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QUALITY CONTROL METHODS THROUGH PRE-DETERMINATION OF FIELDS FOR usRAP PROJECTS

THESIS

A thesis submitted in partial fulfillment of the

requirements for the degree of Master of Science in the

College of Engineering

at the University of Kentucky

By

Zachary W. Heath

Lexington, Kentucky

Director: Dr. Reginald R. Souleyrette, Professor of Civil Engineering

Lexington, Kentucky

2023

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ABSTRACT OF THESIS

QUALITY CONTROL METHODS THROUGH PRE-DETERMINATION OF FIELDS FOR usRAP PROJECTS

The United States Road Assessment Program (usRAP) was designed to rate highways for their ability to protect road users and to make recommendations to engineers and policy makers for investments to enhance road safety. The program is heavily dependent on local road data or characteristics. Pre-populating usRAP requires coders to evaluate sixty-six attributes at 100-meter intervals along a subject highway. In this thesis, methods for obtaining and assuring the quality of some of the usRAP data elements are proposed. Kentucky Transportation Cabinet Highway Information System (HIS) data are used as "ground truth" for roadway grade and curvature. Methods of using light detection and ranging (LiDAR) are explored to either establish or assure the quality of data for roadside severities including cliffs, aggressive vertical faces, upward slopes (15-75 degrees), deep drainage ditches, downward slopes (>-15 degrees), and upward slopes (>=75 degrees) by developing digital cross sections. Methods to use LiDAR to determine roadway grade, curvature, and roadside slope are also explored. These methods are evaluated for feasibility using standard surveying and GIS software. Results indicate that roadway grade and curvature are difficult to estimate using only imagery and LiDAR may be used to measure grade and cross slope only if resolution is adequate. Other methods are proposed for future research and application.

KEYWORDS: Quality Control, United States Road Assessment Program (usRAP), Safer Roads Investment Plan (SRIP), Light Detection and Ranging (LiDAR), Kentucky Transportation Cabinet Highway Information System

Zachary W. Heath

April 7, 2023

QUALITY CONTROL METHODS THROUGH PRE-DETERMINATION OF FIELDS FOR usRAP PROJECTS

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Background / Introduction to usRAP

Roadway safety involves four E's: education, enforcement, emergency response, and engineering. Through these four E's, roadway safety has improved in the United Sates and fatal crash rates continue to decline, though not as much recently. One reason for this improvement is the provision of more forgiving roadways designed by engineers and constructed by road authorities. The engineers and other involved professionals understand that people will make mistakes while operating on the roadway, whether that be in a motor vehicle, on a bicycle, or on foot as a pedestrian. Through many years of research engineers have found many approaches to help create a more forgiving roadway through safety improvement projects. Such projects may include installation of guardrails or eliminating left turns across traffic in all areas that do not have a traffic signal. However, before these safety improvement projects can be started, the segment of roadway in need of improvement must be evaluated.

To evaluate roadways, quality control methods must be put in place. The performance of roadway assessments is impacted by the quality of the data collected during an assessment. The results of roadway evaluations are typically used to present technical results to those who may not be familiar with the field of transportation engineering. It is critical for the results to be accurate because these results are used to inform road authorities to authorize safety improvement projects. (NCHRP 2022) If the results shown reflect a poor rating on a roadway that is safe, such as an access-controlled highway, the integrity of all presented results will be in question. To maintain public trust, it is crucial that these results accurately reflect the current roadway conditions.

One method of roadway assessment used in the United States is the United States Road Assessment Program (usRAP). This program is an innovative and proactive tool for analyzing the safety of a roadway and generating data-driven solutions for correcting hazards. Personnel are trained to look at 100-meter-long sections of roadway and assign a rating to sixty-six attributes for each. These trained people are referred to as "raters" or "coders..." The attributes that raters collect consist of, but are not limited to, identifying

if the roadway segment has street lighting, or determining what the roadside severity is, such as identifying if there is a fixed object on the driver's side of the road such as a tree and if so, how far from the driving surface is it? These segments are typically evaluated using Google Street View or through other methods such as photologs and can be supplemented by aerial photography.

usRAP has a computer program that gives an overall rating for each segment by assigning a star value to it on a scale of one star to five stars. A one-star rating would reflect a route considered to provide the least protection for road users and highest potential for serious crashes. For example, a one-star route can be a narrow two-lane rural route with a cliff on both the driver's side and the passenger's side of the vehicle with no guardrail. A five-star route could represent an access-controlled interstate highway or extremely low speed facility considered to provide the least chance or consequence of a serious crash. Each segment evaluated with usRAP is given a star rating for four road user types: motorcyclists, bicyclists, pedestrians, and vehicle occupants.

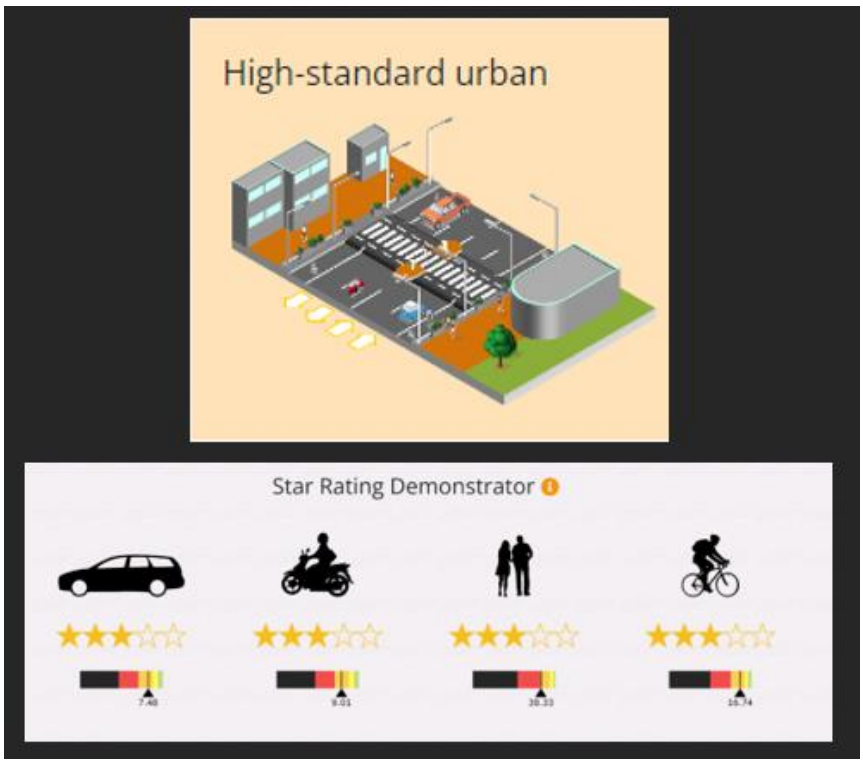
Star ratings are determined by assigning Star Rating Scores (SRS) in the bands as shown in Table 1. Separate bands are used for each of the road user types based on their method of travel. Motorized road user scores are based on likelihood and consequence of head-on crashes, intersection crashes, and run off road crashes. Bicyclists scores are based on run off road crashes, along the roadside and intersection crashes. Pedestrian scores are based on crashes that occur when walking across or along the road. (iRAP 2023)

Table 1 Star Rating / SRS Score Bands

Star Rating	Star Rating Score				
	Vehicle occupants and motorcyclists	Bicyclists	Pedestrians		
			Total	Along	Crossing
5	0 to < 2.5	0 to < 5	0 to < 5	0 to < 0.2	0 to < 4.8
4	2.5 to < 5	5 to < 10	5 to < 15	0.2 to < 1	4.8 to < 14
3	5 to < 12.5	10 to < 30	15 to < 40	1 to < 7.5	14 to < 32.5
2	12.5 to < 22.5	30 to < 60	40 to < 90	7.5 to < 15	32.5 to < 75
1	22.5 +	60+	90 +	15 +	75 +

According to the methodology of usRAP, these bands were set after sensitivity testing was completed with a focus on the following items: The Safe System context and the role of speed, the expected injury severity, the role of star ratings in setting targets, the relationship between star ratings and crash rates, and the distribution of star ratings across a typical road network. An example of a star rating and an SRS score for a high-standard urban roadway can be seen in Figure 1.

Figure 1 Star Rating Demonstrator



Roadways are evaluated with usRAP to consider them for safety investment. Once a group of roadways is selected coding may begin. However, before a team starts a project, they must go through training. The training is given with the intent to let the rater know what to look for as they are collecting data for assessment. There is free online training offered from Iowa State University which is available through this link: https://www.elo.iastate.edu/professional-development/usRAP/

These teams will also typically go through a quality control process before they start a project. For instance, all team members may be tasked to evaluate the same arbitrary number of segments of the same roadway to allow for the coding manager of the project to determine any discrepancies between the judgment of the raters. One team member may identify a roadway hazard as a guardrail, and another identify a fixed object such as a tree that is just beyond the guardrail. These discrepancies can be identified in the quality control training process. One method to do this is to have a team meeting consisting of all raters and the coding manager to review the findings, which will result in increasing the chances that the raters will identity similar roadway attributes and be more consistent in their ratings. This will increase the overall quality of data collection and improve the results of the project.

