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16. Abstract

The INDOT Long-Range Planning Section has developed a set of planning tools that will support the system-level analysis of the state transportation system. These tools are employed to monitor transportation system performance, identify highway needs, and provide a quantitative analysis of the impacts of transportation improvement projects. One such tool is HERS/IN (Indiana Highway Economic Requirements System). The HERS/IN model identifies deficiencies in pavement, capacity, and alignment by referring to the Highway Performance Monitoring System (HPMS) data of the roadway sections. The HERS model uses a method to accommodate the curve and grade data and, based on these data, it identifies highway alignment deficiencies. The roadway curve and grade data were collected in 1994 as a part of INDOT's Pavement Management System. INDOT's Long-Range Planning Section experienced difficulty in verifying these data and breaking it into meaningful segments. Therefore, the Indiana HPMS database did not include the curve and grade data. As a result, alignment deficiencies were not considered in the initial applications of HERS/IN. The objectives of the research project are to evaluate the curve and grade data available to INDOT and suggest a methodology that allows INDOT to identify alignment improvement projects, and to prioritize these projects.

During the course of the project, we researched the various techniques used by other states to prepare the curve and grade database. We also learned about how other states program alignment correction projects. We evaluated the curve and grade data available to INDOT and how it can be used in HERS/IN to identify alignment correction projects. The research project provides INDOT with guidelines on how to efficiently program alignment correction projects.

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Final Report

FHWA/IN/JTRP-2003/14

INDOT HIGHWAY NEEDS ANALYSIS -
IMPACTS OF PHYSICAL FEATURES
(HORIZONTAL AND VERTICAL CURVATURE)

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Indiana Department of Transportation and the
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1 INTRODUCTION

1.1 Background Information

The INDOT Long-Range Planning Section has developed a set of planning tools that will support the system-level analysis of the state transportation system. These tools are employed to monitor transportation system performance, identify highway needs, and provide a quantitative analysis of the impacts of transportation improvement projects. The tools have the ability to forecast travel demand and estimate the economic impact of transportation investments. One such tool is HERS/IN (Indiana Highway Economic Requirements System). HERS/IN is a modified version of the Highway Economic Requirements System (HERS), which was originally developed for the Federal Highway Administration (FHWA) by Jack Faucett Associates with the assistance of the Urban Institute, Cambridge Systematics, Inc., and Bellomo-McGee, Inc. (FHWA, 2000b). The results of the HERS model were used in the preparation of the report to Congress: *Status of the Nation's Highways, Bridges, and Transit: Conditions and Performance* (FHWA, 2000a).

1.2 Background Information on HERS

HERS is a computer model designed to perform highway needs analysis by using the current conditions of the highway system and estimating the investments required for potential improvements to the system. The model uses information about existing highways to identify future highway improvements required. The model is designed to select improvements based on the relative benefit-cost values of alternative improvement options. The strength of the model lies in its ability to analyze the effects of alternative funding levels on highway performance. HERS uses the description of the current state of the highway system described in the HPMS database for its analysis. The model begins with the base year description of the highway system, forecasts changes that are expected to occur in the system, and estimates the potential improvements for each funding period. The length and the number of the funding periods are user specified. For each funding period, HERS forecasts the condition of the section at the end of the funding period and, based on the benefit-cost ratios, it determines which improvements should be made and in what priority. Some examples of questions that HERS can answer are:

- How will a change in highway investment levels affect the conditions and performance of State highway networks?
- How much investment is required to perform all economically beneficial improvements?
- What level of investment is required to maintain the current level of performance in the year 2010?

INDOT has a customized state-level version of the national HERS model, called HERS/IN. HERS/IN is specifically designed to suit Indiana's highway needs analysis system. HERS/IN uses the data contained in INDOT's TransCAD Geographic Information System (GIS) and data produced by the Indiana Statewide Travel Model (ISTM) to perform various analyses (INDOT, 1998). The model has a feature that integrates the model results with INDOT's TransCAD GIS system, which will make it possible to display the model results on state roadway maps (INDOT, 1998a).

The model identifies deficiencies in pavement, capacity, and alignment by referring to the HPMS data of the roadway sections. In the initial applications of the HERS/IN model, focus was given only to capacity deficiencies in the system; analyses of pavement and alignment deficiencies were left out. Since the Pavement Management Section had already developed a list of projects based pavement deficiency, INDOT's Long-Range Planning Section did not include pavement deficiencies in its analysis. Analysis of alignment deficiencies was left out because INDOT did not have the road alignment data. The HERS model uses a method to accommodate the curve and grade data and based on these data, it identifies highway alignment deficiencies. The roadway curve and grade data were collected in 1994 as a part of INDOT's Pavement Management System. INDOT's Long-Range Planning Section experienced difficulty in verifying these data and breaking it into meaningful segments. Therefore, the Indiana HPMS database did not include the curve and grade data. As a result, the alignment deficiency was not considered in the initial applications of HERS/IN. This study is aimed at:

a) Evaluating the curve and grade data available to INDOT.

b) Converting the curve and grade data to a format that allows HERS/IN to identify alignment problems.

c) Suggesting a methodology that allows INDOT to identify alignment improvement projects, and to prioritize these projects.

1.3 Purpose and Scope of the Study

The horizontal and vertical curvature deficiencies are important indicators of the potential for unsafe driving conditions, such as inadequate sight distance. INDOT's Long-Range Planning Section is interested in upgrading the roadways to better geometric design standards. Many highways provide service for transporting commodities to and from rural communities. These roads do not need to be widened from two lanes to four lanes. The two-lane facility can perform well, if the curvature deficiencies are eliminated. This research effort is aimed at identifying such curvature problems and to provide guidelines to the INDOT's Long-Range Planning Section in programming curve-correction projects effectively, by using planning tools such as HERS/IN. The sections identified by HERS/IN as having an alignment deficiency will be displayed on the INDOT's TransCAD Geographic Information System (GIS). This study will also look into the available curve and grade data collection methods and the procedures involved in transforming the data into a format compatible with the HERS format.

2 LITERATURE REVIEW

2.1 Introduction

A literature review was undertaken to document curvature data collection methods, safety effects of geometric improvements on highway curves, effectiveness of the HERS model and safety conscious planning.

2.2 Curvature data collection methods

State DOTs invest a considerable amount of money and time to collect and maintain state roadway inventory data. These data serve as primary information for many transportation-related projects. The data can be categorized into 3 groups: 1) Pavement, 2) Traffic, and 3) Geometric.

One of the objectives of the project was to determine the existing methods available for collecting roadway geometric data, mainly horizontal and vertical alignment.

The report by McWilliam (1952), discusses a methodology for collecting highway alignment and grade data by using an instrumented vehicle fitted with gyroscopes. The vehicle was driven at speeds of 5 to 10 mph. The vehicle was fitted with two gyros. One of the gyros gave readings of the vehicle's heading value by aligning itself towards the earth's magnetic field. The path traversed by the vehicle was plotted. In most cases, accuracies of within 1 percent were achieved in matters of tracing a closed path. The other gyro's readings provided the values for road gradient. The gradient values collected had an error of less than 1/2 percent of true gradient.

According to a survey by the Oklahoma Department of Transportation, state DOTs use as-built plans, topographic maps, and global positioning systems (GPS) for establishing roadway alignment and grade information required for inventory studies (DeFrain et al., 1993). According to the report, most gyro-accelerometer-based navigation equipment and other aircraft-type sensors are designed to work at travel speeds of that of an aircraft, so it is not suitable to use these instruments for roadway applications. Michigan DOT explored navigation equipment and found that an inertial system called PosNav unit was suitable for collecting roadway curve and grade data. The PosNav unit was mounted on the floor of the van and the van was driven at normal highway speeds. The PosNav unit was able to compute its heading relative to the true north. The instrument was able to collect vehicle's heading and relative latitude, longitude and elevation from an initial reference point. A Software program was written to convert the raw data collected by the PosNav unit into curvature and gradient information. (DeFrain et al., 1993)

Connecticut Department of Transportation and Wisconsin Department of Transportation use an instrumented van that collects photolog data and geometric data on roadway heading, grade and superelevation. Wisconsin DOT uses the photologging unit developed by Techwest Enterprises Ltd. (Berg, 1989) while Connecticut DOT have developed their own photologging unit (Connecticut DOT – Data Services Section, 2002). Gyros are used in computing the bearing of the van and the road gradient. The data are collected on both directions at every 0.01 mile interval. Connecticut DOT has developed a software program to derive the roadway's radius of curvature, the location of the point of curvature (PC) and the point of tangency (PT) from the raw database (Connecticut DOT – Data Services Section, 2002). Wisconsin DOT has established methodologies to convert the raw data into vertical and horizontal alignment information (Berg et al., 1989). For the vertical alignment information, because of the large amount of noise in the raw data caused due to the bouncing motion of the vehicle, it was required to smooth the data before using it. The collected grade data was plotted against known grade data and regression models were developed to estimate the error in the raw data. By using the regression models, it was possible to estimate the noise in the data and arrive with an adjusted value for road gradient. The location of the point of curvature (PC) and the point of tangency (PT) for vertical curves could not be computed successfully. For horizontal curves, algorithms were developed by Wisconsin DOT to identify the location of the point of curvature (PC) and the point of tangency (PT). (Berg et al., 1989)

2.3 Safety effects of geometric improvements on highway curves

Horizontal curves can pose a considerable safety problem, especially on rural 2-lane roads (Zeeger et al., 1992). Various studies in the past have shown that the crash rate on curves is 1.5 to 4 times that on similar tangents (Zeeger et al., 1992). Hence, it is essential for us to look into the causes of the high crash rate on a curved section and suggest suitable countermeasures. The design book "Safety Improvements on Horizontal Curves for Two-Lane Rural Roads – Informational Guide" (FHWA, 1990f), provides detailed guidelines for design engineers on how to correct sites with deficient curves.

There have been a number of studies on curve sites aimed at establishing the relationship between the crash rate and the geometric characteristics of the curve site. Efforts have been made to estimate the safety benefits of improving a particular geometric deficiency. Based on these studies, a brief summary of the safety effects and benefits of geometric improvements on Horizontal Curves is presented below.

2.3.1 Curve flattening

Studies have shown that the degree of curvature is the primary factor in determining a curve's potential crash rate. Consequently, curve flattening projects provide the maximum safety benefits (Zeeger et al., 1992). Curve flattening projects are the most expensive, but they are also the most effective in reducing crashes. Some studies have suggested that flattening a curve with curvatures less than 11 degrees of horizontal curvature usually does not prove to be cost-beneficial, making it difficult to justify the project (Lin, 1990). Curve flattening provides a permanent solution to the curvature problem; hence this measure must be given serious consideration.

2.3.2 Providing superelevation and skid resistance

It is suggested that, during pavement resurfacing, it is a good idea to rectify superelevation and skid resistance deficiencies. Although it may not provide a permanent solution to the curvature problem, correcting the superelevation rate provides more than a modicum of safety benefits. In the research study "Zeeger, 1991", the author suggests that correcting the superelevation deficiency by 0.02 provided a crash reduction of 10 to 11 percent.

2.3.3 Spiral transitions

There have been many research articles on the safety benefits of providing a spiral transition to a curve. Unfortunately, the research results contradict each other, with some studies showing that a spiral transition is helpful, while some others finding a negative effect of a spiral transition on safety (Council, 1998). Thus, the safety benefits of providing a spiral transition are not well understood and further research needs to be done in this area.

2.3.4 Widening on Curves

Widening on curves does play a role in reducing curve accidents. This could be a very good solution in places where large vehicles, such as trucks, have a tendency to swerve or drift out of the lane (AASHTO-Policy on the Geometric Design of Highways and Streets, 1990).

2.4 Effectiveness of the HERS model

The results of the national HERS model were used in the preparation of the *Conditions and Performance Report,* popularly known as the C&P Report. The FHWA is required to submit the C&P Report to Congress, describing the state of the nation's highways and the need for future highway investments. The ability of the HERS model to assess highway needs has been found to be quite reasonable. However, HERS results should be used only as a general guideline for estimating the required highway investments and not be used for acquiring precise estimates. It is not appropriate to use estimates generated by HERS for project-level analysis.

The HERS model has its strengths and limitations. Its major strength lies in its ability to evaluate the marginal benefit and cost values of alternative improvement options and thus provide the best combination of improvements. Most other models that are used to study highway needs at the national level select improvements based on the section's engineering deficiency without considering the improvement's economic benefit. However, the HERS model selects improvements among alternative options based mainly on economic merit (FHWA, 2000e).

The HERS model also has several limitations. The most serious limitation is that the HERS model analyzes highway sections in isolation rather than considering the entire roadway network. Hence, factors such as the effect on a highway section because of the changes on a neighboring street is not captured by the model. Also, the model cannot completely account for the uncertainties associated with the data, assumptions, and the various formulae used. The confidence level or the precision of the estimates is not known. In addition, the model makes use of several computational shortcut techniques to calculate the long-term benefits of an improvement. The computational shortcuts only provide an approximate value of the true benefits. The shortcuts were employed many years ago in order to reduce the computation time, but with the present availability of the computational processing power, the shortcuts are no longer necessary (FHWA, 2000e).

In response to the above limitations, FHWA plans to eliminate the computational shortcut techniques. Also, various costs, such as reconstruction costs and resurfacing costs, will be updated. The present model assumes the same pavement deterioration rate for the entire country, but FHWA wishes to modify the model by providing a deterioration rate based on climate zone. HERS operates in a DOS-based computer environment, which is not very user-friendly. FHWA has a proposal to upgrade the model by making it menu-driven and user-friendly.

2.5 Safety Conscious Planning

Safety Conscious Planning (SCP) implies a proactive approach in selecting safety projects. Most of the safety projects are stand-alone projects and are not a part of the planning process. In SCP, we try to incorporate safety into planning. The traditional method followed by most states in identifying safety projects is usually reactive in nature, i.e., road sections are selected for safety improvements based on accident analysis alone. SCP aims at preventing potential accidents and eliminating unsafe conditions. SCP is fairly a new concept and proper guidelines have not been established. The report, "Considering Safety in the Transportation Planning Process" (FHWA, 2002g), discusses how we could incorporate safety into the short-range and the long-range planning process. The report is aimed at providing guidelines for State Department of Transportation (DOTs) and Metropolitan Planning Organization (MPOs) to program safety projects.

3 METHODOLOGY

3.1 Introduction

The HPMS database serves as the input to the HERS model. The HPMS database is in ASCII format. Each record of the database describes a section of the highway system. The HERS model uses the curve and grade information given to it through the input file to perform alignment calculations. The Indiana HPMS database did not have any information on curve and grade, so the project's first task was to provide Indiana HPMS database with the curve and grade data by using the data that was collected in 1994 as part of INDOT Pavement Management System's (PMS) data collection program.

3.2 Extracting the Curve and Grade data information

The curve and grade data of Indiana roads, along with roadway reference location information, were collected in 1994 as part of INDOT Pavement Management System's data collection program. It is believed that the data had been collected using gyro-instruments. When INDOT tried to use this data for its phase 1 HERS/IN analyses, problems developed in assembling the data and interpreting it into meaningful segments. So the initial attempts to provide the Indiana HPMS database with curve and grade information and consequently use it in HERS/IN analyses had produced results of uncertain value.

The initial period of the research study was directed towards examining and understanding the 1994 data. The data is stored in a spreadsheet that consists of 5 columns. Table 3.1 shows an excerpt from the raw 1994 horizontal curve data file.

Table 3.1 1994 Raw Horizontal Curve Data File

INTST-064-13-01	0	0.927	0	W	1
INTST-064-13-01	0	3.776	0	E	0
INTST-064-13-01	0.927	1.061	11.69	W	1
INTST-064-13-01	1.061	4.414	0	W	1
INTST-064-13-01	3.776	3.874	11.89	E	0
INTST-064-13-01	3.874	3.987	14.63	E	0
INTST-064-13-01	3.987	4.068	12.52	E	0
INTST-064-13-01	4.068	4.559	0	E	0
INTST-064-13-01	4.414	4.605	25.82	W	1
INTST-064-13-01	4.433	16.41	0	W	1
INTST-064-13-01	4.56	4.695	11.43	E	0
INTST-064-13-01	4.605	7.24	0	W	1
INTST-064-13-01	4.695	6.734	0	E	0
INTST-064-13-01	5.457	4.433	10.17	W	1
INTST-064-13-01	6.256	5.457	0	W	1
INTST-064-13-01	6.735	6.852	11.54	E	0
INTST-064-13-01	6.852	7.879	0	E	0
INTST-064-13-01	7.24	7.339	10.2	W	1
INTST-064-13-01	7.34	9.715	0	W	1
INTST-064-13-01	7.879	7.979	11.05	E	0
INTST-064-13-01	7.979	8.691	0	E	0
INTST-064-13-01	8.383	6.256	17.4	W	1
INTST-064-13-01	8.691	8.807	15.51	E	0
INTST-064-13-01	8.807	8.859	0	E	0
INTST-064-13-01	8.859	8.989	15.91	E	0
INTST-064-13-01	8.989	9.168	0	E	0

The contents of the data file was segmented into columns. The first column is the section identifier. By referring to the HPMS Field Manual and method it suggested, the elements of the section identifier became clear. It is divided into 4 sub-columns delimited by hyphens. The first sub-column indicates the type of highway, the second sub-column refers to the highway number, while the third sub-column refers to the county number. The last sub-column is a sub-route indicator, which is not of much significance for our study. Decoding the second and third column was difficult because of the absence of continuity in the consecutive rows. We decided that the second column indicates the mile point at which either a curve or a tangent section begins and the third column indicates the mile point at which either a curve or a tangent ends. We would expect the ending mile point of a row to be the starting mile point of the immediate next row, but this is not the case in the database. Confusion was caused by the E's and W's found in the fifth column. We did not know whether the E's and W's referred to the direction of the road, i.e., Eastbound/Westbound, or whether they referred to the deviation of the van's motion from the centerline path. Once again, after studying the HPMS Field Manual and examining numerous specific cases, it was concluded that the fifth column refers to the direction of travel. It was also decided that the milepost values in columns 2 and 3 are numbered from a single reference point, irrespective of the direction of travel.

In the fourth column, by looking at the data, we could guess that it referred to an angle (in degrees). But we did not know whether it referred to the ball-bank indicator angle (See Figure 6.1) or the central angle of the curve (See Figure 3.1). We did not know whether in 1994 there existed data collection vans fitted with instruments that had the capability to directly measure the central angle of a curve. But later, we came across the report by McWilliam (1952), which suggested that there was a high possibility that the 1994 data collection van was fitted with instruments that had the capability to directly measure the central angle of the curve. Therefore we assumed that the fourth column is a measure of the central angle (in degrees) subtended by the curve. The fifth and the sixth columns indicate the direction of travel while the data were collected. A zero indicates that the direction of travel is Eastbound/Northbound.

A one indicates that the direction of travel is Westbound/Southbound. Figure 3.1 will help in understanding the data collection procedure that was used.

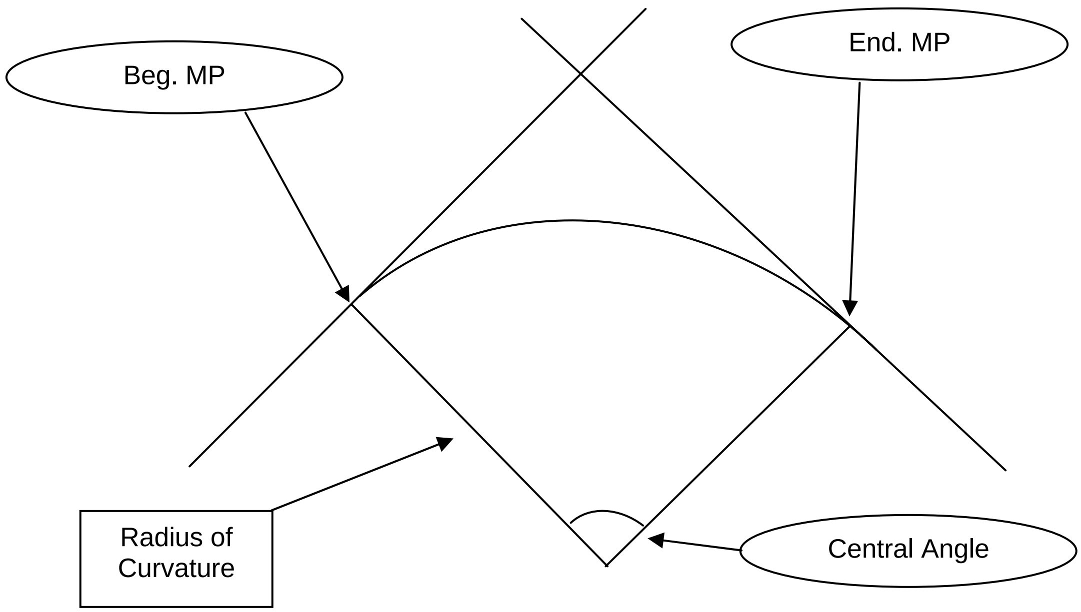


Figure 3.1 Components of a Road Curve

From three parameters, i.e., beginning mile point, ending mile point, and the central angle, we can calculate the radius of curvature by employing the property of circular curves:

$$L = R*\theta$$

where L = Arc Length

R = Radius of Curvature of the arc

θ = Angle subtended by the arc

In Table 3.1, we have the values for sector length L (sector length = ending mile point – beginning mile point) and the values for included angle θ. From L and θ we can calculate the radius of curvature. A sample calculation is provided below:

Let us consider the ninth row of Table 3.1.

INTST-064-13-01	4.414	4.605	25.82	W	1

$$L = (4.605 - 4.414) = 0.191 \text{ miles}$$

$$\theta = (25.82*\pi/180) = 0.45 \text{ radians}$$

$$R = L/\theta = (0.191/0.45) = 0.424 \text{ miles}$$

From the calculated radius of curvature and the measured sector length, we can provide the curve information in the required HPMS format, as described later in Section 3.3.

Some further comments on the curve and grade database follow.

- The data was collected in both directions, but the milepost reference point is always with respect to a single direction, irrespective of the direction of travel. In the N-S direction, the direction of travel of the reference system is always from the south to the north. In the E-W direction, the direction of travel of the reference system is always from the west to the east.
- In the database we observe that the column representing the included angle is either a 0 or has values greater than 10. This indicates that the personnel who collected the data, considered a section to be curved only if that section had an included angle greater than 10 degrees.
- The database is not complete; it appears to cover only about 75 percent of the road-miles in the state highway system.

3.3 Providing alignment information in HERS format

HERS uses alignment information in the format specified in the HPMS Field Manual. For curves, the format is a 91-position field with the curves divided into 13 classes based on their radius as shown in Table 3.2. This is the pre-1998 HPMS format.

Table 3.2 Pre-1998 HPMS Curve Class Format

RADIUS (m)	CURVE CLASS
3906+	1
1206 – 3905	2
716 – 1205	3
506 – 715	4
391 – 505	5
321 – 390	6
251 – 320	7
206 – 250	8
161 – 205	9
126 – 160	10
91 – 125	11
61 – 90	12
< 61	13

Each curve class occupies a total of 7 positions, 2 positions to report the number of curves in a particular class and 5 positions, with an implied decimal (xx.xxx miles), to report the sum of the lengths of all curves in a particular class. The sum of the curve lengths in all 13 classes must be equal to the section length.

The post-1998 HPMS format is shown in Table 3.3. HERS/IN employs the pre-1998 HPMS format while the HERS/ST v 2.0 employs the post-1998 HPMS format.

Table 3.3 Post-1998 HPMS Curve Class format

RADIUS (m)	CURVE CLASS
506+	1
321-505	2
206-320	3
126-205	4
61-125	5
<61	6

An example is provided below to illustrate the procedure for providing curve information.

Example:

A section of road is 2 miles long. It has 1 curve in class 3 that is 0.4 miles long, and 2 curves in class 2 with total length of 0.7 miles. The segments of the road section are shown in Figure 3.2.

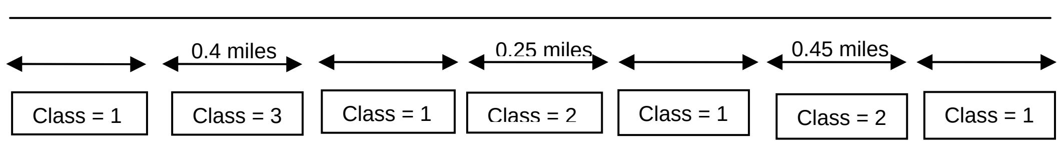


Figure 3.2 Configuration of the road section

The road section has 4 curves in class 1 that have total length 0.9, i.e., [2-(0.4+0.7)] miles.

In the HPMS file, columns 185 through 191 provide information about Curve Class 1. Use columns 185-186 to code the number of curves in class 1; 04 means 4 curves. Columns 187-191 are used to code the total length of curves in class 1; 00090 means 0.90 miles. The similar procedure follows for other curve classes as well. Figure 3.3 shows the result of this procedure.

Col. #	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205
Data	0	4	0	0	0	9	0	0	2	0	0	0	7	0	0	1	0	0	0	4	0

Figure 3.3 HPMS Curve Class Information

The vertical grade information can be provided in a similar manner. Table 3.4 shows the HPMS Grade Class format. The format is the same for both pre-1998 and post-1998 HPMS file.

Table 3.4 HPMS Grade Class Format

Grade Class	Gradient (%)
1	0.0-0.4
2	0.5-2.4
3	2.5-4.4
4	4.5-6.4
5	6.5-8.4
6	8.5+

3.4 Validating the Curve data

The next step was to check the curve data for its validity and whether our interpretation of the data was correct. To do this, we used air photos from Mapquest (Mapquest, 2003). The radius of curvature established from the database was tested with the radius that appeared on the air photo. The procedure used to calculate the radius on the airphoto is explained below.

Figure 3.4 Calculating radius of curvature on the airphoto

Scale: 1 inch = 150m

Procedure used to calculate the radius of curvature on the airphoto:

Step 1: Draw 2 tangents “a” and “b” for the road section, as shown in Figure 3.4.

Step 2: By observation, identify the point of curvature and the point of tangency. Points “PC” and “PT” in Figure 3.4.

Step 3: Draw perpendiculars to “a” and “b” at “PC” and “PT” respectively. Line “c” and “d” in Figure 3.4 are the perpendiculars.

Step 4: The point where “c” and “d” intersect is the center point of the circular curve. Point “C” in Figure 3.4 is the center point. The distance from point “C” to point “PC” or “PT” is the radius of the curve.

