Open Access Library Journal
2019, Volume 6, e5586
ISSN Online: 2333-9721
ISSN Print: 2333-9705

An Innovative GIS Method for Evaluating the Visibility of the Road Using the ArcMap-Tools

Azad Abdulhafedh

Department of Civil Engineering, University of Missouri, Columbia, MO, USA
Email: dr.azad.s.a@gmail.com

How to cite this paper: Abdulhafedh, A. (2019) An Innovative GIS Method for Evaluating the Visibility of the Road Using the ArcMap-Tools. *Open Access Library Journal*, **6**: e5586
https://doi.org/10.4236/oalib.1105586

Received: July 9, 2019
Accepted: July 29, 2019
Published: August 2, 2019

Abstract

Road visibility is critical to motorists in making decisions such as stopping, slow downing, turning, entering a traffic stream from a driveway, or merging into traffic. Adequate visibility allows motorists the time they need to avoid vehicle crashes and conflicts and will help keep roadways operating safely and smoothly. Insufficient visibility is a significant factor in roadway crashes and near collisions. This paper utilizes the ArcMap-GIS viewshed tools, and the location analysis techniques to present an evaluation of the existing visibility on portions of the interstate highway I70 in the State of Missouri compared to AASHTO requirements. The evaluation of the existing visibility is conducted on the I70 segments at Boone, Callaway, and Cooper counties. This method is a useful tool for understanding location-based risks of limited visibility on the I70 or similar highways. The GIS techniques used show that the ArcMap-GIS tools can be used effectively in determining the road visibility and locating the hazardous locations without the need for field visits. Many highways were built years before tools like geographic information systems (GIS) and other computer aided designs were available. Therefore, this method can be considered as a relevant aid for assessing geometric consistency of the I70 interstate highway and similar roads, because it identifies different segments of the road layout that offer considerably different sight distances.

Subject Areas

Civil Engineering

Keywords

Road Visibility, Sight Distance, ArcMap, GIS, Viewsheds, AASHTO Green Book

1. Introduction

According to the American Association of State Highway and Transportation

Officials (AASHTO), the ability of a driver to see ahead on the roadway is of paramount importance for the safe and efficient operation of a vehicle. In general, sight distance refers to the driver's line of sight. Insufficient sight distance is a significant factor in roadway crashes and many other near collisions [1]. Roadway sight distance is a measure of the road visibility, which can be categorized into four types: stopping sight distance; decision sight distance; passing sight distance; and intersection sight distance. Each of these sight distances accounts for the reaction time of the driver and the subsequent time required to complete the associated stopping task. Sight distance is the length of roadway ahead that is visible to the driver [1]-[8]. Moreover, the minimum sight distance at any point on the roadway should be long enough to enable a vehicle traveling at or near the design speed to stop before reaching a stationary object in its path. Although greater length is desirable, sight distance at every point along the highway should be at least that required for a below average driver or vehicle to stop in this distance. Stopping sight distances are calculated using basic principles of physics and the relationships between various design parameters. Providing adequate sight distance on a roadway is one of the central tasks of the designer. Adequate sight distance provides motorists the opportunity to avoid obstacles on the roadway, to merge smoothly with other traffic, and to traverse intersections safely. Ramp, interchange, and intersection designs are typically completed in tightly constrained spaces with many structural, earthwork, and roadway elements present that may obstruct sight distance. These elements are not easily moved; if consideration to sight distance constraints is not given early in the design process, designs may be compromised and may reduce the level of safety on the completed roadway. Therefore, sight distance criteria must be presented in a clear, comprehensive, and unambiguous manner to facilitate the completion of satisfactory roadway design [2] [7]-[17].

For instance, the minimum length of the highway vertical curves is controlled by the required stopping sight distance, driver eye height, and object height. This required length of curve is such that, at a minimum, the stopping sight distance is available at all points along the curve. Sight distance criteria have impact on virtually all elements of highway design and many elements of the traffic operation, and control. The roadway geometric design features, presence of obstacles to sight at the roadsides and the pavement surface condition are fixed by sight distance requirements. The nature of traffic controls, their placement and their effects on traffic stream conditions, such as traffic queues, must take account of sight distance requirements. Adequate stopping sight distance must be provided on 100% of the street and highway system so a driver with the standard eye height of 1080 mm may see an object of 600 mm with sufficient time to stop safely [1] [2] [13] [14] [15].

An essential function in GIS systems is the visibility analysis that provides the ability to analyze the visible areas or judges the intervisibility between two points. ArcGIS allows to determine visibility on a surface from point to point along a given line of sight or across the entire surface in a viewshed that identifies the cells in an input raster that can be seen from one or more observation points or lines. Each cell in the output raster receives a value that indicates how many observation points can see the location [3] [14] [15] [16] [17] [18].

This paper utilizes the GIS tools, the Viewshed applications, and the location science and analysis techniques to present an evaluation of the existing stopping sight distances on portions of the interstate highway I70 in the State of Missouri. The evaluation of the sight distances is conducted on the I70 segments at Boone, Callaway, and Cooper counties. A design speed of 70 mph (110 km/h) was selected for the purpose of evaluation, and a corresponding standard AASHTO stopping sight distance of 730 ft (220 m) was compared against the existing sight distances at these portions of I70.

Many highways were built years before tools like geographic information systems (GIS) and other computer aided design were available. Therefore, this method can be considered as a relevant aid for assessing geometric consistency of the I70 interstate highway and/or similar roads, because it identifies different segments of the road layout that offer considerably different sight distances.

A stopping sight distance profile presented in this paper can also be a useful tool for understanding location-based risk of limited stopping sight distance. The profile shows the spots of insufficient stopping sight distance along the roadway, thereby illustrating the sight distance restrictions and where they occur. This information can help designers understand the severity of a sight distance restriction, how the restriction may interact with other roadway conditions or features, and how/where to implement mitigation strategies [9] [12] [15] [18].

Data

The data used are obtained from the Missouri Spatial Data Information Service (MSDIS) website http://msdis.missouri.edu/. Six quadrangles are used for the analysis, as shown in **Table 1**.

2. Methodology

ArcGIS Desktop (ArcMap version 10.6.1) is used in the analysis. The data is uploaded, and the main goal was to create Viewsheds, generate the I70 profiles and cartographic maps, and identify the points that do not meet the ASSHTO sight distance requirements. The profiles and the classified sections of the I70 were thoroughly inspected, and the existing sight distances of all points on the highway interstate I—70 within Callaway, Boone, and Cooper counties were compared against the recommended AASHTO stopping sight distance of 730 ft (220 m) that corresponds to the design speed of 70 mph (110 km/h) of the I70 interstate highway.

The following steps are conducted throughout the analysis:

- Importing the downloaded E00 interchange files in GIS
- Densifying the I70 raster
- Converting the Vertices of I70 Features to Points

Table 1. Data files used in the analysis.