One common attribute of all highway safety programs is the need for quality control. It is critical for the data collected to be complete and accurate as to allow for the best information to provide an accurate star rating and SRS score. Once data collection is completed on the selected roadway, that roadway can be considered for inclusion in a usRAP Safer Roads Investment Plan (SRIP). This plan provides prioritized countermeasures that will improve the overall star rating and SRS score of the roadway and do so in a cost-effective manner. As professionals in the field of transportation engineering, it is good practice to be good stewards of the tax-payer's dollars and recommend safety improvement projects at the most critical segments of roadway networks. This is done through an accurate star-rating which can provide engineers and other interested parties with a cost-benefit ratio to better make choices. An accurate star rating provides an accurate benefit-to-cost ratio of each recommended safety improvement project. This cost-benefit ratio compares the cost of the safety improvement project to the cost of crashes. Only improvements that meet a user set minimum benefit-cost ratio will be suggested.

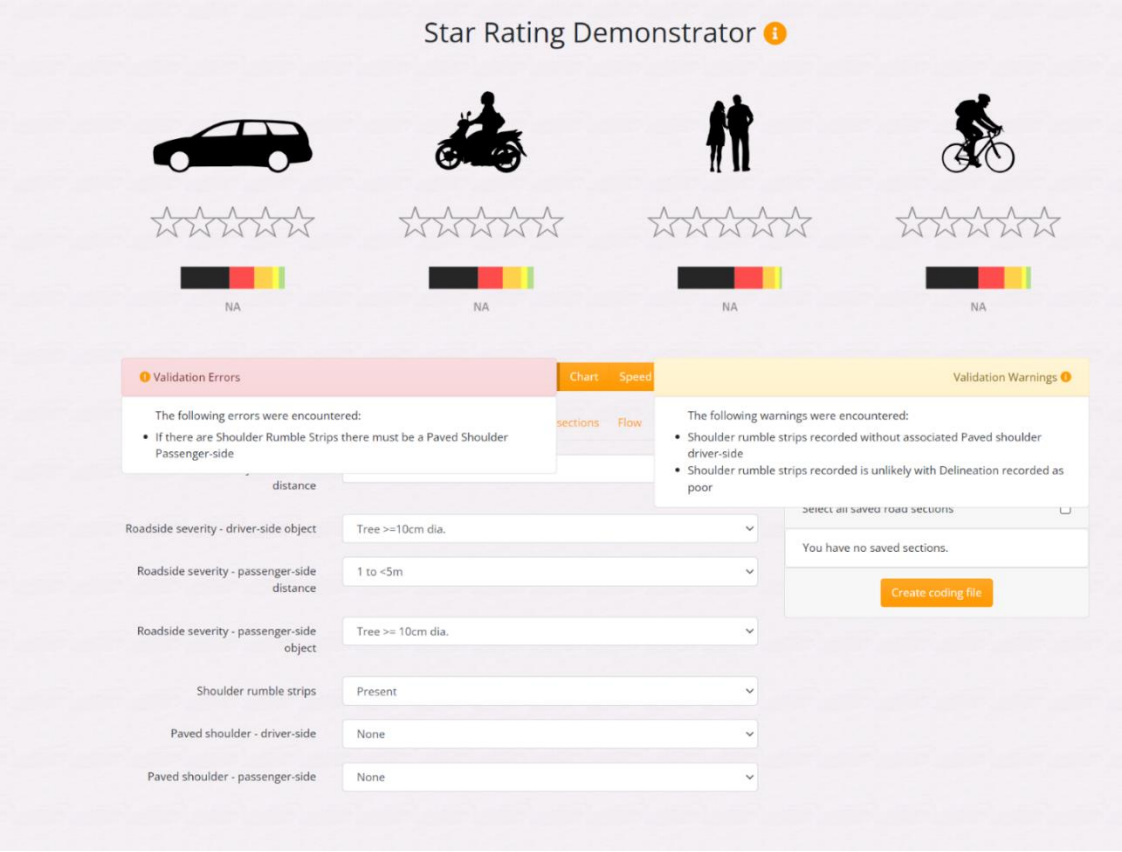
usRAP SRIPs are produced with a computer program provided by the International Road Assessment Program (iRAP) called ViDA. ViDA is Spanish for ‘life,’ an appropriate name as its goal is to decrease roadway fatalities and increase safety of the

roadway. This program is provided online and is available at http://vida.iRAP.org. iRAP is a non-profit organization based in the United Kingdom which was established in 2005 to help coordinate national roadway assessment programs such as usRAP, EuroRAP and AusRAP. ViDA allows for the collected roadway attributes obtained by raters to be entered as an input and then provides the star rating and SRS score for the roadway as an output. The Safer Roads Investment Plan's performance is impacted by the quality of the data collected.

This thesis explores improving quality of safety data using automated methods, namely LiDAR (Light Detection and Ranging) and surveying software. The US Road Assessment Program is used as a test bed for this research. The objective of the thesis is to show how automated methods can improve quality by populating data fields or by using the automated data to check data and assist in training. The thesis also considers if humans should in turn check the data derived from the automated methods.

ViDA has built-in quality control measures in place that validate collected data and ensure results are accurate and make logical sense. The program states what the error is, and it also gives warnings to allow the user to go into the program and verify the accuracy of or make corrections to the data. For example, ViDA will check if a roadway segment coded as having no shoulder but includes shoulder rumble strips and flag it for inconsistency. Such a situation is presented in Figure 2. The program alerts the user as there are shoulder rumble strips present therefore a paved shoulder should also be present. It also gives validation warnings for other attributes that should be double checked.

Figure 2 Star Rating Demonstrator



Literature Review

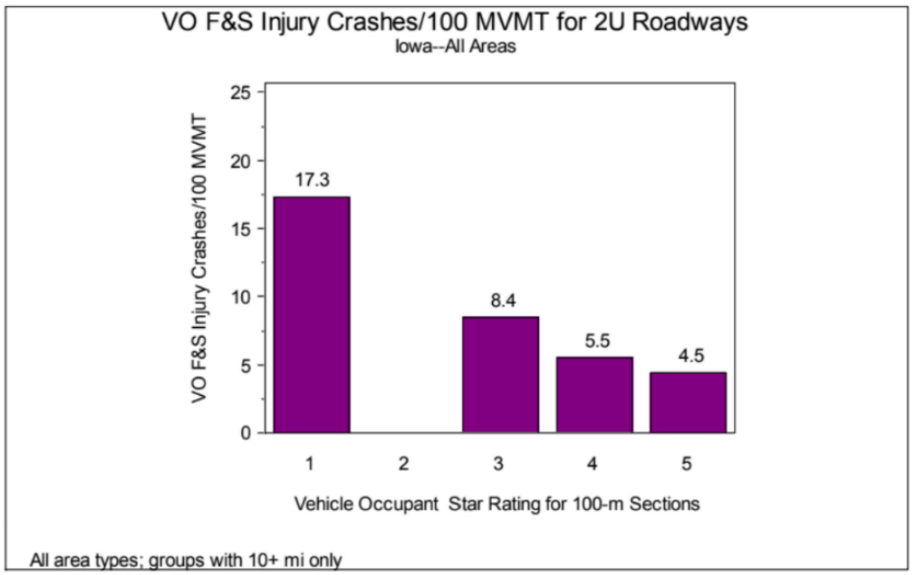
While usRAP requires many data elements (66 in total) to be imported into ViDA, sometimes a road authority may only be interested in one kind of crash, such as run-off road. For such an application, Souleyrette, et al (2016) determined data elements required to evaluate roadside risk. The researchers performed a sensitivity analysis and determined the effects of each of the 60+ elements that have an impact to run off road rating. Their work identified the most critical data elements required to determine the risk ratings for run off road collisions. This research was performed using data from Kentucky which at the time was ranked third in the nation for the highest run off road crash rates.

It was found that the following elements were needed to calculate a star rating: the roadside severity and distance from the edge of the roadway on both the driver and

passenger side, speed limit, grade, lane width, road condition, curvature, quality of the curve, and skid resistance/grip. These elements were given a higher priority because due to their sensitivity if these were coded incorrectly the results would not be accurate. The remaining elements were found to not have a significant impact on run off road collision star ratings. This methodology can apply to quality control as well. The elements previously identified are significant to the star rating score which impacts the overall results and the implementation of the Safer Roads Investment Plan. Therefore, the previously mentioned data elements should be prioritized in quality control.

A research report by Harwood, et al (2010), demonstrated the relationship between star ratings and crash rates. It found a significant correlation between crash rates and star ratings. Comparisons investigated relationships between vehicle-occupant fatal and severe injury crashes, and head-on star ratings and run off road star ratings. The research compared star ratings with crashes on different roadway types in Iowa and Washington. A plot showing the relationship between star ratings and fatal and severe injury crashes can be seen in Figure 3.