As shown in Table 3.5, we found often that there was some difference in the radius, but there was reasonably good agreement in the radius and location of each curve. In HERS/IN, curves are segmented into classes based on the radius range to which they belong, as explained in Section 3.3. The typical difference between the radius on the map and that in the database is much less than the magnitude of the radius range that classifies the curves. Because of this, the curve in the database almost always falls in the appropriate curve class bin, despite having some errors in the value of the radius (as shown in Table 3.5). Therefore, the error will seldom affect the HERS/IN analysis. Moreover, HERS/IN is a preliminary planning tool used to analyze the conditions and performance over a horizon of 25 years. The model is required to do many forecasts, assumptions and approximations as explained in the HERS Technical Report (FHWA, 2000e). In this context, the curve data are sufficient to serve the purpose of a preliminary analysis. Therefore, it was decided that the existing data have acceptable accuracy. After the HERS preliminary analysis is made and after a particular section is selected for an alignment improvement, it would be appropriate to verify the details of road curvature through as-built plans or by field measurements.

Table 3.5 Comparison of 1994 raw horizontal curve data vs. mapquest air photo

No.		1994 curve data	Mapquest	Air photo*
1	Radius (m)	240	300	
	HPMS Curve Class	3	3	
	Point of Curvature (mile post value)	3.196	3.8	
	Point of Tangency (mile post value)	3.226	3.83	
2	Radius (m)	300	270	
	HPMS Curve Class	3	3	
	Point of Curvature (mile post value)	3.353	4	
	Point of Tangency (mile post value)	3.443	4.09	

Table 3.5 Comparison of 1994 raw horizontal curve data vs. mapquest air photo (Continued)

No.		1994 curve data	Mapquest	Air photo*
3	Radius (m)	470	520	
	HPMS Curve Class	2	2	
	Point of Curvature (mile post value)	3.763	4.4	
	Point of Tangency (mile post value)	3.838	4.47	
4	Radius (m)	180	250	
	HPMS Curve Class	4	3	
	Point of Curvature (mile post value)	0.929	0.5	
	Point of Tangency (mile post value)	1.031	0.6	

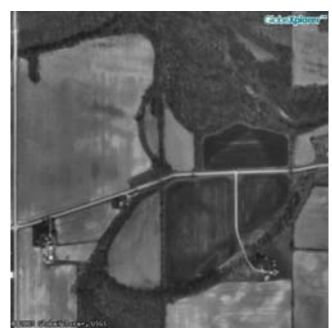
Table 3.5 Comparison of 1994 raw horizontal curve data vs. mapquest air photo (Continued)

No.		1994 curve data	Mapquest	Air photo*
5	Radius (m)	230	220	
	HPMS Curve Class	3	3	
	Point of Curvature (mile post value)	11.945	13.5	
	Point of Tangency (mile post value)	12.02	13.57	
6	Radius (m)	184	150	
	HPMS Curve Class	4	4	
	Point of Curvature (mile post value)	7.997	6.1	
	Point of Tangency (mile post value)	8.087	6.19	

Table 3.5 Comparison of 1994 raw horizontal curve data vs. mapquest air photo (Continued)

No.		1994 curve data	Mapquest	Air photo*
7	Radius (m)	380	450	
	HPMS Curve Class	6	6	
	Point of Curvature (mile post value)	24.505	23.4	
	Point of Tangency (mile post value)	24.58	23.47	
8	Radius (m)	190	220	
	HPMS Curve Class	4	3	
	Point of Curvature (mile post value)	4.114	4.1	
	Point of Tangency (mile post value)	4.176	4.17	

Table 3.5 Comparison of 1994 raw horizontal curve data vs. mapquest air photo (Continued)

No.		1994 curve data	Mapquest	Air photo*
9	Radius (m)	250	300	
	HPMS Curve Class	3	3	
	Point of Curvature (mile post value)	2.155	3.2	
	Point of Tangency (mile post value)	2.211	3.25	
10	Radius (m)	290	300	
	HPMS Curve Class	3	3	
	Point of Curvature (mile post value)	0.652	0.5	
	Point of Tangency (mile post value)	0.753	0.6	

* Photos taken from http://www.mapquest.com . Scale: 1 inch = 400m

4 HERS/IN Test Runs

Acquiring the curve and grade information for each section, as described in Section 3.3, is very time consuming, because there are about 12,000 road sections in the INDOT road inventory. Therefore it was decided to first test the HERS software for a limited number of sections and analyze the output. The curve and grade information for Tippecanoe County was chosen to test the HERS/IN model. The following test runs were made.

Test 1:

Comparing the output when alignment information is provided to output when alignment information is not provided. In this scenario, the input file is provided with curve and grade information. Its output is compared against the output obtained from an input file that does not contain the curve and grade information.

Results:

1. The same sections were selected in both the model outputs.
2. There was a small difference in the Benefit to Cost ratios of the selected sections in the two outputs. Therefore the order of the selected improvements changed.
3. No section was selected for alignment improvement.

Inference:

1. Because the B/C ratios changed, we can infer that the alignment module is functioning.

2) Test 2:

In Test 1, 15 sections were selected for capacity improvement projects. We deliberately made the alignment data on some of these sections deficient.

Results:

1. The same 15 sections were selected in both model outputs.
2. No section was selected for alignment improvement.

Inference:

1. It may be that alignment improvement is not cost beneficial.

3) Test 3:

All curves among the 15 selected sections were deliberately made deficient.

Results:

1. The same sections were selected in both the model outputs.
2. Among the 15 sections, one section was chosen for alignment improvement in addition to capacity improvement.

Inference:

1. The alignment module in HERS/IN is working.

From the three tests, we observe that the alignment data did not have any influence on the sections that were selected for improvement, although it did have influence on the ranking of the improvements. In the documentation for HERS/IN model, it was stated that the pavement component had been turned off. This implied to us that the structure of the HERS/IN model was as shown in Figure 4.1.

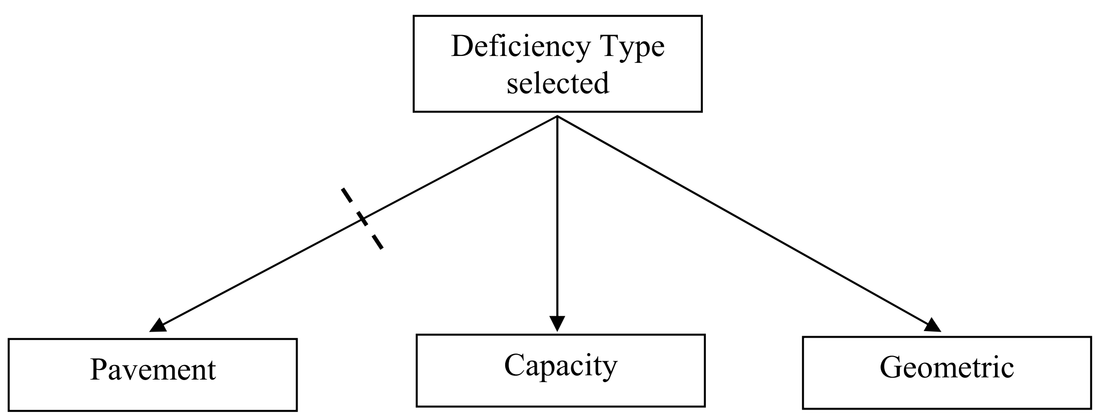


Figure 4.1 Presumed Structure of the HERS/IN model

It was thought that, for a section to be considered for an improvement, it had to have any of the three deficiencies, namely, pavement, capacity and geometric deficiency. However, after a careful examination of the HERS Technical Report (FHWA, 2000e), it was discovered that the model gives a secondary priority level to alignment deficiency. This means that a section with an alignment deficiency will not be considered for analysis, unless it also has a capacity or pavement deficiency. Therefore the actual structure of the HERS/IN model is as shown in Figure 4.2.

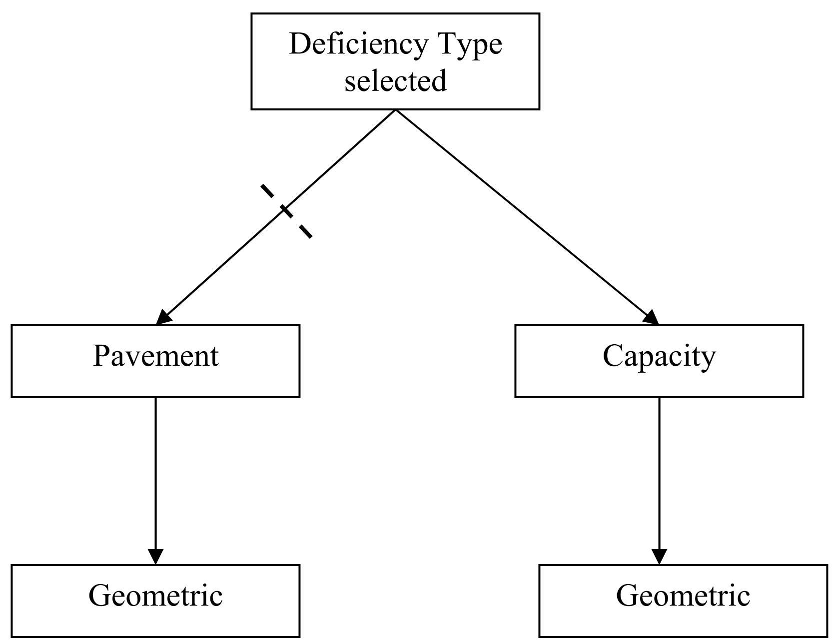


Figure 4.2 Actual Structure of the HERS/IN model

The rationale for this could be:

a) Typically, a highway agency would not do any work to a highway section if there is no capacity or pavement deficiency.

b) The benefits arising out of an alignment improvement alone can rarely exceed the cost of realignment. So, the model might have been designed to not consider this extremely rare case, thus reducing the computation time. We need to remember that the HERS/IN is an extension of the national HERS model developed by FHWA. In this nationwide HERS model, the database was extensive (125,000 sections), so keeping the computation time low may have been an important factor.

By studying the HERS/IN User Manual (INDOT, 1998), it was learned that the pavement analysis module had been disabled. As a result, the model treats all pavements as being in good condition and does not evaluate pavement degradation. The information about the expected pavement improvements determined by the INDOT Pavement Management System (PMS) must be provided externally using the HERS/IN Override mode. Details regarding the HERS/IN Override mode will be provided in Section 4.1.

Discussion:

The alignment module in HERS/IN is dependent on the pavement and the capacity module to be considered for analysis. As a result of disabling the pavement module, a major portion of the alignment module has also been made non-functional. Thus drastically reducing the ability of the HERS/IN model to identify alignment correction projects. From the test runs, it has been observed that a capacity improvement project accompanied by an alignment improvement project is usually not cost beneficial, whether the alignment is deficient or not. Therefore, most of the sections that have both capacity and alignment deficiencies get justified only for a capacity improvement. From the three test runs, we found out that only 1 out of the 15 sections was chosen for alignment improvement, despite making all the curves in these sections clearly deficient. This implies that the model solution will have very few capacity improvement projects that need alignment improvement. Also, the curve and grade database is only around 75 percent complete, so the solution provided by HERS will not be the actual solution for the entire state highway network.

4.1 HERS/IN Override Mode

The HERS/IN has a special feature called the “Override” feature. This feature is not present in the conventional HERS model. The override mode gives the user the ability to override some (or all) of the decisions HERS/IN makes regarding the selection and cost of improvements and the impacts of these improvements on capacity. The user can specify that a particular improvement must be made in a particular year and can even specify the cost of the improvement and the impact of the improvement on capacity (INDOT, 1998).

The HERS/IN input file is in ASCII format, describing each highway section to be analyzed, one record per section. Each record is 504 characters long and is divided into 2 parts. Part A is in the HPMS format and used by the HERS/IN basic mode; Part B is used by the override mode and is optional. It allows the user to inform the model of specific improvements that must be made in specific funding periods. Refer to the HERS/IN User Manual (INDOT, 1998) for instructions on filling in the Part B section.

From the curve and grade database, it was possible to identify the sections that had alignment problems. The records describing these sections were given exogenous information on improvement type and the year of improvement using the Part B section of the HERS/IN input file. All these records were given the same improvement type, i.e., “Reconstruction with Alignment Improvement” and the year of improvement as 2003. The model output contained the benefit, cost, and B/C ratio of the improvement.

4.2 HERS/ST

FHWA, after developing the national HERS model, developed a model called HERS/ST which is suitable for a statewide analysis. The model was initially developed in 1998, and it has been consistently upgraded ever since. The latest version is the HERS/ST v2.0. The HERS/ST v2.0 uses road improvement cost values and traffic growth factors that are suitable to the particular state to which the road sections belong. The HERS/ST v2.0 has a user interface and this makes it very convenient to work with the software as against working with the HERS/IN. Since the HERS/IN model does not have a functioning pavement module and since HERS/ST v2.0 is an upgraded version of the HERS/IN model, it was decided to perform our analysis on the HERS/ST v2.0.

5 DIGITAL ELEVATION MODELS (DEMs)

A consultant to INDOT proposed that they were considering using Digital Elevation Models to establish the vertical alignment grade database for Indiana road inventory. INDOT requested us to study the feasibility of the consultant's proposal. In this chapter we will discuss about Digital Elevation Models and their possible applications. We will check whether Digital Elevation Models can be used to calculate road gradient for the purpose of giving information to inventory studies such as the HPMS.

5.1 Introduction to DEMs

A digital elevation model (DEM) is a digital file that contains elevation values for an area of land at uniformly spaced horizontal intervals. These models are generated mainly from satellite and aerial photos by using image processing technology. Satellite photos of a particular location are taken from different locations and from different angles. These photos are compared with each other and using the properties of parallax, the elevation values of the location are computed. The elevation data are arranged on a square grid with the grid surface representing the horizontal plane. Each grid represents a sampling interval or spacing of the data. Figure 5.1 is an example of a DEM.

5	5.1	5.4	4.9	4.7
4.8	4.7	5	5	5.4
4.9	4.6	4	4	5.2
5.3	5	4.7	5.7	6.8
5.1	5	4.8	6	6.4

Figure 5.1 A DEM showing elevation values of each grid

DEMs are classified based on the sampling interval and the extent of coverage. The USGS currently has 5 types of DEM data:

1. 7.5 x 7.5 Minute DEM 15m x 15m data spacing
2. 7.5 x 7.5 Minute DEM 30m x 30m data spacing
3. 1 x 1-Degree DEM 3 x 3 arc second data spacing
4. 2 x 2 Arc Second DEM 2 x 2 arc second data spacing
5. 15 x 15 Minute Alaska DEM 2 x 3 arc second data spacing

A 7.5 x 7.5 Minute DEM 30m x 30m data spacing means that the map captures an area of 7.5 minutes of Latitude and 7.5 minutes of Longitude with data sampled at every 30 m. The 7.5 x 7.5 Minute DEMs cover an area of approximately 60 square miles. In a similar manner, a 1 x 1 Degree DEM 3 x 3 arc second data spacing refers to a map that captures an area of 1 degree of Latitude and 1 degree of Longitude with data sampled at every 3 arc seconds. The 7.5 x 7.5 Minute DEM 30m x 30m data spacing has greater accuracy than the 1 x 1 Degree DEM 3 x 3 arc second data spacing, but it covers a smaller area than the latter three (USGS, 2002a).

5.2 Applications of Digital Elevation Models

Digital Elevation Models are used to understand the nature of land topography in a region. They are being employed extensively in fields such as hydrology, agriculture, urban planning, environmental assessment, transportation, and mining. Some of the specific uses of DEMs are listed below.

- In flood control, to predict the extent of floods at different water levels in the reservoir
- Predicting the spread of forest fires
- In determining the extent of cut and fill required for projects related to civil engineering
- To determine the visibility of a place from an elevated location
- In highway design, to compare the different road alignment options
- In reservoir volumetric analysis

The usefulness of a DEM product to a particular project is governed mainly by two factors, namely, availability of the DEM for the region and the level of accuracy of the DEM. It is not economical to have a very accurate DEM over a very large area, so there is always a trade off between the sampling interval of the DEM and its accuracy level. Currently, a lot of effort is being made to increase the level of accuracy of a DEM, for a given area and under a given budget constraint.

5.3 Accuracy of a DEM

As mentioned earlier, the accuracy level of a DEM plays a major role in determining the purpose and extent to which it can be used. The vertical accuracy of a DEM is computed as the difference between elevation value of the point on the DEM and the true elevation. A DEM's accuracy is a function of factors such as the method or technology used in the preparation of the DEM, the density or the sampling interval, and the type of terrain. The report by Gong et al., 2000 has a detailed study of the effects of each of these factors on accuracy. Their results showed that the accuracy of a DEM increases with a decrease in sampling interval and this relationship is linear.

5.4 Can the DEMs that are currently available be used to compute road gradient?

The answer is "No," because of issues of accuracy with the available DEMs. For a fixed budget, there is always a trade-off between the extent of area covered by the DEM and its accuracy. At present, a lot of research is being focused on obtaining good resolution DEMs at a reasonable cost. While DEM accuracy is not well assessed, some studies suggest accuracy of anywhere between 2 to 15 meters (USGS, 2002a) while another study (Krupnik, 2000) suggests suggests 1 to 2 m. High resolution DEMs with 0.5m accuracy have also been developed, but it is difficult to obtain and very expensive to use them extensively. The DEMs that are downloadable for free are the USGS DEMs with a vertical accuracy of between 2m and 15m (USGS, 2002a). For the calculation of a road section's gradient, this is substantial error. The example below illustrates the risk involved in using DEM data to compute a road's gradient.

Let's say a road section A has about 300m of constant road grade as shown in Figure 5.2. The true road gradient of the section is 2 percent.

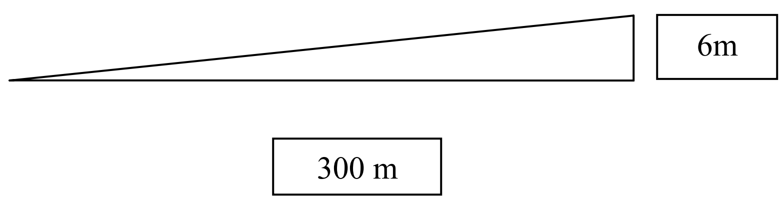


Figure 5.2 Longitudinal Profile of Road Section A

A DEM that is downloadable from the USGS website has an accuracy of between 2m and 15m. Let's say that the DEM of the road section A has a vertical accuracy of ±7m.

The maximum gradient calculated by using this DEM would be

[(6+7)/300]*100 = 4.33 percent. The gradient calculated by using DEMs is 4.33 percent but the true gradient is 2 percent.

We can similarly calculate the gradient for other values of error as shown in Table 5.1. The third column in Table 5.1 is filled using the HPMS grade class format as specified in Table 3.4.

Table 5.1 Gradient calculated for different values

Error in DEM	Gradient Calculated (%)	HPMS Grade Class
-7	-0.33	1
-6	0	1
-5	0.33	1
-4	0.66	2
-3	1	2
-2	1.33	2
-1	1.66	2
0	2	2
1	2.33	2
2	2.6	3
3	3	3
4	3.3	3
5	3.6	3
6	4	3
7	4.3	3

The true gradient is 2 percent and therefore the true HPMS Grade Class is 2. In order to find the probability that the HPMS Grade Class calculated by using the DEMs will be the same as that of the true HPMS Grade Class, we need to know the probability distribution function of the DEM's error. The probability distribution function of a DEM's error has not been established. In our example, for the sake of simplicity, let us assume a probability distribution function as shown in Figure 5.3.

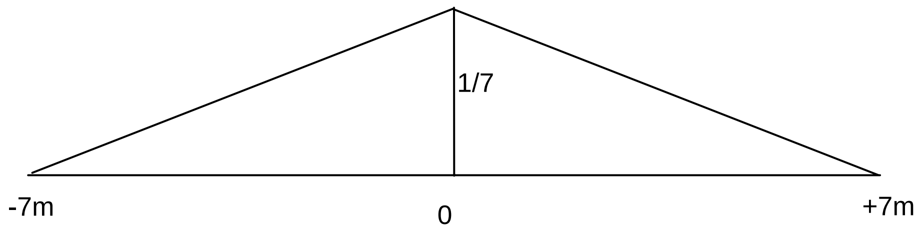


Figure 5.3 Assumed probability distribution function of the vertical accuracy of the DEM

From Table 5.1, we observe that the HPMS Grade Class calculated by using the DEMs will be the same as that of the true HPMS Grade Class whenever the DEM error is approximately between -4 and +1. The area of the shaded region shown in Figure 5.4 will approximate the probability that the HPMS Grade Class is computed correctly.

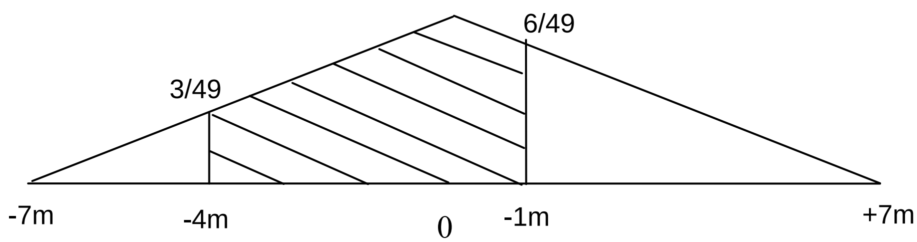


Figure 5.4 Area showing the region where the HPMS Grade Class will be calculated correctly

Area of the shaded region = 1- Sum of the area of the two triangles that are not shaded.

= 1- ((0.5*3*3/49) + (0.5*6*6/49))

= 1- (0.09 + 0.36) = 0.55

Therefore, for the road section shown in Figure 5.2 and for the probability distribution function of the vertical accuracy of a DEM shown in Figure 5.3, the probability that the HPMS Grade Class calculated by using the DEMs will be the same as that of the true HPMS Grade Class is 55 percent.

The above analysis is performed by assuming that there is perfect horizontal positional accuracy. But in reality this may not be the case. There are at least three ways in which DEM data can be inadequate for purposes of determining the elevation of a roadway. For purposes of this discussion, let us say that the DEM data refer to the average elevation of about 9 points chosen randomly (or uniformly) within a grid square of size 15 meters by 15 meters. We are trying to determine the elevation of a rural two-lane road (width 7.2 meters in Figure 5.5) in rolling terrain.

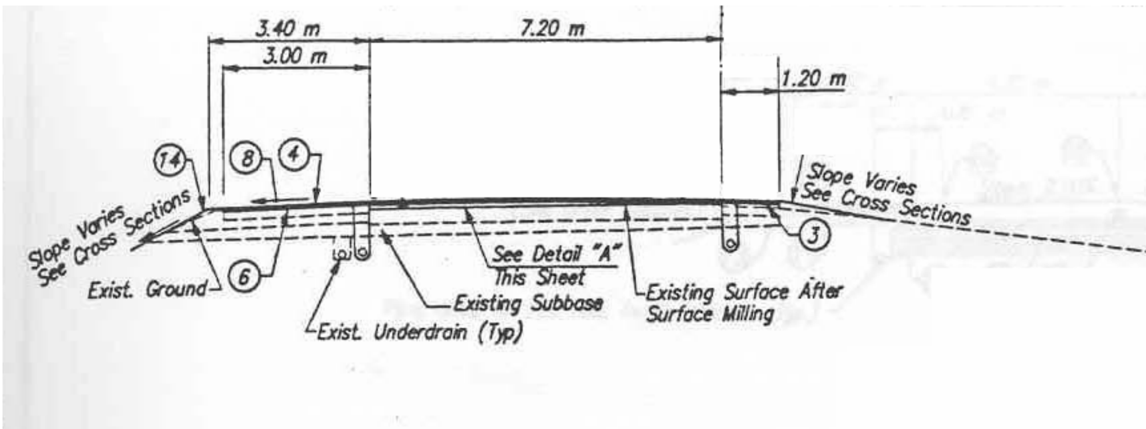


Figure 5.5 Typical Profile of a Road Section (INDOT, 2002b)

1. Only a portion of the roadway and its shoulders passes through the center of a 15m x 15m DEM grid square. A majority of the points used to compute an average elevation for the grid square will not lie on the roadway or on its shoulders, but rather on the adjacent ground. If the roadway is higher than all or most of the off-roadway points, the grid square's average elevation will understate the elevation of the roadway.
2. Even in the unlikely event that the roadway's centerline happens to pass through the center of the grid square, the same problems as in Case 1 are likely. Including the 3.40-meter and 1.20-meter shoulders, the roadway and shoulders would occupy 11.8 meters of the 15-meter grid square. It is likely that some of the nine points will not lie on the roadway or shoulders, thereby underestimating (as in Case 1) the true elevation of the roadway.

3. We are presuming that, not only are the elevations of each individual point are accurate, but also that the horizontal locations of grid squares and roadways in the database are accurate and consistent with each other. But in reality this may not be the case. (USGS, 2003b).

If the elevation of a roadway cannot be determined with sufficient accuracy, it is futile to try to compute the gradient on a section of that roadway. As the position of a roadway in successive grid squares varies along a section of highway, the degree of inaccuracy in roadway elevation will also vary. Any such inaccuracies, when incorporated into a computation of gradient, may cancel each other or be compounded. The example that follows will illustrate a related situation.