Quadrangle Code	Type of the file	County
g38092h2.e00.gz	E00	Boone-Callaway
g38092h3.e00.gz	E00	Boone
g38092h4.e00.gz	E00	Boone
g38092h5.e00.gz	E00	Boone-Cooper
g38092h10.e00.gz	E00	Callaway
g38091h8.e00.gz	E00	Callaway

- Adding new parameters to the attribute table of the point's raster that control the visibility analysis in the viewsheds. These parameters are (OFFSET A = 1.08 m presenting the height of the driver's eye recommended by AASHTO, OFFSET B = 0.6 m presenting the height of object above the road surface recommended by AASHTO, AZIMUTH 1 = 0, AZIMUTH 2 = 180 degrees, Vertical Angle 1 = +90 degrees, Vertical Angle 2 = −90 degrees, RADIUS 1 = 0, RADIUS 2 = 560 m presenting the radius of curvature recommended by AASHTO).
- Creating viewsheds for all points of the I70 raster
- Buffering the DEMs by a distance of 200 m
- Clipping the DEMs by the road buffers
- Connecting the buffered-clipped DEMs of all segments together by ArcMap Mosaic tools
- Generating the I70 profiles, and classified maps from the viewshed's
- Identifying the IDs, and the geographic coordinates of all the points along the highway that did not meet the AASHTO recommended sight distance of 220 m

The main steps of the procedure are detailed below:

1) Import the E00 interchange files:

The E00 interchange files that are downloaded from the MSDIS website, were imported as follows:

(Arc Toolbox ≥ Conversion Tools ≥ To Coverage ≥ Import from E00).

2) Densify the I—70 rasters':

Steps used are:

(Arc Toolbox ≥ Editing Tools ≥ Densify).

The Densification method was chosen to be (Distance), and the value of the Distance entered was (220 meter), which is the AASHTO recommended sight distance that corresponds to the design speed (70 mph).

3) Feature Vertices to Points:

The feature vertices of the I—70 are converted to points using,

(Arc Toolbox ≥ Data Management Tools ≥ Features ≥ Feature Vertices to Points).

4) Add new fields and parameters to the attribute table of the new Vertices to Points layer:

In order to control the visibility area, and creating the viewsheds accordingly, the following fields and parameters were added to the attribute table of the Vertices to Points layer:

- OFFSET A_1 = 1.08 meter, which presents the height of the driver's eye above the road surface that is recommended by AASHTO Green Book, 2011.
- OFFSETB = 0.6 meter, which presents the height of the visible object on the road surface recommended by AASHTO Green Book, 2011.
- AZIMUTH_1 = 0 degree, which defines the start angle of the scan range
- AZIMUTH 2 = 180 degree, which defines the end angle of the scan range
- Vertical Angle 1 (VERT 1) = 90 degree, which defines the upper vertical angle limit of the scan
- Vertical Angle 2 (VERT 2) = −90 degree, which defines the lower vertical angle limit of the scan
- RADIUS 1 = 0 meter, which defines the start distance from which visibility is determined
- RADIUS 2 = 560 meter, which defines the end distance from which visibility is determined, this value was chosen because it presents the recommended radius of curvature by AASHTO that corresponds to the design speed of (70 mph).

5) Creating Viewsheds

Viewsheds are created for all points at once, using the following steps:

(Arc Toolbox ≥ 3D Analysis Tools ≥ Visibility ≥ Viewsheds),

The input raster: the quadrangle raster file,

The input points feature: The Vertices To Points,

The output Raster: the Viewshed that corresponds to the quadrangle used, The Z factor was used as 1,

The earth curvature corrections is checked to be applied, and

The Refractivity Coefficient is taken as the default value of 0.13

6) Modify the DEM by Buffering the Highway:

Each quadrangle raster layer of the I—70 interstate highway is buffered using an adequate distance around the I—70 for the purpose of evaluating the sight distances along the highway, and a distance of 200 meter is chosen as the buffering distance, as follows: (Customize ≥ Toolbar ≥ Editor ≥ Buffer).

7) Clipping the DEMs by the road buffer:

Each buffered quadrangle is clipped by the road buffer, as follows:

(Customize ≥ Toolbar ≥ Editor ≥ Clip).

8) Mosaic the modified DEMs of all quadrangles together:

The modified DEMs from the different quadrangles are connected together using the Mosaic command, as follows:

(Arc Toolbox ≥ Data Management Tools ≥ Raster ≥ Raster Dataset ≥ Mosaic to New Raster), The input raster's used were all created viewsheds of all the quadrangles.

The number of bands is =1,

The mosaic operator is the default (LAST), The mosaic Mode is the default (FIRST).

9) Identifying the locations that did not meet the recommended AASHTO Stopping Sight Distance of 220 m:

The profile of each quadrangle's viewshed is inspected along the I—70 interstate highways to highlight the locations or spots that did not meet the recommended AASHTO Stopping Sight Distance of (220 m). The points that fell short of the AASHTO standard sight distance were identified by inspection, and their IDs, and their geographic coordinates were determined by right-clicking on the location and using the "identify tools" that give the required information on that specific point or location.

3. Results and Findings

The map of the I70 profile at each quadrangle is generated from its corresponding viewshed and is classified into 5 classes to further show the locations that are visible and non-visible on the map. Since the points are separated originally by a distance of 220 m when converted from vertices to points, then obviously the non-visible locations are those points that did not meet the AASHTO recommended sight distance of 220 m along the highway profile. A thorough inspection is conducted for the whole profile at each quadrangle, and the non-visible points are identified in term of their IDs and geographic coordinates and tabulated to present the locations of the insufficient sight distances along the I70 highway. The Object IDs, the Pixel Values, and the counts for each viewshed can be obtained from the attribute table of the viewshed and were tabulated for each viewshed/quadrangle. The overall profile of the I70 highway at each quadrangle, and the classified sections are shown below with the tables that contain the points that did not meet the AASHTO sight distance.

3.1. 1st Quadrangle

The I—70 Profile at the 1st quadrangle in Callaway County is shown in Figure 1 below:

The classified section of the I—70 Interstate Highway at the 1st quadrangle in the Callaway County is shown in Figure 2 and Figure 3.

For the 1st quadrangle (g38091h8, located in Callaway County), the Object IDs, the Pixel Values, and the counts are found from the attribute table of the viewshed, and as shown in Table 2.

The locations that did not meet the AASHTO standard stopping sight distance of 220m at the 1st quadrangle, are shown in Table 3.

3.2. 2nd Quadrangle

The I—70 Profile at the 2nd quadrangle in Callaway County is shown in Figure 4.

The classified section of the I—70 Interstate Highway at the 2nd quadrangle in the Callaway County is shown in Figure 5 and Figure 6.

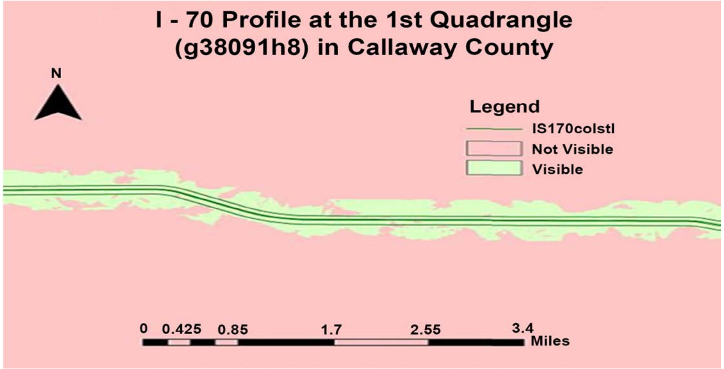

Figure 1. The I—70 Profile (Visible/Not Visible) at the 1st quadrangle in Callaway County.

