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Using Quasi-Horizontal Alignment in the absence of the actual alignment

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ABSTRACT

Horizontal alignment is a major roadway characteristic used in safety and operational evaluations of many facility types. The Highway Safety Manual (HSM) uses this characteristic in crash prediction models for rural two-lane highways, freeway segments, and freeway ramps/C-D roads. Traffic simulation models use this characteristic in their processes on almost all types of facilities. However, a good portion of roadway databases do not include horizontal alignment data; instead, many contain point coordinate data along the roadways. SHRP 2 Roadway Information Database (RID) is a good example of this type of data. Only about 5% of this geodatabase contains alignment information and for the rest, point data can easily be produced. Even though the point data can be used to extract actual horizontal alignment data but, extracting horizontal alignment is a cumbersome and costly process, especially for a database of miles and miles of highways. This research introduces a so called "Quasi-Horizontal Alignment" that can be produced easily and automatically from point coordinate data and can be used in the safety and operational evaluations of highways.

SHRP 2 RID for rural two-lane highways in Washington State is used in this study. This paper presents a process through which Quasi-Horizontal Alignments are produced from point coordinates along highways by using spreadsheet software such as MS EXCEL. It is shown that the safety and operational evaluations of the highways with Quasi-Horizontal Alignments are almost identical to the ones with the actual alignments. In the absence of actual alignment the Quasi-Horizontal Alignment can easily be produced from any type of databases that contain highway coordinates such geodatabases and digital maps.

1. Introduction

A majority of highway safety and operational evaluation models require horizontal alignment data to conduct such evaluations efficiently and properly. However, many agencies lack such data for the major portion of their highways in their databases and have only point coordinates, in the form of Latitude/Longitude or Cartesian coordinates (e.g., a series of (X,Y) coordinates) that when linked together, give an approximation of the horizontal alignment. Agencies are increasingly using mobile data collection systems or electronic maps to obtain highway data. One of the immediate results of such data collection methods are roadway points coordinate data. The coordinate data can later be used to derive the alignment data of the road. This type of data collection is becoming quite fast and low-cost compared to the more precise geometry data collection such as on-site surveying.

Much of point data collected through mobile data collection systems or electronic maps can be processed in an efficient and automated manner to produce data for the entire length of highway projects such as lane width, shoulder width, grade, roadside, etc. An exception is the horizontal alignment data. Except for the mobile data collection systems that now a days produce horizontal alignment from their collected point data, it is relatively time consuming and costly for the other point data collection systems to produce horizontal alignment from point coordinate data and the process usually requires human intervention in different stages.

This research presents a relatively simple algorithm generating a "Quasi-Horizontal Alignment" from point coordinate data that can be used in the safety and operational evaluation of highways. The algorithm produces Quasi-Horizontal Alignment automatically from point data with some straight forward equations. It can be coded in regular spreadsheet programs (i.e., EXCEL) and can be used for large databases containing point coordinate data. As part of the process, a maximum radius, R_{max}, is estimated in advance, as the threshold value for producing Quasi-Horizontal Alignment. In the

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Quasi-Horizontal Alignment, tangents and curves with radii flatter than R_{max} are approximated by tangents, and curves with radii equal or sharper than R_{max} are approximated by compound curves with radii close to the actual radii of the curves.

Horizontal alignment is a major factor in safety and operational evaluations of rural two-lane highways. These facilities lack horizontal alignment data in many databases. In this study the Quasi-Horizontal Alignment is produced for a sample of 30 sections of rural two-lane highways, each between 2 and 3 miles of length, and the safety and operational evaluations of these alignments are compared to those of the same highways with the actual horizontal alignment. The comparison shows that the results are almost identical. IHSDM software, 2015 is used to conduct the evaluations. The IHSDM Crash Prediction Module (CPM) – a faithful implementation of the Highway Safety Manual (HSM), 2010 Part C Predictive Method – is used for the safety evaluation, and the Traffic Analysis Module (TAM) is used for operational evaluation.

Part C of the HSM contains crash prediction models for different types of highways. The general structure of these mathematical models includes a Safety Performance Function (SPF) and a series of Crash Modification Factors (CMFs).

The HSM crash prediction model for Rural Two-lane highways and its CMF for horizontal alignment are the focus of this research. This CMF has the following form:

$$CMF_{3r} = \frac{(1.55 \times L_c) + \left(\frac{80.2}{R}\right) - (0.012 \times S)}{(1.55 \times L_c)} \tag{1}$$

Where:CMF_{3r} = crash modification factor for the effect of horizontal alignment on total crashes;L_c = length of horizontal curve (miles) which includes spiral transitions, if present;R = radius of curvature (feet); and$S$ = 1 if spiral transition curve is present; 0 if spiral transition curve is not present; 0.5 if a spiral transition curve is present at one but not both ends of the horizontal curve.

The value of this CMF is 1 for tangents and larger than 1 for horizontal curves. As the radius or the length of the curve decreases, the value of this CMF increases. If the radius or the length of the curve is less than 100 ft, then 100 ft should be used in Eq. (1). Also if there is a compound curve (adjacent curves with the same direction curvature) the horizontal curve length used in Eq. (1) is the total length of the compound curve for all curves CMFs of the compound curve.

TWOPAS – the microscopic traffic simulation model used in the IHSDM Software (2015) Traffic Analysis Module (TAM) – had been developed for rural two-lane highways and had been used for the development of the two-lane models of the Highway Capacity Manual for years. This microscopic simulation model uses the horizontal alignment information along with the posted speed and traffic flow. The model simulates the traffic and produces traffic operational measures such as average speed and percent time following that can be used to determine the Level of Service (LOS).