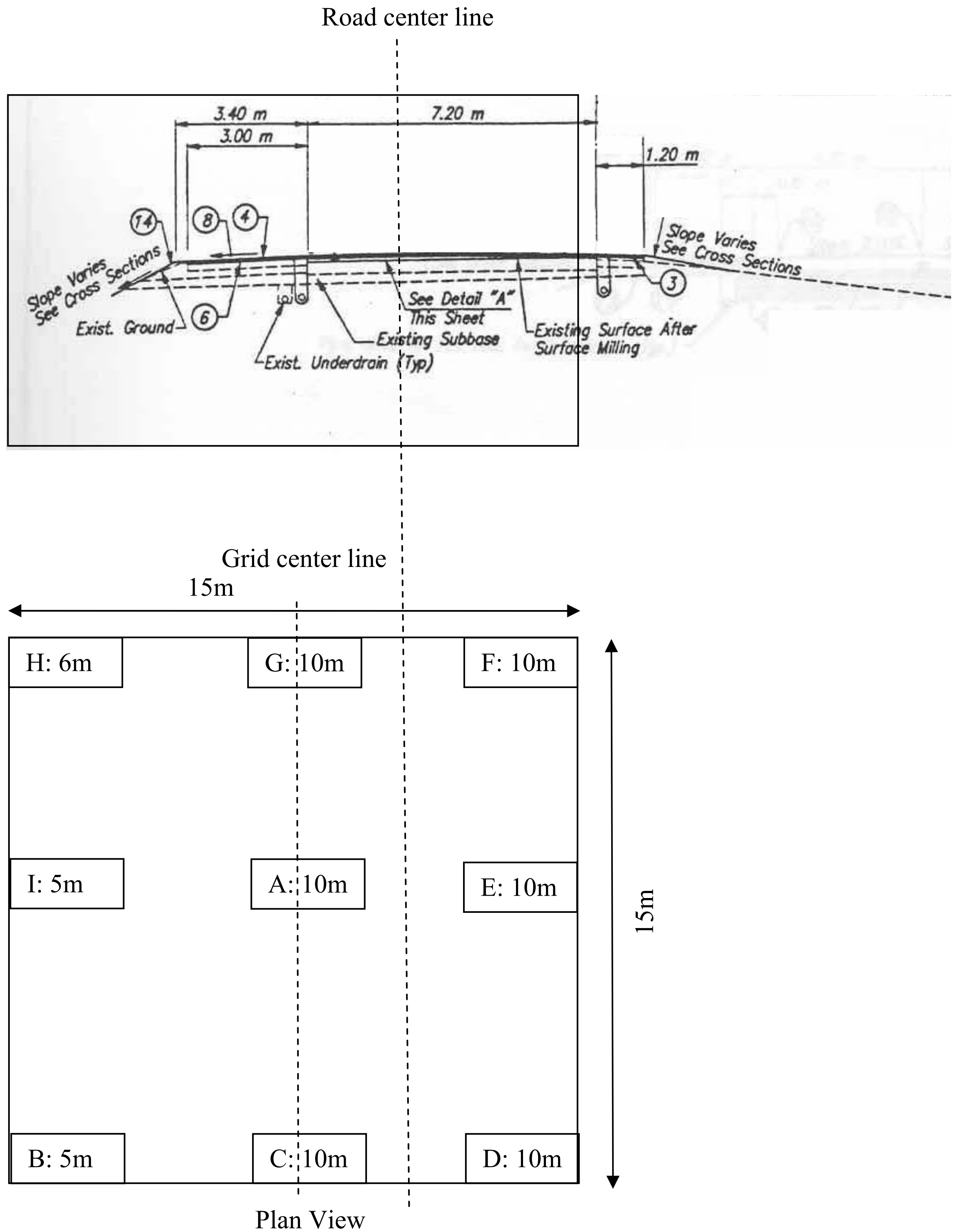


Figure 5.6 Plan view of the 15m x 15m grid with elevation values

Figure 5.6 shows the plan view of the 15m x 15m grid along with the elevation values at various points on the grid square. We observe that the center line of the road does not coincide with the center line of the grid square. Let us assume that the elevation value of the grid square is computed by considering the average elevation value of the 9 points shown in Figure 5.6.

Elevation value of the grid square = (10 + 5 + 10 + 10 + 10 + 10 + 10 + 6 + 5)/9

= 76/9 = 8.4m

True elevation value of the road section = 10m

Therefore, error in computing the elevation value using a DEM = 10 – 8.4 = 1.6m.

6 Survey

As part of our research efforts, we wanted information on how other states collected road curvature and grade information required for the HPMS file and how these data were used in programming their curve/alignment correction projects. INDOT wanted to know the different methodologies employed by other states for listing curve correction projects and then prioritizing them. The survey was aimed to give INDOT information on the experience of other state DOTs in programming curve correction projects and the technology used by them for providing FHWA with curvature and grade database as required by the HPMS file.

A questionnaire was prepared by the research team. In order to encourage a good response rate, the questionnaire was kept short. The questions were well framed, focused and easy to comprehend. The survey consisted of 4 questions. The first 2 questions were designed to provide information on the data collection procedure used by the state DOTs for acquiring the alignment database for the HPMS file. The questions are:

- What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (Item No. 63 to 68-Curves by Class)?
- What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (Item No. 72-77-Grades by Class)?

The last 2 questions were aimed at providing information on the ranking process. The last 2 questions are:

- What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?
- How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?

The survey was sent via email to the states that were represented by TRB Committee A1D09, Statewide Data and Information Systems. The survey was sent during the third week of December, 2002. We received responses from 5 states. A summary of the survey responses was presented in the A1D09 Committee Meeting at the TRB Annual Meeting 2003. In order to disseminate our survey to the other states, we acquired the contact address of each state's HPMS coordinator and emailed them the survey. This was done in the 4th week of January 2003. By early March, 2003 we had received survey responses from totally 17 states. The table below shows a summary of the "Curve Correction Projects" survey responses.

6.1 Summary of the "Curve Correction Projects" Survey Responses

Q1. What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (Item No. 63 to 68-Curves by Class)?

Q2. What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (Item No. 72-77-Grades by Class)?

Q3. What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?

Q4. How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?

Table 6.1. Summary of the "Curve Correction Projects" Survey Responses

State	*Question 1*	*Question 2*	*Question 3*	*Question 4*
Alaska	Does not report	Does not report	Based on accident analysis	Based on accident analysis
Arkansas	Using ARAN (photo logging van)	Using ARAN (photo logging van)	Based on geometric deficiency	No ranking system
California	Contract plans	Contract plans	Based on accident analysis	B/C ratio
Connecticut	Using ARAN	Using ARAN	No Response	No Response
Florida	Contract plans + Using GIS (ArcInfo)	No Response	No stand-alone such projects. Merged with capacity improvement projects	No ranking system
Hawaii	Using ARAN	Using ARAN	No comprehensive criteria	Ranking system not yet developed
Iowa	Contract plans	Contract plans	Based on accident analysis	Project is a stand-alone priority

Table 6.1 Summary of the “Curve Correction Projects” Survey Responses (Continued)

State	*Question 1*	*Question 2*	*Question 3*	*Question 4*
Kentucky	Contract plans + field measurement	Contract plans + field measurement	Very few such stand-alone projects	No ranking system
Louisiana	Using ball-bank indicator	Not collected	Based on geometric deficiency + accident analysis	Decided by DOT + MPO’s
Montana	Contract plans	Contract plans	Based on accident analysis	B/C ratio
Nevada	Contract plans	Contract plans	No Response	No Response
New Jersey	Using a DMI located in their vehicle	Using a DMI located in their vehicle	No Response	No Response
New York State	Contract plans	Contract plans	Based on accident analysis	Goal is to reduce 1500 accidents each year
Ohio	Contract plans + field measurement	Contract plans + field measurement	Based on geometric deficiency + accident analysis	Projects should meet a specific program goal.
Oregon	Contract plans	Contract plans	Based on accident analysis	B/C ratio + other factors

Table 6.1 Summary of the “Curve Correction Projects” Survey Responses (Continued)

State	*Question 1*	*Question 2*	*Question 3*	*Question 4*
Pennsylvania	Contract plans + field measurement	Contract plans + field measurement	Based on accident analysis	B/C ratio
Puerto Rico	Using ARAN	Using ARAN	Based on geometric deficiency	No Response

6.2 Analysis of the survey results

Question 1:

What are the methods used by the state DOTs to collect the statewide horizontal curve data for the HPMS data file (Item No. 63 to 68-Curves by Class)?

The following are the methods used by the state DOTs to provide the statewide horizontal curve data for the HPMS data file.

a) Contract plans: This method is employed by 10 states out of the 17 responding. This methodology is labor intensive.

b) Field Measurement: This method is employed by 3 states out of the 17. It is also labor intensive.

c) Using ball-bank indicator:

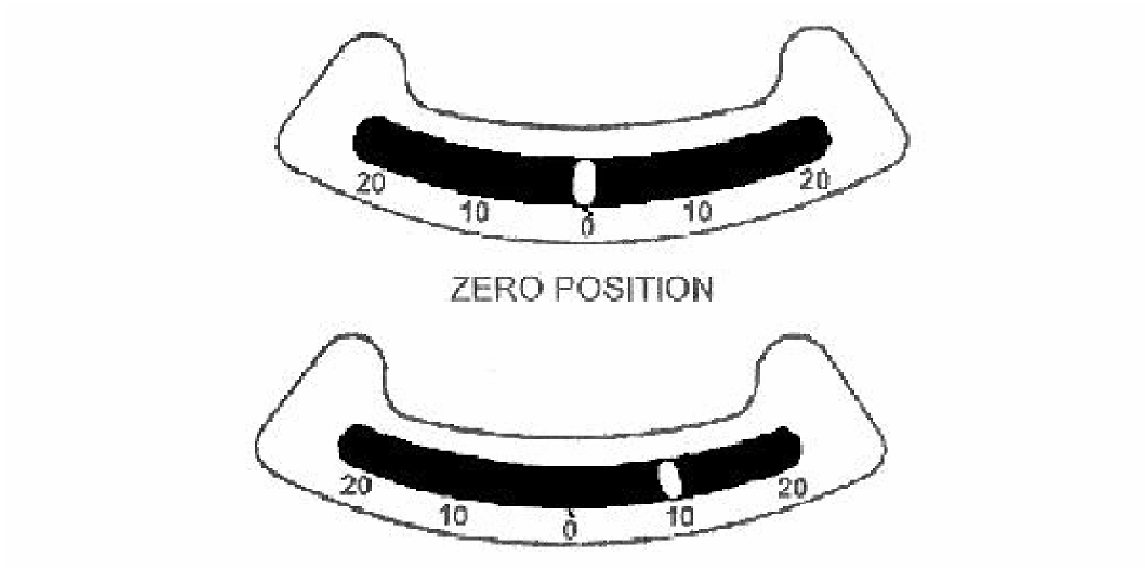


Figure 6.1 Ball-bank indicator (FHWA, 2000h)

According to the MUTCD (FHWA, 2000h), a ball-bank indicator (Figure 6.1) is used in determining the recommended speed (advisory speed) for a turn or a curve. The ball-bank readings and the corresponding recommended speeds are shown in Table 6.2.

Table 6.2 Ball-bank reading and corresponding recommended speeds

Ball-bank reading (degrees)	Recommended speed (mph)
14	20 or a lower speed
12	25 or 30
10	35 or higher speed

From Table 6.2, we can say that, if the ball-bank reading is around 14 degrees while driving at around 20mph, then the advisory speed should be set at around 20mph. Similarly, if the ball-bank reading is around 12 degrees while driving at around 25mph, then the advisory speed should be set at around 25mph and if the ball-bank reading is around 10 degrees while driving at around 35mph, then the advisory speed should be set at around 35mph. “The State of Louisiana uses the Ball Bank to determine at what speed a certain degree on the ball bank is exceeded. This speed is then related to a curve class. For example, if the speed determined by the ball bank is from 40-45, then the HPMS curve class is 4” (Appendix, Survey on Curve Correction Projects-Louisiana). The ball-bank indicator is an inclinometer whose specific purpose is to help determine the safe driving speeds through curves. It is a simple, widely available instrument, and it can indicate whether a road section is straight or curved, but it is not possible to calculate the degree or radius of a curve using a ball-bank indicator.

d) Using an ARAN (Automated Road Analyzer): The ARAN is a photo logging data collection van that collects the roadway pavement conditions and pavement data. It is employed by 5 of the 17 states. This method is gaining increasing popularity as an efficient data collection system and more states are switching to this method. The ARAN is provided with a set of gyroscopes and also with curve analysis software, making it possible to provide the user with the curve data in a quick and efficient manner. The Indiana HERS/HPMS database contains the entire Indiana road inventory, which amounts to about 11,500 miles. For INDOT requirements, using an ARAN appears to be the most suitable method. INDOT has currently employed a private consultant from Oklahoma called Pathway Services, Inc. to perform the photo logging data collection. This task began in August 2002 and is expected to be completed by December 2003.

Question 2:
What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (Item No. 72-77-Grades by Class)?
The responses to this question were essentially the same as those of the first question. The first question’s observations and inferences can be applied here as well.

Question 3:

What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?

Usually, Curve Correction/Alignment Improvement projects are broadly identified based on either an existing geometric deficiency or a high accident rate.

a) Based on existing geometric deficiency: 2 of the 17 states select their alignment projects based on the geometric deficiency identified at that section. A section's deficiency is determined based on whether it meets the required design criteria, as suggested by *AASHTO Policy on the Geometric Design of Highways and Streets, 1987*. Refer to the AASHTO manual for details on the design criteria. This method of identifying safety projects is proactive in nature. In other words, in the proactive method, a section's accident history, which is a performance measure, does not come into picture. A safety project is identified based on the section's design features alone. This technique has its own pros and cons. By being proactive, you are essentially rectifying potentially hazardous sections, thus eliminating potential accidents. But at the same time you may be ignoring sections which appear to be well designed but are performing poorly. It becomes difficult to justify a safety improvement to a section which does not meet the design criteria but has only a few accidents on it, while there is another section which has a history of high accident rate, but is left untouched because it does meet the design criteria.

b) Based on high accident rate: 9 of the 17 states opt for this method. The technique is reactive in nature. When a cluster of accidents is identified at a section, it prompts the highway personnel to look into its design characteristics and make suitable improvements. Here, sections qualify for a safety improvement based on their accident record. Such safety projects are easier to justify and implement. But the disadvantage of such a method is that there could be sections that are very poorly designed with respect to safety, but due to unknown factors, they may not have a high accident rate. Consequently, such locations remain undetected and unimproved. These potentially hazardous locations can pose a serious threat to road safety.

c) Merging with capacity improvement projects: Florida DOT does not have any curve/alignment correction projects that are stand-alone, but are instead considered while performing capacity improvement projects. Here, we observe that a safety project (curve correction project) is incorporated into the planning process (capacity improvement project).

Question 4:
How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?
Here, most safety projects are prioritized based on their benefit-cost ratios. Some states have curve/alignment correction projects that are purely stand-alone projects and therefore not requiring ranking or prioritization. Some state DOTs like NYSDOT decide on safety projects based on a specific goal, such as reduction of 1500 accidents in the next year.

6.3 Inference from the survey results

It can be inferred that using the video logging van for curvature and grade data collection is the most efficient and suitable method for INDOT needs.
The process of identifying a curve/alignment correction project by the various states is represented in Figure 6.2.

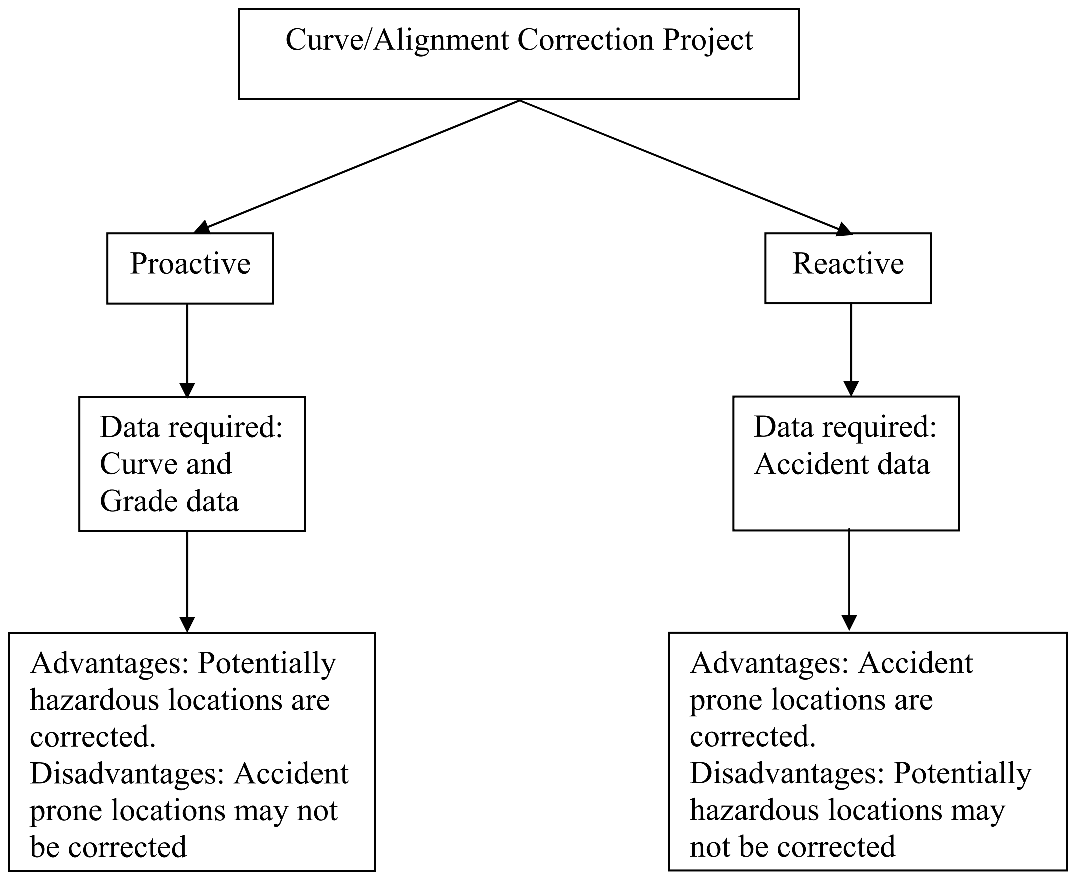


Figure 6.2 Process of identifying a curve/alignment correction project

In Figure 6.2 it can be observed that the existing methods for selecting curve correction projects have their pros and cons. We also observe that safety projects such as a curve correction project are not integrated into the planning process. Most of these projects are stand-alone. Such solutions may not be effective in the long-run. We wish to deploy a new methodology for selecting curve correction projects, that which encompasses the benefits of both the proactive and reactive techniques and also which merges itself into the wider comprehensive view of the planning process. The details of the methodology are discussed in Chapter 8. Information on incorporating a safety project within the planning process is available at www.fhwa.dot.gov/planning/scp (FHWA, 2003i).

7 Curve and Grade Data Collection using a Videologging Van

The videologging van is a mobile data collection system used to collect pavement, geometry and other highway features data for the statewide roadway inventory database. The van is equipped with a video camera that captures video images of the roadway section while simultaneously preparing the section's road inventory. This methodology is being extensively employed by state agencies, with Connecticut DOT being among the forerunners. There are private agencies like Roadware Group Inc. and Pathway Services Inc. that provide the videologging van technology and perform the data collection for the state DOTs. In August 2002, Indiana DOT hired Pathway Services Inc. to collect pavement data for the whole state as part of the pavement management program. In addition to the pavement data, Pathway Services Inc. collected geometric data, such as heading and grade, so that it could be used to generate a curvature and grade database for the HERS analysis.

7.1 Van set-up

The van used by Pathway Services was equipped with 3 video cameras. There was 1 camera for the forward direction and one for each side of the van. Pavement conditions such as roughness, IRI (or PSR), and texture were measured with the help of laser sensors attached to the van. The van was also configured with gyroscopic instruments which measured the vehicle's heading, roll, and pitch as it traversed the road. These gyroscopes collected data at fixed distances and the data were matched with the corresponding location information and with the image of the location. The heading gyroscope was used to collect horizontal curvature data, while the vertical gyroscope was used to collect the vertical curvature data.

7.2 Horizontal Curvature data

The heading gyroscope collects the heading data as the van traverses the road. The point where the heading value changes is the point where the road alignment is changing. The heading value is ideally expected to be constant when the van is traveling on a straight/tangent section, but due to internal disturbances and due to the van motion, the heading value is disturbed even when it is on a tangent section. The disturbance causes data fluctuations of small magnitudes on tangent sections. This can pose problems and cause ambiguity in identifying the beginning of the curve (point of curvature) and the end of the curve (point of tangency). Hence, in order to overcome this issue, Pathway Services Inc. has developed software that cleans the data from unwanted fluctuations. The software uses the concept of a high pass filter. This is an electronic filter that allows only frequencies above a minimum threshold to pass through. The rest are discarded. Consequently, it is possible to estimate the location of the point of curvature (PC) and the point of tangency (PT). By using the PC and PT values, we can calculate the radius and the degree of curvature. The example provided below will help in understanding the filtering process.

Let's consider a 2-mile section on Interstate 65. Let's say that the section has a horizontal curve. Let the point of curvature and the point of tangency be at milepost 1.2 and milepost 1.6, respectively. When the video logging van traverses this section, the data collected by the video logging van will be similar to Table 7.1.

Table 7.1 Raw data collected by the video logging van

Section Identifier	Starting MP	Ending MP	Δ Heading (degrees)
I-65-79	1.0	1.1	0.23
I-65-79	1.1	1.2	-0.04
I-65-79	1.2	1.3	2.6
I-65-79	1.3	1.4	3.2
I-65-79	1.4	1.5	2.5
I-65-79	1.5	1.6	2.2
I-65-79	1.6	1.7	0.6
I-65-79	1.7	1.8	-0.9
I-65-79	1.8	1.9	0.009

A change in the heading value is an indicator that the van is traveling on a curved section. A sudden change in the heading value helps us to identify the point of curvature and the point of tangency. But because of the van's motion and other internal disturbances, there will be a change in the heading value, even when the van is traveling on a tangent section. Thus, it becomes difficult to identify exactly the point of curvature and the point of tangency. The raw data are passed through the high pass filter. Let's say that the filter allows only Δ Heading values greater than 1 degree. The Δ Heading values which are less than 1 degree are treated as 0. The filtered data will be as shown in Table 7.2.

Table 7.2 High Pass Filtered data

Section Identifier	Starting MP	Ending MP	Δ Heading (degrees)
I-65-79	1.0	1.1	0
I-65-79	1.1	1.2	0
I-65-79	1.2	1.3	2.6
I-65-79	1.3	1.4	3.2
I-65-79	1.4	1.5	2.5
I-65-79	1.5	1.6	2.2
I-65-79	1.6	1.7	0
I-65-79	1.7	1.8	0
I-65-79	1.8	1.9	0

From Table 7.2, we can say that the point of curvature is at milepost 1.2 and the point of tangency is at milepost 1.6.

7.3 Vertical Curvature data

A vertical gyroscope is used to collect the vertical curvature data. The general form of the parabolic equation applied to vertical curves, is

$$y = ax^2 + bx$$

where, $a = (G_2 – G_1)/ 2L$

$b = G_1$

G_1 = starting grade

G_2 = ending grade

L = length of the vertical curve

Table 7.3 shows an example of vertical grade data collected from the video logging process.

Table 7.3 An example of vertical grade data collected from the video logging process

Starting MP	Starting Grade (%)	Ending MP	Ending grade (%)	Length of curve (m)
7.449	2.058	7.724	-2.196	440

The parabolic equation for the vertical curve in Table 7.3 can be established by computing a and b.

$$a = (G_2 – G_1)/ 2L = (-2.196 - 2.058)/2*440 = -0.0048$$

$$b = G_1 = 2.196$$

At $x = 0$, $y = 0$

At $x = 440m$, $y = -0.0048*440^2 + 2.058*440 = 24m$

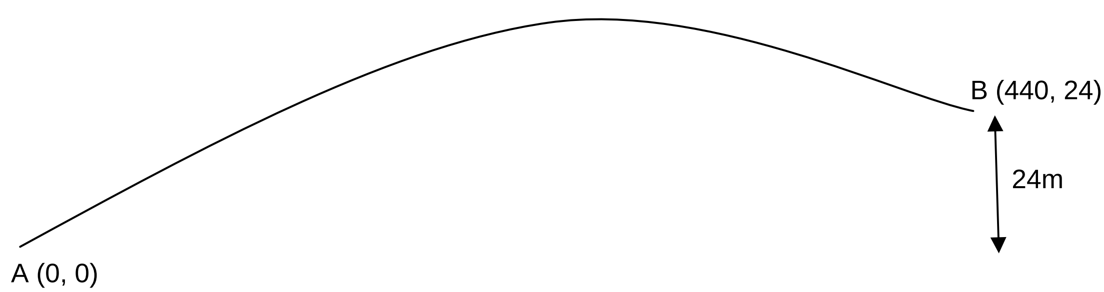


Figure 7.1 Vertical Curve

In Figure 7.1, A is the Point of Curvature (PC) and B is the Point of Tangency (PT). The point where the gradient begins to change is the Point of Curvature (PC). The Point of Tangency (PT) is the point where the gradient becomes constant. Here again, the raw data experience inherent fluctuations and noise, making it hard to determine the value of the constant grade. A software algorithm that employs the concept of a *moving average* *filter* is employed to flush out the noise and find the gradient. A moving average filter is a filter used in smoothing a series of data. Here, the value of a data point is replaced by the average of a certain number of previous data points.

A 3-point moving average filter can be mathematically represented as follows:

$$n' = [n + (n' - 1) + (n' - 2)]/3$$

where n' = filtered value of the n^{th} data point,

n = original value of the n^{th} data point.

Let us consider an example in order to understand the concept and the use of a moving average filter for establishing vertical grade values. Let us consider the data collected on a constant vertical grade as shown in Figure 7.2. The van collects grade data at regular intervals as indicated in Figure 7.2. Let us assume that the true gradient of the road segment is 5 percent.

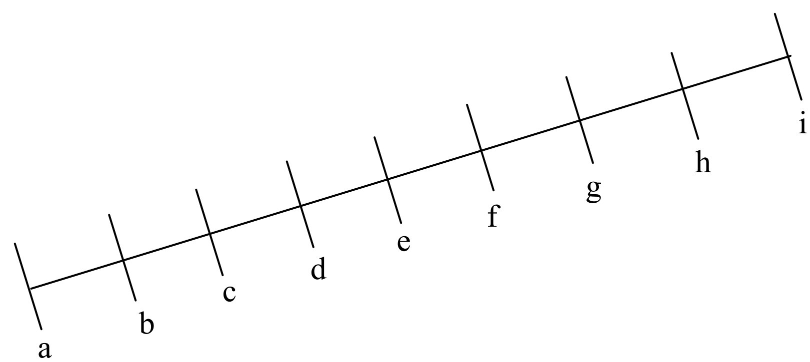


Figure 7.2 Vertical Profile of the road gradient

For simplicity, let us consider a 3-point moving average filter. In Table 7.4, by using the 3-point moving average filter, the raw data shown in column # 2 are converted to filtered data shown in column # 3.