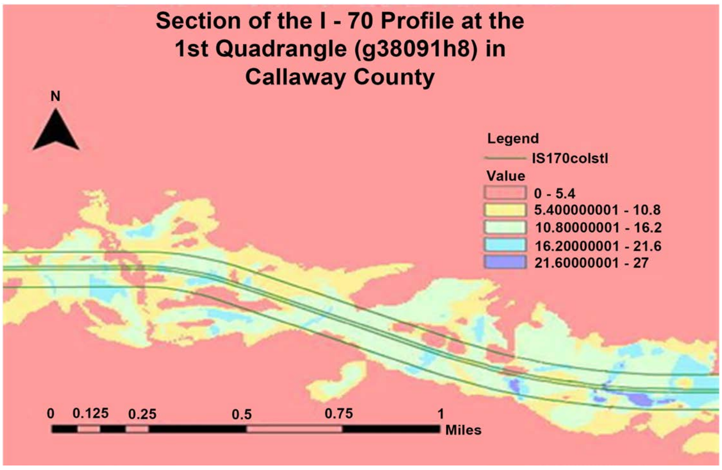

Figure 2. The I—70 Profile (Visible/Not Visible) at the 1st quadrangle in Callaway County.

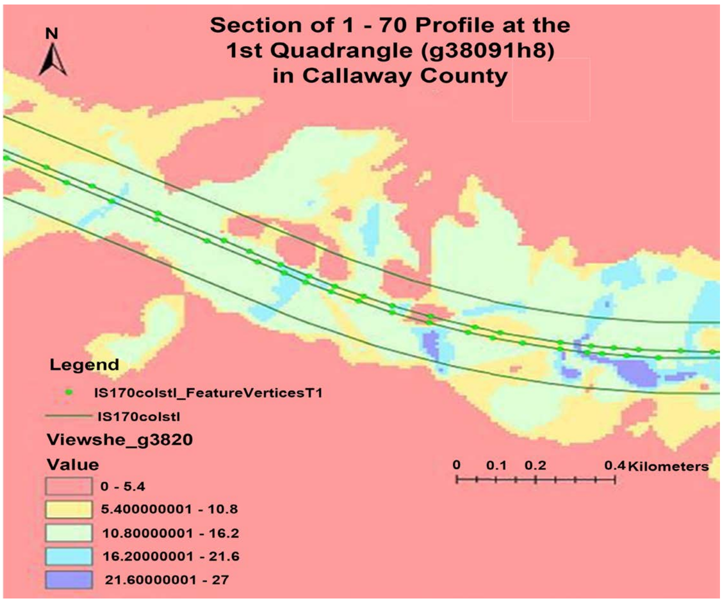

Figure 3. The classified I—70 Profile (second image) at the 1st quadrangle in Callaway County.

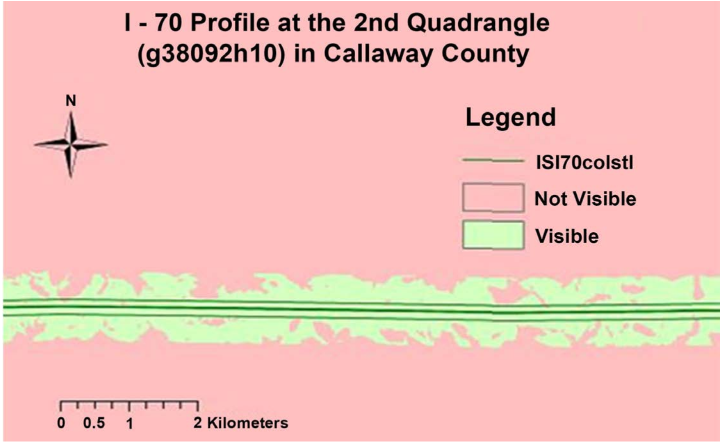

Figure 4. The I—70 Profile (Visible/Not Visible) at the 2nd quadrangle in Callaway County.

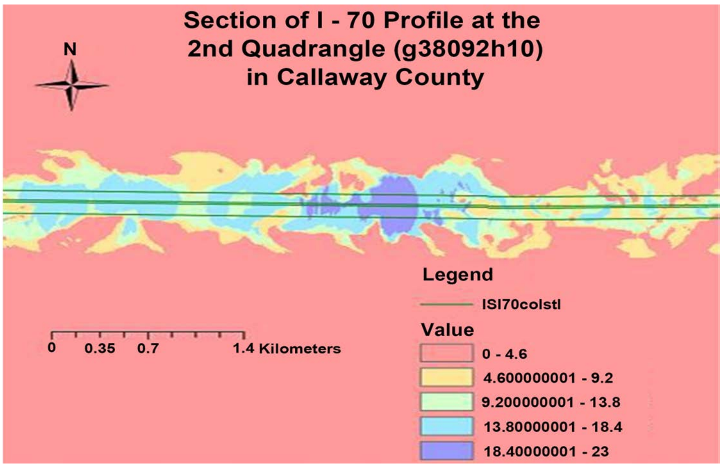

Figure 5. The I—70 classified Profile at the 2nd quadrangle in Callaway County.

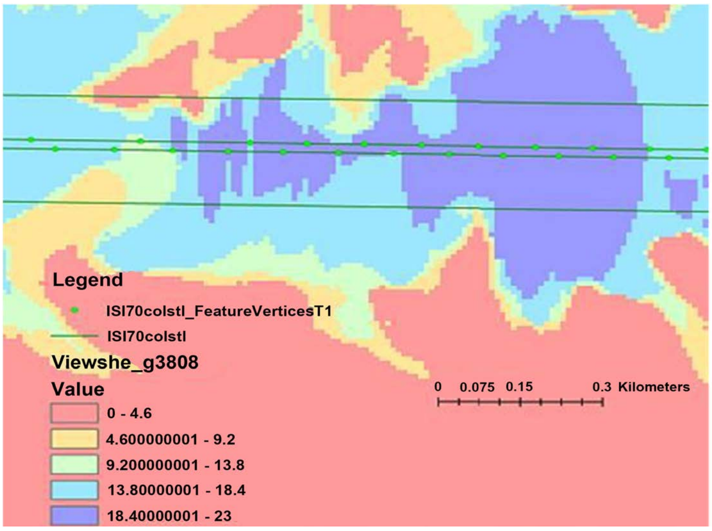

Figure 6. The I—70 classified Profile (second image) at the 2nd quadrangle in Callaway County.

Table 2. Object IDs and counts in Callaway County.

Object ID	Pixel Value	Count	Object ID	Pixel Value	Count
1	0	1,454,397	15	14	2575
2	1	5296	16	15	1467
3	2	7557	17	16	1514
4	3	6687	18	17	793
5	4	10,249	19	18	996
6	5	7817	20	19	533
7	6	8953	21	20	439
8	7	6626	22	21	280
9	8	7479	23	22	287
10	9	5466	24	23	269
11	10	6326	25	24	224
12	11	5372	26	25	83
13	12	5372	27	26	70
14	13	2887	28	27	2

Table 3. Objects and locations of insufficient sight distance at 1st quadrangle.