The main purpose for this research is to develop an easy-to-obtain surrogate horizontal alignment that can be used in the absence of the actual alignment in the crash prediction and traffic simulation processes. The IHSDM modules, CPM and TAM, were used for the safety and operational evaluation of the 30 test highway sections. For highway sections that are used in these experiments, the probability that the estimated value for number of crashes predicted by the CPM for Quasi-Horizontal Alignment falls within 5% of the number of crashes predicted for the actual alignment is about 95% and the probability that the operational measures produced by the TAM for Quasi-Horizontal Alignment falls within 5% of the number of operational measures for the actual alignment is about 99%.

2. Related research

The related research reviewed here is focused on the techniques used for extracting horizontal alignment data from point data.

Karimi and Liu (2004) used image processing techniques to extract coordinates from satellite images. The proposed process extracts road data from satellite images and vectorizes the extracted data for GIS databases. Coordinates obtained through this process can later be used for the extraction of horizontal alignment.

Carlson et al. (2005) identified 10 techniques for obtaining horizontal curves and conducted a controlled experiment on 8 of these techniques to measure 18 horizontal curves on rural two lanes to evaluate their accuracy, precision, and cost. The tested methods were:

- Ball Bank Indicator
- Chord Length
- Compass
- Field Survey
- GPS Unit
- Lateral Acceleration
- Plan Sheet
- Advisory Speed Plate

Compared to the Field Survey method, all other methods had a relative error less than 7.5%, with the Plan Sheet and the GPS methods being the most accurate with relative errors of −0.9% and 1.2%, respectively. However, all methods needed human interaction for identifying curve locations.

Imran et al. (2006) employed non-linear regression to deduct the horizontal alignment of a road based on the path of a control vehicle (coordinate data). As an extension for *ArcView*, this application could identify horizontal tangents, spirals, and simple curves from coordinate data. The application of the model on a 25-km section of a two-lane highway test case was successful. However, this procedure cannot be used for a consistent and comprehensive application of the algorithm on a large-scale database because the tangents need to be identified by the user.

Easa et al. (2007) presented a method for establishing road horizontal alignment using IKONOS 1-m spatial resolution, a type of new generation commercial satellite imagery. This process identified the characteristics of simple curves as well as reverse curves. The process started with image processing that identified edges in the image by using some thresholds. The outcomes of this step were coordinates that were used in the second step. The standard Hough Transform algorithm was used to identify tangents vs. curves. The process started with identifying tangents on both sides of the curve, and then continued with identifying the curve characteristics. Curves could be simple or reverse. This was an interactive procedure and the entire process for a road that contains many tangents and curves could not be automated.

Dong et al. (2007) continued the work of Easa et al. (2007) using IKONOS 1-m spatial resolution imagery. They added a process to the algorithm that could extract the spiral curves as well. Similar to the previous work, this one also needs human interaction and cannot be fully automated.

Pratt et al. (2009) developed the “Texas Roadway Analysis Measurement Software” (TRAMS) program to measure curve geometry while driving through the curve. TRAMS uses data from a GPS receiver and an electronic ball-bank indicator and calculated curve radius, deflection angle, and superelevation rate. The process was (a) filtering the heading data for the noise with Kalman filtering as an option; (b) dividing the curve into 25-ft segments and for each segment the deflection angle was calculated; (c) deriving a sixth-order polynomial that predicted the deflection angle along the curve; (d) joining the segments if necessary to have deflection

Table 1
Curvature Data for Highways Used in Experiments.

Highway Section	Length (ft)	Length (mi)	AADT	Posted Speed
Quasi Align 01	15494	2.93	18371	55
Quasi Align 02	11213	2.12	18371	55
Quasi Align 03	13477	2.55	5145	60
Quasi Align 04	13370	2.53	6109	60
Quasi Align 05	17325	3.28	11962	50
Quasi Align 06	11092	2.10	5029	60
Quasi Align 07	12096	2.29	5029	60
Quasi Align 08	15748	2.98	5029	60
Quasi Align 09	17200	3.26	5240	60
Quasi Align 10	11845	2.24	9042	30
Quasi Align 11	11020	2.09	9042	30
Quasi Align 12	19468	3.69	5170	60
Quasi Align 13	10765	2.04	11000	30
Quasi Align 14	11500	2.18	11000	30
Quasi Align 15	13100	2.48	11000	30
Quasi Align 16	11439	2.17	11000	30
Quasi Align 17	11620	2.20	5013	60
Quasi Align 18	11949	2.26	5013	60
Quasi Align 19	10907	2.07	5334	60
Quasi Align 20	12395	2.35	5334	60
Quasi Align 21	10809	2.05	3839	60
Quasi Align 22	11000	2.08	3839	60
Quasi Align 23	12347	2.34	3839	60
Quasi Align 24	13295	2.52	3524	60
Quasi Align 25	16407	3.11	3524	60
Quasi Align 26	16641	3.15	4763	60
Quasi Align 27	13661	2.59	6855	60
Quasi Align 28	14000	2.65	6855	60
Quasi Align 29	12000	2.27	6855	60
Quasi Align 30	15864	3.00	6855	60

angles greater than 5 for each segment; (e) calculating the superelevation by using the ball-bank readings and speed; and finally (f) calculating the radii of segments along the same curve and choosing the smallest radius for the determination of the advisory speed. This software focused on estimating curvature along curve sections and did not extract the entire horizontal alignment data.