Figure 3 Relationship Between Star Ratings and Fatal & Serious Injury Crashes



The relationship between star ratings and fatal and severe injury crashes as seen in Figure 3 from the research completed by Harwood, et al (2010), documents that star ratings are accurate in depicting the overall safety of the roadway. This can be seen by the crash statistics seen in Figure 3. This further motivates the need for quality control. If a roadway was accurately rated and assigned one star, it can be shown to road administration that the roadway justifies a safety improvement which will increase safety for those who use the roadway.

Methodology

There are many distinct types of errors that may occur in the coding process for roadway assessment programs. Errors can come from lack of training, complacency, fatigue, and judgment. First it should be determined which of these attributes are the most prone to error. Then what can be done to reduce the errors should be investigated. This thesis examines a validation report from a usRAP project in Kentucky. This validation report consists of 46 errors and 4212 warnings. A sample of this validation data can be found in Figure 4. The most common error was the raters identifying shoulder rumble strips but also identifying that there is no shoulder present. These errors and warnings outlined in the validation report are a result of the built-in quality control methods in place within the ViDA program.

Figure 4 US-RAP Project Validation Sample Data

Row number	Report Severity	Report Text
7	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
8	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
9	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
13	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
14	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
15	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
16	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
17	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
18	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
19	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
20	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
21	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
22	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
23	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
24	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
25	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
26	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
27	warning	Unlikely combination of Area Type (urban) and Land Use Driver-side (rural)
27	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
28	warning	Unlikely combination of Area Type (urban) and Land Use Driver-side (rural)
29	warning	Unlikely combination of Area Type (urban) and Land Use Driver-side (rural)
29	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)
30	warning	Unlikely combination of Area Type (urban) and Land Use Driver-side (rural)
30	warning	Unlikely combination of Property Access Points (none) and Land Use Driver-Side (developed) and, or Passenger-Side (developed)

Out of all these items, it was found that area type, property access points, and median type were most often flagged as a warning. A suggested reason for this is that raters may be looking at "more critical" attributes such as speed limit, grade, lane width, road condition, curvature, quality of the curve, and skid resistance/grip. If some of these fields can be pre-populated, it would allow for the raters to focus on less attributes and allow more attention to fields in which data is not pre-populated. A list of common errors in usRAP coding can be found in the Appendix.

LiDAR Applications to Determine Roadway Grade

One critical component identified by Souleyrette, et al (2016) is roadway grade. At times this could be difficult for raters to determine based on the quality of the Google Street View image being used. The most common discrepancy is judgment, and this error has often been overlooked due to the broad ranges for roadway grade in usRAP. While roadway grades uphill in one direction are obviously downhill in the other, usRAP uses the absolute value of the roadway grades. The ranges and their corresponding codes can be seen in Table 2.

Table 2 usRAP Roadway Grade Codes

Code	Description
5	≥ 10%
4	≥ 7.5% to <10%
3	≥ 5% to <7.5%
2	≥ 4% to <5%
1	≥ 0% to <4%

With such a broad range for the roadway grades, it is possible that coders can correctly code roadway grades. However, it may be difficult to determine what the roadway grade is from a single Google Street View image. For example, Figure 5 shows a roadway with a 6 percent grade which is a code 3 (5-7.5 percent). It is easy to see how difficult it is to accurately code a road near the boundary of a rating category.

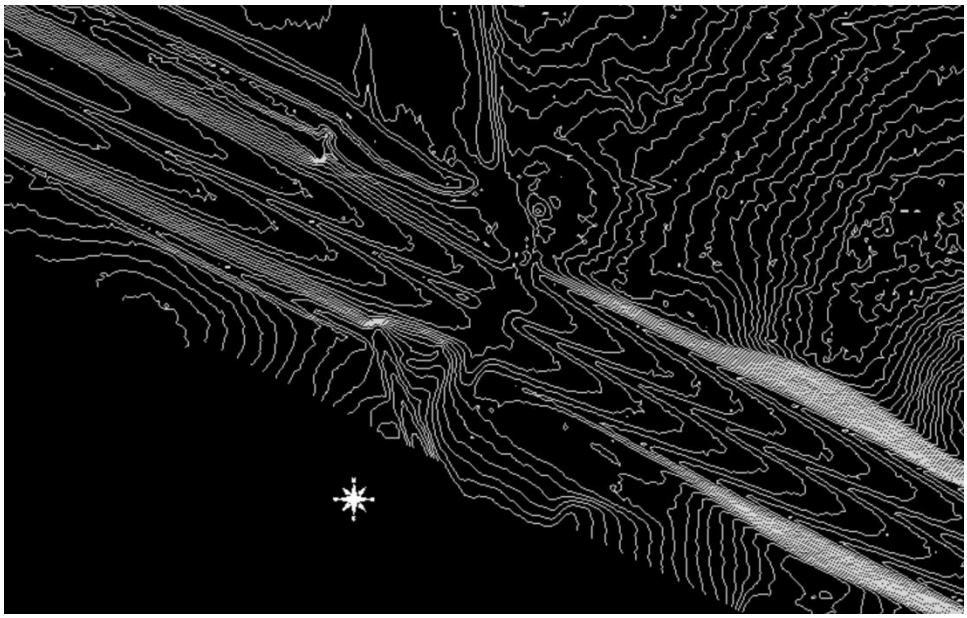
Figure 5 Google Street View

Using the demonstrator tool in ViDA it was found that roadway grade does impact star ratings and SRS scores. A standard rural road with a 0-7.5 percent roadway grade has a star rating of two and an SRS score of 17.72 for cars and 19.54 for motorcycles. When the roadway grade was changed to 7.5-10 percent the SRS scores increased to 21.27 for cars and 23.09 for motorcycles, but the rating remained at two stars. The same was done for a high standard rural road. The roadway grade for the high standard rural roadway was set to 0-7.5 percent. This resulted in an SRS score of 8.33 and 11.29 for motorcycles. This roadway was also rated as three stars for both modes. The roadway grade was then changed to 7.5-10 percent, and this resulted in a three-star rating for cars and an SRS score of 10.35. However, for motorcycles, the star rating was reduced to two stars and the SRS score changed to 12.96.

LiDAR can be used to spot check the Kentucky Transportation Cabinet Highway Information System (HIS) data or the data collected by a rater for roadway grade in Kentucky. Kentucky has a statewide LiDAR data program called KYFromAbove. This program will allow for digital elevation models to be downloaded to determine the

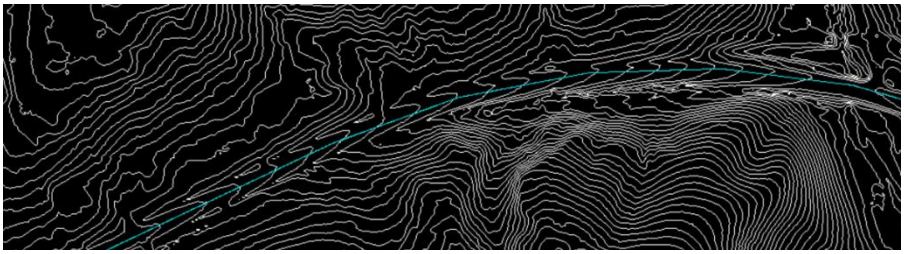
elevation changes on roadways and the roadway grade. The LiDAR data can be used in any GIS or AutoCAD program. Data is available statewide which will allow for a 10 meter (32.8 feet) digital elevation model (DEM). This will work in some instances; however, various spot checks must be made and if the roadway is near a cliff or steep downwards slope you may get some numbers that are far off and not accurate. This thesis suggests using 5-foot DEM which can be used to create 2-foot contours and be more accurate in determining the roadway grade. 5-foot DEMs are also available through KYFromAbove. An example of a roadway with LiDAR data can be seen in Figure 6. KYFromAbove can also help with several other fields such as curvature and can clear up any discrepancies with Google Earth imagery that may be older or not clear.

Figure 6 LiDAR Data



Sample data was taken from a usRAP project to compare the roadway grade that the coders collected versus those roadway grades calculated from LiDAR data. The sample data used is from a usRAP segment on US HWY 62 in Lawrenceburg, Kentucky. The sample data is shown in Figure 7.