Table 7.4 3-point moving average filtered data

Data Points	Raw data (%)	Filtered data (%)
A	4.9	4.9
B	5	5
C	5.8	5.23
D	5.2	5.14
E	4.4	4.92
F	4.9	4.98
G	4.2	4.7
H	4	4.56
I	5	4.75

Since the true gradient of the road segment shown in Figure 7.2 should be constant, a comparison of the variance of column # 3 with that of column # 2 will help us in understanding the effectiveness of the moving-average filter.

Table 7.5 Comparison of variance of raw data vs variance of filtered data

	Video log raw data	Filtered data
Mean	4.8	4.9
Variance	0.264	0.038

Because the variance of the filtered data is less than that of the raw data, we can conclude that the filtered data is a better representative of a dataset that is supposed to have constant values. The mean of the filtered data, which is 4.9, can be considered as the gradient of the road segment.

7.4 Videolog Curve and Grade data

Data Collection:

The data collection began in August 2002. As of January 2003, data collection efforts have been completed for the Northern 3 districts of Indiana. Data was collected at every

52 feet and stored in a database program developed by the consultant. Around mid-March 2003, the Purdue research team was given the curvature part of the videolog data.

Data characteristics:

1. The data are compiled/formatted in a text file, which can be pulled into a spreadsheet. The database covers about 4600 miles of Indiana roads, which amounts to around 50 percent of the Indiana roadway inventory that comes under the jurisdiction of INDOT.
2. Data are collected in both directions.
3. Data are collected using the statewide continuous milepost reference system. This is inconsistent with the reference system used in the HERS/IN input file, which uses the “county to county” milepost reference system.

7.5 Validating the video log horizontal curve data

We assessed the accuracy of the video log horizontal curve data by using airphotos from Mapquest (reference). Table 7.6 shows the methodology employed to validate the videolog horizontal curve data.

Table 7.6 Comparison of videolog horizontal curve data vs. mapquest airphoto

No.		Raw data	Mapquest	Airphoto*
1	Radius (m)	180	200	
	HPMS Curve Class	4	4	
	Point of Curvature (mile post value)	0.032	0.0	
	Point of Tangency (mile post value)	0.126	0.094	
2	Radius (m)	306	300	
	HPMS Curve Class	3	3	
	Point of Curvature (mile post value)	6.471	6	
	Point of Tangency (mile post value)	6.572	6.1	

Table 7.6 Comparison of videolog horizontal curve data vs. mapquest airphoto (Continued)

No.		Raw data	Mapquest	Airphoto*
3	Radius (m)	326	250	
	HPMS Curve Class	2	3	
	Point of Curvature (mile post value)	14.229	15	
	Point of Tangency (mile post value)	14.328	15.099	
4	Radius (m)	550	650	
	HPMS Curve Class	1	1	
	Point of Curvature (mile post value)	34.020	31	
	Point of Tangency (mile post value)	34.120	31.1	

Table 7.6 Comparison of videolog horizontal curve data vs. mapquest airphoto (Continued)

No.		Raw data	Mapquest	Airphoto*
5	Radius (m)	330	300	
	HPMS Curve Class	2	3	
	Point of Curvature (mile post value)	0.123	0	
	Point of Tangency (mile post value)	0.284	0.161	
6	Radius (m)	339	320	
	HPMS Curve Class	2	2	
	Point of Curvature (mile post value)	5.091	4.8	
	Point of Tangency (mile post value)	5.190	4.9	

Table 7.6 Comparison of videolog horizontal curve data vs. mapquest airphoto (Continued)

No.		Raw data	Mapquest	Airphoto*
7	Radius (m)	360	400	
	HPMS Curve Class	2	2	
	Point of Curvature (mile post value)	11.765	11.5	
	Point of Tangency (mile post value)	11.870	11.605	
8	Radius (m)	386	350	
	HPMS Curve Class	2	2	
	Point of Curvature (mile post value)	11.870	11.605	
	Point of Tangency (mile post value)	11.985	11.72	

Table 7.6 Comparison of videolog horizontal curve data vs. mapquest airphoto (Continued)

No.		Raw data	Mapquest	Airphoto*
9	Radius (m)	416	400	
	HPMS Curve Class	2	2	
	Point of Curvature (mile post value)	0.080	0.080	
	Point of Tangency (mile post value)	0.313	0.313	
10	Radius (m)	334	350	
	HPMS Curve Class	2	2	
	Point of Curvature (mile post value)	8.760	8.5	
	Point of Tangency (mile post value)	8.859	8.599	

*Photos taken from http://www.mapquest.com. Scale: 1 inch = 400m

7.6 Providing HERS/ST input file with the video log curve data

The raw curve and grade data from video logging needed to be adjusted and arranged into the specific format required by HPMS. Refer to the HPMS Field Manual (FHWA, 1998d) for the format specifications. This conversion was cumbersome and time consuming. The task was performed in the 3 steps described below.

Step 1:

The video log data were collected in the continuous reference system. Therefore, the first issue was transforming the curve data collected in the continuous reference system to the county to county reference system as required by the HERS file. This transformation was achieved by employing suitable logical commands in Microsoft Excel. Some of the logical commands employed were “if’s”, “nested if’s” and “or” operators. Minor approximations and assumptions had to be made for this task. For example, while identifying the location of the starting mile point of a county, it was assumed that this point lies in the middle of 2 curves that are one after the other but lie in different counties. The example shown below will help in understanding the assumption made while identifying the starting milepoint of a county. Let’s take a sample portion of the Video log Curvature data. The data are shown in Table 7.7.

Table 7.7 Curvature data

Road Name	County #	Starting MP	Ending MP	Radius (m)
S-10	75	65	65.8	500
S-10	75	72.2	73	670
S-10	50	76	76.4	340
S-10	50	82	82.9	890

In Table 7.7, we observe that data are collected on State Road 10 in county numbers 75 and 50 using a continuous milepost reference system. In order to convert the data to a county-to-county milepost reference system, we need to identify the starting milepoint of county number 50. In Table 7.7, we observe that the starting mile point of county number 50 lies between 73 and 76 continuous milepost reference system. We make the assumption that the starting mile point of county number 50 is at 74.5 (midway between 73 and 76) of the continuous milepost reference system.

Step 2:

After the above transformation, the collected horizontal and vertical curve data needed to be modified into a format required by the HERS software. Suitable mathematical formulae were employed to convert the horizontal curve radius into an HPMS curve class and to convert vertical curvatures into grades and arrange them by grade class. Section 3.3 explains the HPMS curve class and grade class categories.

Step 3:

The curve and grade data from Step 2 must be provided as horizontal and vertical alignment information into the HPMS road sections. The pre-1998 HPMS allots 91 columns for the horizontal curve information and 42 columns for the vertical curve information. Microsoft Excel was used to transform the curve and grade data into horizontal and vertical alignment information as required by HPMS.

7.7 Analysis of HERS/ST output

The video logging task is only about 50 percent complete. Therefore, in our analysis we have provided only about 50 percent of the HERS road sections with curve and grade data. A complete curvature database will not be available until the completion of the video logging data collection program.

a) Indiana road sections that have horizontal curvature deficiency

Table 7.8 shows the list of road sections with horizontal curvature deficiency identified by HERS/ST v2.0.

Table 7.8 Indiana road sections that have horizontal curvature deficiency

Section Identifier	Starting MP	Ending MP	Horizontal Defieciency *
08-S-218-0-01	0	1.27	4
50-S-010-0-01	19.92	23.07	4
52-S-218-0-01	8.84	11.42	4
66-S-143-0-01	0	1.5	4
75-S-010-0-01	1.76	2.03	4
80-U-031-0-01	4	12.89	4
57-S-003-0-01	9.5	11.03	3
66-U-035-0-01	5.4	8.31	3
68-U-036-0-01	15.49	18.81	3
68-S-032-0-01	6.81	10.93	3
80-S-028-0-01	0	0.58	3
01-S-101-0-01	0	2.01	2
01-U-033-0-01	0	2.71	2
02-U-024-0-01	31.26	33.39	2
02-U-030-0-01	25.17	26.5	2
08-U-421-0-01	22.96	24.66	2
08-S-218-0-01	17.49	18.41	2
12-U-421-0-01	19.38	22.47	2
17-S-001-0-01	8.06	9.07	2
17-S-001-0-01	3.92	3.93	2
20-S-013-0-01	0	1.02	2
21-S-001-0-01	14.44	14.94	2
24-S-121-0-01	4.7	4.83	2
25-S-017-0-01	9.1	9.39	2
25-S-014-0-01	23.92	24.02	2

Table 7.8 Indiana road sections that have horizontal curvature deficiency (Continued)

Section Identifier	Starting MP	Ending MP	Horizontal Defieciency *
27-S-026-0-01	17.89	19.46	2
27-S-026-0-01	19.46	21.49	2
37-S-010-0-01	0.53	4.01	2
37-U-231-0-01	33.8	34.46	2
44-S-120-0-01	11.28	12.32	2
45-S-002-0-01	0	3.17	2
45-S-002-0-01	6.09	7.34	2
46-U-020-0-01	18.05	18.5	2
48-S-128-0-01	0	0.99	2
50-S-017-0-01	13.68	14.43	2
50-S-010-0-01	12.06	12.27	2
52-U-031-0-01	0	1.5	2
56-S-055-0-01	0	2.01	2
56-S-055-0-01	31.69	33.73	2
57-U-033-0-01	16.81	17.31	2
57-S-009-0-01	11.79	13.76	2
64-S-002-0-01	15.18	16.35	2
66-S-014-0-01	4.04	10.01	2
66-S-119-0-01	9.01	11.01	2
66-S-014-0-01	20.38	23.21	2
68-S-032-0-01	0	0.35	2
68-S-032-0-01	17.05	22.16	2
75-U-035-0-01	16.5	18.48	2
75-S-023-0-01	10.81	12.11	2
76-S-004-0-01	5.14	5.32	2

Table 7.8 Indiana road sections that have horizontal curvature deficiency (Continued)

Section Identifier	Starting MP	Ending MP	Horizontal Defieciency *
91-S-016-0-01	12.06	13.27	2
91-U-024-0-01	15.87	17.21	2
91-S-039-0-01	4.89	11.6	2
91-S-016-0-01	16.28	18.25	2
92-S-205-0-01	0	0.08	2
92-S-005-0-01	16.41	22.49	2

* The coded value represents the degree of deficiency. 4 = severely deficient, 3 = moderately deficient, 2 = mildly deficient

Geographical representation of the sections listed in Table 7.8 is shown in Figure 7.3 using TransCAD 4.0.

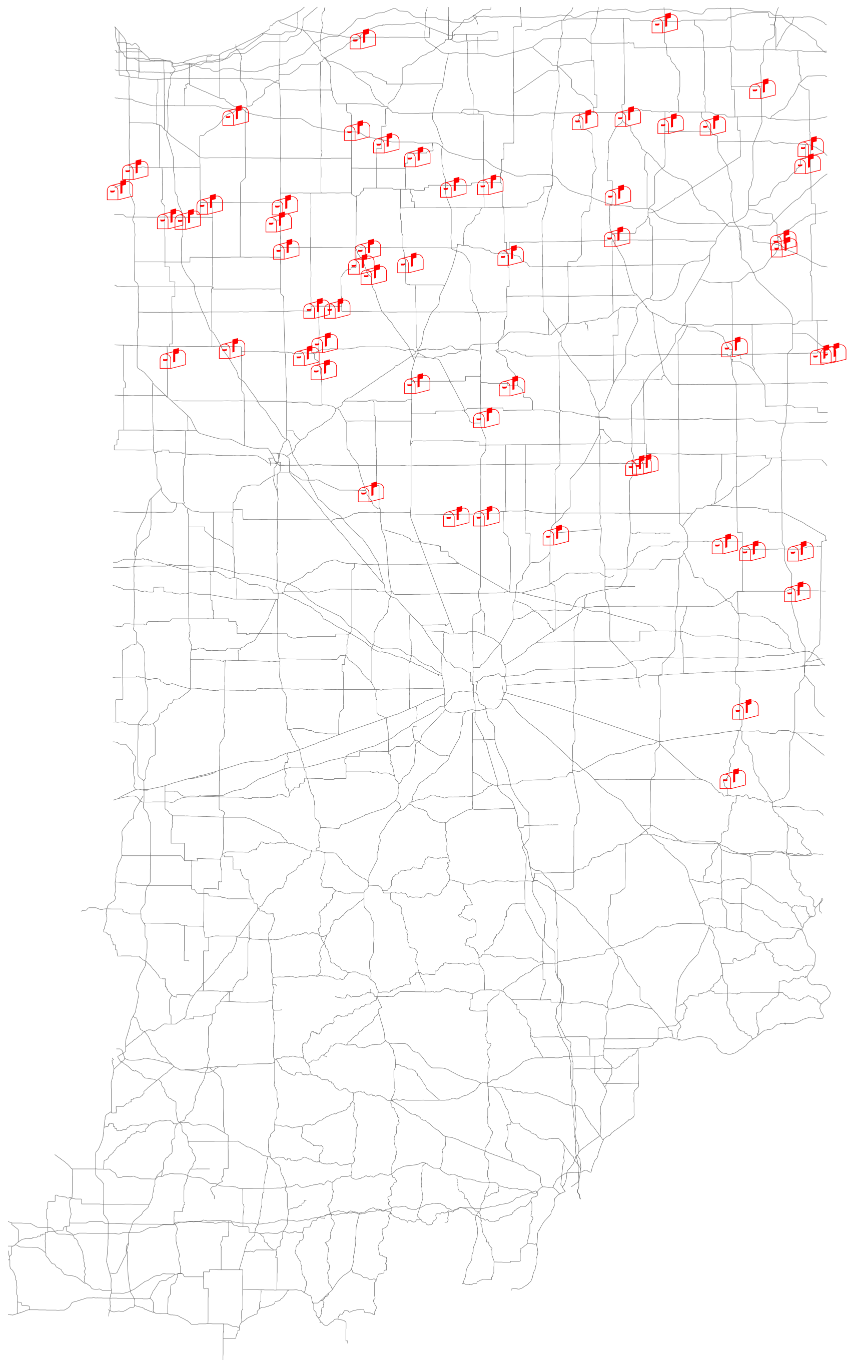


Figure 7.3 Highway sections with deficient horizontal curves

b) Indiana road sections that have vertical grade deficiency

Table 7.9 shows the list of road sections with horizontal curvature deficiency identified by HERS/ST v2.0.

Table 7.9 Indiana road sections that have vertical grade deficiency

Section Identifier	Starting MP	Ending MP	Vertical deficiency*
01-S-218-0-01	5.73	5.87	4
01-S-218-0-01	5.6	5.73	4
01-S-218-0-01	6.64	6.91	4
08-U-421-0-01	12.38	13.15	4
17-S-427-0-01	8.78	8.8	4
33-S-103-0-01	0.12	0.45	4
33-S-038-0-01	4.9	5.09	4
35-S-218-0-01	1.36	4.92	4
35-S-218-0-01	0	1	4
35-S-218-0-01	1	1.36	4
35-S-105-0-01	15.63	15.96	4
35-S-218-0-01	4.92	6.92	4
35-S-218-0-01	13.02	14.5	4
35-S-218-0-01	11.75	11.97	4
35-S-218-0-01	12.36	13.02	4
35-S-218-0-01	12.04	12.36	4
35-S-218-0-01	11.97	12.04	4
35-S-218-0-01	15.54	17.53	4
35-S-218-0-01	14.5	15.54	4
48-S-128-0-01	4.34	4.46	4
52-S-019-0-01	23.45	24.53	4
57-S-005-0-01	12.95	13.06	4

Table 7.9 Indiana road sections that have vertical grade deficiency (Continued)

Section Identifier	Starting MP	Ending MP	Vertical deficiency*
64-S-002-0-01	19.88	20.12	4
70-S-244-0-01	8.24	8.42	4
71-U-006-0-01	3.48	3.56	4
85-S-524-0-01	0	0.1	4
85-S-218-0-01	2.78	4.28	4
85-S-218-0-01	0.12	2.34	4
85-S-218-0-01	0	0.12	4
85-S-218-0-01	2.34	2.78	4
89-S-227-0-01	2.85	3.4	4
90-S-218-0-01	5.95	9.61	4
90-S-218-0-01	0	2.94	4
90-S-218-0-01	2.94	3.95	4
90-S-218-0-01	3.95	5.76	4
90-S-218-0-01	5.76	5.95	4
90-S-218-0-01	9.61	13.94	4
01-S-218-0-01	4.95	5.46	3
01-S-218-0-01	5.87	5.94	3
01-S-218-0-01	5.94	5.97	3
01-S-218-0-01	6.29	6.32	3
01-S-218-0-01	6.91	6.97	3
01-S-218-0-01	6.97	7	3
01-S-218-0-01	13.74	14.09	3
01-S-218-0-01	8.99	12.54	3
01-S-218-0-01	12.54	13.74	3
20-S-013-0-01	21.02	21.37	3
20-S-013-0-01	19.8	20.21	3

Table 7.9 Indiana road sections that have vertical grade deficiency (Continued)

Section Identifier	Starting MP	Ending MP	Vertical deficiency*
33-S-140-0-01	0	0.16	3
33-S-140-0-01	0.16	0.32	3
35-S-105-0-01	14.89	15	3
43-S-015-0-01	1.98	2.02	3
44-U-020-0-01	13.1	13.45	3
46-U-035-0-01	8.66	9	3
76-S-127-0-01	4.83	5.04	3
76-S-001-0-01	1.14	1.52	3
76-S-001-0-01	1.52	1.86	3
81-S-044-0-01	1.7	2.68	3
89-S-001-0-01	5.02	5.17	3
92-S-005-0-01	13.02	13.32	3

* The coded value represents the degree of deficiency. 4 = severely deficient, 3 = moderately deficient, 2 = mildly deficient. Note: In order to avoid a large number of rows in Table 7.9, the sections with vertical deficiency value of 2 is not shown.

Geographical representation of the sections listed in Table 7.9 is shown in Figure 7.4 using TransCAD 4.0.

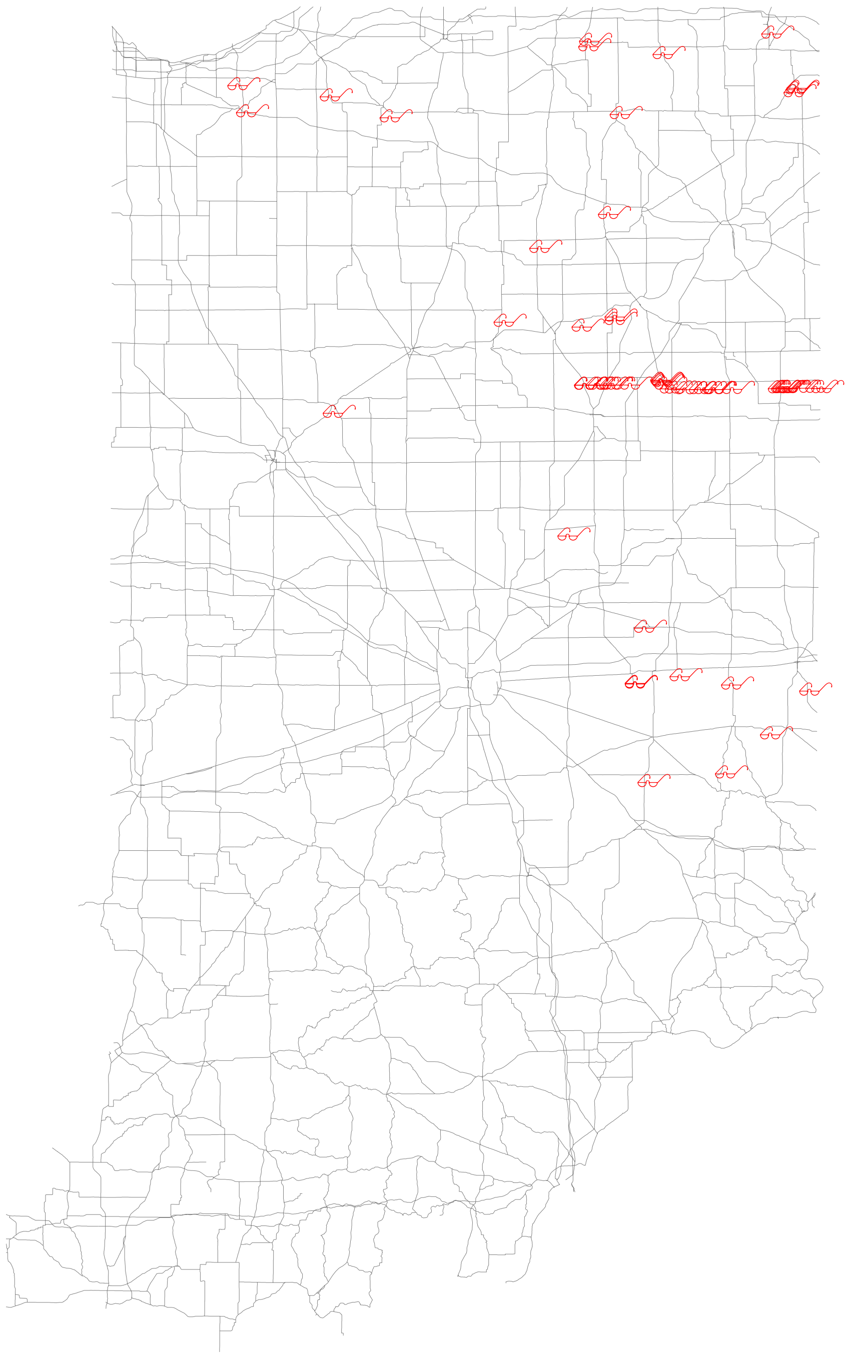


Figure 7.4 Highway sections with deficient vertical grade

c) Sections identified by HERS/ST for "Resurface and improve shoulders with Alignment Improvement "

Table 7.10 shows the list of road sections identified by HERS/ST v2.0 for "Resurface and improve shoulders with Alignment Improvement".

Table 7.10 Sections identified by HERS/ST for "Resurface and improve shoulders with Alignment Improvement"

Section ID	Starting MP	Ending MP	Benefit/Cost Ratio
08-U-421-0-01	12.38	13.15	7.2
43-S-015-0-01	1.98	2.02	7.5
44-U-020-0-01	13.1	13.45	11.9
46-U-035-0-01	8.66	9	4.9
64-U-006-0-01	8.76	9.1	5
66-U-035-0-01	5.4	8.31	4.2
68-S-032-0-01	6.81	10.93	1.9
71-U-006-0-01	3.48	3.56	4.7
75-S-010-0-01	1.76	2.03	1.6
89-S-001-0-01	5.02	5.17	6.9
01-S-218-0-01	4.95	5.46	7.7
01-S-218-0-01	5.73	5.87	14.7
01-S-218-0-01	5.6	5.73	15.9
01-S-218-0-01	5.87	5.94	18.7
01-S-218-0-01	5.94	5.97	22.3
01-S-218-0-01	6.29	6.32	11.1
01-S-218-0-01	6.64	6.91	8.2
01-S-218-0-01	6.91	6.97	6.7
01-S-218-0-01	6.97	7	3.1

Table 7.10 Sections identified by HERS/ST for "Resurface and improve shoulders with Alignment Improvement" (Continued)

Section ID	Starting MP	Ending MP	Benefit/Cost Ratio
24-S-121-0-01	6.21	6.51	4.9
33-S-140-0-01	0	0.16	20.4
33-S-140-0-01	0.16	0.32	25.8
35-S-218-0-01	1.36	4.92	6.4
35-S-218-0-01	0	1	3.6
35-S-218-0-01	1	1.36	3.5
35-S-218-0-01	4.92	6.92	7.1
35-S-218-0-01	13.02	14.5	6.9
35-S-218-0-01	11.75	11.97	15.2
35-S-218-0-01	12.36	13.02	10.3
35-S-218-0-01	11.97	12.04	15.2
35-S-218-0-01	15.54	17.53	6.7
35-S-218-0-01	14.5	15.54	6.7
50-S-010-0-01	19.92	23.07	4.4
52-S-019-0-01	23.45	24.53	3.4
85-S-218-0-01	2.78	4.28	3.5
85-S-218-0-01	0.12	2.34	4.5
85-S-218-0-01	2.34	2.78	3.5
90-S-218-0-01	5.95	9.61	3.1
90-S-218-0-01	0	2.94	3.7
90-S-218-0-01	2.94	3.95	5.6
90-S-218-0-01	3.95	5.76	6.7
90-S-218-0-01	5.76	5.95	6.6
90-S-218-0-01	9.61	13.94	3.2
92-S-005-0-01	13.02	13.32	9.4

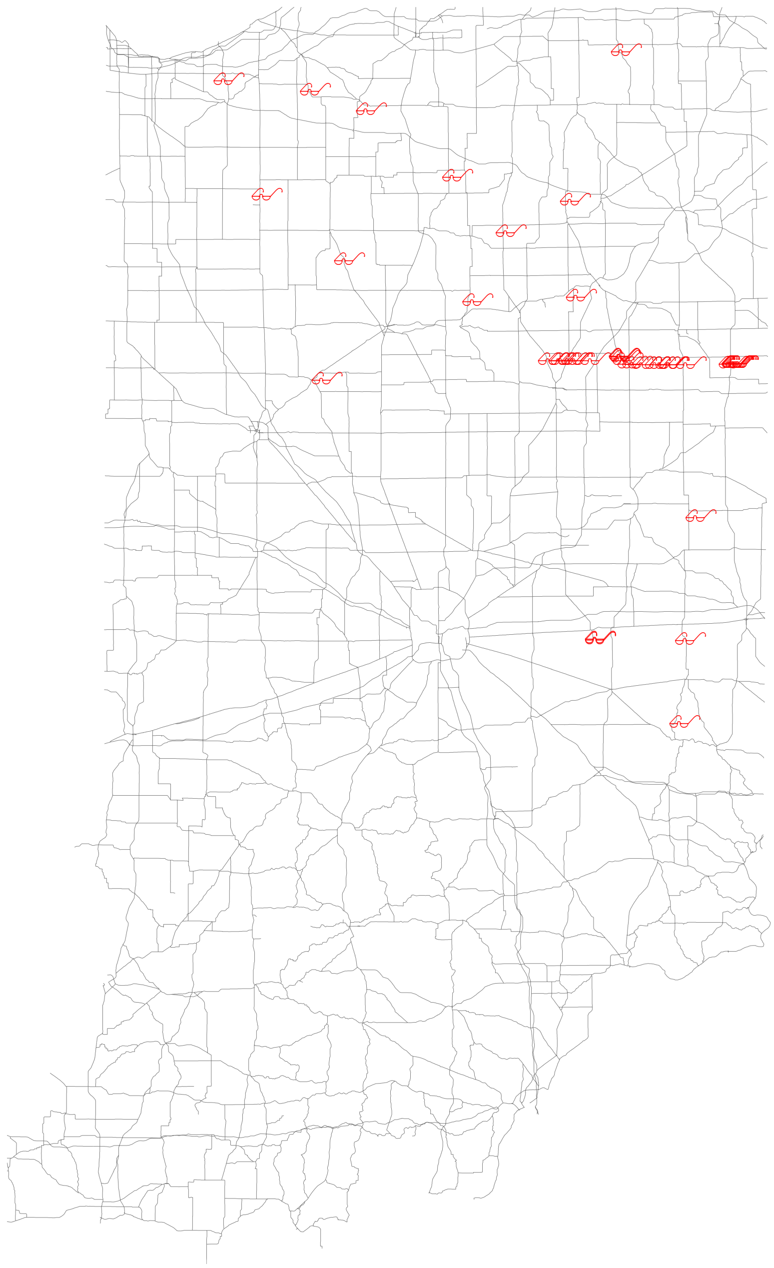


Figure 7.5 Highway sections identified by HERS/ST for “Resurface and improve shoulders with Alignment Improvement”

d) Sections identified by HERS/ST v2.0 for "Resurface with Alignment Improvement"

Table 7.11 shows the list of road sections identified by HERS/ST for "Resurface with Alignment Improvement".

