entire network. The sum of the frequency of delta changes is included (the total number of curvature changes in the entire route system), as well as the total distance of segments with Delta Classes.

Table C: Summarization by Delta Class of the initial class change data.

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**

Delta-Class-Category: the curve class change. For instance, A→B represents the segments where curvature class was originally an A-curve, but became a B-curve after the data edits.

Number of Routes: is the number of routes that each delta class exists on. For instance, the delta class change of A→D has occurred on 1,857 routes. However, the level to which a route has changed is completely irrelevant. Even if A→B change happens 100 times on one route, it still only counts as 1 occurrence (route) in this column. This column does not have a SUM value because these are not a unique number of routes where the changes occur, since one route could (and normally does) have multiple delta classes.

Total Delta-Class Count: the number of times that each delta class change has occurred in the entire centerline feature class. For instance, the delta class change of A→B has occurred 14,175 times in the entire centerline file.

Sum of Delta Distances: the total distance (in meters and miles) that each delta class change has occurred on throughout the entire region. For instance, in Table C the delta class change A→D has occurred on 109,200 meters (67.9 miles) throughout the state.

In the case of Vermont, the sum total of 2,026,864 meters of centerline change were contained in the total GIS centerline file – suggesting that 6.28% of the mileage (2,027km÷32,277km) was subject to a change in curvature class upon correctively editing the centerline to ensure alignment with the true road representation.

By summarizing changes across the network in individual states or localities, Works Consulting and its clients can detect systematic patterns and evaluate routes on a case-by-case basis to understand how to edit centerlines to match curve data calculation. The accumulation of these changes over time can be understood by preserving legacy files of the centerline files and evaluating what large-scale changes have occurred using Statistical Analysis based on Summarization. On a more case-by-case basis, the visualization of calculated wedges allows Works and its clients to edit centerlines to more appropriately reflect which curvatures are present, and to better understand the extent that vertex placing has on the future of the MIRE expectations for SHAs.

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