Hummer et al. (2010) conducted research for North Carolina DOT to produce a procedure for curve warning signing, delineation, and advisory speeds on horizontal curves. This study had also the objective of determining how States can use the HSM crash prediction model for rural two-lane highway segments more effectively. Estimation of the calibration factor for this model was also one of the objectives in this study. For this model, horizontal curvature data is the major factor after AADT in estimating the calibration factor. Another part of this project was to evaluate three GIS programs that identify curvature of highways. Two of these programs, Florida DOT's "Curvature Extension" (2010) and Esri's "Curve Calculator" (2009) were designed to analyze a single curve at a time. The third program, New Hampshire DOT's "Curve Finder" (2010) has a method that can be deployed on a route or a network of routes. This research found all three GIS methods good enough for the purpose of safety evaluation (i.e., crash prediction). However, none of these methods produces alignment data good enough for design and engineering applications. The "Curve Finder" had the advantage that it can be used over a route or network of routes.

Hans et al. (2012) from the Center for Transportation Research and Education (CTRE) have studied the issue of identifying curves in the Iowa State DOT database. Their primary objective was to refine the horizontal curve databases. They also had a secondary objective to evaluate the accuracy of geometric parameter estimates and to test the sensitivity of safety performance to errors in curve parameters. They used three primary techniques to assess the horizontal curvature and developed an Excel spreadsheet to automate the process. The three techniques were (a) circular regression; (b) Newton iteration of the modified circular curve equation; and (c) a comparison of the results of the other two techniques. The results of the above techniques in conjunction with the length of the site were used to identify if the site was a tangent, a circular curve, or "other" type of alignment. Their conclusion was that the automated process will produce results that are good enough for a basic safety evaluation but needs manual refinement to produce an accurate horizontal alignment.

Othman et al. (2012) used naturalistic driving data Field Operational Test (FOT) data to identify horizontal curve characteristics, including the radii of curves, as well as the curve starting and ending points. The proposed process had several steps in which MATLAB scripts were used in their implementation. One major difference between this study and the others was that for identifying curvature on each of the highways, it used data from multiple runs on that highway by different drivers. This research was limited to identifying simple curves characteristics.

Li et al. (2012) presented a fully automated method for identifying curves and extracting horizontal curve data from GIS roadway maps. An application called "CurveFinder" had been developed on the ArcMap platform based on ArcObjects, which is the programmable package of ArcGIS. The application identified simple and compound curves, but not spirals. Tangents shorter than 600 ft were also not identified and were considered part of compound curves. Besides the tangent length threshold of 600 ft there were also two other thresholds. A bearing threshold dictated if a new segment was part of a tangent, part of a new curve, or the continuation of the current curve. This method seemed to be fully automated, and, as long as the entire data was available in a GIS layer, all of the curves in that layer could be identified and the radii could be estimated. A threshold of 1.25° was found to minimize the number of errors in finding curves. A length threshold was identified if a curve was a simple curve or compound. A 2.5% length difference between theoretical and actual length of curve was suggested in the paper.

Of all methods reviewed for alignment extraction, the work of Li et al. (2012) seems to be the most effective. However, in the short run it is quite costly for agencies to manage their data and apply this type of model to their data to obtain horizontal curvature for

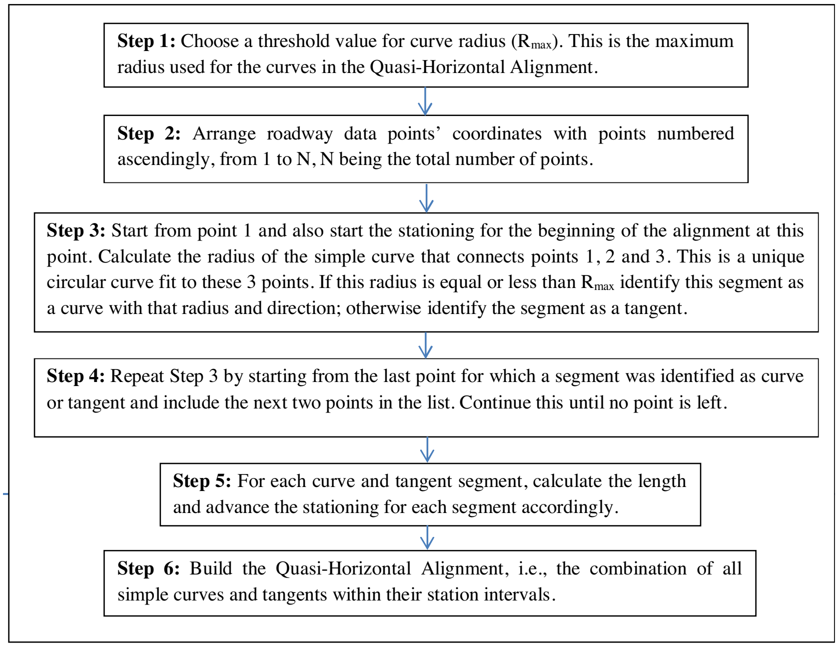


Fig. 1. Producing "Quasi-Horizontal Alignments".

their entire database. Also, even though there is some validation of the extracted curvature in the report, still it is not clear how good the extracted data are when crash prediction models are applied to that data.

3. SHRP2 Roadway Information Database (RID) Used in Experiments

The Second Strategic Highway Research Program (SHRP 2 NDS, 2015) "was established by Congress to investigate the underlying causes of highway crashes and congestion in a short–term program of focused research. The objective is to identify countermeasures which will significantly improve highway safety through an understanding of driving behaviors." SHRP 2 Safety Project produced two types of databases, the Naturalistic Driving Study (NDS) databases and Roadway Information Database (RID). The RID includes roadway, traffic volume, and historic crash data, and is comprised of 6 geodatabases, each one for the states of Florida, Indiana, New York, North Carolina, Pennsylvania, and New York. The main objective for developing the RID geodatabases was to use them in conjunction with the NDS data to better understand human behavior during driving operations. However, the use of these databases can be expanded beyond the original objective.