Table 7.11 Sections identified by HERS/ST for "Resurface with Alignment Improvement"

Section ID	Starting MP	Ending MP	Benefit/Cost ratio
01-S-218-0-01	8.99	12.54	2.7
01-S-218-0-01	12.54	13.74	2.2
35-S-218-0-01	12.04	12.36	9
52-S-218-0-01	8.84	11.42	1.6
66-S-143-0-01	0	1.5	3.1
76-S-001-0-01	1.14	1.52	9.7
76-S-001-0-01	1.52	1.86	5.5
85-S-218-0-01	0	0.12	4.2
57-S-003-0-01	9.5	11.03	2.4
68-U-036-0-01	15.49	18.81	1.7
80-U-031-0-01	4	12.89	3.7
80-S-028-0-01	0	0.58	1.8
81-S-044-0-01	1.7	2.68	2.7

Geographical representation of the sections listed in Table 7.11 is shown in Figure 7.6 using TransCAD 4.0.

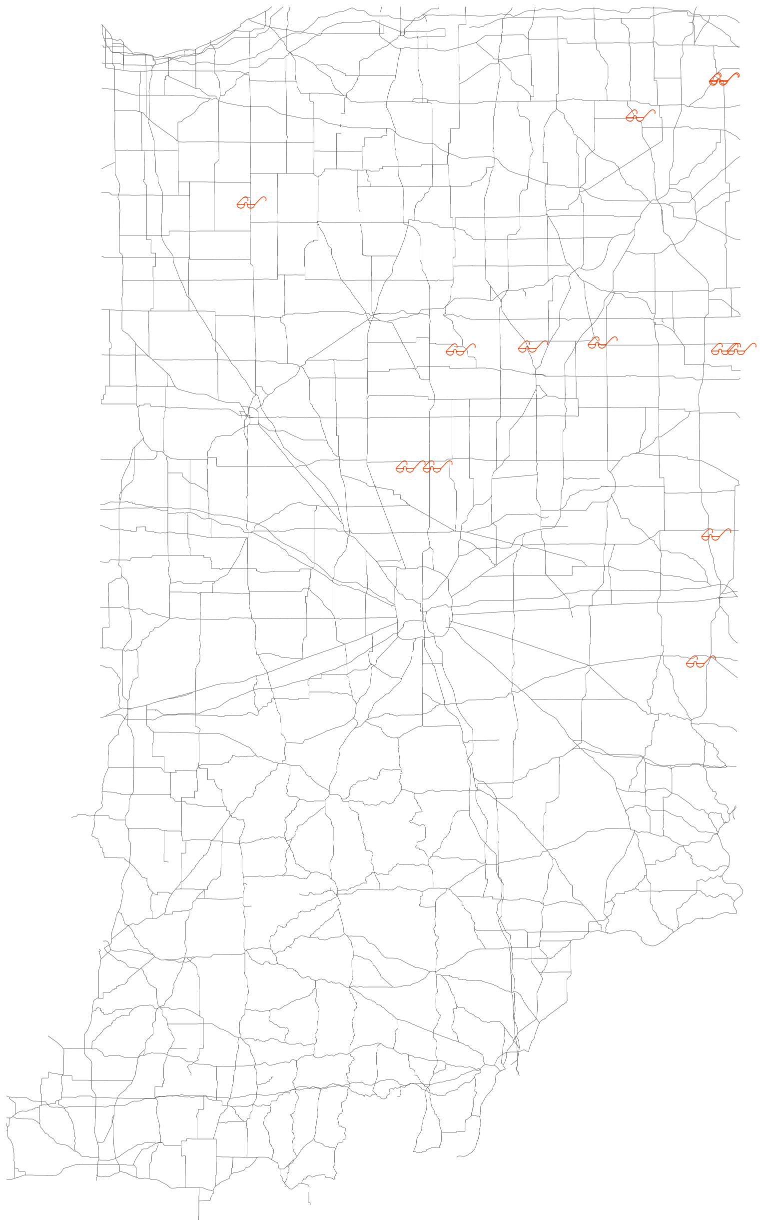


Figure 7.6 Highway sections identified by HERS/ST for “Resurface with Alignment Improvement”

8 Programming Curve and Grade Correction Projects

This chapter suggests a methodology to program curve/grade correction projects more effectively. It is based on the results of the survey of the state DOTs, the HERS analysis, and some insights perceived in curve and grade correction projects. The rationale and the justification of this methodology to be an efficient method is explained in the following paragraphs.

8.1 Rationale and justification of the methodology

First, we need to understand clearly the goal of our efforts. The goal is "Programming Curve and Alignment Correction projects *effectively*." The meaning of "effectively" must be well defined. Our methodology treats "effectively" as, "For a given amount of dollars available for transportation projects (which encompasses all types of projects, e.g., pavement maintenance, capacity, and safety projects), what combination of such projects will provide the maximum benefit in dollar equivalents." This is similar to the definition of "effectively" employed in the HERS software (FHWA, 2000e). From the survey, we learned that almost all states program their curve correction projects (which are safety projects) without coordination with the planning process. It is often the case that incorporating safety into the planning process can give you a higher benefit than treating the two criteria separately.

In merging a curve/grade correction project into the planning process, we first need to find the road improvements that provide both safety project benefits and planning project benefits. We can list the following improvement projects that have this quality:

1) Reconstruction

Here, it could be possible to rectify an existing alignment deficiency while reconstructing a road segment. Thus, we can merge a safety project into a maintenance project.

2) Resurfacing

While resurfacing the pavement at a curved section, it is possible to reduce its hazard potential by improving its superelevation characteristics. Although this may not be the best way to rectify alignment deficiency, it does have a safety benefit.

3) Adding/Widening Lanes

Adding/widening lanes is predominantly a capacity improvement project, but with more lanes or widened lanes, it is possible to reduce the degree of curvature and thus also reduce the hazard potential of the curved section. Again, this improvement is not the best solution for rectifying alignment deficiencies, but it does carry safety benefits.

The above list is diagrammatically shown in Figure 8.1.

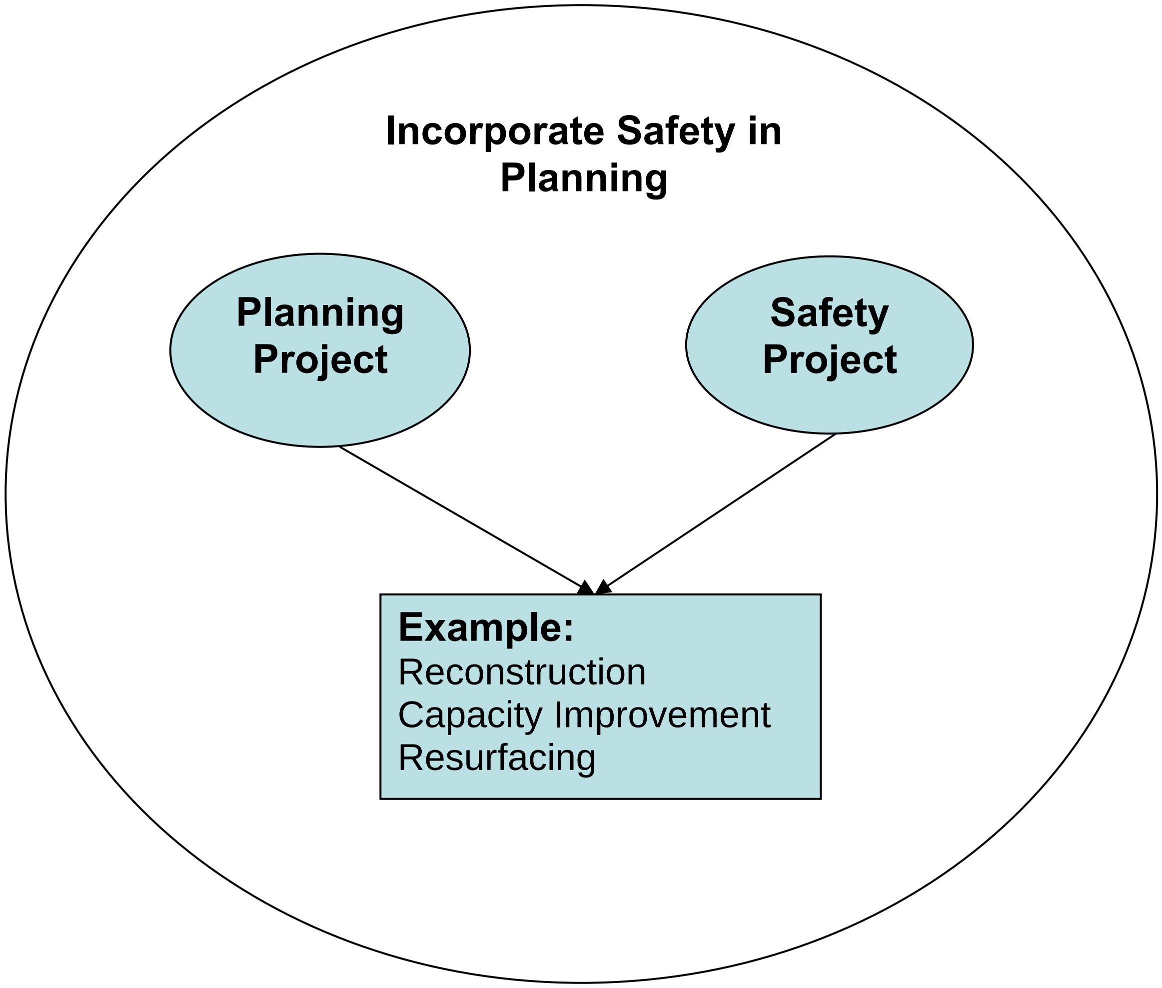


Figure 8.1 Incorporating Safety into the Planning Process

The potential effectiveness of the above methodology can be demonstrated using a numerical example. Let us consider 3 road sections that are competing with each other to justify an improvement project on them, with a constraint on the available budget. Let these road sections be called A, B and C. The type of deficiency and the improvement project's cost and benefit values are given in Table 8.1 and Table 8.2.

Case 1

Safety Projects and Planning Projects are disjoint.

Table 8.1 Project's Benefit-Cost Values (Case 1)

Curve Correction (Safety Project)		
Section Name :	A	B
Cost (units)	1	1
Benefit (units)	3	2
B/C	*3*	2

Pavement Reconstruction (Maintenance Project)		
Section Name :	B	C
Cost (units)	1	1
Benefit (units)	1.5	2
B/C	1.5	*2*

From Table 8.1, we observe that if safety projects and planning projects are disjoint, then, based on the B/C ratio, we can conclude that Section A and Section C will be the projects selected from their respective lists. Section A provides a B/C value of 3 as a safety project, while a maintenance project on Section C provides a B/C value of 2.

Case 2

Safety projects incorporated into planning.

Table 8.2 Project's Benefit-Cost Values (Case 2)

Safety Projects within Planning Process			
Section Name :	A	B	C
Cost (units)	1	1	1
Benefit (units)	3	*3.5*	2
B/C	3	*3.5*	3

As seen in Table 8.2, if the safety projects are included within the planning process, then Section B will be the project selected, with a B/C ratio of 3.5.

8.2 Comment

The example above provides a simplified approach for understanding the underlying concept behind our methodology. In reality, we face challenges such as estimating the exact quantitative safety benefits of a safety improvement. Also, the cost of the maintenance project may increase while incorporating safety into it. For example, when a curve superelevation correction project is included along with the pavement resurfacing project, the cost of the project may increase. However, this does not change the fact that the methodology provided could be a better way to program our curve and grade correction projects.

8.3 Implementing the Methodology

First, we recognize that HERS is a planning tool that identifies pavement and capacity deficiencies and then looks into the geometric deficiencies. Figure 8.2 shows the HERS logic in identifying alignment deficiency.

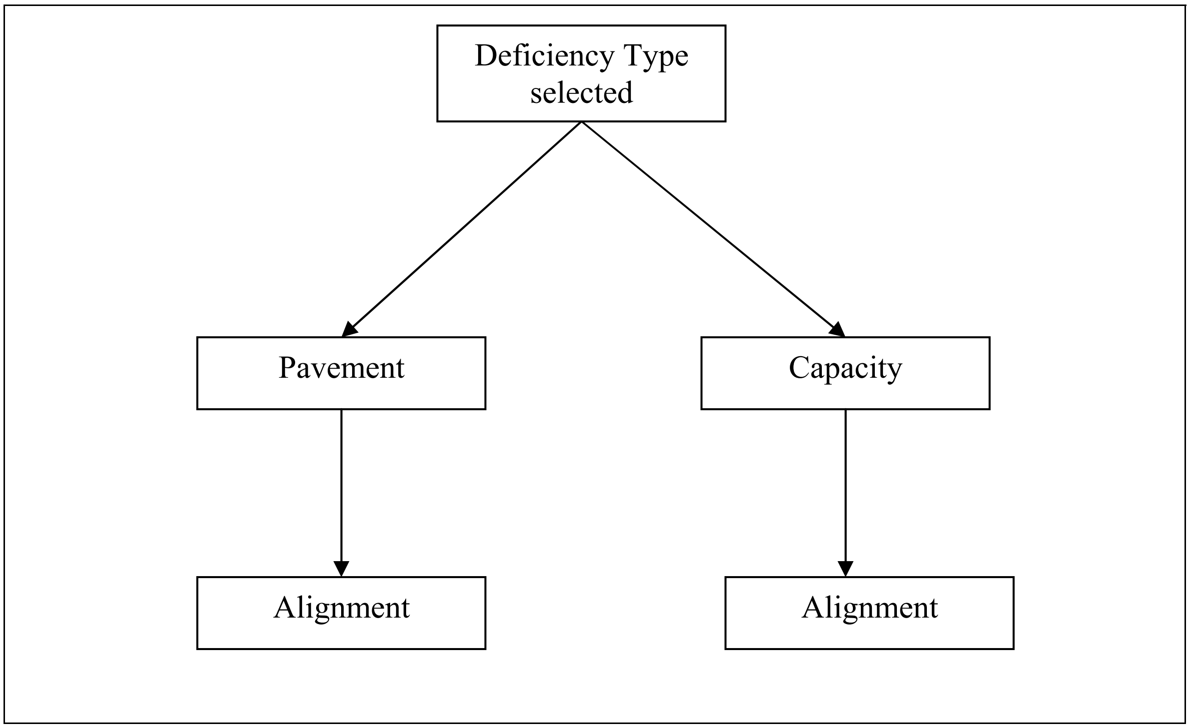


Figure 8.2. Logic in HERS for identifying alignment deficiency

The HERS logic is essentially incorporating an Alignment Correction Project into the Planning Process. Also, we notice that the HERS input file does not contain crash data, implying that the safety projects selected by HERS will be based solely on a section's geometric characteristics. This is one of the limitations of HERS in identifying safety projects. Figure 8.3 depicts the structure of the methodology suggested by the research team for programming alignment correction projects.

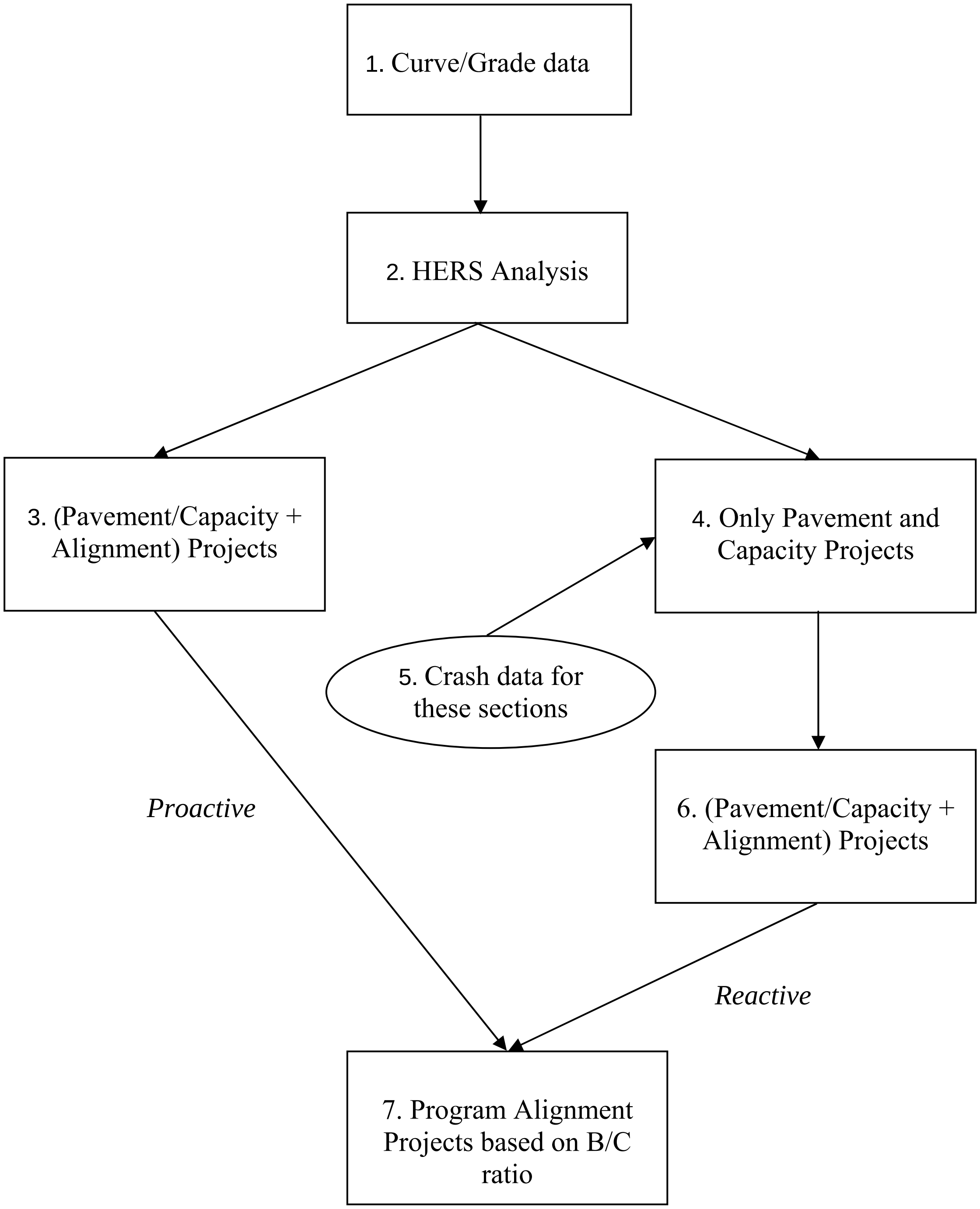


Figure 8.3 Flow Chart showing the recommended methodology for programming alignment correction projects.

8.4 Explanation of the Flow chart

Step 1:

Provide curve and grade data to the HERS file.

Step 2:

Perform HERS analysis.

Step 3:

HERS identifies (pavement/capacity + alignment improvement) projects and provides their B/C values. This is a proactive manner of identifying safety projects because HERS considers only geometric characteristics for identifying alignment deficient sections and does not account for crash history.

Step 4:

HERS identifies the pavement/capacity improvement projects and provides their B/C values. According to HERS, the sections identified in Step 4 do not qualify for an alignment improvement.

Step 5:

Provide the sections identified in Step 4 with crash data.

Step 6:

Using the crash data, it is possible to identify whether the sections that require pavement/capacity improvement have a safety problem as well. If a safety problem is identified at the section and if this safety problem is caused due to an alignment deficiency, then we can correct the alignment in addition to performing the pavement/capacity improvement on the section. Using this concept, identify the (pavement/capacity + alignment improvement) projects and estimate their B/C values. This is a reactive manner of identifying safety projects, because it incorporates crash data to identify its safety projects.

Step 7:

Combine the projects identified in Step 3 and Step 6 and prioritize them using B/C values.

8.5 Discussion of the methodology's attributes and effectiveness

The method combines proactive, reactive, and planning approaches for programming alignment correction projects. By combining the approaches, we are programming safety projects in a broader comprehensive view context and avoiding the drawbacks of a single approach. Alignment correction projects identified through this technique have the potential to be more cost-beneficial in the long-run than alignment correction projects identified through the usual proactive or reactive approach. However, we do understand that the methodology assumes that we have all the data and perfect information available. In the real world, this is not the case. The methodology does not take into account extraneous factors, such as the political and public decisions that influence a project's selection and implementation. However, use of this methodology can assist the decision maker in making more informed decisions while identifying and programming curve correction projects.

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LIST OF REFERENCES

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Appendix A Survey on Curve Correction Projects

Survey on Curve Correction Projects

(Data and Decision-Making)

Alaska

- *What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

  Alaska Department of Transportation and Public Facilities (ADOT&PF) does not report horizontal curve data for HPMS. We are aware of this, and will try to report in future years. ADOT&PF is collecting DGPS centerline coordinates for Alaskan highways. We have prioritized the road systems for collecting and converting the DGPS coordinates to route coverages (NHS, state maintained, Alaska Highway System, local roads). No plan exists at this time to collect horizontal curve data for any of these road networks.

  We did collect detailed curve and grade data for 26 National Highway System roads during the late 1980's. The project established new monuments, updated old monuments, and provided a robust set of curve and grade data for ADOT&PF. The hope of this project was to integrate the data into the Department's transportation database for design, construction, and analysis for the various road networks. Additional objectives included installing permanent milepost markers for reference locations. However, the project was never extended. The data is still available if you are interested.

- *What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

  Alaska Department of Transportation and Public Facilities (ADOT&PF) does not report vertical curve data for HPMS. We are aware of this, and will try to report in future years. ADOT&PF is collecting DGPS centerline coordinates for Alaskan highways. However, the vertical component has not been used operationally due to the accuracy. We have prioritized the road systems for collecting and converting the DGPS coordinates to route coverages (NHS, state maintained, Alaska Highway System, local roads). No plan exists at this time to collect vertical curve data for any of these road networks.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

  ADOT&PF does not have a specific list of prioritized/ranked Curve Correction/ Alignment Improvement projects. ADOT&PF does maintain such a list for Highway Safety Improvement (HSIP) which includes a detailed accident analysis. New curve and grade data may be collected as part of this improvement process.

- *How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?*

  See response to Question #3.

- Please give your name, job title, mailing address, and email address. Thank you.

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Survey on Curve Correction Projects

(Data and Decision-Making)

Arkansas

- *What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

  We gather horizontal curve data for the HPMS sample sections using the Automatic Road Analyzer (ARAN) vehicle's gyroscope.

- *What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

  We gather vertical grade data for the HPMS sample sections using the Automatic Road Analyzer (ARAN) vehicle's gyroscope.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

  Under AHTD 3R (Resurfacing, Restoration and Rehabilitation) Policy, reconstruction of horizontal curves is considered when the existing horizontal curve design (radius and superelevation) corresponds to a speed that is more than 15 mph below the average running speed established for the project, and the traffic volume is more than 750 vpd. Reconstruction of vertical curves is considered when the existing vertical curve design, based on stopping sight distance provided, corresponds to a speed that is more than 20 mph below the average running speed established for the project, the traffic volume is more than 1500 vpd, and the curve hides major hazards from view. Horizontal and vertical alignment improvements are designed in accordance with the *AASHTO Policy on the Geometric Design of Highways and Streets.*

- *How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?*

  There is no ranking system; priorities are established by the Highway Commission.

- *Please give your name, job title, mailing address, and email address. Thank you.*
  Questions concerning HPMS contact:

  Hilda Harris, Highway Performance and Needs Analyst II
  Hilda.Harris@ahtd.state.ar.us
  Arkansas State Highway and Transportation Department
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  Engineer of Roadway Design
  Arkansas State Highway and Transportation Department
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  PO Box 2261
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Survey on Curve Correction Projects

(Data and Decision-Making)

California

- *What are the methods that your state employs to collect the statewide* _horizontal_ *curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

  The curve radii are taken from the contract plans on an ongoing basis. This allows us to code the values for the curve classes on the state highway system.

- *What are the methods that your state employs to collect the statewide* _vertical_ *grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

  The grades are taken from the contract plans on an ongoing basis. This allows us to code the values for the grade classes on the state highway system.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

  Caltrans uses a computer analysis process (Table C process) to identify locations that need a traffic investigation performed. All of our curve correction projects are identified through this process as well as other types of improvements, ie, shoulder widening, intersection improvements, etc.
  See attached detailed write-up on the Table C process.

- *How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?*

  Caltrans utilizes a benefit/cost calculation to determine how the curve correction will be prioritized. If the project is over a certain threshold (Safety Index > 200) then the department categorizes the project as an “010 – Safety Improvement” and will be given top priority in terms of providing resources to deliver and to construct the project. The funding will come from other projects (if needed) that are of lower priority. If the curve correction does not satisfy the requirements from the benefit/cost calculation then it will be defined as a “operational improvement” and be prioritized with other operational type projects.