Figure 7 Roadway Centerline with LiDAR Data



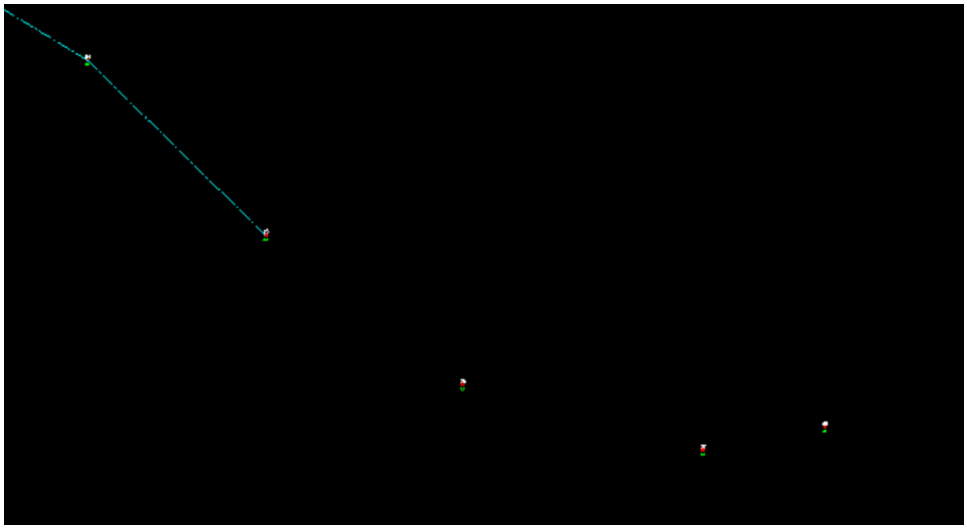
The raters assigned a code of 1 (0-4 percent) to this segment of roadway. Using the LiDAR data, the roadway grade was found to be 2.75 percent. Therefore, in this case the LiDAR roadway grade matched the roadway grade provided by the coder. Roadway grade at times can be difficult to determine just by looking at an image. This difficulty can be a result of a two-dimensional image lacking proper depth perception. Due to this it is recommended that the roadway grade is to be pre-populated with HIS data before raters are asked to evaluate the roadway.

While computer methods, e.g., LiDAR can be used to check raters, raters can and should be used to check the fields pre-populated by automatic methods as well. For example, a human may be better at estimating the character of a slope over 100 meters, especially if it changes a lot and the automatic measurements are only taken at one point.

Applications to Determine Roadway Curvature with AutoCAD

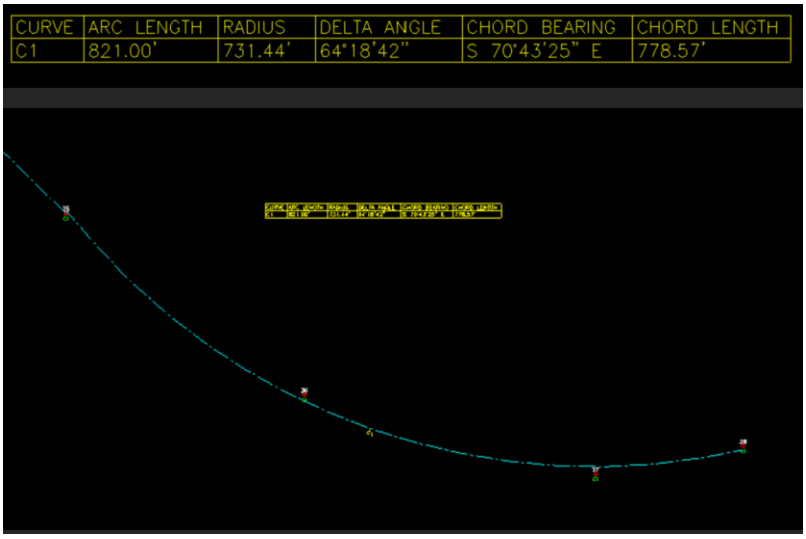
AutoCAD programs can be used to help determine roadway curvature. Though this method is extensive, requires some assumption, and demands some time, it can be used as a spot check for road authorities that do not have data to spot check the HIS data. The first step to do this is to draw a polyline between the points leading up to the curve as seen in Figure 8. The point at the end of the polyline is an assumed point of curvature (PC).

Figure 8 Curvature Linework



The next step would be to create a best fit curve for the centerline points. This will require assumption of the location of the point of curvature (PC) and point of tangent (PT). This results in the curve seen in Figure 9. This curve data can then be used to find the approximate design speed of the curve. Table 3 shows the usRAP codes for curvature.

Figure 9 Curvature Calculations



CURVE	ARC LENGTH	RADIUS	DELTA ANGLE	CHORD BEARING	CHORD LENGTH
C1	821.00'	731.44'	64°18'42"	S 70°43'25" E	778.57'

Table 3 usRAP Roadway Curvature Codes

Code	Description
4	Very Sharp (≤ 25 mph)
3	Sharp (25 mph - 45mph)
2	Moderate (45 mph - 60mph)
1	Straight (60 mph +)

Curvature can be determined by finding the design speed. The curve seen in Figure 9 was rated as a 2 (moderate 45mph-60mph) by the raters. This can be verified by using the American Association of State Highway and Transportation Officials (AASHTO) methods for finding the design speed of a curve. The AASHTO 2011 equation can be seen below:

$$0.01e + f = \frac{V^2}{15R}$$

$$Where:$$

$$e = rate\ of\ superelevation$$

$$f = side\ friction\ (demand\ factor)$$

$$V = vehicle\ speed\ (mph)$$

$$R = radius\ of\ curve\ (ft)$$

Using this equation, the standard maximum rate of roadway superelevation (percent) and the standard maximum side friction demand factor for Kentucky would be assumed. The maximum rate of roadway superelevation used was 12 percent. The side friction value used was 0.14. These values were used with the AASHTO 2011 equation and resulted in the following:

$$0.01(12) + 0.14 = \frac{V^2}{15(731.44)}$$

$$V = 53.4 \approx 53\, mph$$

The curve was found to have an approximate design speed of 53 miles per hour. Therefore, it matched the rater code of 2 (moderate). It is important to note that a design speed of 53 miles per hour is not a typical design speed but can be used as an approximation of the code range (45-60mph). The solution of a 53mph design speed can come from error induced by approximating the point of curvature and point of tangent. The example curve is also exceedingly long. The solution would be more accurate if it were on a shorter curve. Though this method is limited due to assumptions, it can still be used by road authorities that do not have curvature data available to spot check the HIS curvature data.

LiDAR Applications to Determine Roadside Severities with Carlson Survey

usRAP has the raters collect the roadside severity on both the driver and passenger side of the roadway along with the distance from the edge of the roadway. Using LiDAR some of these roadside severities can be identified such as: cliffs, aggressive vertical faces, upwards slopes (15-75 degrees), deep drainage ditches, downwards slopes (>-15 degrees), and upward slopes (>=75 degrees). While there are other codes such as trees and guardrails, LiDAR cannot be used to detect them. These roadside severities can be identified through reading the contours for different terrain features. For example, in Figure 10 an upwards slope is seen at the end of the arrow. When the same area is looked at in Google Street View you can clearly see the upwards slope as shown in Figure 11.

Figure 10 Upwards Slope in LiDAR Data

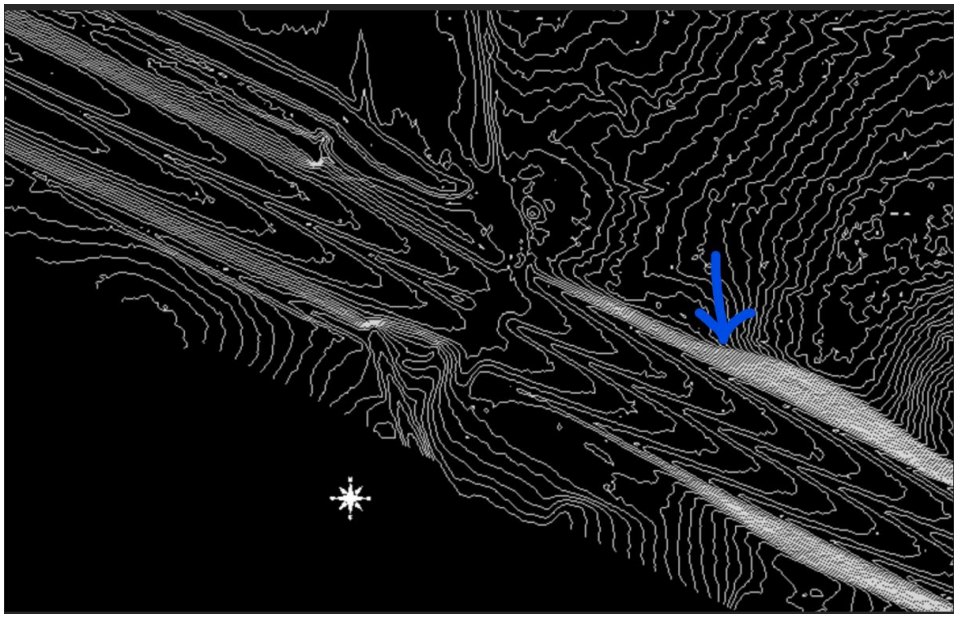


Figure 11 Upwards Slope in Google Street View

While this upwards slope was easy to identify based on the contours of the map, it is important to understand that the map shown in Figure 10 is the result of using a 5-foot

DEM. A 5-foot DEM has a point every 5 feet in a grid-like form that fits over the terrain surface at ground level as seen in Figure 12.