Object ID	Pixel Value	Geographic Coordinates of the Location (m)	
E-W Direction			
5	4	594,070.439	4,311,304.627
10	9	592,567.603	4,311,304.627
9	8	590,605.714	4,311,563.919
7	6	587,562.999	4,312,132.774
W-E Direction			
10	9	588,541.959	4,311,735.898
6	5	589,507.691	4,311,735.898
3	2	592,748.843	4,310,876.001

For the 2nd quadrangle (g38092h10, located in Callaway County), the Object IDs, the Pixel Values, and the counts are found from the attribute table of its viewshed, and as shown in **Table 4**.

The locations that did not meet the AASHTO standard stopping sight distance of 220m at the 2nd quadrangle, are shown in **Table 5**.

3.3. 3rd Quadrangle

The I—70 Profile at the 3rd quadrangle in Boone-Callaway Counties is shown in **Figure 7**.

The classified section of the I—70 Interstate Highway at the 3rd quadrangle in the Boone-Callaway Counties is shown in **Figure 8** and **Figure 9**.

Table 4. Object IDs and Counts at the 2nd quadrangle.

Object ID	Pixel Value	Count	Object ID	Pixel Value	Count
1	0	1446,655	13	12	3908
2	1	5874	14	13	3188
3	2	9128	15	14	3595
4	3	7247	16	15	3306
5	4	9042	17	16	2667
6	5	6795	18	17	1500
7	6	8777	19	18	1400
8	7	6038	20	19	1194
9	8	6728	21	20	573
10	9	5223	22	21	664
11	10	5626	23	22	177
12	11	4281	24	23	16

Table 5. Locations with insufficient sight distance at the 2nd quadrangle.

Object ID	Pixel Value	Geographic Coordinates of the Location (m)	
E-W Direction			
5	4	585,828.440	4,312,081.055
7	6	584,124.520	4,312,081.055
1	0	578,716.426	4,312,144.555
1	0	578,769.343	4,312,144.555
10	9	578,155.508	4,312,165.722
7	6	577,605.174	4,312,155.139
3	2	577,404.090	4,312,176.305
2	1	576,451.588	4,312,218.639
4	3	576,176.421	4,312,218.726
W-E Direction			
6	5	576,620.922	4,311,901.138
7	6	576,747.922	4,311,954.055
7	6	576,949.006	4,311,774.138
5	4	577,531.090	4,311,784.721
4	3	578,536.509	4,311,795.305
3	2	579,086.843	4,311,763.555

For the 3rd quadrangle (g38092h2, located between Boone-Callaway Counties), the Object IDs, the Pixel Values, and the counts were found from the attribute table of its viewshed, and as shown in Table 6.

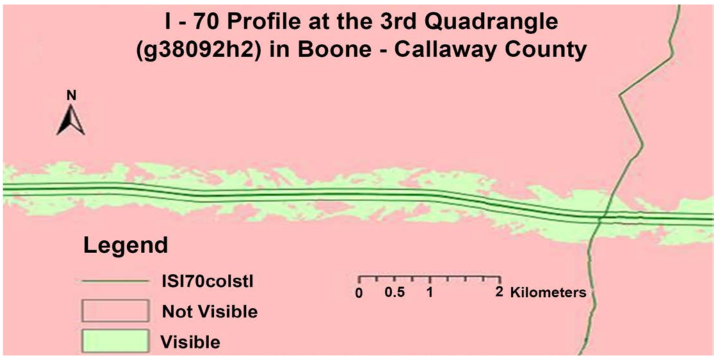

Figure 7. The I—70 Profile (Visible/Not Visible) at the 3rd quadrangle in Boone-Callaway Counties.

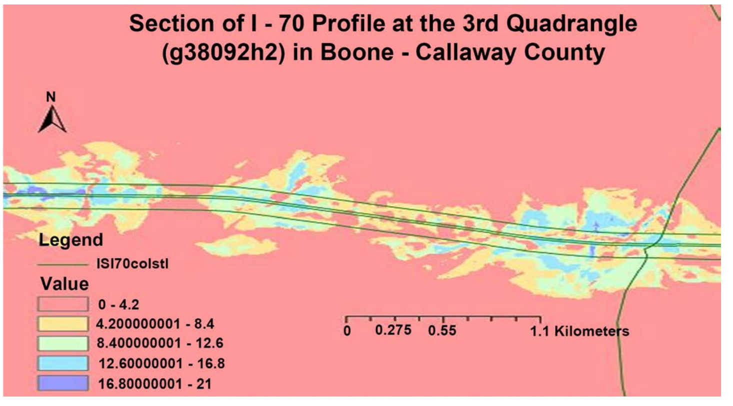

Figure 8. The I—70 classified Profile at the 3rd quadrangle in Boone-Callaway Counties.

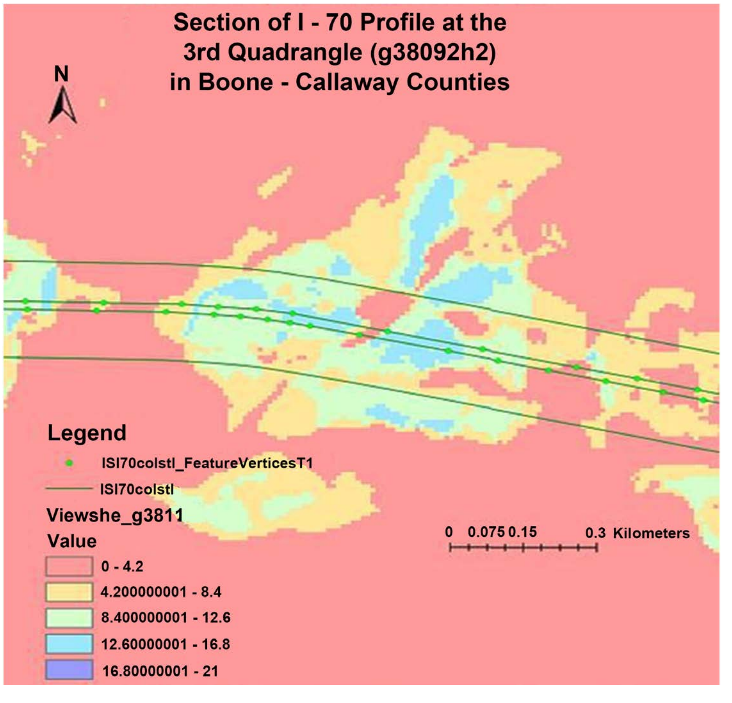

Figure 9. The I—70 classified Profile (second image) at the 3rd quadrangle in Boone-Callaway Counties.

Table 6. Object IDs and Counts at the 3rd quadrangle.

Object ID	Pixel Value	Count	Object ID	Pixel Value	Count
1	0	1,454,209	12	11	3765
2	1	6567	13	12	3177
3	2	9834	14	13	2272
4	3	7810	15	14	1999
5	4	10,174	16	15	1265
6	5	7095	17	16	834
7	6	7310	18	17	274
8	7	6295	19	18	146
9	8	7310	20	19	99
10	9	5550	21	20	55
11	10	5036	22	21	24

The locations that did not meet the AASHTO standard stopping sight distance of 220 m at the 3rd quadrangle, are shown in Table 7.