- *Please give your name, job title, mailing address, and email address. Thank you.*

Survey on Curve Correction Projects
(Data and Decision-Making)
Connecticut

- *What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

  Vehicle azimuth data is collected at 4 meter intervals for the entire state maintained network as part of the annual Photo Log process. Vehicle azimuth is an accurate estimate of road azimuth. This data is checked for errors and stored in a computer database that is accessible to a variety of highway management application programs. One of these programs is a unique horizontal curvature analysis program developed by an outside contractor that uses the azimuth data. The HPMS curve sections are analyzed by this program, and the curvature output is then automatically processed to meet FHWA HPMS format specifications.

- *What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

  Vehicle pitch data is collected at 4 meter intervals for the entire state maintained network as part of the annual Photo Log process. When combined with vehicle distance- to-the-road data collected at the wheel wells an accurate estimate of road grade is obtained. This data is checked for errors and stored in a computer database that is accessible to a variety of highway management application programs. The HPMS grade sections are automatically processed to meet FHWA HPMS format specifications.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

- *How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?*

- *Please give your name, job title, mailing address, and email address. Thank you.*

Survey on Curve Correction Projects

(Data and Decision-Making)

Florida

- *What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

  In the past, horizontal curves by class have been derived from construction plans when available, or estimated in the field informally by Planning personnel (not surveyors). We also now have a GIS (ArcInfo) application that an operator can use to compare a sample segment in the map to a set of standard arcs to determine the curve class of that segment.

- *What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

  Most grades in Florida are Class A (0.0 to 0.4 %). Grade class of any steeper grades are estimated in the field by Planning personnel.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

  Florida's State Highway System has few if any curve correction problems severe enough to warrant correction as stand-alone projects. When adding lanes to meet a capacity improvement need, we do improve alignment to current standards (if necessary).

- *How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?*

  Since there are no stand-alone curve correction projects, there is no need to rank them against competing projects.

- *Please give your name, job title, mailing address, and email address. Thank you.*

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Survey on Curve Correction Projects

(Data and Decision-Making)

Hawaii

- *What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

  We've only done this one time on a pilot project in 2001 using Roadware's ARAN system and having Roadware process the data for us per the HPMS field manual.

- *What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

  Same as above.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

  We don't have any comprehensive criteria that I know of.

- *How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?*

  Our project ranking system is something still way in the development phase.

- *Please give your name, job title, mailing address, and email address. Thank you*

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Survey on Curve Correction Projects

(Data and Decision-Making)

Iowa

- *What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

  The Iowa Department of Transportation collected most of its curve data in the early 1980's by road crews taking a variety of measurements. Updates to that data occur several ways. Curve measurements are taken from construction plans provided to the Office of Transportation Data. Road crews taking road inventory also have an active role in curve measurement.

- *What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

  The Iowa Department of Transportation also collected most of its grade data in the early 1980's by road crews using a slope meter. Updates to that data occur in a variety of ways. Grade measurements are taken from construction plans provided to the Office of Transportation Data. Road crews taking inventory also continue to use a slope meter for grade measurement.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

  The Iowa Department of Transportation uses the total number of non-animal, non-intersection related crashes through the curve as the primary criteria.

- *How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?*

  The project is a stand-alone priority – one of 10 equal priority areas in the Office of Traffic and Safety.

- *Please give your name, job title, mailing address, and email address. Thank you.*

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Survey on Curve Correction Projects

(Data and Decision-Making)

Kentucky

- *What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

  Horizontal curve data is collected on rural arterials and urban principal arterials for HPMS sample reporting purposes. In Kentucky, since internally we use state system coding (state primary, state secondary, rural secondary, and supplemental) as a criteria for data collection, we have horizontal curve data on most state primary and secondary routes (this covers HPMS reporting needs). Each curve and tangent segment is coded as a separate curve. Data is entered into database from construction plans or from field inventory forms. In field data collection a 100' tape is used to establish a chord 68' in length between two points on the most distinguishable edge of the pavement near the center of the curve. A measurement is then taken in tenths of a foot from the chord at the 34' mark on the tape to the nearest edge of the pavement. Each tenth of a foot is equal to one degree of curvature.

- *What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

  Vertical curve data is collected on the same routes as identified above for horizontal curve data collection. Once again data is enter from construction plans or from field inventory forms. Data is collected in the field using a gradient measuring device. Each grade and tangent segment is coded as a separate grade. A measurement is taken at the steepest point.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

Kentucky does not specifically identify projects as "curve correction/alignment improvement projects". Some projects do have this facet as their principal goal, but not all that many vis-à-vis lane widening, capacity addition, or more general safety improvements.

- *How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?*

Since there is no specific special category of "curve correction/alignment improvement projects", there is no particular procedure for ranking them.

- *Please give your name, job title, mailing address, and email address. Thank you.*

Questions 1 and 2 answered by Ed Whittaker, 3 and 4 by Bruce Siria.

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Survey on Curve Correction Projects

(Data and Decision-Making)

Louisiana

- *What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

We are in the process of developing a system to calculate curve data using GPS coordinates. This system is still 2-3 years away from being used. Currently, we are using the Ball Bank to determine at what speed a certain degree on the ball bank is exceeded. This speed is then related to a curve class. For example, if the speed determined by the ball bank is from 40-45, and then the HPMS curve class is “D”.

- *What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

Vertical grade data is not being collected at this time. Since Louisiana is relatively flat, vertical data is not a major issue in Louisiana. All vertical curves in Louisiana will be almost flat, except at bridge approaches.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

A number is calculated called the Horizontal Curve Design Speed. This number is a combination of the degree of curve (if available), the ball bank speed, and the number of curves in the segment and sight distance. Another key element is whether or not the segment is considered to be an abnormal crash site.

- *How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?*

  There is a separate LADOTD committee which determines which of these projects will be selected. We supply our information on these locations to the committee and they can select any of these projects or other projects. Recommendations to the committee are accepted from the DOTD Highway District

  Administrators and also the individual MPO's (each of the major cities planning organizations). The committee then uses our information and the recommendations to decide which projects will be selected. These projects have a certain budget within DOTD, which limits the number of projects each year.

- *Please give your name, job title, mailing address, and email address. Thank you.*

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Survey on Curve Correction Projects

(Data and Decision-Making)

Montana

- *What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

  The HPMS coordinator annually reviews all new reconstruct project plans for changes to the horizontal and vertical curve database and updates the HPMS database accordingly.

- *What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

  See answer above.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

  We do not have specific criteria to list roadway sections for such improvements. We will initiate an improvement project under our Safety Engineering Improvement Program (SEIP) when an accident cluster is identified and a favorable benefit/cost ratio for an improvement is determined.
  Within the limits of projects nominated for improvements, curve corrections or alignment improvements will be considered to bring the curves to our current geometric design standards.

- *How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?*

  The SEIP projects are ranked/prioritized by the Benefit/cost ratios.

- *Please give your name, job title, mailing address, and email address. Thank you.*

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Survey on Curve Correction Projects

(Data and Decision-Making)

Nevada

- *What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

  This data is taken from the current alignment contract using radius data shown on curves.

- *What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

  This information is again obtained from the current alignment contract using elevations and percent grade from the profile portion.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

  This will have to be obtained from NDOT's Design Division.

- *How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?*

  This will have to be obtained from NDOT's Design Division

- *Please give your name, job title, mailing address, and email address. Thank you.*

  Jim Epley

  Federal Programs Manager

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  To contact NDOT's Design Div. on questions 3 and 4 contact;

  Wayne Kinder, Chief Road Design Engineer

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Survey on Curve Correction Projects

(Data and Decision-Making)

New Jersey

- *What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

The methods we use are based on the HPMS Field Manual. Supplied by FHWA. Our trained technicians ride the section using a DMI located in their vehicle and will do other measurements if needed to calculate curve data.

- *What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

The methods we use are based on the HPMS Field Manual supplied by FHWA. Our trained technicians ride the section using a DMI located in their vehicle and will do other measurements if needed to calculate grade data.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

We collect the actual roadway data for HPMS; we do not make or suggest any recommendations for Curve Correction/Alignment Improvement. Data is then supplied to FHWA in the annual HPMS Submittal due June 15^{th} of each year.

- How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?

  N/A

- *Please give your name, job title, mailing address, and email address. Thank you.*

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Survey on Curve Correction Projects
(Data and Decision-Making)
New York State

- *What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

  Field personnel review contract plan documents that cover the section in question.

- *What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

  Field personnel review contract plan documents that cover the section in question.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

  Criteria used includes review of the accident history which is usually part of a Highway Safety Investigation. Automated PIL listings (Priority Investigation Locations or High Accident Locations) are generated to locate so called "hot spots". Once addressed, geometric improvements to reduced potential accidents are then evaluated. The SAFETAP (Safety Appurtenance) program is a low cost set aside program aimed at addressing safety deficient locations. Usually SAFETAP projects consist of adding left or right turn lanes at intersections, widening shoulders, and other safety type improvements.

- *How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?*

  Priority is based on PIL listings. One of the Department safety goals is to evaluate 20% of the PIL's each year. In this way, within 5 years most PIL's will be evaluated. Overall, the Department's goal is to reduce 1500 accidents each year through this program.

- *Please give your name, job title, mailing address, and email address. Thank you.*

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Survey on Curve Correction Projects

(Data and Decision-Making)

Ohio

- *What are the methods that your state employs to collect the statewide* <u>*horizontal*</u> *curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

  There is, at present, no single, precise methodology or instrumentation that is used by ODOT field personnel to measure road curvature or grade at point locations in a field setting. There have been a number of district-level surveys to collect such information for state roads, dating back to the 1940's, and this information has been compiled in an electronic database. The file now contains information concerning the complete length of all "state" routes. In addition, whenever a significant road maintenance/rehabilitation/reconstruction project is completed, information concerning horizontal curves and vertical grades is extracted from the project plans and is used to update the file. Over many years, this information has become a significant portion of the overall database.

  If the HPMS section being surveyed is part of a construction project, curvature and grade information are extracted directly from the project plans. If the section is not located in a project

  area, the database is consulted, following an on-site visit. If, for some reason, the database does not show appropriate grade/curvature information for the location where the inspector has observed it, he/she will estimate the needed information using their experience with known road alignments. This situation does not occur frequently.

- *What are the methods that your state employs to collect the statewide* <u>*vertical*</u> *grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

The Ohio Department of Transportation's (ODOT's) comments concerning collection of data on road curvature and data on road grade are essentially the same, so the comments for question 1 apply to question 2.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

While ODOT does not have a specific program to address curve/alignment improvements, sufficiency ratings of all sections of state highways are maintained which provide a composite measure of the adequacy of each section of highway. Criteria in three (3) categories, Functionality & Geometrics, Conditions and Accidents & Usage are used to establish a composite sufficiency rating index. Both curve and grade are included in the Functionality & Geometrics category and can be used to identify sections of highway that may be substandard with respect to horizontal and vertical alignments. Typically highway projects are identified through several capital programs including Safety/Congestion, Pavement and Bridge Preservation, Major New Construction, Major Interstate re-habilitation and other capital programs (Transit, Aviation, Local, etc.) Each program has a process to identify and prioritize potential projects for both the short and long term time frames. Curve and grade deficiencies are considered as projects are identified from the above programs. Example if a high crash site is identified for improvement and deficient geometrics is a contributing factor, then improvements could be made to the horizontal and/or vertical alignments if warranted.

- *How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?*

As mentioned above, no specific program exists to address curve correction projects unless it falls into one of the capital programs. Funding for capital programs are determined by ODOT's Fund Management Committee which is responsible for appropriate allocation of dollars to each program. Projects are identified in the Major New Construction program through The Transportation Review Advisory Council (TRAC).

The Transportation Review Advisory Council, created by the Ohio General Assembly in 1997 to bring an open, fair, numbers-driven system to choosing major new transportation projects, is composed of the director of ODOT and eight appointees chosen for experience in transportation, business or economic development. The governor names six members; the president of the Ohio Senate names one and the speaker of the Ohio House names one.

The amount of money available for major new capacity projects is certified to the TRAC by the director of ODOT after funds for system preservation are determined. Historically, the TRAC has had about $300 million a year to pay for projects, including design, right of way, and construction.

A major new project is one that will cost ODOT more than $5 million and do one or more of the following: reduce congestion, increase mobility, provide connectivity, increase a region''s accessibility for economic development. In general, the TRAC puts a priority on state and federal highways.

TRAC holds six public hearings around the state August through October each year. A draft project list is published each December.

Projects are identified in each of the other programs using a specific program process to achieve/meet program goals established by the Funds Management Committee. (Example, a District will utilize budget to identify appropriate mix of preservation projects to ensure that 93% of the priority system highways have a Pavement Condition Rating > 65 by FY 2004)

- *Please give your name, job title, mailing address, and email address. Thank you.*

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Survey on Curve Correction Projects

(Data and Decision-Making)

Oregon

- *What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

  Since 1990 all horizontal curve data has been taken directly from contract plans as construction is completed on our highways. The information entered into our database from the alignment sheets includes beginning curve/spiral milepoint , tangent milepoint, entering and exiting bearing, and all curve and spiral data. The HPMS Curves by Class data is based on this information.

- *What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

  Since 1990 all vertical curve data has been taken directly from contract plan profile sheets as construction is completed on our highways. The information entered into our database includes the curve milepoint, VPI elevation, curve length and grade. The HPMS Grades by Class data is based on this information.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

  ODOT does not identify areas for improvement specifically for curve or alignment improvements. Rather, high crash location sites are identified by the Safety Priority Index System (SPIS) that uses all crashes in a three-year time period to prioritize areas for further engineering investigation or improvement. More information on the program can be found here: http://www.odot.state.or.us/traffic/safety/spis.htm

- *How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?*

  All stand-alone safety projects have a benefit-cost analysis completed that is based on the number of expected reductions in crashes for the project life. This B/C ratio is used for prioritization but is not the only factor considered in project selection.

- *Please give your name, job title, mailing address, and email address. Thank you.*

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Survey on Curve Correction Projects

(Data and Decision-Making)

Pennsylvania

- *What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

  Curve data is usually obtained from “as built” plans. When these plans are not available, agencies that collect HPMS data for Pennsylvania have used traditional survey methods.

- *What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

  Grade data is usually obtained from “as built” plans. When these plans are not available, agencies that collect HPMS data for Pennsylvania have used traditional survey methods.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

  The Pennsylvania Department of Transportation (PENNDOT) has eleven District Engineering Offices. Each District office receives maps from the central office in Harrisburg that plot where crash clusters occur on PENNDOT owned roads in that District. The Safety Engineers for the Districts review this information to determine where improvements should be made and to prioritize these improvements. If a section of road has been approved and scheduled for improvements, the Safety Engineers in the Districts will be consulted prior to the start of project design to determine if any curve correction/alignment improvements should be included in that project.

- *How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?*

  Each year every District office is allocated an amount of "safety" money. Many times this money is used to fund Curve Correction Projects. Projects using the "safety" money would be prioritized at the District level and included in the District's Business Plan. If the project has already been approved for funding from the Department's Twelve Year Program and the curve correction is being included in the highway project, it would have gone through the Department's Twelve Year Program process. To receive funding from the Twelve Year Program, the project would have competed for funding with all other eligible projects in Pennsylvania.

- *Please give your name, job title, mailing address, and email address. Thank you.*

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Survey on Curve Correction Projects
(Data and Decision-Making)
Puerto Rico

- *What are the methods that your state employs to collect the statewide horizontal curve data for the HPMS data file (HPMS Item No. 63 to 68-Curves by Class)?*

  The Automatic Road Analyzer (ARAN) is used to measure and collect geometric data. Using the heading gyro to obtain the relative direction in which ARAN is pointed and Distance Measurement Instrument (DMI) sensor for distance measures we can obtain readings in degrees (heading) and distance in meters in order to calculate curve radius. The data is reported in meters respectively.

- *What are the methods that your state employs to collect the statewide vertical grade data for the HPMS data file (HPMS Item No. 72-77-Grades by Class)?*

  The Vertical grade data is collected by the ARAN using the Pitch and roll gyro sensors. The pitch jointly with the DMI, measure the longitudinal gradient and the roll gyro measure the transverse slope of the road. Data is reported in percent (%) of rise overrun at each station interval defined by the operator.

- *What are the criteria used to list a roadway section for Curve Correction/Alignment Improvement?*

  The Puerto Rico Highway and Transportation Authority uses the geometric criteria suggested by AASHTO and our Highway Design manual. It would be good that those criteria can be loaded to the HPMS software for data validation and analysis while entering the Puerto Rico HPMS data.

- *How are the listed Curve Correction Projects prioritized/ranked against the other competing transportation projects?*

  Mr. Benigno Rivera can give you detailed information about the ranking use in the Authority.

- *Please give your name, job title, mailing address, and email address. Thank you.*

Appendix B HERS/ST Results

Results from HERS/ST

1. Sections identified for horizontal curve deficiency by HERS/ST:

SectionID	Start MP	EndMP
01-S-116-0-01	5.11	6.59
01-S-101-0-01	0	2.01
01-U-033-0-01	0	2.71
02-U-024-0-01	31.26	33.39
02-U-030-0-01	25.17	26.5
02-S-001-0-01	4.68	6.39
02-S-101-0-01	7.02	10.89
02-S-101-0-01	4.28	6.45
02-S-101-0-01	15.42	17.14
03-S-046-0-01	21.2	22.22
06-S-038-0-01	2.03	2.08
07-S-046-0-01	8.53	8.91
08-S-218-0-01	0	1.27
08-S-018-0-01	1.96	2.11
08-U-421-0-01	22.96	24.66
08-S-018-0-01	15.7	17.68
08-S-218-0-01	17.49	18.41
10-S-060-0-01	11.06	13.23
12-U-421-0-01	19.38	22.47
13-S-062-0-01	2.65	3.54
13-S-145-0-01	5.88	7.93
13-S-062-0-01	6.06	9.25
13-S-037-0-01	6.02	6.44
13-S-062-0-01	9.25	12.57
13-S-066-0-01	9.51	10.56
13-S-037-0-01	12.84	13.27
13-S-037-0-01	14.23	14.28
13-S-066-0-01	20.19	20.86
13-S-066-0-01	25.47	28.27
15-S-062-0-01	4.87	5.46
15-S-056-0-01	1.67	2.05
15-S-056-0-01	2.17	2.23
17-S-327-0-01	3.04	6.55
17-S-327-0-01	8.97	12.01
17-S-327-0-01	7.9	8.25
17-S-001-0-01	1.52	3.92
17-S-001-0-01	5.96	8.06

	17-S-001-0-01	8.06	9.07	
	17-S-001-0-01	3.92	3.93	
	17-S-001-0-01	17.19	21.12	
	19-S-145-0-01	4.68	5.08	
	20-S-013-0-01	0	1.02	
	20-S-015-0-01	20.13	20.32	
	20-S-013-0-01	5.6	8.14	
	20-S-013-0-01	4.83	5.6	
	20-S-013-0-01	14.04	15.95	
	21-S-121-0-01	0	2.09	
	21-S-121-0-01	2.09	3.95	
	21-S-001-0-01	14.44	14.94	
	22-S-062-0-01	3.01	3.82	
	22-S-062-0-01	3.82	4.06	
	24-U-052-0-01	25.1	25.16	
	24-S-121-0-01	0	3.38	
	24-U-052-0-01	9.41	10.48	
	24-S-121-0-01	4.9	6.21	
	24-S-121-0-01	4.03	4.18	
	24-S-121-0-01	4.7	4.83	
	24-U-052-0-01	17.95	18.01	
	25-S-017-0-01	2.5	4.09	
	25-S-017-0-01	4.09	5.45	
	25-S-017-0-01	9.1	9.39	
	25-S-017-0-01	0	2.5	
	25-S-019-0-01	0	1.97	
	25-S-014-0-01	24.83	26.82	
	25-S-019-0-01	4.3	6.82	
	25-S-014-0-01	23.92	24.02	
	26-S-056-0-01	0	1.24	
	26-S-056-0-01	2.56	5.55	
	26-S-056-0-01	1.33	1.4	
	26-S-056-0-01	2.21	2.56	
	27-S-013-0-01	9.65	13.78	
	27-S-013-0-01	14.41	16.4	
	27-S-005-0-01	0	3	
	27-S-026-0-01	19.46	21.49	
	27-S-026-0-01	17.89	19.46	
	28-U-231-0-01	12.72	16.01	
	28-S-043-0-01	1.46	3.65	
	28-U-231-0-01	8.19	8.31	
	28-U-231-0-01	18.97	19.15	
	28-S-043-0-01	0	1.46	
	28-S-043-0-01	8.02	9.84	
	28-S-043-0-01	3.65	4.7	
	28-S-043-0-01	5.51	8.02	
	28-S-043-0-01	4.7	5.51	

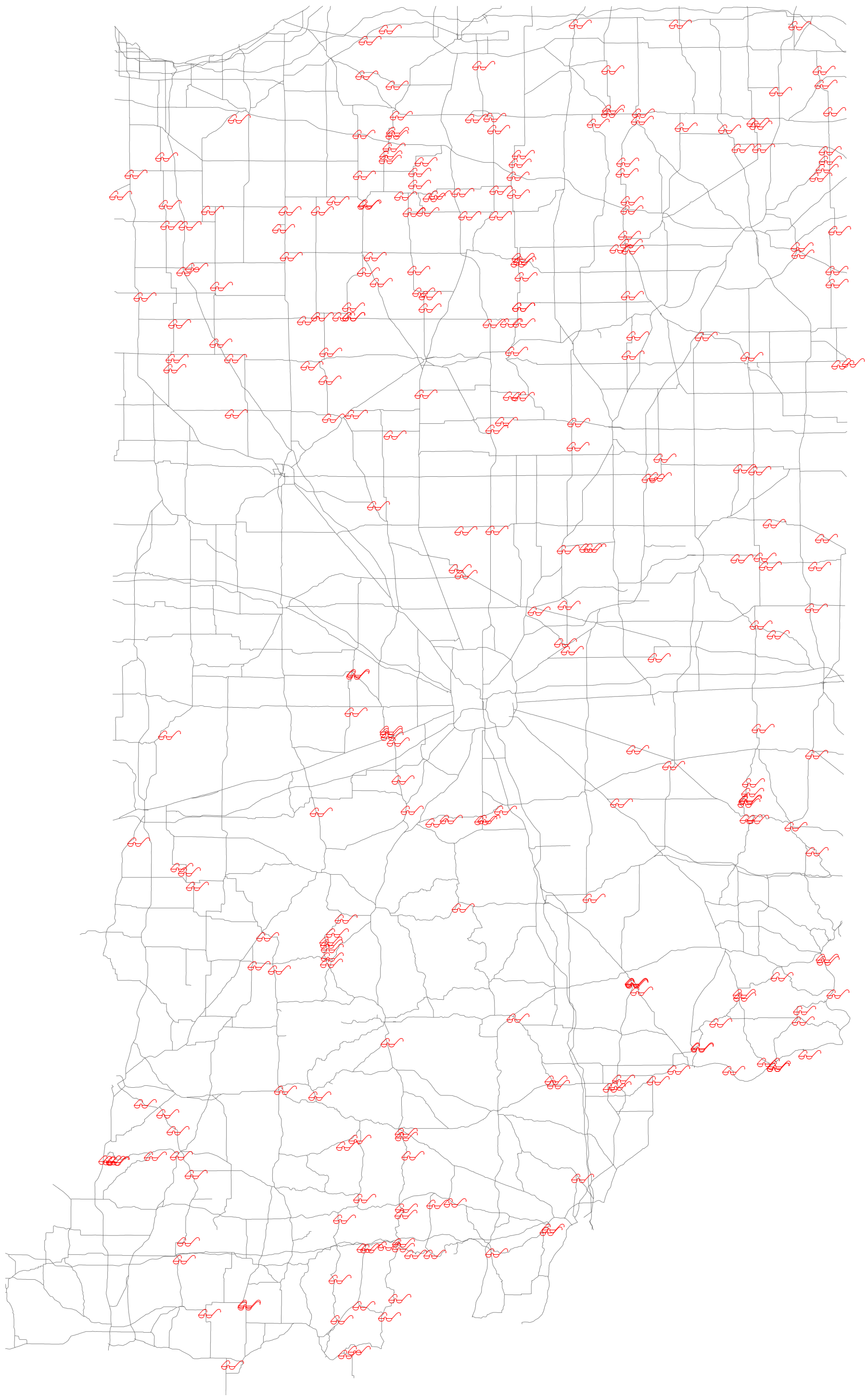
	29-S-038-0-01	0	1.04	
	29-S-238-0-01	8.73	9.02	
	29-S-038-0-01	16.59	17.52	
	30-S-013-0-01	0.08	0.22	
	31-S-062-0-01	9.55	9.63	
	32-S-075-0-01	9.29	16.58	
	32-S-039-0-01	5.41	6.88	
	32-S-039-0-01	8.44	12.12	
	32-S-039-0-01	7.98	8.44	
	32-S-039-0-01	7.19	7.41	
	32-S-075-0-01	17.4	21.6	
	32-S-075-0-01	17.01	17.4	
	33-S-234-0-01	3.55	5.07	
	35-S-105-0-01	12.74	14.74	
	35-S-105-0-01	8.55	12.74	
	35-S-116-0-01	0	0.1	
	35-S-105-0-01	22.69	26.71	
	36-U-050-0-01	13.11	13.26	
	37-U-231-0-01	5.92	6.02	
	37-S-014-0-01	2.01	3.98	
	37-S-014-0-01	0	2.01	
	37-S-010-0-01	0.53	4.01	
	37-U-231-0-01	17.15	19.71	
	37-U-231-0-01	33.8	34.46	
	38-S-026-0-01	0	2.97	
	38-S-026-0-01	3.47	6.37	
	39-S-062-0-01	6.78	7.06	
	39-S-062-0-01	12.12	12.27	
	39-S-056-0-01	23.03	24.35	
	39-S-062-0-01	20.7	21.6	
	39-S-062-0-01	20.5	20.7	
	39-S-062-0-01	28.43	30.68	
	40-S-007-0-01	4.83	6.57	
	40-S-003-0-01	11.37	11.57	
	40-S-003-0-01	11.57	11.7	
	40-S-003-0-01	11.7	11.76	
	41-S-044-0-01	5.35	7.25	
	41-S-044-0-01	4.64	5.07	
	41-S-044-0-01	9.3	10.16	
	42-S-061-0-01	14.63	16.5	
	42-S-061-0-01	4.15	5.12	
	42-S-061-0-01	8.36	8.7	
	43-S-019-0-01	11.45	12.94	
	43-S-019-0-01	18.07	20.06	
	43-S-019-0-01	15.18	18.07	
	43-S-019-0-01	20.06	22.06	
	44-S-120-0-01	11.28	12.32	