Figure 12 DEM Grid Example

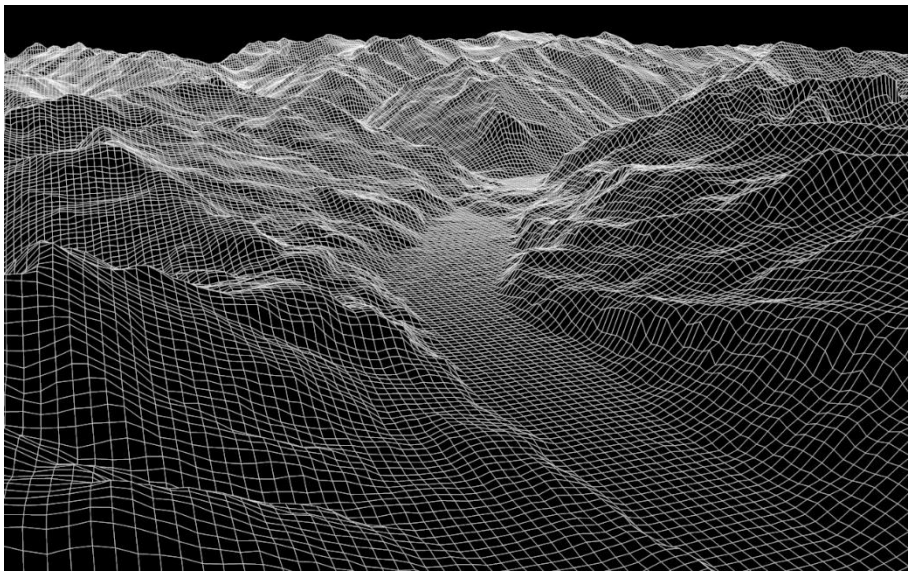
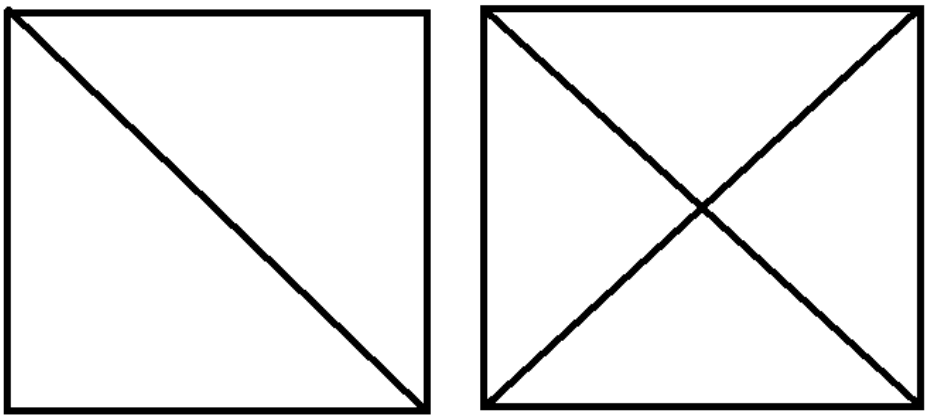


Figure 13 DEM Resolution Example



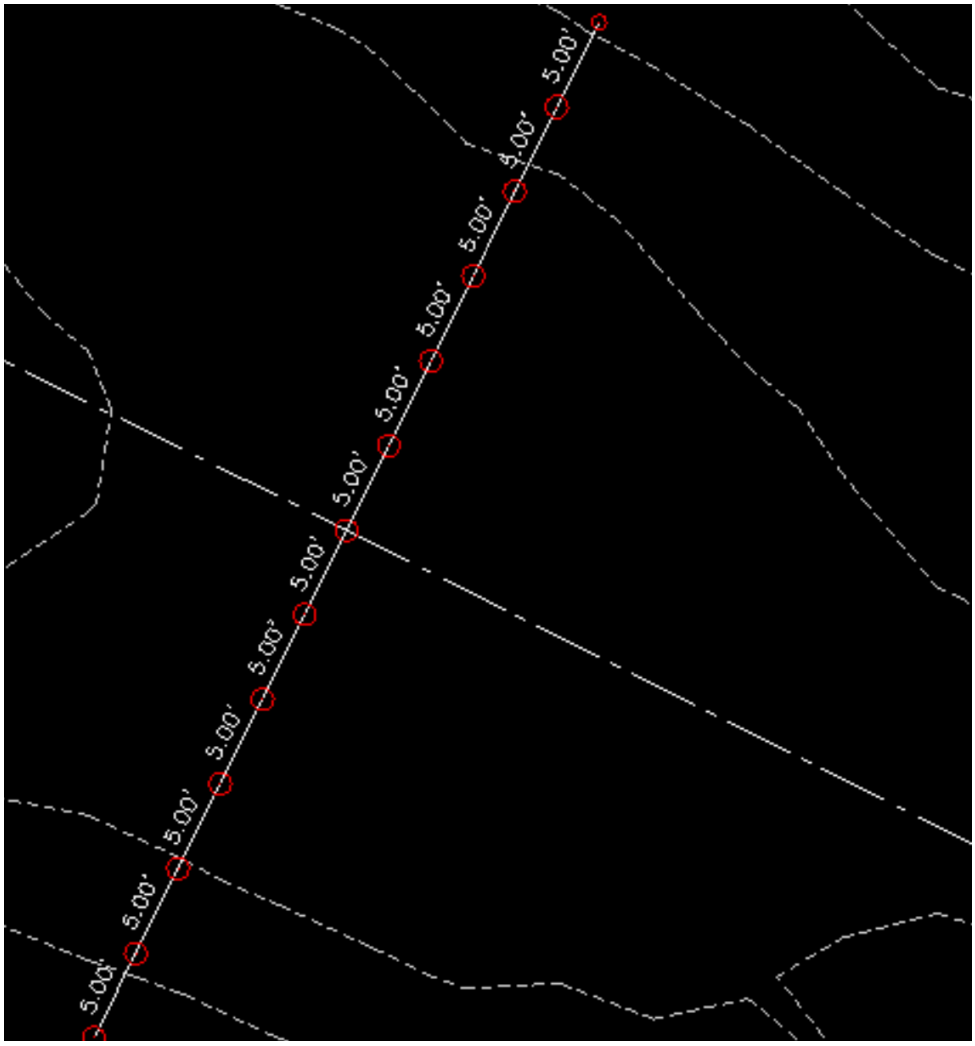
These grids are used to make triangles and through a triangulation process a user can obtain an elevation for any point within the grid as seen in Figure 13. While Figure 13 is a simple representation of the triangulation process, until a solution is made. The tighter the DEM grid is the more accurate the results. Kentucky offers a statewide DEM at 10-meter (32.8 feet) grids. This should not be used, and the 5-foot grid should be used.

A 5-foot DEM is also available from KYFromAbove. The reason for this is improved accuracy, thus giving better results. For example, Figure 14 shows a roadway that when a 10-meter DEM was brought in showed a roadway slope of 17 percent which was an error. This error is due to triangulation of points on the surface of the bridge and the ground surface under the bridge.

Figure 14 Google Street View

Roadside severities such as cliffs, aggressive vertical faces, upwards slopes (15-75 degrees), deep drainage ditches, downwards slopes (>-15 degrees), and upward slopes (>=75 degrees) can be found through digital cross sections. The cross section will be perpendicular to the centerline point as seen in Figure 15. This will allow for the degree of slope between points to be evaluated. As an example, this thesis will evaluate 2 centerline points each 300 feet apart from each other.

Figure 15 LIDAR Cross Section



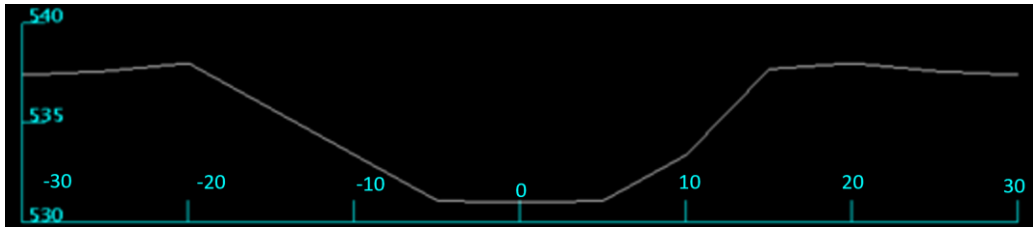
A table can be developed for each point on the cross section where points are established every five feet. The example in Figure 15 results in the data outlined in Table 4. This process takes about 30 minutes maximum per centerline cross section. This point reflects a steep slope on each roadside. It would be considered an upwards slope (15-75 degrees) in usRAP.

Table 4 LiDAR Cross Section Results

Elevation (ft)	Distance from CL	Slope (%)	Degree	usRAP Code
537.4	-30	4	2	N/A
537.6	-25	8	5	N/A
538.0	-20	46	25	upwards slope (15-75 degrees)
535.7	-15	46	25	upwards slope (15-75 degrees)
533.4	-10	46	25	upwards slope (15-75 degrees)
531.1	-5	2	1	N/A
531	0	2	1	N/A
531.1	5	46	25	upwards slope (15-75 degrees)
533.4	10	86	40	upwards slope (15-75 degrees)
537.7	15	6	3	N/A
538	20	8	5	N/A
537.6	25	4	2	N/A
537.4	30	4	2	N/A

A cross section of the points in Table 4 can be seen in Figure 16 where the X axis is the distance from the centerline of the roadway and the Y axis is the elevation.