3.4. 4th Quadrangle

The I—70 Profile at the 4th quadrangle in Boone County is shown in Figure 10.

The classified section of the I—70 Interstate Highway at the 4th quadrangle in the Boone County is shown in Figure 11 and Figure 12.

For the 4th quadrangle (g38092h3, located in Boone County), the Object IDs, the Pixel Values, and the counts were found from the attribute table of its viewshed, and are shown in Table 8.

The locations that did not meet the AASHTO standard stopping sight distance of 220 m at the 4th quadrangle are shown in Table 9.

3.5. 5th Quadrangle

The I—70 Profile at the 5th quadrangle in Boone County is shown in Figure 13.

The classified section of the I—70 Interstate Highway at the 5th quadrangle in the Boone County is shown in Figure 14 and Figure 15.

For the 5th quadrangle (g38092h4, located in Boone County), the Object IDs, the Pixel Values, and the counts were found from the attribute table of its viewshed are shown in Table 10.

The locations that did not meet the AASHTO standard stopping sight distance of 220 m at the 5th quadrangle, are shown in Table 11.

3.6. 6th Quadrangle

The I—70 Profile at the 6th quadrangle in Boone-Cooper Counties is shown in Figure 16.

Table 7. Locations with insufficient sight distance at the 3rd quadrangle.

Object ID	Pixel Value	Geographic Coordinates of the Location (m)	
		E-W Direction	
3	2	574,534.162	4,312,171.232
13	12	573,391.160	4,312,255.898
3	2	573,010.159	4,312,308.815
3	2	573,010.159	4,312,298.232
5	4	571,327.406	4,312,668.649
11	10	570,237.320	4,312,689.816
8	7	568,046.566	4,312,668.649
5	4	565,675.895	4,312,763.899
4	3	565,294.894	4,312,795.650
		W-E Direction	
5	4	565,517.144	4,312,393.482
14	13	566,744.813	4,312,435.816
5	4	567,591.482	4,312,351.149
6	5	568,575.734	4,312,277.065
5	4	569,507.069	4,312,298.232
1	0	569,877.486	4,312,287.649
3	2	571,253.322	4,312,277.065
1	0	572,131.741	4,312,128.898
5	4	574,449.496	4,311,811.398
2	1	575,359.664	4,311,758.481

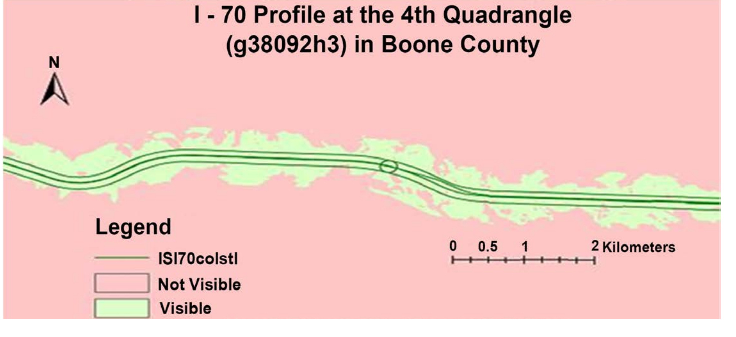

Figure 10. The I—70 Profile (Visible/Not Visible) at the 4th quadrangle in Boone County.

The classified section of the I—70 Interstate Highway at the 6th quadrangle in the Boone-Cooper Counties is shown in Figure 17-19.

For the 6th quadrangle (g38092h5, located in Boone-Cooper Counties), the Object IDs, the Pixel Values, and the counts were found from the attribute table of its viewshed, and are shown in Table 12.

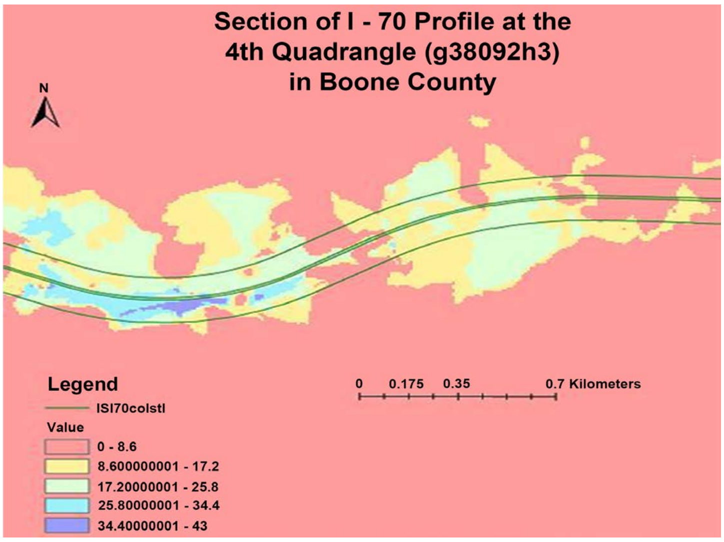

Figure 11. The I—70 classified Profile at the 4th quadrangle in Boone County.

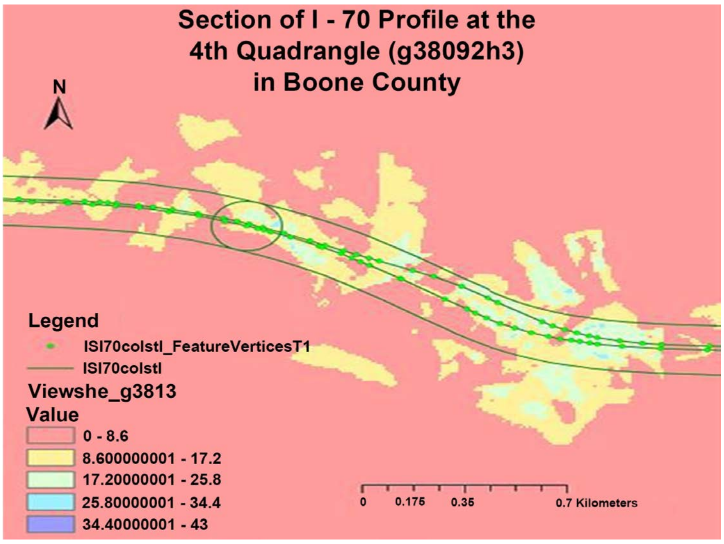

Figure 12. The I—70 classified Profile (second image) at the 4th quadrangle in Boone County.

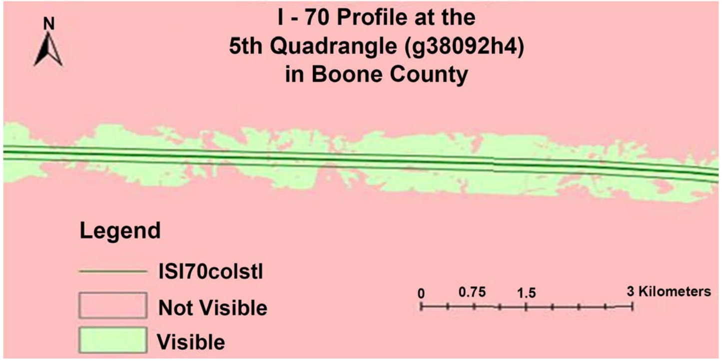

Figure 13. The I—70 Profile (Visible/Not Visible) at the 4th quadrangle in Boone County.