	45-S-002-0-01	0	3.17	
	45-S-002-0-01	6.09	7.34	
	45-S-055-0-01	1.53	5.75	
	45-S-055-0-01	11.82	13.31	
	46-S-004-0-01	6.53	10.3	
	46-U-020-0-01	18.05	18.5	
	47-U-050-0-01	12.12	13.25	
	48-S-013-0-01	8.62	8.91	
	48-S-128-0-01	0	0.99	
	48-S-128-0-01	5.5	6.5	
	48-S-128-0-01	4.64	5.26	
	50-S-017-0-01	7.56	9.04	
	50-S-017-0-01	13.68	14.43	
	50-S-010-0-01	0	1.11	
	50-S-017-0-01	0.77	2.03	
	50-S-117-0-01	1.01	1.79	
	50-S-017-0-01	10.39	13.68	
	50-S-010-0-01	5.95	6.74	
	50-S-010-0-01	7.26	7.99	
	50-S-010-0-01	12.06	12.27	
	50-S-010-0-01	19.92	23.07	
	50-S-110-0-01	10.74	16.41	
	50-S-331-0-01	0	1.01	
	50-S-106-0-01	0	0.74	
	50-S-331-0-01	20.85	21.25	
	50-S-331-0-01	17.62	18.81	
	51-U-231-0-01	12.94	13.1	
	51-U-150-0-01	9.17	11.24	
	52-S-016-0-01	10.72	15.14	
	52-S-016-0-01	7.57	10.72	
	52-U-031-0-01	0	1.5	
	52-S-018-0-01	3.99	6	
	52-S-016-0-01	1.6	4.15	
	52-S-218-0-01	6.9	8.84	
	52-S-218-0-01	8.84	11.42	
	52-S-019-0-01	17.97	18.33	
	52-S-016-0-01	5.07	5.11	
	52-S-019-0-01	27.68	34.02	
	55-S-039-0-01	12.62	13.88	
	55-S-039-0-01	5.76	6.27	
	55-S-044-0-01	2.6	4.57	
	55-S-044-0-01	5.83	6.01	
	56-S-055-0-01	9.93	15.64	
	56-S-055-0-01	0	2.01	
	56-S-055-0-01	2.55	3.54	
	56-S-055-0-01	31.69	33.73	
	56-S-114-0-01	0	2.07	

	57-S-005-0-01	2.16	6.34	
	57-S-005-0-01	0	2.16	
	57-U-033-0-01	16.81	17.31	
	57-S-005-0-01	12.95	13.06	
	57-S-008-0-01	12.42	13.41	
	57-S-009-0-01	11.79	13.76	
	57-S-003-0-01	9.5	11.03	
	58-S-056-0-01	0.28	6.14	
	58-S-056-0-01	9.66	9.84	
	59-S-056-0-01	0	0.76	
	59-S-056-0-01	3.18	3.94	
	59-S-037-0-01	7.32	9.53	
	59-S-037-0-01	11.79	11.99	
	59-S-056-0-01	15.58	15.97	
	60-S-043-0-01	2.8	3.81	
	60-S-043-0-01	0	0.51	
	60-S-043-0-01	8.64	10.57	
	61-U-041-0-01	6.28	10.67	
	62-S-066-0-01	29.8	33.47	
	62-S-066-0-01	34.79	38.08	
	62-S-066-0-01	15.25	22.31	
	62-S-066-0-01	12.7	13.82	
	62-S-145-0-01	1.49	3.37	
	62-S-145-0-01	10.56	10.66	
	62-S-070-0-01	0	0.63	
	62-S-062-0-01	11.97	12.82	
	62-S-062-0-01	12.82	12.97	
	63-S-061-0-01	1.69	3.3	
	63-S-056-0-01	9.78	10.25	
	63-S-056-0-01	3.97	4.35	
	63-S-056-0-01	15.69	16.2	
	64-S-002-0-01	15.18	16.35	
	65-S-069-0-01	7.71	8.21	
	66-S-143-0-01	0	1.5	
	66-S-014-0-01	4.04	10.01	
	66-S-119-0-01	9.01	11.01	
	66-S-119-0-01	0	4.13	
	66-U-035-0-01	5.4	8.31	
	66-S-014-0-01	20.38	23.21	
	67-U-231-0-01	0	1.05	
	68-U-036-0-01	15.49	18.81	
	68-S-032-0-01	0	0.35	
	68-S-001-0-01	0	3.02	
	68-S-032-0-01	6.81	10.93	
	68-S-028-0-01	6.75	9.84	
	68-S-001-0-01	14.46	15.93	
	68-S-028-0-01	17.89	21.37	

	68-S-032-0-01	17.05	22.16	
	69-S-062-0-01	3.59	7.55	
	69-S-062-0-01	2.56	3.59	
	70-U-052-0-01	1.65	3.21	
	70-S-044-0-01	9.16	9.5	
	71-U-020-0-01	0	0.31	
	71-S-023-0-01	2.07	2.27	
	71-S-004-0-01	0	0.66	
	71-S-331-0-01	8.64	10.13	
	72-S-003-0-01	9.19	10.34	
	72-S-003-0-01	5.98	6.17	
	72-S-003-0-01	7.47	8.02	
	73-S-244-0-01	1.75	3.77	
	74-U-231-0-01	8.29	11.04	
	74-U-231-0-01	24.14	24.38	
	74-S-062-0-01	2.97	3.52	
	74-S-062-0-01	13.02	13.5	
	75-U-035-0-01	16.5	18.48	
	75-S-023-0-01	8.02	9	
	75-S-023-0-01	14.39	15.95	
	75-S-010-0-01	1.76	2.03	
	75-S-039-0-01	1.02	2.01	
	75-S-010-0-01	13.08	18.07	
	75-S-010-0-01	19.46	19.8	
	75-S-010-0-01	19.8	21.21	
	75-S-008-0-01	8.51	8.63	
	75-S-023-0-01	9	10	
	75-S-023-0-01	10.81	12.11	
	75-S-023-0-01	13.61	14.39	
	76-S-004-0-01	5.14	5.32	
	76-S-127-0-01	5.77	6.9	
	76-S-001-0-01	1.86	2.8	
	76-S-001-0-01	4.81	8.17	
	78-S-129-0-01	2.37	8.46	
	78-S-056-0-01	8.02	8.09	
	78-S-056-0-01	8.09	8.49	
	78-S-056-0-01	8.49	8.56	
	78-S-101-0-01	0	0.28	
	78-S-056-0-01	20.1	20.61	
	80-U-031-0-01	4	12.89	
	80-S-028-0-01	0	0.58	
	81-S-044-0-01	5.49	5.6	
	84-S-159-0-01	4.51	6.54	
	84-S-159-0-01	6.54	6.7	
	84-S-159-0-01	0	0.32	
	84-S-063-0-01	9.6	11.08	
	87-S-061-0-01	19.85	20.02	

87-S-062-0-01	15.56	16.56
88-S-039-0-01	2.04	3.11
88-S-039-0-01	1.04	1.49
89-U-035-0-01	19.94	20.09
90-S-116-0-01	9.9	10.47
91-S-018-0-01	0	3.44
91-S-119-0-01	4.58	5.55
91-U-024-0-01	0	2.88
91-S-016-0-01	12.06	13.27
91-U-024-0-01	15.87	17.21
91-S-016-0-01	9.01	12.06
91-S-039-0-01	4.89	11.6
91-S-016-0-01	16.28	18.25
91-S-016-0-01	18.25	19.27
92-S-005-0-01	8.84	13.02
92-S-014-0-01	3.87	5.95
92-S-014-0-01	1.07	2.58
92-S-205-0-01	0	0.08
92-S-005-0-01	16.41	22.49
92-S-005-0-01	14.4	16.41



GIS representation of sections identified for horizontal curve deficiency by HERS/ST

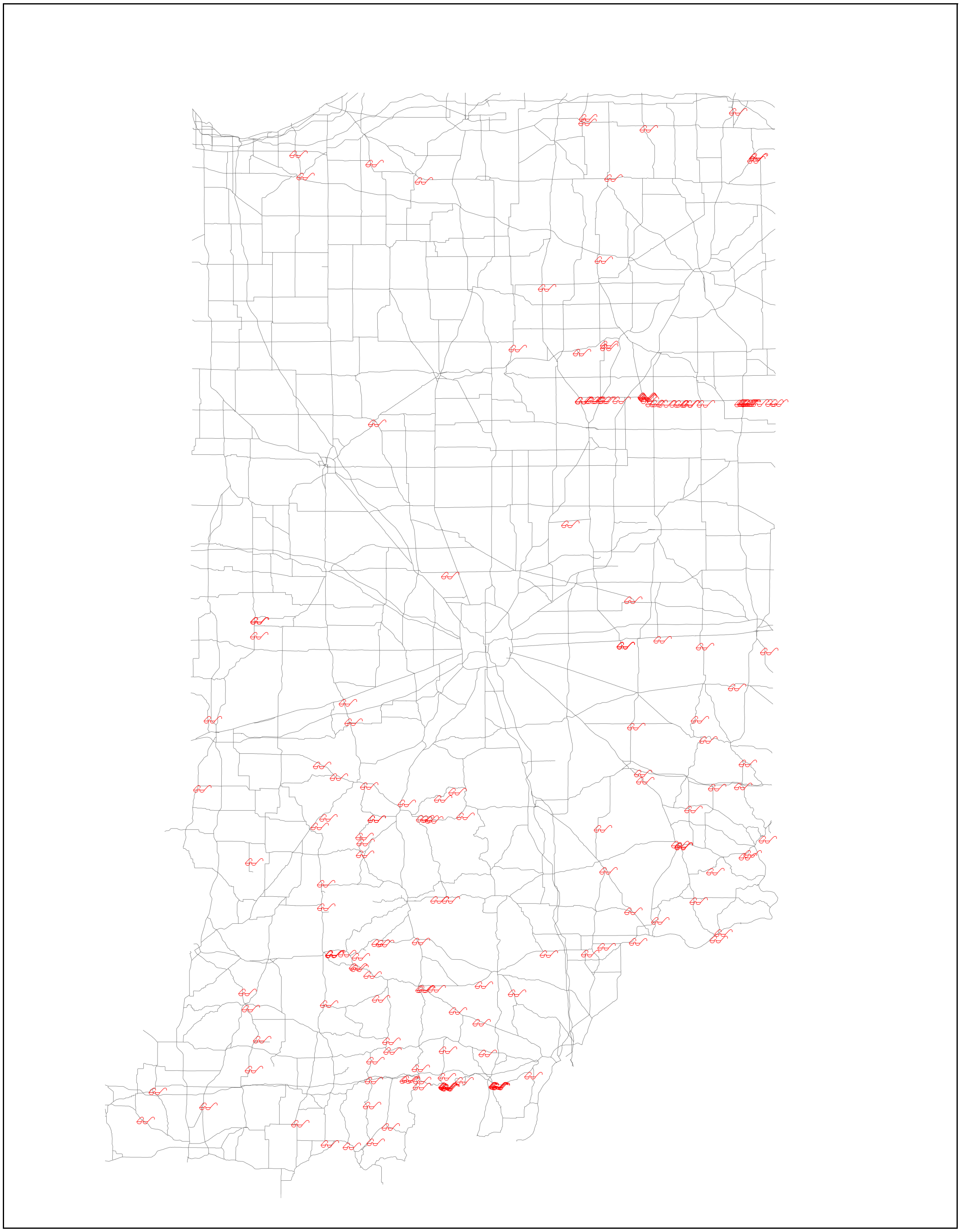
2. Sections identified for vertical grade deficiency by HERS/ST:

SectionID	StartMP	EndMP
01-S-218-0-01	5.73	5.87
01-S-218-0-01	5.6	5.73
01-S-218-0-01	6.64	6.91
06-S-032-0-01	18.97	20.22
07-S-045-0-01	0	2.75
07-S-046-0-01	6.55	8.53
07-S-045-0-01	4.95	6.56
08-U-421-0-01	12.38	13.15
13-S-062-0-01	2.03	2.65
13-S-064-0-01	3.95	6.22
13-S-066-0-01	0	1.76
13-S-062-0-01	13.81	14.02
13-S-062-0-01	14.65	14.89
13-S-062-0-01	14.18	14.45
13-S-062-0-01	14.02	14.06
13-S-062-0-01	14.06	14.18
13-S-062-0-01	14.45	14.65
13-S-062-0-01	14.89	14.94
13-S-066-0-01	11.98	12.08
13-S-037-0-01	8.6	9.84
13-S-066-0-01	19	20.19
15-U-050-0-01	9.6	10.9
15-S-062-0-01	1.58	4.87
15-S-046-0-01	5.24	6.12
15-U-050-0-01	11.2	11.67
15-U-050-0-01	16.62	16.77
16-S-003-0-01	0	1.23
16-U-421-0-01	6.39	7.41
16-S-046-0-01	14.56	16.18
17-S-427-0-01	8.78	8.8
19-S-145-0-01	4	4.68
22-S-062-0-01	0	1.59
24-U-052-0-01	23.9	24.45
28-U-231-0-01	21.29	23.21
31-S-062-0-01	0	1.45
31-S-062-0-01	10.4	10.66
31-S-062-0-01	10.14	10.18
31-S-062-0-01	9.97	10.14
31-S-062-0-01	10.25	10.4
31-S-062-0-01	10.18	10.25

	31-S-062-0-01	10.85	11.69	
	31-S-062-0-01	10.66	10.85	
	31-S-064-0-01	6.47	7.36	
	33-S-103-0-01	0.12	0.45	
	33-S-038-0-01	4.9	5.09	
	35-S-218-0-01	1.36	4.92	
	35-S-218-0-01	0	1	
	35-S-218-0-01	1	1.36	
	35-S-105-0-01	15.63	15.96	
	35-S-218-0-01	4.92	6.92	
	35-S-218-0-01	13.02	14.5	
	35-S-218-0-01	11.75	11.97	
	35-S-218-0-01	12.36	13.02	
	35-S-218-0-01	12.04	12.36	
	35-S-218-0-01	11.97	12.04	
	35-S-218-0-01	15.54	17.53	
	35-S-218-0-01	14.5	15.54	
	39-S-056-0-01	10.2	11.25	
	39-S-056-0-01	1.68	4.02	
	39-S-007-0-01	9.16	9.67	
	42-S-061-0-01	2.36	4.15	
	47-U-050-0-01	0.75	1.93	
	47-U-050-0-01	1.93	2.36	
	47-S-037-0-01	3.11	3.68	
	47-U-050-0-01	23.33	25.82	
	47-U-050-0-01	26.27	27.18	
	48-S-128-0-01	4.34	4.46	
	51-U-150-0-01	11.24	11.86	
	51-U-050-0-01	2.84	3.3	
	51-U-050-0-01	2.64	2.77	
	51-U-050-0-01	2.77	2.84	
	51-U-050-0-01	6.18	6.86	
	51-U-150-0-01	11.86	14.33	
	51-U-150-0-01	16.05	16.31	
	51-U-050-0-01	10.34	12.75	
	52-S-019-0-01	23.45	24.53	
	53-S-037-0-01	16.95	17.75	
	53-S-046-0-01	18.74	21.69	
	53-S-046-0-01	16.05	17.41	
	53-S-046-0-01	17.41	18.74	
	59-S-056-0-01	0.9	2.22	
	59-S-056-0-01	18.74	22.8	
	59-S-056-0-01	15.97	16.11	
	60-S-043-0-01	0	0.34	
	60-S-046-0-01	13.62	14.25	
	61-S-047-0-01	0	1.04	
	61-U-041-0-01	22.74	23	

	62-S-037-0-01	5.3	6.11	
	62-S-066-0-01	0.8	1.07	
	63-S-061-0-01	3.95	4.17	
	63-S-061-0-01	12.69	12.94	
	63-S-056-0-01	11.63	12.2	
	64-U-006-0-01	8.76	9.1	
	64-S-002-0-01	19.88	20.12	
	65-S-066-0-01	9.07	9.52	
	65-S-065-0-01	2.45	2.96	
	67-U-231-0-01	3.13	3.98	
	67-U-231-0-01	8.18	8.97	
	69-U-421-0-01	13.49	13.57	
	69-U-050-0-01	10.38	10.82	
	69-U-421-0-01	12.46	12.57	
	69-S-048-0-01	3.9	4.22	
	69-S-046-0-01	7.44	7.6	
	70-S-244-0-01	8.24	8.42	
	71-U-006-0-01	3.48	3.56	
	72-S-056-0-01	0.25	1	
	74-S-070-0-01	7.18	7.73	
	74-S-062-0-01	3.52	3.68	
	78-S-056-0-01	9.31	9.92	
	78-S-056-0-01	7.25	8.02	
	78-S-129-0-01	12.41	13.4	
	82-S-057-0-01	7.73	7.92	
	84-S-063-0-01	1.1	2.08	
	84-U-150-0-01	9	10.46	
	85-S-524-0-01	0	0.1	
	85-S-218-0-01	2.78	4.28	
	85-S-218-0-01	0.12	2.34	
	85-S-218-0-01	0	0.12	
	85-S-218-0-01	2.34	2.78	
	88-S-060-0-01	19.03	19.89	
	88-U-150-0-01	0	1.27	
	88-U-150-0-01	6.97	7.17	
	89-S-227-0-01	2.85	3.4	
	90-S-218-0-01	5.95	9.61	
	90-S-218-0-01	0	2.94	
	90-S-218-0-01	2.94	3.95	
	90-S-218-0-01	3.95	5.76	
	90-S-218-0-01	5.76	5.95	
	90-S-218-0-01	9.61	13.94	
	13-S-062-0-01	2.65	3.54	
	13-S-062-0-01	6.06	9.25	
	28-S-043-0-01	0	1.46	
	28-S-043-0-01	3.65	4.7	
	28-S-043-0-01	5.51	8.02	

	39-S-062-0-01	20.7	21.6	
	40-S-003-0-01	11.37	11.57	
	57-S-005-0-01	12.95	13.06	
	59-S-056-0-01	15.58	15.97	
	60-S-043-0-01	0	0.51	
	62-S-070-0-01	0	0.63	
	72-S-003-0-01	5.98	6.17	
	01-S-218-0-01	4.95	5.46	
	01-S-218-0-01	5.87	5.94	
	01-S-218-0-01	5.94	5.97	
	01-S-218-0-01	6.29	6.32	
	01-S-218-0-01	6.91	6.97	
	01-S-218-0-01	6.97	7	
	01-S-218-0-01	13.74	14.09	
	01-S-218-0-01	8.99	12.54	
	01-S-218-0-01	12.54	13.74	
	14-U-231-0-01	2.28	5.6	
	20-S-013-0-01	21.02	21.37	
	20-S-013-0-01	19.8	20.21	
	24-U-052-0-01	10.48	17.92	
	24-S-121-0-01	6.21	6.51	
	28-U-231-0-01	2.17	5.14	
	33-S-140-0-01	0	0.16	
	33-S-140-0-01	0.16	0.32	
	35-S-105-0-01	14.89	15	
	43-S-015-0-01	1.98	2.02	
	44-U-020-0-01	13.1	13.45	
	46-U-035-0-01	8.66	9	
	51-U-231-0-01	0	1.73	
	60-U-231-0-01	0.39	1.84	
	60-S-046-0-01	5.31	8.38	
	60-S-046-0-01	0	3.37	
	61-U-041-0-01	18.79	20.69	
	62-S-145-0-01	10.66	12.25	
	62-S-145-0-01	17.79	19.45	
	76-S-127-0-01	4.83	5.04	
	76-S-001-0-01	1.14	1.52	
	76-S-001-0-01	1.52	1.86	
	77-S-159-0-01	3.74	5.41	
	81-S-044-0-01	1.7	2.68	
	88-S-056-0-01	6.79	8.36	
	89-S-001-0-01	5.02	5.17	
	92-S-005-0-01	13.02	13.32	
	13-S-145-0-01	5.88	7.93	



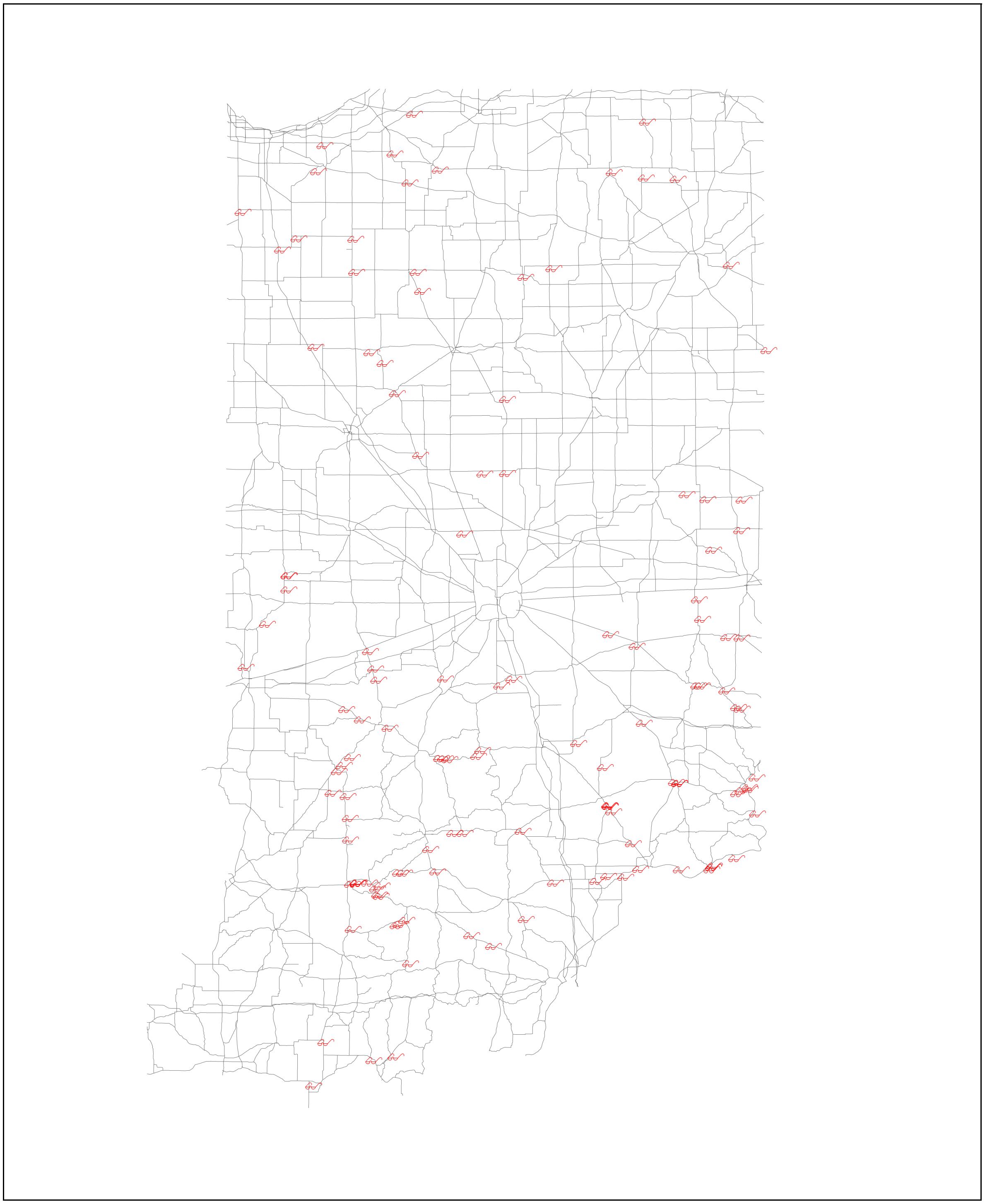
GIS representation of sections identified for vertical grade deficiency by HERS/ST

3. Sections identified for alignment improvements by HERS/ST in Funding Period 3:

SectionID	StartMP	EndMP	Improvement Type ▲	BCR
20-S-015-0-01	20.13	20.32	14	13.2
01-U-033-0-01	0	2.71	12	2.4
02-U-024-0-01	31.26	33.39	12	2.7
03-S-046-0-01	21.2	22.22	12	36.4
06-S-032-0-01	18.97	20.22	12	7.8
07-S-046-0-01	6.55	8.53	12	9.8
07-S-046-0-01	8.53	8.91	12	58.2
08-U-421-0-01	12.38	13.15	12	7.2
08-U-421-0-01	22.96	24.66	12	5.5
12-U-421-0-01	19.38	22.47	12	2.3
14-U-231-0-01	2.28	5.6	12	2.8
15-U-050-0-01	11.2	11.67	12	4.6
15-S-056-0-01	2.17	2.23	12	65.7
15-U-050-0-01	16.62	16.77	12	42.9
16-S-003-0-01	0	1.23	12	5
16-U-421-0-01	6.39	7.41	12	2.2
21-S-001-0-01	14.44	14.94	12	5.7
24-U-052-0-01	25.1	25.16	12	12.6
24-U-052-0-01	10.48	17.92	12	4.4
24-U-052-0-01	9.41	10.48	12	11.8
24-U-052-0-01	17.95	18.01	12	10.6
24-U-052-0-01	23.9	24.45	12	5.2
25-S-014-0-01	23.92	24.02	12	15.3
28-U-231-0-01	2.17	5.14	12	2
28-U-231-0-01	8.19	8.31	12	9
28-U-231-0-01	18.97	19.15	12	17
37-S-010-0-01	0.53	4.01	12	4.1
37-U-231-0-01	33.8	34.46	12	6.4
39-S-056-0-01	1.68	4.02	12	2.5
39-S-062-0-01	6.78	7.06	12	22.4
39-S-062-0-01	12.12	12.27	12	37.1
39-S-056-0-01	23.03	24.35	12	7.6
40-S-007-0-01	4.83	6.57	12	26.2
40-S-003-0-01	11.37	11.57	12	60.5
40-S-003-0-01	11.57	11.7	12	38.4
40-S-003-0-01	11.7	11.76	12	38.4
41-S-044-0-01	5.35	7.25	12	17
41-S-044-0-01	9.3	10.16	12	18.8
43-S-015-0-01	1.98	2.02	12	7.5
44-U-020-0-01	13.1	13.45	12	11.9
45-S-002-0-01	6.09	7.34	12	7.1
46-U-035-0-01	8.66	9	12	4.9