Figure 16 LIDAR Cross Section Results



The same methodology was applied to the point perpendicular with a slope as seen in Figure 10. The results of such are outlined in Table 5. A view of the cross section used for this section of roadway can be seen in Figure 17. A cross section of the points in Table 5 can be seen in Figure 18 where the X axis is the distance from the centerline of the roadway and the Y axis is the elevation.

Figure 17 LiDAR Cross Section

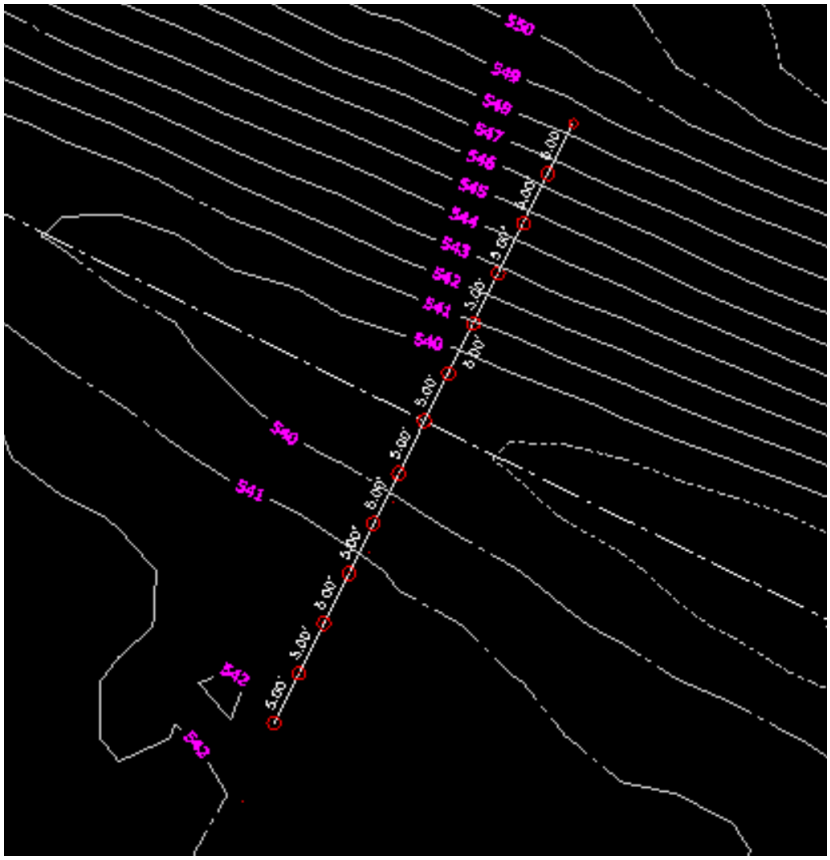
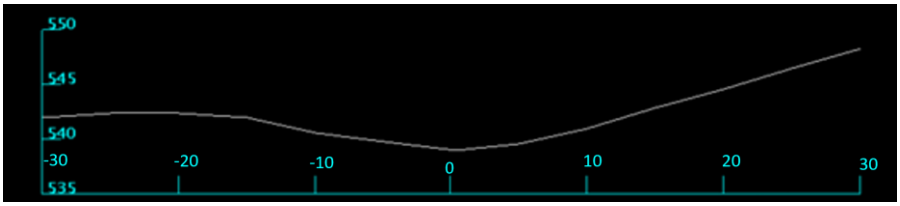


Table 5 LiDAR Cross Section Results

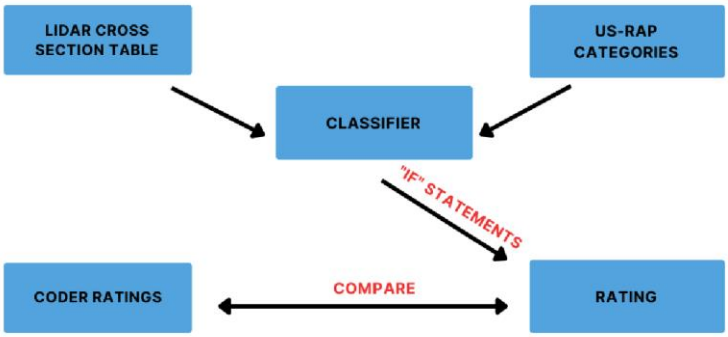
Elevation	Distance from CL	Slope (%)	Degree	usRAP Code
542.0	-30	8	1	N/A
542.4	-25	0	0	N/A
542.4	-20	8	5	N/A
542.0	-15	28	16	upwards slope (15-75 degrees)
540.6	-10	16	9	N/A
539.8	-5	16	9	N/A
539.0	0	12	7	N/A
539.6	5	28	16	upwards slope (15-75 degrees)
541.0	10	38	21	upwards slope (15-75 degrees)
542.9	15	34	18	upwards slope (15-75 degrees)
544.6	20	38	21	upwards slope (15-75 degrees)
546.5	25	36	20	upwards slope (15-75 degrees)
548.3	30	6	3	N/A

Figure 18 LIDAR Cross Section Results



This point reflects a steep slope on each roadside. It would be considered an upwards slope (15-75 degrees) in usRAP. These methods can be used for any usRAP centerline point. The resulting values can be used to classify any potential roadside severities that include upward and downward slopes, cliffs, deep drainage ditches, and aggressive vertical faces. While the methods in the thesis outline obtaining this data manually, the process could be automated in future research to determine the rating of the roadside severity based on usRAP categorization. This can then be compared to coder ratings. A simple flow chart of the proposed automation can be seen in Figure 19.

Figure 19 Flow Chart of Cross Section Automation



While it would be beneficial to automate this process, it must be kept in mind that these cross sections evaluate the roadway at only a single point. The coders for usRAP are tasked with evaluating the whole 100-meter section of roadway. During the development of the automation process, this must be accounted for. For instance, a particular roadway may have an aggressive vertical face at the cross section point but 50-meters up the road, in the same 100-meter segment, it has a deep drainage ditch. To correctly evaluate this the entire roadway must be evaluated for roadside severities. While computer methods, e.g., LiDAR can be used to check raters, raters can and should be used to check the fields pre-populated by automatic methods. For example, a human may

be better at estimating the character of a slope over 100 meters, especially if it changes a lot and the automatic measurements are only taken at one point. Creating cross sections can be tedious by hand but if it is automated it would be straightforward to evaluate the roadway every 5 meters or so and find the most severe spot. It is possible that if this is developed the usRAP methodology could be changed to accommodate this automation.

HIS Data Sources

Two critical attributes to usRAP as identified by Souleyrette, et al (2016) are speed limit and lane width. These can be pre-determined using data from the Kentucky Transportation Cabinet Highway Information System (HIS). Speed limits throughout the state can be found by using the following link.
https://apps.transportation.ky.gov/hiswebquery/SL_Query.aspx

This is easier to use than a rater assuming a speed limit or looking for a speed limit sign along the segment they are rating. A sample of speed limit data for US routes in Jessamine County, KY is shown in Figure 20.

Figure 20 HIS Posted Speed Limit Data

COUNTY NAME	ROUTE	BEGIN MP	END MP	Posted Speed Limit
Jessamine	057-US-0027 -000	0	15.2780	55
Jessamine	057-US-0027X -000	0	0.80	55
Jessamine	057-US-0027X -000	0.80	1.0320	45
Jessamine	057-US-0027X -000	1.0320	2.07	35
Jessamine	057-US-0027X -000	2.07	2.38	25
Jessamine	057-US-0027X -000	2.38	3.89	35
Jessamine	057-US-0068 -000	0	12.0190	55

The Kentucky Transportation Cabinet Highway Information System data also provides information on horizontal curves, lane width, number of lanes, right shoulder width, median type, pavement type, and various other information as seen in Table 6. HIS also offers GIS extracts which are available here:https://transportation.ky.gov/Planning/Pages/HIS-Extracts.aspx

Table 6 HIS Data Links

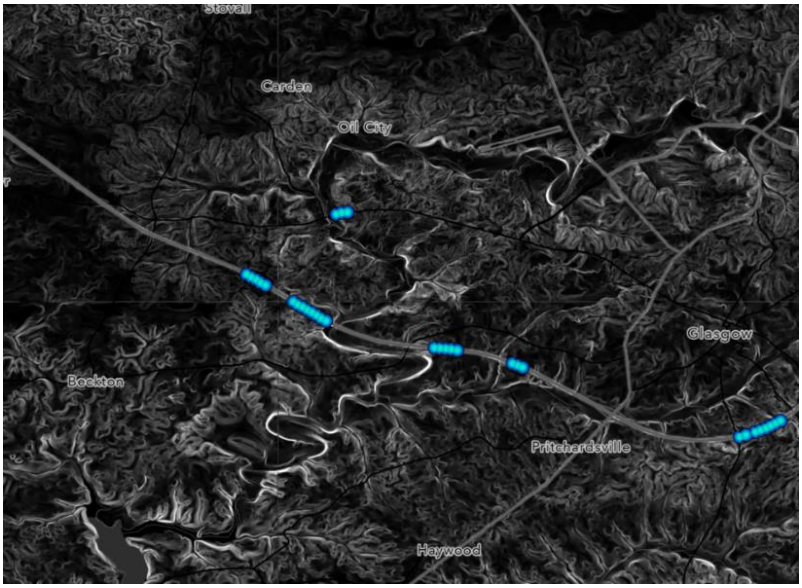
• Appalachian Development Highway System
• Bike Route System

• Bridge Locations
• Coal Haul (Tons Hauled Annually)
• Functional Classification System
• Horizontal Curve
• HPMS Sample Segments
• Lane Information
• Median / (un)Divided Highway Information
• National Highway System
• Pavement Type
• Posted Speed Limits
• Route Log
• Scenic Byway System
• Shoulders (Right (outer) Side)
• State System
• STAA - National Truck Network (NN)
• Traffic Count Information
• Truck Weight Class

Identifying Roadside Severities with ArcGIS Pro

LiDAR can be entered and used to evaluate roadway segments for usRAP. Figure 21 shows the statewide grade data from KYFromAbove along with some centerline points. The darker the shade, the lower the elevation, which can help identify locations of deep drainage ditches or cliffs.