The core of the RID geodatabases is the geolocation information of state highways in terms of latitude and longitude and in the form of point/line elements conflated on Esri's Street-map Premium road network (which is based on a version of the NAVTEQ road network). In each geodatabase, about 5% of the data have also been completed by adding actual horizontal alignments that are the results of surveillance and post process by instrumented vehicles. This is a perfect database for this research, in that it contains both point location and actual horizontal alignment data for the same set of highways (for about 5% of the entire network). The Quasi-Horizontal Alignment is produced from point data and the safety and operational evaluations of these alignments are compared to the ones obtained from the same highways but with actual horizontal alignment.

There were 30 highway sections with length between 2.0 and 3.7 miles with known actual horizontal alignment selected from the Washington State RID geodatabase. For the purpose of this selection the database was sorted based on route IDs and continuous sections of lengths longer than 2.00 miles were identified from the top of the list. Table 1 shows the main characteristics of these highways (labeled as "Quasi Align 01" through "Quasi Align 30").

The Quasi-Horizontal Alignment and also the actual horizontal alignment and other relevant data were used to run the IHSDM CPM and TAM on the projects. The CPM estimated the predicted number of crashes by applying the HSM model pertaining to rural two-lane highways and the TAM produced average speed and percent time following (percentage of travel time that vehicles are impeded by other vehicles) for the projects.

4. Quasi-Horizontal Alignment

The Quasi-Horizontal Alignment is a surrogate for the actual horizontal alignment of the roads. The main inputs used in producing this alignment are Cartesian coordinates of roadway points. Most of states have a relatively good road centerline representation by Latitude/Longitude that can be easily converted into Cartesian coordinate system using GIS tools. These tools can also create point station data along digital maps by resolutions specified by the users. For projects with un-known actual horizontal alignments, this data may be obtained from instrumented vehicles driven on the road, digital maps, survey, satellite images, or other sources. Many State databases have all sorts of data available for their network, except the horizontal alignment. Fig. 1 shows the main steps used in producing Quasi-Horizontal Alignments. The following sub-sections explain these steps in details.

Curve radii in the Quasi-Horizontal Alignment are calculated from the following equation:

$$R_n = \frac{(a \times b \times c)}{4 \times \sqrt{s(s-a) \times (s-b) \times (s-c)}} \tag{2}$$

Where:R_n = Radius of curve fitting points n, $n+1$, and $n+2$ (ft).a = Distance between points $(n+1)$ and $(n+2)$ calculated from coordinates of these two points (ft).b = Distance between points n and $(n+1)$ calculated from coordinates of these two points

Table 2
Safety Evaluation of the RID Highway Sections.

Highway Section	3-year Crash Prediction – Actual Alignment	3-year Crash Prediction – Quasi-Horizontal Alignment	Prediction Difference (%)	Weighted CMF Difference (%)
Quasi Align 01	59.23	59.57	−0.6	−1.3
Quasi Align 02	43.00	42.80	0.5	−0.4
Quasi Align 03	18.90	18.81	0.5	0.6
Quasi Align 04	20.97	20.88	0.4	0.5
Quasi Align 05	44.91	45.51	−1.3	−1.4
Quasi Align 06	11.96	12.04	−0.7	−1.6
Quasi Align 07	13.59	13.28	2.3	1.0
Quasi Align 08	17.91	18.81	−5.0	−4.8
Quasi Align 09	26.58	25.74	3.2	1.6
Quasi Align 10	23.51	24.42	−3.9	−4.4
Quasi Align 11	23.38	22.99	1.7	−1.0
Quasi Align 12	25.14	24.69	1.8	3.1
Quasi Align 13	26.52	26.71	−0.7	−0.8
Quasi Align 14	30.57	31.27	−2.3	−2.7
Quasi Align 15	35.27	35.67	−1.1	−1.6
Quasi Align 16	27.31	28.82	−5.5	−5.3
Quasi Align 17	12.59	12.44	1.2	0.8
Quasi Align 18	13.16	13.70	−4.1	−3.5
Quasi Align 19	13.00	13.07	−0.5	−3.6
Quasi Align 20	14.63	14.82	−1.3	−3.6
Quasi Align 21	8.91	9.27	−4.0	−5.2
Quasi Align 22	9.89	9.73	1.6	−0.5
Quasi Align 23	10.99	11.67	−6.2	0.2
Quasi Align 24	10.22	10.31	−0.9	−2.0
Quasi Align 25	14.44	14.70	−1.8	−2.8
Quasi Align 26	20.34	20.52	−0.9	−0.9
Quasi Align 27	19.77	20.38	−3.1	−2.2
Quasi Align 28	19.43	19.51	−0.4	−0.4
Quasi Align 29	17.09	17.00	0.5	−0.6
Quasi Align 30	23.04	23.09	−0.2	−0.6

(ft).c = Distance between points n and $(n+2)$ calculated from coordinates of these two points (ft).

$$s = \frac{(a+b+c)}{2}$$

This is a popular way of calculating the radius of a simple curve passing through three points when the coordinates of those three points are available. This method does not provide the center of the curve; however, for the purpose of this study we don't need that information. When points n, $(n+1)$ and $(n+2)$ line up completely, s will become equal to c and the radius becomes infinity (i.e., a tangent). In these cases the radius is obviously larger than R_{max} and the segment is automatically identified as a tangent.