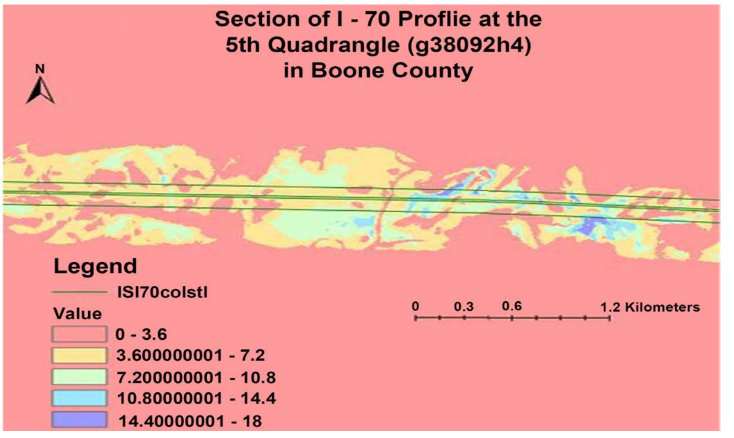

Figure 14. The I—70 classified Profileat the 5th quadrangle in Boone County.

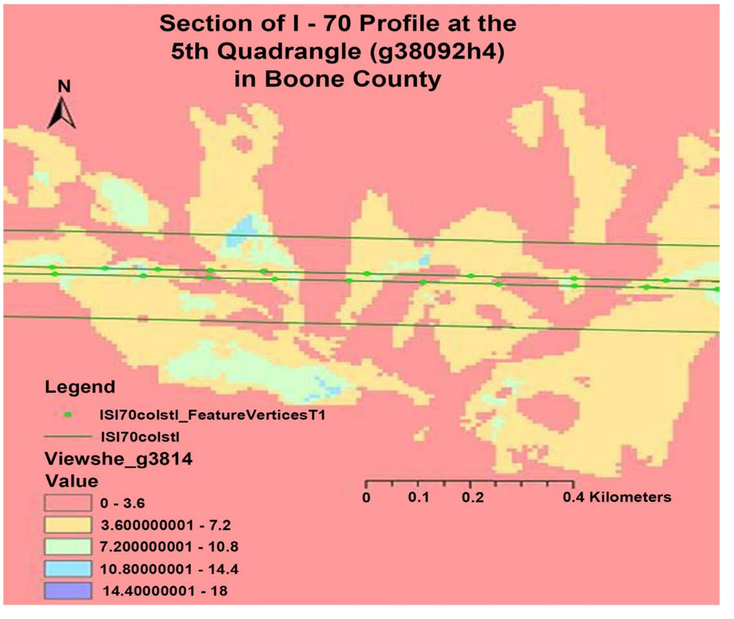

Figure 15. The I—70 classified Profile (second image) at the 5th quadrangle in Boone County.

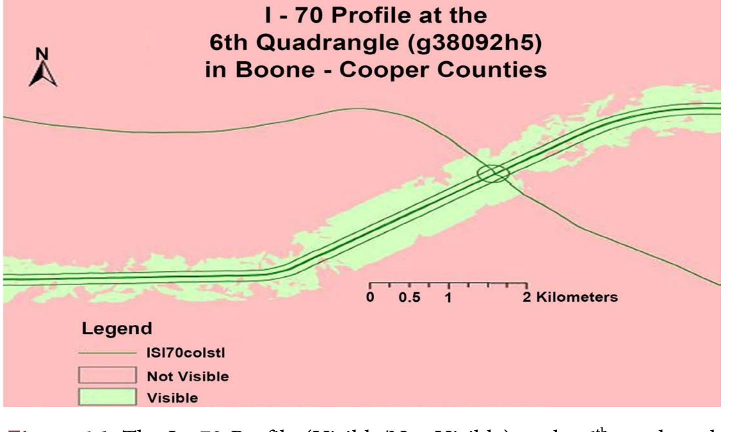

Figure 16. The I—70 Profile (Visible/Not Visible) at the 6th quadrangle in Boone-Cooper Counties.

Table 8. Object IDs and Counts at the 4th quadrangle.

Object ID	Pixel Value	Count	Object ID	Pixel Value	Count
1	0	1,455,300	23	22	747
2	1	5453	24	23	397
3	2	8129	25	24	249
4	3	7526	26	25	224
5	4	7179	27	26	171
6	5	7177	28	27	202
7	6	5648	29	28	117
8	7	5522	30	29	113
9	8	4985	31	30	97
10	9	4005	32	31	45
11	10	3136	33	32	52
12	11	3430	34	33	32
13	12	2625	35	34	29
14	13	2162	36	35	25
15	14	1667	37	36	15
16	15	1480	38	37	7
17	16	1574	39	38	9
18	17	1482	40	39	8
19	18	1573	41	40	18
20	19	1465	42	41	24
21	20	1312	43	42	33
22	21	650	44	43	8

Table 9. Locations with insufficient sight distance at the 4th quadrangle.

.Object ID	Pixel Value	Geographic Coordinates of the Location (m)	
		E-W Direction	
9	8	564,484.794	4,312,796.278
3	2	563,860.376	4,312,828.028
1	0	563,341.792	4,312,859.778
6	5	562,706.790	4,312,859.778
14	13	561,775.455	4,312,912.695
1	0	560,600.703	4,313,230.196
12	11	560,240.869	4,313,463.029
1	0	559,563.534	4,313,653.530
7	6	558,579.282	4,313,695.863
		W-E Direction	
6	5	556,250.944	4,313,092.612
10	9	557,256.363	4,313,367.779
1	0	557,563.280	4,313,357.196
8	7	558,653.366	4,313,293.696
1	0	559,309.534	4,313,261.946
5	4	559,859.868	4,313,177.279
3	2	560,367.869	4,312,912.695
2	1	561,457.955	4,312,574.028

Table 10. Object IDs and Counts at the 5th quadrangle.

Object ID	Pixel Value	Count	Object ID	Pixel Value	Count
1	0	1,444,159	11	10	2337
2	1	9470	12	11	1253
3	2	12,220	13	12	824
4	3	10,870	14	13	475
5	4	12,793	15	14	249
6	5	10,557	16	15	170
7	6	9428	17	16	125
8	7	6862	18	17	30

Table 11. Locations with insufficient sight distance at the 5th quadrangle.