Figure 21 Statewide Grade in ArcGIS Pro



The route with centerline points shown in Figure 21 is the Louie B Nunn Cumberland Parkway. For application we considered the following point to determine possible roadside severities (38.04399516, -86527195100). This centerline point has an aggressive vertical face on the driver's side. If this point is cross referenced with the KYFromAbove data, we find that high elevation difference is clearly shown. (Figure 22). Query of the location reveals a 30 percent slope at the location. If the same location is viewed on Google Street view, the result is (Figure 23).

Figure 22 Percent Slope in ArcGIS Pro

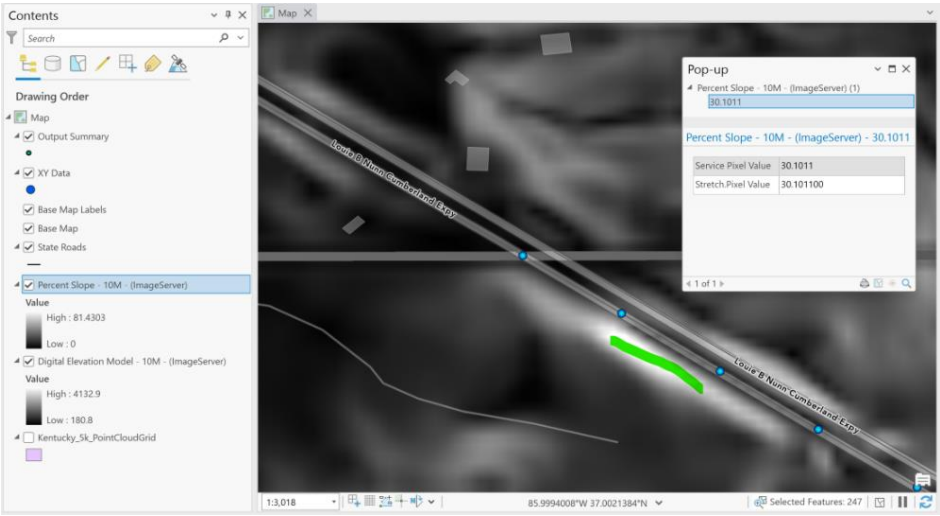
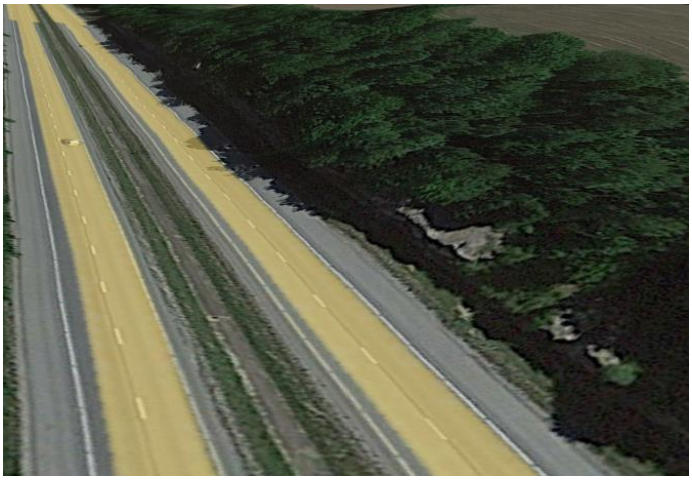


Figure 23 Aggressive Vertical Face

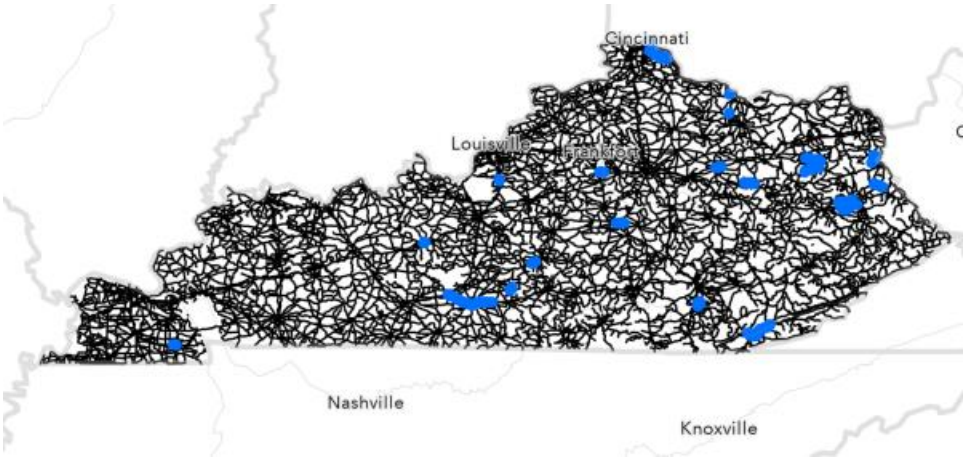


It can clearly be seen that there is an aggressive vertical face on the passenger side of the roadway here. This was identified as an area where there may be roadside severity based on statewide grade information from KYFromAbove. This requires manual effort but proves as an alternative method to determining or checking roadside severity ratings.

Analysis Using ArcGIS Pro

For analysis, thirty roadway projects for usRAP evaluation were examined with the goal of pre-populating roadway grade and curvature. ArcGIS Pro was used. A map of all the projects can be seen in Figure 24.

Figure 24 usRAP Projects in ArcGIS Pro



The blue in Figure 24 shows the locations of the selected projects. Using geoprocessing tools these points were spatially joined to shapefiles from HIS which contained roadway grade and roadway curvature. These points were also spatially joined to LiDAR data to determine roadway grade.

Due to a lack of sufficient processing power the DEM resolution from KYFromAbove was set to 10-meters. This caused some issues; for instance, a roadway grade of 17 percent is seen in the data as there is one data point on the roadway and one on the ditch and the program triangulated between the two. All areas that were above 4 percent grade were manually inspected to ensure accuracy. This can be prevented if the processing power is available to process 5-foot DEM resolutions. This centerline point can be found in Figure 14.

Results

The thirty usRAP projects were evaluated to see how many times the coder's code matched the HIS and LiDAR data for roadway curvature and roadway grade. These comparisons can be seen in Table 7.

Table 7 Number of Matches Rater Code to HIS and LiDAR Data

Row Labels	Count of Project ID	Sum of Curve Rater vs HIS	Sum of Grade Rater vs Lidar	Sum of Grade Rater vs HIS	Sum of Grade Lidar vs HIS
003-US-0062	38	23	17	3	8
005-LN-9008	361	252	280	289	300
007-US-0119	257	164	214	250	209
011-KY-0052	62	57	50	42	41

015-I - 0065	14	14	11	11	14
018-KY- 0080	29	29	27	28	26
019-I - 0275	11	11	11	11	11
019-I - 0275 - 010	12	12	7	5	2
019-I - 0471	82	82	60	60	60
019-KY- 0009 - 010	36	36	20	24	12
019-KY- 0010	8	5	6	1	1
019-KY- 0547	60	44	31	11	13
019-KY- 0915	57	39	41	16	17
019-KY- 2345	21	11	15	7	6
032-KY- 0007	113	98	93	58	58
032-KY- 0032	160	59	95	14	21
043-US- 0062	16	14	13	6	6
058-KY- 0825	227	93	191	92	95

058-US-0460	125	102	69	48	76
063-KY-1223	10	6	7	7	8
063-KY-2392	37	26	31	28	24
063-KY-3431	50	39	32	39	39
064-KY-0645	85	76	27	2	47
064-KY-1185	87	47	53	6	17
064-KY-3398	39	16	28	7	10
081-KY-0324	3	2	3	3	3
081-KY-3056	4	2	0	0	3
081-US-0068	8	8	2	2	7
083-US-0460	72	54	23	24	56
085-US-0068	40	28	17	11	19
087-I - 0064	50	50	12	11	49
109-US-0068	38	38	29	38	29
(blank)					

Grand Total	2212	1537	1515	1154	1287

Each of these thirty projects were then evaluated to see to what percentage the rater matches the method of pre-population. The results of this are seen in Table 8.