The simplicity of the calculations in this method makes it possible to program it in a spreadsheet and apply it to thousands of lines of coordinate data at once. The limit to the size of input data is only determined by the computer memory limit, which is quite vast for today's computers. For the purpose of this study, we applied this to the coordinate data of each experiment highway separately. Fig. 2 shows a screen shot of the first page of the spreadsheet for the first highway, "Quasi-Align-01." In this example, there are coordinates available for 318 points and the Quasi-Horizontal Alignment produced for the IHSDM software is comprised of 23 curves and 8 tangents, whereas the actual alignment has 5 curves and 7 tangents.

In Fig. 2, the input data in columns "A" and "B" are the (X, Y) Cartesian coordinates. The output data reflected in columns "AV" to "AZ" are the Quasi-Horizontal Alignment data produced in the format suitable for the IHSDM software. Positive values of "Radius Sign" and "Radius Ahead" show that the curve direction is to the right and negative values of these variables show that the curve direction is to the left. In the example shown in Fig. 2, a curve with a radius of 2027 ft is approximated by a compound curve comprised of 6 curves with radii of 2618, 2226, 1461, 1242, 2001, and 3232 ft. The total length of these curves is close to the length of the actual curve; because these curves form a compound curve the effect of length in equation 1 is almost the same for both the Quasi-Horizontal curve and the actual curve. The RID geodatabases do not have any spiral curves in their alignments; therefore, the effect of spiral curves is not reflected in this study.

5. Database resolution and selection of points used in the algorithm

Databases that carry point location data have different resolutions determined by the average distances between consecutive points. In the RID "location" data, this resolution is about 0.004 mile (about 21 ft). In this database, the resolution comes from the frequency by which the instrumented vehicle has collected data and has recorded the location. The algorithm was first applied to the data including all points. The results were not satisfactory. The problem was that the collection of the curves that were generated to approximate one single actual curve were not connected, did not form compound curves, and were separated by additional tangents. It was concluded that the points are too close to generate curves at each move. The experiments were repeated by using 1 of every 2, 1 of every 3, 1 of every 4, and 1 of every 5 points in the algorithm. The case using 1 of every 4 points was found satisfactory with respect to the curves connectivity and radii being close to the actual curve. For cases with higher or lower resolution some curves were identified disconnected or identified with curve lengths quite different from the actual lengths, respectively. This option that matches a point data resolution of about $4 \times 0.004 = 0.016$ mile provided satisfactory results for all 30 highway sections. It was concluded that the resolution of about 80–90 ft for point data is appropriate for this process.

6. Applying crash prediction module of the IHSDM

The IHSDM CPM was applied to the "Actual Horizontal Alignment" and "Quasi-Horizontal Alignment" alternatives for all 30

	A	B	D	E	F	G	H	I	J	K	L	M
	Input Data			Calculations								
1	X	Y		DeltaX1	DeltaY1	ABS Tangent	ABS Heading	Heading	Radius Sign	a	b	c
90	1920336	17389703.4		-82.1	-21.23	3.8672	75.502	255.5	1	84.801	84.556	169.334
91	1920254	17389682.2		-82.5	-18.51	4.4574	77.355	257.36				
92	1920172	17389663.7		-83.1	-14.93	5.5673	79.817	259.82	1	84.425	84.507	168.902
93	1920089	17389648.7		-83.68	-11.77	7.1074	81.991	261.99				
94	1920005	17389637		-85.08	-9.552	8.9071	83.594	263.59	1	85.619	83.819	169.367
95	1919920	17389627.4		-83.7	-4.508	18.565	86.917	266.92				
96	1919836	17389622.9		-83.14	-1.597	52.059	88.9	268.9	1	83.159	85.732	168.794
97	1919753	17389621.3		-85.63	4.1807	20.482	87.205	272.8				
98	1919667	17389625.5		-84.45	6.2819	13.443	85.746	274.25	1	84.682	84.456	169.101
99	1919583	17389631.8		-83.88	9.8186	8.5433	83.324	276.68				
100	1919499	17389641.6		-83.18	13.724	6.0612	80.632	279.37	1	84.306	84.532	168.822
101	1919416	17389655.3		-83	16.003	5.1867	79.087	280.91				
102	1919333	17389671.3		-82.43	17.624	4.6773	77.932	282.07	1	84.297	84.376	168.670
103	1919250	17389688.9		-82.32	18.522	4.4444	77.319	282.68				
104	1919168	17389707.5		-82.25	19.607	4.195	76.592	283.41	-1	84.555	84.916	169.472
105	1919086	17389727.1		-82.6	19.691	4.195	76.592	283.41				
106	1919003	17389746.8		-82.25	19.607	4.1949	76.592	283.41	1	84.555	84.617	169.172

	N	O	P	Q	R	S	AV	AW	AX	AY	AZ
							Input into the IHSDM				
1	s=(a+b+c) /2	Radius Ahead	Alpha	Beta	Curve Length		Align. Type	Start Sta.	End Sta.	Radius	Direction
90	169.345	2618	1.85607	1.85071	169.364		Curve	7441.632	7610.996	2618	Right
91											
92	168.917	2226	2.17302	2.17511	168.942		Curve	7610.996	7779.938	2226	Right
93											
94	169.402	1461	3.35791	3.28728	169.462		Curve	7779.938	7949.400	1461	Right
95											
96	168.843	1242	3.83619	3.95493	168.924		Curve	7949.400	8118.325	1242	Right
97											
98	169.12	2001	2.42512	2.41865	169.151		Curve	8118.325	8287.476	2001	Right
99											
100	168.83	3132	1.54228	1.54641	168.843		Curve	8287.476	8456.318	3132	Right
101											
102	168.671	7890	0.61216	0.61274	168.673		Tangent	8456.318	8624.988		
103											
104	169.472	-107395271	0.00005	0.00005	169.472		Tangent	8624.988	8794.460		
105											
106	169.172	16310	0.29703	0.29725	169.172		Tangent	8794.460	8963.632		