Object ID	Pixel Value	Geographic Coordinates of the Location (m)	
		E-W Direction	
3	2	553,098.683	4,313,800.369
2	1	552,103.848	4,313,885.036
1	0	552,082.681	4,313,874.453
1	0	549,786.093	4,313,990.870
2	1	548,558.424	4,314,012.036
1	0	548,209.173	4,314,012.036
2	1	547,743.506	4,314,033.203
2	1	545,838.502	4,314,086.120
10	9	545,108.250	4,314,075.536
8	7	543,446.664	4,314,160.203
		W-E Direction	
1	0	544,430.916	4,313,736.869
1	0	544,759.000	4,313,726.286
6	5	545,870.252	4,313,705.119
1	0	548,188.006	4,313,620.452
3	2	549,299.259	4,313,599.285
2	1	550,040.094	4,313,556.952
1	0	551,701.680	4,313,504.035
2	1	553,119.850	4,313,398.202

Table 12. Object IDs and Counts at the 6th quadrangle.

Object ID	Pixel Value	Count	Object ID	Pixel Value	Count
1	0	1,428,067	11	10	7063
2	1	7641	12	11	4147
3	2	10,903	13	12	3441
4	3	8864	14	13	2200
5	4	10,727	15	14	2005
6	5	9442	16	15	767
7	6	9873	17	16	190
8	7	7181	18	17	91

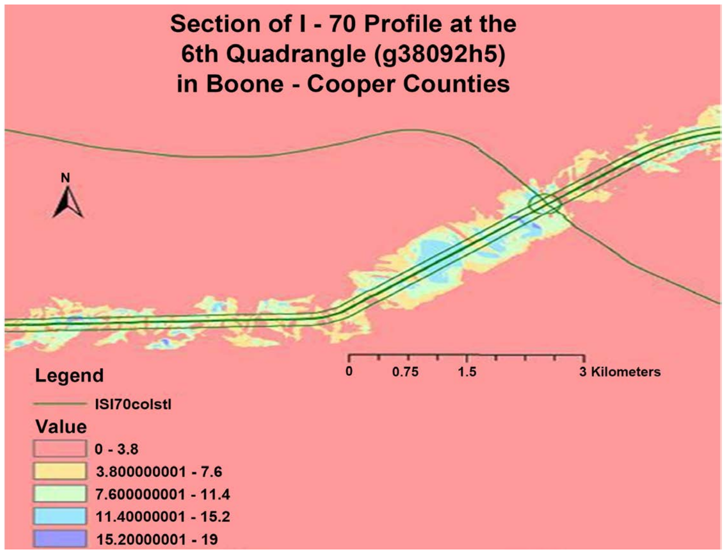

Figure 17. The I—70 classified Profileat the 6th quadrangle in Boone-Cooper Counties.

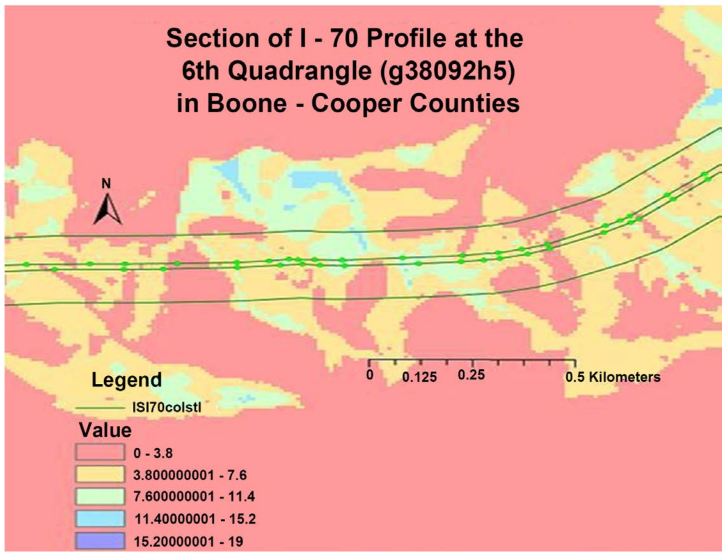

Figure 18. The I—70 classified Profile (second image) at the 6th quadrangle in Boone-Cooper Counties.

The locations that did not meet the AASHTO standard stopping sight distance of 220 m at the 6th quadrangle, are shown in Table 13.

4. Conclusions

Stopping Sight Distance is a measure of the road visibility and is defined as the length of roadway ahead that is visible to the driver. This distance allows a driver to see an object in the roadway and stop their vehicle before colliding with the object. A roadway should be designed to provide continuous stopping sight distance throughout the route. Sight distance criteria have impact on virtually all elements of highway design and many elements of the traffic operation, control,

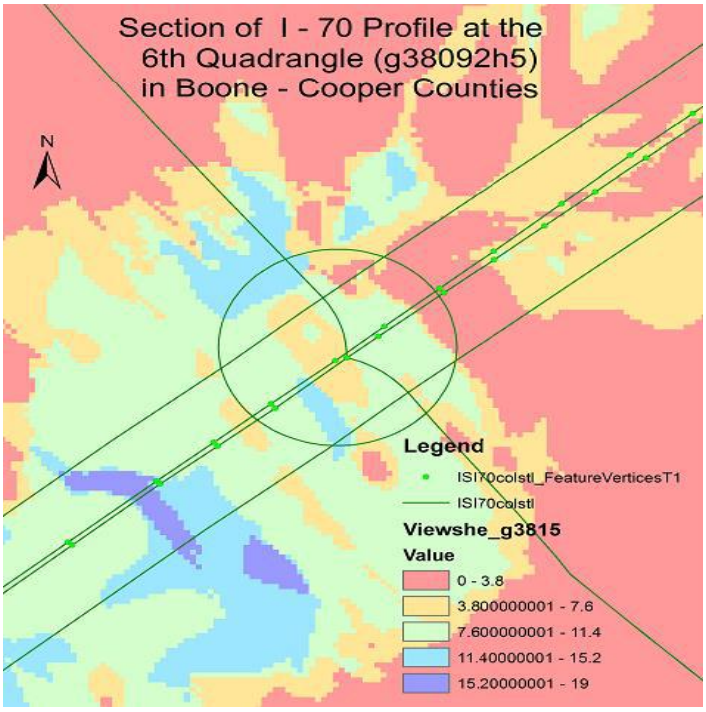

Figure 19. The I—70 classified Profile (third image) at the 6th quadrangle in Boone-Cooper Counties.

Table 13. Locations with insufficient sight distance at the 6th quadrangle.

Object ID	Pixel Value	Geographic Coordinates of the Location (m)	
		E-W Direction	
5	4	540,590.674	4,313,656.531
2	1	540,299.631	4,313,365.489
1	0	540,233.485	4,313,325.801
3	2	539,717.547	4,312,915.696
2	1	532,600.241	4,310,322.774
		W-E Direction	
1	0	532,798.679	4,309,859.753
2	1	533,830.556	4,309,846.524
3	2	535,920.769	4,309,965.586
5	4	536,754.208	4,309,965.586
1	0	539,915.985	4,312,465.904
1	0	540,352.548	4,312,862.780
1	0	540,431.923	4,312,902.467
3	2	540,696.507	4,313,167.051
5	4	542,971.928	4,313,749.136

and their effects on traffic stream conditions. A methodology was presented in this paper to evaluate the current existing sight distances at portions of the I70 interstate highway in the State of Missouri within the Callaway, Boone, and