Table 8 Percentage of Matches Rater Code to HIS and LiDAR Data

Row Labels	Precent match of Curve Rater vs HIS	Precent match of Grade Rater vs Lidar	Precent match of Grade Rater vs HIS	Precent match of Grade Lidar vs HIS
003-US-0062	61%	45%	8%	21%
005-LN-9008	70%	78%	80%	83%
007-US-0119	64%	83%	97%	81%
011-KY-0052	92%	81%	68%	66%
015-I - 0065	100%	79%	79%	100%
018-KY-0080	100%	93%	97%	90%
019-I - 0275	100%	100%	100%	100%
019-I - 0275 - 010	100%	58%	42%	17%
019-I - 0471	100%	73%	73%	73%

019-KY-0009 - 010	100%	56%	67%	33%
019-KY-0010	63%	75%	13%	13%
019-KY-0547	73%	52%	18%	22%
019-KY-0915	68%	72%	28%	30%
019-KY-2345	52%	71%	33%	29%
032-KY-0007	87%	82%	51%	51%
032-KY-0032	37%	59%	9%	13%
043-US-0062	88%	81%	38%	38%
058-KY-0825	41%	84%	41%	42%
058-US-0460	82%	55%	38%	61%
063-KY-1223	60%	70%	70%	80%
063-KY-2392	70%	84%	76%	65%
063-KY-3431	78%	64%	78%	78%
064-KY-0645	89%	32%	2%	55%

064-KY-1185	54%	61%	7%	20%
064-KY-3398	41%	72%	18%	26%
081-KY-0324	67%	100%	100%	100%
081-KY-3056	50%	0%	0%	75%
081-US-0068	100%	25%	25%	88%
083-US-0460	75%	32%	33%	78%
085-US-0068	70%	43%	28%	48%
087-I - 0064	100%	24%	22%	98%
109-US-0068	100%	76%	100%	76%

The values that show a low percent match can be flagged and evaluated to determine if it is rater error or if the segment of roadway changes rapidly within a 100-meter segment and automated methods can not accurately evaluate the roadway at the specified point. For example, on 081-KY-3056 there was no match between the rater roadway grade codes, LiDAR, and HIS roadway grade. The rater coded the roadway as a 3 (5-7.5 percent grade). The HIS and LiDAR roadway grades show a code of 1 (0-4 percent). The roadway can be seen in Figure 25.

The Summary Table (Table 9) shows that rater roadway grade matches the least with HIS roadway grade. A suggested reason for this difference is the lack of depth perception provided by a two-dimensional photo from Google Street View. A two-

dimensional photo may not provide an accurate representation of current roadway conditions. Due to this it is suggested that roadway grade fields for usRAP be pre-populated with HIS roadway grade data. It can also be seen that the LiDAR roadway grade matches poorly with the HIS roadway grade data. The reason for this is the LiDAR roadway grade data used was a 10-meter DEM. A 5-foot DEM should have been used because it would have provided more accurate answers. However, due to lack of processing power a 10-meter DEM was used. In future work a 5-foot DEM should be used.

Figure 25 Google Street View

Table 9 Summary Table

Project ID	Curve (Rater matches HIS)	Grade (Rater matches Lidar)	Grade (Rater matches HIS)	Grade (Lidar matches HIS)
10-80101.00	82%	55%	38%	61%
10-8802.00	62%	31%	28%	87%
3-80150.00	70%	78%	80%	83%
3-8706.00	70%	43%	28%	48%
4-80102.00	100%	76%	100%	76%
5-391.30	100%	79%	79%	100%

6-352.00	85%	53%	41%	27%
6-81.00	100%	73%	73%	73%
6-8105.06	52%	71%	33%	29%
6-8105.07	100%	58%	42%	17%
7-80001.00	61%	45%	8%	21%
9-192.01	41%	60%	7%	10%
9-192.03	24%	56%	12%	21%
9-228.00	87%	82%	51%	51%
9-8802.00	39%	61%	11%	17%
IP20000021	68%	72%	28%	30%
IP20000087	100%	93%	97%	90%
IP20040019	92%	81%	68%	66%
IP20070153	88%	81%	38%	38%
IP20080296	73%	60%	20%	20%
IP20080669	89%	32%	2%	55%
IP20080672	54%	61%	7%	20%
IP20080674	41%	72%	18%	26%
IP20150064	100%	24%	22%	98%
IP20190187	64%	83%	97%	81%
IP20210057	91%	45%	45%	91%
9-8906.00	50%	0%	0%	75%
IP20210103	73%	72%	76%	73%
IP20210112	91%	33%	39%	67%
IP20210124	100%	100%	100%	100%
IP20210128	41%	84%	41%	42%
Average	74%	62%	43%	55%
Standard Deviation	23%	22%	31%	29%

Conclusions / Recommendations

This thesis suggests that if there is a reduction in the number of fields that raters for a usRAP project must collect, it would in turn improve the quality control of the project. This will allow for the raters to focus on fewer items thus reducing the possibility of making mistakes. It was discovered that LiDAR can be used to identify some roadside hazards such as: Cliffs, aggressive vertical faces, upwards slopes (15-75 degrees), deep drainage ditches, downwards slopes (>-15 degrees), and upward slopes (>=75 degrees) through methods of cross section. LiDAR data can also be used to accurately account for roadway grades if at a low enough DEM resolution such as 5-feet. HIS was found to be a reliable source of roadway grade and roadway curvature information for pre-population. It is suggested to use the data from HIS to help pre-populate the following fields: Median type and width, right shoulder type and width, number of lanes and width of the lanes, along with speed limits. These methods can also be used to check the rater code for the accuracy of roadway grade and roadway curvature. While computer methods, e.g., LiDAR can be used to check raters, raters can and should be used to check the fields pre-populated by automatic methods as well. While these methods are suggested additional statistical analysis should be completed to prove that the methods in this thesis should be used.

Limitations

These methods of quality control are limited by the data provided by HIS and the LiDAR information from KYFromAbove. The age of the data may play a role in not accurately representing the most current roadway conditions. The results will only be as accurate as these data sources are. It would be beneficial to perform various spot checks on the data to ensure accuracy. For example, a human may be better at estimating the character of a slope over one hundred meters, especially if it changes a lot and the automatic measurements are only taken at one point.

While compiling the roadway grade data it was found that there is a need to clean the data if larger than a 5-foot DEM resolution is used. For instance, if a roadway shows a grade greater than 4 percent that grade must be verified through visual inspection. There

can be errors in the points used within the LiDAR data. While this is a concern, it can be very quicky identified and fixed. For instance, if a roadway grade of 17 percent is seen in the data it may be because there is one LiDAR point on the roadway and one LiDAR point in the ditch causing an error in the calculation of the triangulation between the two. This can be resolved by using a 5-foot DEM resolution which is also available from the same data source.

While the LiDAR cross section method is effective in identifying roadway severities such as cliffs, aggressive vertical faces, upwards slopes (15-75 degrees), deep drainage ditches, downwards slopes (>-15 degrees), and upward slopes (>=75 degrees), a limitation was found. The cross-section method may be effective in identifying that there is a cliff on the side of the road. However, the LiDAR data has no way of knowing if there is a guardrail there. The guardrail would be the roadside severity and not the cliff. Therefore, instances like this must be filtered and resolved.

Also, two points are required to determine the roadway grade with LiDAR. There must be one centerline point past the area of study to establish roadway grade for all segments of interest.

Future Research

Due to time limitations of this project, collection of data showing raters evaluating all usRAP fields versus the pre-determination of data for comparison was unable to be collected. It is a suggestion for future research to have a study comparing results of a usRAP project with some pre-population vs no pre-population. A statistical analysis should be completed on the results to prove that the methods suggested in this thesis should be used.

Another topic that came up in the development of this thesis is the possible need for data confidence intervals for usRAP. If these can be established, it would help to provide results with a reasonable range of expectations. The quality control methods

outlined in this thesis are a good measure to increase the reliability of confidence intervals.

It would be suggested that research be done to automate the LiDAR cross section method using the flow chart as seen in Figure 19 as a guideline. This will allow for usRAP projects to automatically collect roadside severities if they are cliffs, aggressive vertical faces, upwards slopes (15-75 degrees), deep drainage ditches, downwards slopes (>-15 degrees), and upward slopes (>=75 degrees). It must be kept in mind that these cross sections evaluate the roadway at a single point. The coders for usRAP are tasked with evaluating the whole 100-meter section of roadway. A method for automatically obtaining the most severe conditions within the one hundred meters is desired...

Appendix

List of common errors in usRAP coding:

- Incorrect code for land use.
- Not correctly differentiating between frangible and non-frangible objects.
- Incorrect code for roadway curvature.
- Coder name not being an email address.
- Incorrect code for upgrade cost.
- Incorrect code for median types.
- Incorrect code for roadside severities.
- Incorrect code for paved shoulder widths.
- Incorrect code for roadway condition / skid resistance / grip.

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