Fig. 2. Screen Shot of the Spreadsheet for "Quasi-Align-01" Highway.

experimental highways. Different R_{max} values were applied to the data (4000 ft, 5000 ft, 6000 ft, 7000 ft, and 8000 ft). In these experiments, an R_{max} value of 7000 ft was found to be an appropriate threshold value to identify almost all curves. For each of the experimental highways, all data except the horizontal alignment data were the same for both alignment alternatives. All predictions were made for three years by using the 2012 AADT available in the RID. Table 2 shows these predictions for the highways with actual and Quasi-Horizontal Alignments. As the percent difference values show, the strong majority of cases have a difference less than 5%. This table also shows the differences between length-weighted average of the horizontal curvature CMFs for the actual horizontal and the quasi-horizontal alignments. All of these differences are also 5.3% or less. The average of all of these percentages is −1.5%.

7. Applying traffic analysis module of the IHSDM

The IHSDM TAM was applied to the "Actual Horizontal Alignment" and "Quasi-Horizontal Alignment" alternatives for all 30 experimental highways. The TAM was run for one hour operation. The hourly traffic flow used in the simulation was estimated from the 2012 AADT available in the RID. The hourly volume was assumed to be 15% of the AADT and distributed evenly for both directions of the travel. Table 3 shows the average speed and percent time following for the highways with actual and Quasi-Horizontal Alignments. In this table, the values that are compared are alternatively grayed out to make the visual comparison easier. Almost all values for the "Actual Horizontal Alignment" alternatives are very close to those for the "Quasi-Horizontal Alignments."

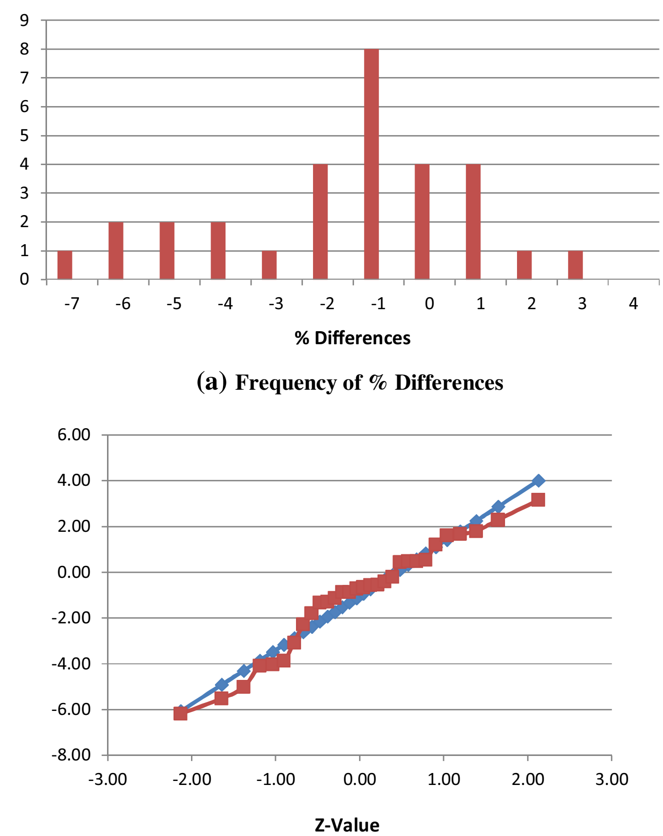
8. Evaluation of the proposed model

Table 4 shows the percentages of differences for predicted number of crashes, average operating speed, and percent time following.

To further evaluate the quality of the model presented in this study, first the normality of the differences is studied. Fig. 3 shows the predicted crashes frequencies of differences and the graphical normality test for the Quasi-Horizontal Alignment highways vs. the highways with Actual alignments.

The probabilities that the safety and operational measures of the Quasi-Horizontal Alignment fall within 5% of those corresponding to the actual alignment were then calculated. The method used for this purpose provides a satisfactory measure for evaluating the confidence interval of the outcome. To calculate this probability, % time following for the "Quasi Align 20" highway was eliminated from the calculations as an outlier. Table 5 shows the way these probabilities were calculated for predicted crashes, average speed, and percent time following.

The probability that the predicted crashes for the highway with the Quasi-Horizontal Alignment falls within 5% of the predicted crashes for the highway with actual alignment is 95%. For the two operational measures (Average Speed and Percent Time Following) both of the probabilities are more than 99%.



(a) Frequency of % Differences

(b) Graphical Normality Test

Fig. 3. Frequency of% Differences and Graphical Normality Test for Predicted Crashes.

Table 3
Operational Evaluation of the RID Highway Sections.

Highway Section	Average Speed – Actual Alignment	Average Speed – Quasi-Horizontal Alignment	% Time Following – Actual Alignment	% Time Following – Quasi-Horizontal Alignment
Quasi Align 01	49.9	50.4	91	91
Quasi Align 02	50.2	50.5	90	90
Quasi Align 03	49	49.2	61	61
Quasi Align 04	49.1	49.5	66	66
Quasi Align 05	45.7	45.7	85	85
Quasi Align 06	55.3	55.1	54	54
Quasi Align 07	54.8	55	54	55
Quasi Align 08	53.8	53.6	57	57
Quasi Align 09	48	48.9	64	64
Quasi Align 10	27.5	27.5	82	82
Quasi Align 11	27.6	27.5	82	82
Quasi Align 12	50.6	51.5	62	62
Quasi Align 13	26.6	26.6	86	86
Quasi Align 14	26.4	26.4	87	87
Quasi Align 15	26.3	26.3	87	87
Quasi Align 16	26.6	26.6	86	87
Quasi Align 17	56.1	56.2	53	53
Quasi Align 18	54.3	53.5	55	56
Quasi Align 19	54.2	54.9	58	58
Quasi Align 20	54.1	55	59	50
Quasi Align 21	56.1	56.2	47	47
Quasi Align 22	54.4	55	48	47
Quasi Align 23	53.1	53.7	50	50
Quasi Align 24	56.5	56.3	45	45
Quasi Align 25	52.1	52.5	49	49
Quasi Align 26	50.5	51.5	57	57
Quasi Align 27	54.4	53.7	67	67
Quasi Align 28	55.8	55.7	66	66
Quasi Align 29	54.7	55.2	66	66
Quasi Align 30	54.6	54.5	68	68