Cooper counties. The method used hereby utilized the GIS capability of analyzing the visibility of a line or area through creating viewsheds for six quadrangles along the I70 alignment. A standard AASHTO stopping sight distance of 730 ft (220 m) was compared to the existing sight distances, and the IDs and coordinates of the points that did not meet the AASHTO requirements were identified. The steps used to generate the viewsheds and profile maps of the I70 interstate highway were as follows:

- Importing the E00 interchange files into GIS coverage files
- Densifying the I70 raster
- Converting the Vertices of I70 Features to Points
- Adding new parameters to the attribute table of the point's raster that control the visibility analysis in the viewsheds. These parameters were (OFFSET A = 1.08 m presenting the height of the driver's eye recommended by AASHTO, OFFSET B = 0.6 m presenting the height of object above the road surface recommended by AASHTO, AZIMUTH 1 = 0, AZIMUTH 2 = 180 degrees, Vertical Angle 1 = +90 degrees, Vertical Angle 2 = −90 degrees, RADIUS 1 = 0, RADIUS 2 = 560 m presenting the radius of curvature recommended by AASHTO).
- Creating viewsheds for all points of the I70 point's raster at once
- Buffering the DEMs by a distance of 200 m
- Clipping the DEMs by the road buffers
- Connecting the buffered-clipped DEMs of all segments together by Mosaic tools
- Generating the I70 profiles, and classified maps from the viewshed's raster's
- Identifying the IDs, and the geographic coordinates of all the points along the highway that did not meet the AASHTO recommended sight distance of 220 m

This method can be considered as a relevant aid for assessing geometric consistency of the I70 interstate highway and/or similar roads, because it identifies adjacent segments of the road layout that offer considerably different sight distances. In addition, the stopping sight distance profile presented in this paper can also be a useful tool for understanding location-based risks of limited stopping sight distance. The profile shows the spots of insufficient stopping sight distance along the roadway, thereby illustrating the sight distance restrictions and where they occur. This information can help designers understand the severity of a sight distance restriction, how the restriction may interact with other roadway conditions or features, and how/where to implement mitigation strategies. The method presented in this paper can be further expanded to include other types of highway sight distances, such as the passing sight distances, and the decision sight distances which are classified as important highway design criteria besides the stopping sight distances presented hereby. Also, additional portions of the I70 alignment can be added for the purpose of sight distance evaluation. Crash analysis at the locations that did not meet the AASHTO sight distance requirements can be further conducted for enhancing the safety at these locations.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] American Association of State Highway and Transportation Officials (AASHTO) (2011) A Policy on Geometric Design of Highways and Streets. Washington DC.

[2] Azimi, M. and Hawkins, H. (2013) Algorithm for Analyzing Horizontal Sight Distance from Lane Centerline Coordinates. *Transportation Research Record*: *Journal of the Transportation Research Board*, **2358**, 12-19. https://doi.org/10.3141/2358-02

[3] Ben-Arieh, D., Chang, S., Rys, M. and Zhang, G. (2004) Geometric Modeling of Highways Using Global Positioning System Data and B-Spline Approximation. *Journal of Transportation Engineering*, **130**, 632-636. https://doi.org/10.1061/(ASCE)0733-947X(2004)130:5(632)

[4] Cai, H. and Rasdorf, W. (2008) Modeling Road Centerlines and Predicting Lengths in 3-D Using LIDAR Point Cloud and Planimetric Road Centerline Data. *Computer-Aided Civil and Infrastructure Engineering*, **23**, 157-173. https://doi.org/10.1111/j.1467-8667.2008.00518.x

[5] Abdulhafedh, A. (2017) Identifying Vehicular Crash High Risk Locations along Highways via Spatial Autocorrelation Indices and Kernel Density Estimation. *World Journal of Engineering and Technology*, **5**, 198-215. https://doi.org/10.4236/wjet.2017.52016

[6] Castro, M., Iglesias, L., Rodríguez-Solano, R. and Sánchez, J.A. (2006) Geometric Modelling of Highways Using Global Positioning System (GPS) Data and Spline Approximation. *Transportation Research Part C—Emerging Technologies*, **14**, 233-243. https://doi.org/10.1016/j.trc.2006.06.004

[7] Fisher, P.F. (1996) Extending the Applicability of Viewsheds in Landscape Planning. *Photogrammetric Engineering and Remote Sensing*, **62**, 1297-1302.

[8] Imran, M., Hassan, Y. and Patterson, D. (2006) GPS-GIS-Based Procedure for Tracking Vehicle Path on Horizontal Alignments. *Computer-Aided Civil and Infrastructure Engineering*, **21**, 383-394. https://doi.org/10.1111/j.1467-8667.2006.00444.x

[9] Khattak, A.J. and Shamayleh, H. (2005) Highway Safety Assessment through Geographic Information System-Based Data Visualization. *Journal of Computing in Civil Engineering*, **19**, 407-411. https://doi.org/10.1061/(ASCE)0887-3801(2005)19:4(407)

[10] Kitzpatrick, K., Fambro, D.B. and Stoddard, A.M. (2000) Safety Effects of Limited Stopping Sight Distance on Crest Vertical Curves. *Transportation Research Record*: *Journal of the Transportation Research Board*, **1701**, 17-24. https://doi.org/10.3141/1701-03

[11] Abdulhafedh, A. (2017) A Novel Hybrid Method for Measuring the Spatial Autocorrelation of Vehicular Crashes: Combining Moran's Index and Getis-Ord G_i Statistic. *Open Journal of Civil Engineering*, **7**, 208-221. https://doi.org/10.4236/ojce.2017.72013

[12] Nehate, G. and Rys, M. (2006) 3D Calculation of Stopping-Sight Distance from GPS Data. *Journal of Transportation Engineering*, **132**, 691-698. https://doi.org/10.1061/(ASCE)0733-947X(2006)132:9(691)

[13] Polus A., Livneh, M. and Frischer B. (2000) Evaluation of the Passing Process on Two-Lane Rural Highways. *Transportation Research Record*: *Journal of the Transportation Research Board*, **1701**, 53-60. https://doi.org/10.3141/1701-07

[14] Rose, E.R., Hawkins, H.G., Holick, A.J. and Bligh, R.P. (2004) Evaluation of Traffic Control Devices: First Year Activities. FHWA/TX-05-0-4701-1, Texas Transportation Institute.

[15] Berbel, D.C., Castro, M., Medina. L.C. and Maria, S.P.G. (2014) Sight Distance Studies on Roads: Influence of Digital Elevation Models and Roadside Elements. *Procedia—Social and Behavioral Sciences*, **160**, 449-458. https://doi.org/10.1016/j.sbspro.2014.12.157

[16] Abdulhafedh, A. (2017) How to Detect and Remove Temporal Autocorrelation in Vehicular Crash Data. *Journal of Transportation Technologies*, **7**, 133-147. https://doi.org/10.4236/jtts.2017.72010

[17] Shaker, A., Yan, W.Y. and Easa, S. (2011) Construction of Digital 3D Highway Model Using Stereo IKONOS Satellite Imagery. *Geocarto International*, **26**, 49-67. https://doi.org/10.1080/10106049.2010.537785

[18] Tsai, Y., Hu, Z. and Wang, Z. (2010) Vision-Based Roadway Geometry Computation. *Journal of Transportation Engineering*, **136**, 223-233. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000073