	46-U-020-0-01	18.05	18.5	12	4.5	
	47-U-050-0-01	0.75	1.93	12	3.5	
	47-U-050-0-01	1.93	2.36	12	3.7	
	47-S-037-0-01	3.11	3.68	12	8.9	
	47-U-050-0-01	12.12	13.25	12	19.4	
	47-U-050-0-01	23.33	25.82	12	4.4	
	51-U-150-0-01	11.24	11.86	12	2.7	
	51-U-231-0-01	0	1.73	12	3.8	
	51-U-231-0-01	12.94	13.1	12	36.1	
	51-U-150-0-01	9.17	11.24	12	9	
	51-U-050-0-01	2.84	3.3	12	1.5	
	51-U-050-0-01	2.64	2.77	12	4.4	
	51-U-050-0-01	2.77	2.84	12	6	
	51-U-050-0-01	6.18	6.86	12	4.5	
	51-U-150-0-01	11.86	14.33	12	1.6	
	51-U-050-0-01	10.34	12.75	12	3.4	
	53-S-046-0-01	18.74	21.69	12	5.6	
	53-S-046-0-01	16.05	17.41	12	5.7	
	53-S-046-0-01	17.41	18.74	12	6.3	
	57-U-033-0-01	16.81	17.31	12	6.8	
	57-S-009-0-01	11.79	13.76	12	2.9	
	59-S-056-0-01	0	0.76	12	8.4	
	59-S-056-0-01	0.9	2.22	12	2.1	
	59-S-056-0-01	3.18	3.94	12	15.6	
	60-S-046-0-01	5.31	8.38	12	5.5	
	60-S-046-0-01	13.62	14.25	12	4.1	
	60-S-046-0-01	0	3.37	12	3.3	
	61-U-041-0-01	18.79	20.69	12	5.9	
	61-U-041-0-01	6.28	10.67	12	4.2	
	61-S-047-0-01	0	1.04	12	2	
	61-U-041-0-01	22.74	23	12	2.4	
	62-S-066-0-01	0.8	1.07	12	6.9	
	64-S-002-0-01	15.18	16.35	12	7.6	
	64-U-006-0-01	8.76	9.1	12	5	
	66-U-035-0-01	5.4	8.31	12	2.9	
	66-S-014-0-01	20.38	23.21	12	2.9	
	67-U-231-0-01	3.13	3.98	12	15.5	
	67-U-231-0-01	0	1.05	12	31.1	
	67-U-231-0-01	8.18	8.97	12	16.3	
	68-S-032-0-01	0	0.35	12	4.7	
	68-S-032-0-01	6.81	10.93	12	2.8	
	68-S-032-0-01	17.05	22.16	12	1.7	
	69-U-421-0-01	13.49	13.57	12	8.6	
	69-U-050-0-01	10.38	10.82	12	7.3	
	70-U-052-0-01	1.65	3.21	12	8.4	
	70-S-044-0-01	9.16	9.5	12	18.4	
	71-U-006-0-01	3.48	3.56	12	4.7	

72-S-056-0-01	0.25	1	12	11.8
72-S-003-0-01	7.47	8.02	12	35.9
74-U-231-0-01	24.14	24.38	12	34.5
75-U-035-0-01	16.5	18.48	12	2.5
75-S-010-0-01	1.76	2.03	12	5.9
78-S-056-0-01	7.25	8.02	12	11.2
78-S-056-0-01	8.02	8.09	12	46.8
78-S-056-0-01	8.09	8.49	12	50.9
78-S-056-0-01	8.49	8.56	12	41.4
81-S-044-0-01	5.49	5.6	12	38.4
84-U-150-0-01	9	10.46	12	4
88-S-060-0-01	19.03	19.89	12	15.3
88-U-150-0-01	0	1.27	12	2.8
88-U-150-0-01	6.97	7.17	12	6.7
89-S-001-0-01	5.02	5.17	12	6.9
89-U-035-0-01	19.94	20.09	12	8.5
91-U-024-0-01	0	2.88	12	1.9
13-S-145-0-01	5.88	7.93	11	2
15-U-050-0-01	9.6	10.9	11	3.2
15-S-056-0-01	1.67	2.05	11	54.9
28-U-231-0-01	12.72	16.01	11	1.3
28-U-231-0-01	21.29	23.21	11	1
36-U-050-0-01	13.11	13.26	11	34.9
39-S-007-0-01	9.16	9.67	11	2.7
47-U-050-0-01	26.27	27.18	11	1.6
52-U-031-0-01	0	1.5	11	1.7
55-S-039-0-01	5.76	6.27	11	13.5
57-S-003-0-01	9.5	11.03	11	2.6
58-S-056-0-01	9.66	9.84	11	14.8
60-U-231-0-01	0.39	1.84	11	1
62-S-037-0-01	5.3	6.11	11	0.9
66-S-014-0-01	4.04	10.01	11	1.8
68-U-036-0-01	15.49	18.81	11	1
69-U-421-0-01	12.46	12.57	11	8.6
74-U-231-0-01	8.29	11.04	11	23.4
78-S-101-0-01	0	0.28	11	9.9
80-U-031-0-01	4	12.89	11	2.6
80-S-028-0-01	0	0.58	11	4.1
81-S-044-0-01	1.7	2.68	11	2.7
91-U-024-0-01	15.87	17.21	11	2.2



GIS representation of sections identified for alignment improvements by HERS/ST in Funding Period 3

4. Sections identified for alignment improvements by HERS/ST in Funding Period 4:

SectionID	StartMP	EndMP	Improvement Type	BCR
57-S-005-0-01	12.95	13.06	14	38.6
01-S-116-0-01	5.11	6.59	12	1
01-S-218-0-01	4.95	5.46	12	7.7
01-S-218-0-01	5.73	5.87	12	14.7
01-S-218-0-01	5.6	5.73	12	15.9
01-S-218-0-01	5.87	5.94	12	18.7
01-S-218-0-01	5.94	5.97	12	22.3
01-S-218-0-01	6.29	6.32	12	11.1
01-S-218-0-01	6.64	6.91	12	8.2
01-S-218-0-01	6.91	6.97	12	6.7
01-S-218-0-01	6.97	7	12	3.1
02-U-030-0-01	25.17	26.5	12	2.5
02-S-001-0-01	4.68	6.39	12	12.7
02-S-101-0-01	7.02	10.89	12	1.4
02-S-101-0-01	15.42	17.14	12	1.8
06-S-038-0-01	2.03	2.08	12	7.6
07-S-045-0-01	0	2.75	12	2.8
07-S-045-0-01	4.95	6.56	12	10.2
08-S-218-0-01	0	1.27	12	4.6
08-S-018-0-01	1.96	2.11	12	4.7
08-S-018-0-01	15.7	17.68	12	12.9
10-S-060-0-01	11.06	13.23	12	16.3
13-S-062-0-01	2.65	3.54	12	8.5
13-S-062-0-01	2.03	2.65	12	0.6
13-S-062-0-01	6.06	9.25	12	1.7
13-S-066-0-01	0	1.76	12	1
13-S-062-0-01	9.25	12.57	12	1.3
13-S-062-0-01	13.81	14.02	12	6
13-S-062-0-01	14.65	14.89	12	2.4
13-S-062-0-01	14.18	14.45	12	5.6
13-S-062-0-01	14.02	14.06	12	5.7
13-S-062-0-01	14.06	14.18	12	6
13-S-062-0-01	14.45	14.65	12	2.4
13-S-062-0-01	14.89	14.94	12	2.5
13-S-066-0-01	9.51	10.56	12	8.3
13-S-037-0-01	12.84	13.27	12	12.7
13-S-037-0-01	14.23	14.28	12	37.2
13-S-066-0-01	19	20.19	12	5.6
13-S-066-0-01	25.47	28.27	12	1.9
15-S-062-0-01	1.58	4.87	12	4.4
15-S-062-0-01	4.87	5.46	12	22.9
15-S-046-0-01	5.24	6.12	12	11.8

16-S-046-0-01	14.56	16.18	12	7.5
17-S-327-0-01	3.04	6.55	12	20
17-S-001-0-01	1.52	3.92	12	18.9
17-S-001-0-01	5.96	8.06	12	8.7
17-S-001-0-01	8.06	9.07	12	9.7
17-S-001-0-01	3.92	3.93	12	10.3
19-S-145-0-01	4	4.68	12	1.7
19-S-145-0-01	4.68	5.08	12	1.9
20-S-013-0-01	5.6	8.14	12	3.3
20-S-013-0-01	14.04	15.95	12	13.7
21-S-121-0-01	0	2.09	12	4.4
21-S-121-0-01	2.09	3.95	12	9.8
22-S-062-0-01	0	1.59	12	6.8
22-S-062-0-01	3.01	3.82	12	60.2
24-S-121-0-01	0	3.38	12	4.9
24-S-121-0-01	4.9	6.21	12	2.3
24-S-121-0-01	4.03	4.18	12	11.9
24-S-121-0-01	4.7	4.83	12	8.8
24-S-121-0-01	6.21	6.51	12	4.9
25-S-017-0-01	2.5	4.09	12	1.6
25-S-019-0-01	0	1.97	12	4.4
25-S-014-0-01	24.83	26.82	12	5.9
25-S-019-0-01	4.3	6.82	12	4.3
26-S-056-0-01	0	1.24	12	4.7
26-S-056-0-01	2.56	5.55	12	1
26-S-056-0-01	1.33	1.4	12	5.7
27-S-005-0-01	0	3	12	8.4
27-S-026-0-01	19.46	21.49	12	7.9
27-S-026-0-01	17.89	19.46	12	4
28-S-043-0-01	1.46	3.65	12	1.7
28-S-043-0-01	0	1.46	12	4.4
28-S-043-0-01	3.65	4.7	12	2.9
29-S-038-0-01	0	1.04	12	5
29-S-038-0-01	16.59	17.52	12	26.7
30-S-013-0-01	0.08	0.22	12	24
31-S-062-0-01	0	1.45	12	2.2
31-S-062-0-01	9.55	9.63	12	32.3
32-S-075-0-01	9.29	16.58	12	2.9
32-S-039-0-01	5.41	6.88	12	10.1
32-S-039-0-01	8.44	12.12	12	14.6
32-S-039-0-01	7.98	8.44	12	10
32-S-039-0-01	7.19	7.41	12	9.5
32-S-075-0-01	17.4	21.6	12	3.2
32-S-075-0-01	17.01	17.4	12	9.2
33-S-140-0-01	0	0.16	12	20.4
33-S-140-0-01	0.16	0.32	12	25.8
33-S-234-0-01	3.55	5.07	12	6.1

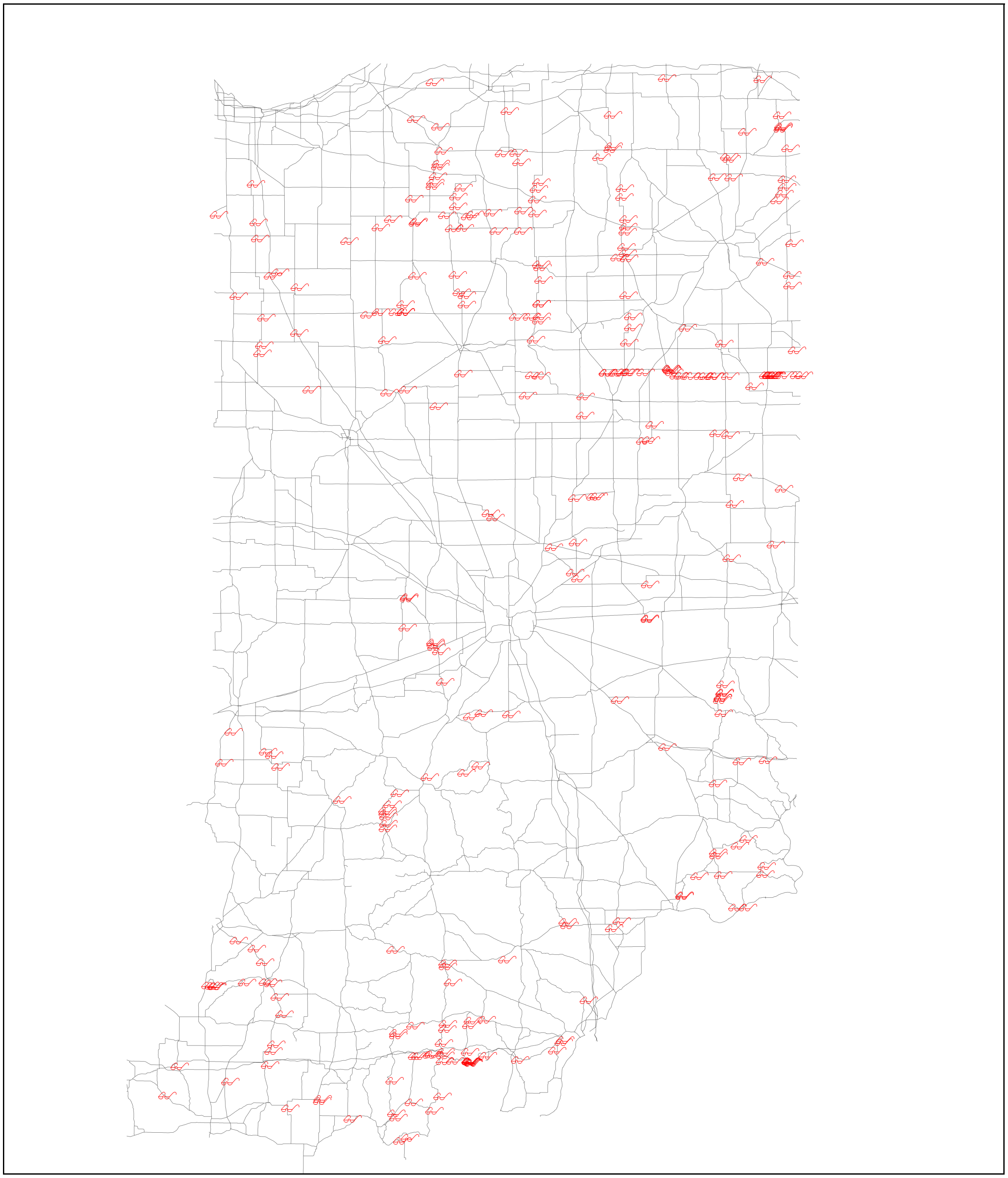
35-S-218-0-01	1.36	4.92	12	6.4
35-S-218-0-01	0	1	12	3.6
35-S-218-0-01	1	1.36	12	3.5
35-S-105-0-01	12.74	14.74	12	3.4
35-S-105-0-01	8.55	12.74	12	5.4
35-S-105-0-01	15.63	15.96	12	11.7
35-S-218-0-01	4.92	6.92	12	7.1
35-S-218-0-01	13.02	14.5	12	6.9
35-S-218-0-01	11.75	11.97	12	15.2
35-S-218-0-01	12.36	13.02	12	10.3
35-S-218-0-01	11.97	12.04	12	15.2
35-S-218-0-01	15.54	17.53	12	6.7
35-S-218-0-01	14.5	15.54	12	6.7
35-S-105-0-01	22.69	26.71	12	6.3
37-U-231-0-01	17.15	19.71	12	3.2
38-S-026-0-01	0	2.97	12	4.9
38-S-026-0-01	3.47	6.37	12	3.5
39-S-062-0-01	20.7	21.6	12	30.5
39-S-062-0-01	20.5	20.7	12	22.4
39-S-062-0-01	28.43	30.68	12	9.3
41-S-044-0-01	4.64	5.07	12	9.5
42-S-061-0-01	14.63	16.5	12	5.7
42-S-061-0-01	4.15	5.12	12	7.1
42-S-061-0-01	8.36	8.7	12	17.6
43-S-019-0-01	18.07	20.06	12	4.4
43-S-019-0-01	15.18	18.07	12	3.6
43-S-019-0-01	20.06	22.06	12	5.9
45-S-002-0-01	0	3.17	12	3.6
45-S-055-0-01	1.53	5.75	12	2.3
46-S-004-0-01	6.53	10.3	12	2.3
48-S-013-0-01	8.62	8.91	12	9.4
48-S-128-0-01	0	0.99	12	5.4
48-S-128-0-01	5.5	6.5	12	11.3
48-S-128-0-01	4.64	5.26	12	15.8
50-S-017-0-01	13.68	14.43	12	11.9
50-S-010-0-01	0	1.11	12	4
50-S-017-0-01	0.77	2.03	12	3.1
50-S-117-0-01	1.01	1.79	12	1.2
50-S-017-0-01	10.39	13.68	12	11.8
50-S-010-0-01	5.95	6.74	12	3.1
50-S-010-0-01	7.26	7.99	12	3.3
50-S-010-0-01	12.06	12.27	12	17.3
50-S-010-0-01	19.92	23.07	12	3.3
50-S-331-0-01	0	1.01	12	2.1
50-S-106-0-01	0	0.74	12	3.2
50-S-331-0-01	20.85	21.25	12	13.9
50-S-331-0-01	17.62	18.81	12	5.6

52-S-016-0-01	7.57	10.72	12	4.5
52-S-018-0-01	3.99	6	12	3.1
52-S-019-0-01	23.45	24.53	12	3.4
55-S-039-0-01	12.62	13.88	12	17.7
55-S-044-0-01	2.6	4.57	12	10.7
55-S-044-0-01	5.83	6.01	12	4.6
56-S-055-0-01	31.69	33.73	12	4.9
57-S-005-0-01	2.16	6.34	12	7.7
57-S-005-0-01	0	2.16	12	6.6
58-S-056-0-01	0.28	6.14	12	3.8
59-S-037-0-01	7.32	9.53	12	6.2
59-S-037-0-01	11.79	11.99	12	12.5
59-S-056-0-01	15.58	15.97	12	27.3
60-S-043-0-01	2.8	3.81	12	7
60-S-043-0-01	0	0.51	12	9.3
60-S-043-0-01	8.64	10.57	12	4.2
62-S-066-0-01	29.8	33.47	12	1
62-S-066-0-01	12.7	13.82	12	4.4
62-S-145-0-01	1.49	3.37	12	1.9
62-S-145-0-01	10.56	10.66	12	4
62-S-070-0-01	0	0.63	12	9.1
62-S-062-0-01	11.97	12.82	12	3.5
63-S-061-0-01	1.69	3.3	12	5.6
63-S-061-0-01	3.95	4.17	12	3.8
63-S-056-0-01	9.78	10.25	12	7.5
63-S-056-0-01	3.97	4.35	12	1.8
63-S-061-0-01	12.69	12.94	12	12.6
63-S-056-0-01	15.69	16.2	12	4.1
63-S-056-0-01	11.63	12.2	12	20.4
65-S-066-0-01	9.07	9.52	12	17.4
68-S-028-0-01	6.75	9.84	12	1.4
68-S-001-0-01	14.46	15.93	12	4.4
69-S-062-0-01	3.59	7.55	12	1.9
69-S-062-0-01	2.56	3.59	12	5.8
69-S-046-0-01	7.44	7.6	12	17.1
71-S-023-0-01	2.07	2.27	12	10.2
71-S-004-0-01	0	0.66	12	1.6
72-S-003-0-01	9.19	10.34	12	25
72-S-003-0-01	5.98	6.17	12	12.2
73-S-244-0-01	1.75	3.77	12	6.4
74-S-070-0-01	7.18	7.73	12	8.1
74-S-062-0-01	2.97	3.52	12	38.8
75-S-023-0-01	14.39	15.95	12	5.8
75-S-010-0-01	19.46	19.8	12	1.3
75-S-010-0-01	19.8	21.21	12	1.7
75-S-008-0-01	8.51	8.63	12	11.7
75-S-023-0-01	10.81	12.11	12	3.3

75-S-023-0-01	13.61	14.39	12	3
76-S-001-0-01	1.86	2.8	12	5.2
76-S-001-0-01	4.81	8.17	12	1.2
78-S-129-0-01	2.37	8.46	12	2.9
78-S-056-0-01	9.31	9.92	12	9.1
78-S-129-0-01	12.41	13.4	12	3.1
78-S-056-0-01	20.1	20.61	12	19.6
82-S-057-0-01	7.73	7.92	12	4.4
84-S-159-0-01	4.51	6.54	12	2.8
84-S-063-0-01	1.1	2.08	12	9
84-S-159-0-01	6.54	6.7	12	4.9
84-S-159-0-01	0	0.32	12	18.5
84-S-063-0-01	9.6	11.08	12	47.4
85-S-218-0-01	2.78	4.28	12	3.5
85-S-218-0-01	0.12	2.34	12	4.5
85-S-218-0-01	2.34	2.78	12	3.5
87-S-062-0-01	15.56	16.56	12	6.7
88-S-056-0-01	6.79	8.36	12	11.2
88-S-039-0-01	2.04	3.11	12	2
88-S-039-0-01	1.04	1.49	12	8.8
90-S-218-0-01	5.95	9.61	12	3.1
90-S-218-0-01	0	2.94	12	3.7
90-S-218-0-01	2.94	3.95	12	5.6
90-S-218-0-01	3.95	5.76	12	6.7
90-S-218-0-01	5.76	5.95	12	6.6
90-S-218-0-01	9.61	13.94	12	3.2
91-S-016-0-01	12.06	13.27	12	2.7
91-S-016-0-01	9.01	12.06	12	1.2
91-S-016-0-01	16.28	18.25	12	1.3
92-S-005-0-01	8.84	13.02	12	8.2
92-S-014-0-01	3.87	5.95	12	3.2
92-S-005-0-01	13.02	13.32	12	9.4
92-S-005-0-01	14.4	16.41	12	3.2
01-S-101-0-01	0	2.01	11	6.2
01-S-218-0-01	13.74	14.09	11	2.2
01-S-218-0-01	8.99	12.54	11	2.7
01-S-218-0-01	12.54	13.74	11	2.2
02-S-101-0-01	4.28	6.45	11	12.2
08-S-218-0-01	17.49	18.41	11	2.6
13-S-064-0-01	3.95	6.22	11	6.5
13-S-037-0-01	6.02	6.44	11	5.7
13-S-066-0-01	11.98	12.08	11	4.5
13-S-037-0-01	8.6	9.84	11	1.4
13-S-066-0-01	20.19	20.86	11	12.5
17-S-327-0-01	8.97	12.01	11	11.7
17-S-327-0-01	7.9	8.25	11	7
17-S-001-0-01	17.19	21.12	11	14.1

20-S-013-0-01	0	1.02	11	20.3
20-S-013-0-01	4.83	5.6	11	9
22-S-062-0-01	3.82	4.06	11	7.2
25-S-017-0-01	4.09	5.45	11	1.4
25-S-017-0-01	9.1	9.39	11	4
25-S-017-0-01	0	2.5	11	5.3
26-S-056-0-01	2.21	2.56	11	2
27-S-013-0-01	9.65	13.78	11	23.5
27-S-013-0-01	14.41	16.4	11	10.9
28-U-231-0-01	21.29	23.21	11	1.6
28-S-043-0-01	8.02	9.84	11	3.1
28-S-043-0-01	5.51	8.02	11	3.8
28-S-043-0-01	4.7	5.51	11	2.2
29-S-238-0-01	8.73	9.02	11	9
35-S-218-0-01	12.04	12.36	11	9
35-S-116-0-01	0	0.1	11	5.7
37-U-231-0-01	5.92	6.02	11	12.2
37-S-014-0-01	2.01	3.98	11	2
37-S-014-0-01	0	2.01	11	2
43-S-019-0-01	11.45	12.94	11	6.1
44-S-120-0-01	11.28	12.32	11	14.7
45-S-055-0-01	11.82	13.31	11	11.1
50-S-017-0-01	7.56	9.04	11	13.4
50-S-110-0-01	10.74	16.41	11	10.5
51-U-150-0-01	16.05	16.31	11	0.9
52-S-016-0-01	10.72	15.14	11	3
52-S-016-0-01	1.6	4.15	11	1.4
52-S-218-0-01	6.9	8.84	11	3.6
52-S-218-0-01	8.84	11.42	11	1
52-S-019-0-01	17.97	18.33	11	0.9
52-S-016-0-01	5.07	5.11	11	2.1
52-S-019-0-01	27.68	34.02	11	2.8
53-S-037-0-01	16.95	17.75	11	2.2
56-S-055-0-01	9.93	15.64	11	0.8
56-S-055-0-01	0	2.01	11	1.5
56-S-055-0-01	2.55	3.54	11	0.7
56-S-114-0-01	0	2.07	11	0.7
57-S-008-0-01	12.42	13.41	11	27.6
62-S-066-0-01	34.79	38.08	11	1.3
62-S-037-0-01	5.3	6.11	11	1.5
62-S-066-0-01	15.25	22.31	11	0.7
62-S-062-0-01	12.82	12.97	11	3.2
65-S-069-0-01	7.71	8.21	11	19
65-S-065-0-01	2.45	2.96	11	2.8
66-S-143-0-01	0	1.5	11	3.1
66-S-119-0-01	9.01	11.01	11	5.2
66-S-119-0-01	0	4.13	11	5

68-U-036-0-01	15.49	18.81	11	1.9
68-S-001-0-01	0	3.02	11	4.9
68-S-028-0-01	17.89	21.37	11	8
69-S-048-0-01	3.9	4.22	11	3.3
71-U-020-0-01	0	0.31	11	10.9
71-S-331-0-01	8.64	10.13	11	32.3
74-S-062-0-01	3.52	3.68	11	14
74-S-062-0-01	13.02	13.5	11	9.5
75-S-023-0-01	8.02	9	11	2.5
75-S-039-0-01	1.02	2.01	11	8.6
75-S-010-0-01	13.08	18.07	11	24.8
75-S-023-0-01	9	10	11	2.6
76-S-004-0-01	5.14	5.32	11	13.9
76-S-127-0-01	5.77	6.9	11	17.9
76-S-001-0-01	1.14	1.52	11	9.7
76-S-001-0-01	1.52	1.86	11	5.5
85-S-218-0-01	0	0.12	11	4.2
87-S-061-0-01	19.85	20.02	11	20.5
90-S-116-0-01	9.9	10.47	11	6
91-S-018-0-01	0	3.44	11	5.4
91-S-119-0-01	4.58	5.55	11	4
91-S-039-0-01	4.89	11.6	11	19.2
91-S-016-0-01	18.25	19.27	11	1.8
92-S-014-0-01	1.07	2.58	11	11.2
92-S-205-0-01	0	0.08	11	22.3
92-S-005-0-01	16.41	22.49	11	3.3



GIS representation of sections identified for alignment improvements by HERS/ST in Funding Period 4