Table 4
Percentage of Differences between Safety and Evaluation Measures of the Actual Alignment and the Quasi-Horizontal Alignment.

Name	Predicted Crashes Difference (%)	Average Speed Difference (%)	% Time Following Difference (%)
Quasi Align 01	−0.6	−1.0	0.0
Quasi Align 02	0.5	−0.6	0.0
Quasi Align 03	0.5	−0.4	0.0
Quasi Align 04	0.4	−0.8	0.0
Quasi Align 05	−1.3	0.0	0.0
Quasi Align 06	−0.7	0.4	0.0
Quasi Align 07	2.3	−0.4	−1.9
Quasi Align 08	−5.0	0.4	0.0
Quasi Align 09	3.2	−1.9	0.0
Quasi Align 10	−3.9	0.0	0.0
Quasi Align 11	1.7	0.4	0.0
Quasi Align 12	1.8	−1.8	0.0
Quasi Align 13	−0.7	0.0	0.0
Quasi Align 14	−2.3	0.0	0.0
Quasi Align 15	−1.1	0.0	0.0
Quasi Align 16	−5.5	0.0	−1.2
Quasi Align 17	1.2	−0.2	0.0
Quasi Align 18	−4.1	1.5	−1.8
Quasi Align 19	−0.5	−1.3	0.0
Quasi Align 20	−1.3	−1.7	**15.3**
Quasi Align 21	−4.0	−0.2	0.0
Quasi Align 22	1.6	−1.1	2.1
Quasi Align 23	−6.2	−1.1	0.0
Quasi Align 24	−0.9	0.4	0.0
Quasi Align 25	−1.8	−0.8	0.0
Quasi Align 26	−0.9	−2.0	0.0
Quasi Align 27	−3.1	1.3	0.0
Quasi Align 28	−0.4	0.2	0.0
Quasi Align 29	0.5	−0.9	0.0
Quasi Align 30	−0.2	0.2	0.0
Mean	−1.0	−0.4	0.0
SD	2.4	0.9	0.9

Table 5
Probabilities of Measures Corresponding to Quasi-Horizontal Alignments Falling within 5% of those Corresponding to Actual Alignments.

Expressions	Predicted Crashes	Average Speed	Percent Time Following
$Z_{min} = \frac{X_{min} - Mean}{SD}$	−1.6770	−5.3790	−5.8268
$Z_{max} = \frac{X_{max} - Mean}{SD}$	2.5436	6.2701	5.8074
$P(Z < Z_{min})$	0.0468	0.0001	0.0001
$P(Z > Z_{max})$	0.9945	0.9999	0.9999
Probabilities	0.9477	0.9998	0.9998

Where:
X_{min} = Minimum percentage of the differences (−5).
Mean = Mean value of the difference (−1.0, 0.4, and 0.0 for Predicted Number of Crashes, Average Speed, and Percent Time Following, respectively).
X_{max} = Maximum value of the differences (+5).
SD = Standard Deviation of the differences (2.4, 0.9, and 0.9 for Predicted Number of Crashes, Average Speed, and Percent Time Following, respectively).
Z_{min} = minimum Z value associated with X_{min}.
Z_{min} = maximum Z value associated with X_{max}.
$P(Z < Z_{min})$ = Probability that Z is smaller than Z_{min}, from Standard Normal Table.
$P(Z > Z_{max})$ = Probability that Z is larger than Z_{max}, from Standard Normal Table.
Probability = Rounded value of $P(Z > Z_{max}) - P(Z < Z_{min})$.

9. Limitations

The RID geodatabases do not include any spiral curves. It is not clear whether the six states from which these data are gathered do not design spiral curves for rural two-lane highways or the process used for determining the actual alignments lacks this capability. Further investigation may be needed for clarification.

There might be short curves in the actual alignment with relatively flat radii (larger than R_{max}). The Quasi-Horizontal Alignment would replace these curves with tangents, and as a result a CMF that could be significantly larger than 1.00 (e.g., a 100 ft curve with the radius of 7000 will have a CMF of about 1.4) is replaced by 1.0. In these cases, even though the crash rates predicted by using the Quasi-Horizontal Alignment for that short segment differs significantly from the crash rate calculated for the actual alignment, the effect on the total number of crashes for the entire highway is very small since the length of the segment is very short.

HSM crash prediction models can use crash history data to estimate more reliable expected number of crashes. This process that is called Empirical Bayes (EB) analysis adds project crash history as another source of information to the prediction that increases the accuracy of the results. EB analysis may be conducted in two ways, one by assigning each crash to a specific site/homogenous segment and the other, by assigning all crashes to the entire project. With respect to the segmentation of the alignment into homogenous segments, the Quasi-Horizontal Alignment is split into much more number of homogenous segments compared to the actual alignment. Therefore, the use of this alignment may not be appropriate for EB analysis with site-specific crash history data. However, EB with project-level crash history data will probably work fine since in this process crashes are assigned to the entire project.

The model proposed in this research is for rural two-lane highways only. Other highway types that use horizontal alignment data in the HSM crash prediction models are Freeway Segments, Freeway Speed-change Lanes, Freeway Collector/Distributor Roads, and Freeway Ramps (detailed in newly published Chapters 18 and 19 of the HSM). Recent research is also proposing new CMFs for rural multilane highway models. Summary, Conclusion and Future Research

10. Summary, conclusion and future research

A surrogate horizontal alignment (Quasi-Horizontal Alignment) is proposed for use in the safety and operational evaluation of rural two-lane highways in the absence of the actual horizontal alignment data. Coordinates of points along the highway are required to build this surrogate alignment. In the experiments the predicted number of crashes for the Quasi-Horizontal Alignment fell within the 5% of the predicted number of crashes for the highway with actual alignment in 95% of the cases. These percentages for the operational measures (average speed and percent time following) were both more than 99%.

SHRP 2 RID contains hundreds of thousands of miles of highway data. Of these highways only about 5% have the actual horizontal alignment included in this database. The experiments conducted by the author show that for the remaining 95% of the alignments adding point coordinate data is relatively easy. Also, many States databases in the United States have almost every major data needed for safety and operational evaluations except the horizontal alignment data. In most cases, the corresponding agencies have coordinate data available within their highway inventories or can produce that data with small effort and cost. Several states' data inventories were identified that contained data similar to the SHRP 2 point data, even collected by the same type of instrumented vehicles.

There are methods that can be used to extract the horizontal alignment data from coordinate data. However, there is no standard available to evaluate the quality of these conversions. In addition, many States do not currently have resources to go through this process on a large scale. These circumstances make the use of the proposed model in using the Quasi-Horizontal Alignment instead of the actual alignment beneficial.

Since crash prediction models are developed by using a few years of data from a few states calibration factors are needed to make the predictions made by crash prediction models valid for different States and regions and also for different time periods. The process of calculating calibration factors requires that the models are applied to a significant number of sites that for many facility types include horizontal alignment. In some cases, such as SHRP 2 RID the databases lack horizontal alignment. A future direction of work is to examine whether the use of Quasi-Horizontal Alignment instead of the actual horizontal alignment will produce a valid calibration factor.

Conducting similar studies for facilities other than rural two-lane highways are potential steps in continuing this research. There are major differences in the Horizontal Alignment CMF between the rural two-lane model and other models, especially for freeways. These differences will probably cause major differences in the results as well.

The R_{max} and the resolution of the point data identified in this research may need to be confirmed, and revised if necessary, when a different database is used. Conducting research on how these parameters may change can be part of future research related to this topic.

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References

Carlson, Paul J., Burris, Mark, Black, Kit, Rose, Elisabeth R., 2005. Comparison of radius-Estimating techniques for horizontal curves, transportation research record. J. Transp. Res. Board, 76–83 (No. 1918, Transportation Research Board of the National Academies, Washington, D.C.).

Dong, Haibin, Easa, Said M., Li, Jonathan, 2007. Approximate extraction of spiralled horizontal curves from satellite imagery. J. Surv. Eng. 133 (February (1)), ASCE (No. 1).

Easa, Said M., Dong, Haibin, Li, Jonathan, 2007. Use of satellite imagery for establishing road horizontal alignments. J. Surv. Eng. 133 (February (1)), ASCE (No. 1).

Hans, Zachary, Souleyrette, Reginald, Bogenreif, Corey, 2012. Horizontal Curve Identification and Evaluation. Center for Transportation Research and Education Iowa State University, pp. 10–369 (InTrans Project).

Highway Safety Manual (HSM), 2010. American Association of Highway and Transportation Officials (AASHTO), Highway Safety Manual, Part C, July 2010.

Hummer, Joseph E., Rasdorf, William J., Findley, Daniel J., Zegeer, Charles V., Sundstrom, Carl A., 2010. Procedure for Curve Warning Signing, Delineation, and Advisory Speeds for Horizontal Curves. North Carolina State University Department of Civil, Construction and Environmental Engineering (FHWA/NC/2009-07).

IHSDM Software, 2015. Federal Highway Administration (FHWA) Interactive Highway Safety Design Model (IHSDM) (Last accessed July 2015) Public Website: http://www.ihsdm.org/wiki/Welcome.

Imran, M., Hassan, Y., Patterson, D., 2006. GPS–GIS-based procedure for tracking vehicle path on horizontal alignments. Comput.-Aided Civ. Infrastruct. Eng., 21.

Karimi, Hassan A., Liu, Shuo, 2004. Developing an automated procedure for extraction of road data from high-resolution satellite images for geospatial information systems. J. Transp. Eng. 130 (September (No. 5)) (ASCE).

Li, Zhixia, Chitturi, Madhav V., Bill, Andrea R., Noyce, David A., 2012. Automated identification and extraction of horizontal curve information from geographic information system roadway maps, transportation research record. J. Transp. Res. Board, 80–92 (No. 2291, Transportation Research Board of the National Academies, Washington, D.C.).

Othman, Sarbaz, Thomson, Robert, Lannér, Gunnar, 2012. Using naturalistic field operational test data to identify horizontal curves. J. Transp. Eng. 138 (September (No. 9)) (ASCE).

Pratt, Michael P., Miles, Jeffrey D., Bonneson, James A., 2009. Workshops on Using the GPS Method to Determine Curve Advisory Speeds. Texas Department of Transportation Research and Technology Implementation Office (FHWA/TX-10/5-5439-01-1).