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A Novel GIS Approach for Locating No-Passing Zones and Assessing Passing Sight Distance on Two-Lane, Two-Way Highways: A Case Study of MO Route 5 in the State of Missouri, USA

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Abstract

On two-lane, two-way highways faster vehicles frequently overtake slower moving vehicles. In order to secure a safe passing maneuver, the passing driver should be able to see a sufficient distance ahead, clear of traffic, to complete the passing maneuver without cutting off the passed vehicle before meeting an opposing vehicle. This is called the minimum recommended passing sight distance ahead, which is considered as an important factor in the marking of passing zones and no-passing zones along two-lane, two-way highways. In this paper, a novel Geographic Information System (GIS)-based viewshed analysis is developed to assess existing passing sight distances on two-lane, two-way highways using the American Association of State Highway and Transportation Officials (AASHTO) criteria. This new approach is extremely beneficial in that passing sight distance can be rapidly estimated for highways over a large geographic extent without using the traditional field methods, such as the two-vehicle method or putting personnel at risk. The developed method was applied to evaluate passing sight distance on Missouri Route-5, a two-lane, two-way highway in the state of Missouri, USA. The results indicate that the developed approach provides a precise assessment of passing sight distance, and effectively locates the passing zones and no-passing zones along the highway.

Subject Areas

Transportation Engineering

Keywords

GIS Viewsheds, Passing Sight Distance, No-Passing Zones, AASHTO Criteria

for Passing Maneuver

1. Introduction

Passing sight distance (PSD) is the distance that drivers must be able to see along the road ahead to safely and efficiently initiate and complete passing maneuvers of slower vehicles on two-lane, two-way highways using the lane normally reserved for opposing traffic [1] [2]. PSD is a consideration along two-lane, two-way roads on which drivers may need to assess whether to initiate, continue, and complete or abort passing maneuvers. In the US, a high percentage of roads are two-lane, two-way highways on which faster vehicles frequently overtake slower moving vehicles. In order to secure a safe passing maneuver, the passing driver should be able to see a sufficient distance ahead, clear of traffic, to complete the passing maneuver without cutting off the passed vehicle before meeting an opposing vehicle [1] [2] [3] [4] [5]. Therefore, passing sight distance is considered an important factor in both the design of two-lane, two-way (TLTW) highways and the marking of passing zones (PZ) and no-passing zones (NPZ) on two-lane, two-way highways. The efficiency of traffic operation of many two-lane, two-way highways depends on how often faster drivers are able to pass slower drivers. For example, where faster drivers encounter a slower driver but are unable to pass, vehicle platoons are built up, and cause a decrease in the level of service and inversely affect safety, fuel consumption and emissions. The capacity of a two-lane, two-way road is increased if a large percentage of the roadway's length can be used for passing maneuvers [5]. There is no need to consider passing sight distance on multilane highways that have two or more traffic lanes in each direction of travel, because passing maneuvers are expected to occur within the limits of the traveled way for each direction of travel. However, multilane roadways should have continuously adequate stopping sight distance, with greater-than-design stopping sight distances [1] [2] [3] [4] [5]. In the US, the design of two-lane highway is based on AASHTO Green book criteria, however, the marking of passing zones and no-passing zones is based on the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) criteria. The use of separate PSD criteria for design and marking is justified based on different needs in design and traffic operation [4] [5]. However, since the current US highway system operates with relatively low level of crashes related to passing maneuvers and PSD, which indicates that the highway system can be operated safely with passing and no-passing zones marked with the current MUTCD criteria, therefore changing the current MUTCD PSD criteria to equal the AASHTO criteria, or some intermediate value, is not recommended because it would decrease the frequency and length of passing zones on two-lane, two-way highways. This would decrease the traffic level of service and might encourage illegal passes at locations where passing maneuvers are currently legal [6]. As such, the AASHTO Green Book has adapted the MUTCD PSD values for the design of two-lane, two-way highways. AASHTO Green book uses both the height of the driver's eye and the object height as 1.08 m (3.5 ft) above the road surface [4] [5]. This object height is based on a vehicle height of 1.33 m (4.35 ft), which represents the 15th percentile of vehicle heights in the current passenger car population, less an allowance of 0.25 m (0.85 ft), which is a near-maximum value for the portion of the vehicle height that needs to be seen for another driver to recognize a vehicle. The choice of an object height equal to the driver eye height makes design of passing sight distance reciprocal (*i.e.*, when the driver of the passing vehicle can see the opposing vehicle, the driver of the opposing vehicle can also see the passing vehicle). Passing sight distances calculated on this basis are also considered adequate for night conditions because headlight beams of an opposing vehicle generally can be seen from a greater distance than a vehicle can be recognized in the daytime [1] [2] [3] [4] [5]. While there may be occasions, where multiple passing occurs when two or more vehicles pass a single vehicle, or a single vehicle passes two or more vehicles. However, it is not practical to assume such conditions in developing minimum passing sight distance criteria. Instead, PSD is determined for a single vehicle passing a single vehicle [5]. Longer passing sight distances are recommended in the design and these locations can accommodate for an occasional multiple passing. AASHTO Green book uses two theoretical models for the sight distance needs of passing drivers based on the assumption that a passing driver will abort the passing maneuver and return to his or her normal lane behind the overtaken vehicle if a potentially conflicting vehicle comes into view before reaching a critical position in the passing maneuver beyond which the passing driver is committed to complete the maneuver. The first model is called the Glennon 1998 model that assumes that the critical position occurs where the passing sight distance to complete the maneuver is equal to the sight distance needed to abort the maneuver [7]. The second model is called the Hassan *et al.* 1996 model, which assumes that the critical position occurs where the passing sight distances to complete or abort the maneuver are equal or where the passing and passed vehicles are abreast, whichever occurs first [8]. The following assumptions are made regarding the driver behavior in the passing maneuvers and PSD calculations based on the Glennon (1998) and Hassan *et al.* (1996) models [1] [2] [3] [4] [5]:

- The speeds of the passing and opposing vehicles are equal to the design speed.
- The overtaken vehicle travels at uniform speed.
- The Speed differential between the passing and overtaken vehicles is 19 km/h (12 mph).
- The passing vehicle has sufficient acceleration capability to reach the specified speed differential relative to the overtaken vehicle by the time it reaches the critical position, which generally occurs about 40 percent of the way through the passing maneuver.
- The lengths of the passing and overtaken vehicles are 5.8 m (19.0 ft).
- The passing driver's perception-reaction time in deciding to abort passing a

vehicle is 1.0 sec.

- If a passing maneuver is aborted, the passing vehicle will use a deceleration rate of 3.4 m/s^2 (11.2 ft/s^2), the same deceleration rate used in stopping sight distance criteria.
- For a completed or aborted pass, the space headway between the passing and overtaken vehicles is 1.0 sec.
- The minimum time clearance between the passing and opposed vehicles at the point at which the passing vehicle returns to its normal lane is 1.0 sec.

The latest AASHTO Green Book (2018) does not provide specific formulae for calculating the required PSD, however, previous version of the Green Book (AASHTO 2001 and 2004) used the minimum passing sight distance for TLTW highways as the sum of the following four distances:

1) d_1 = Distance traversed during perception and reaction time and during the initial acceleration to the point of encroachment on the opposing lane, and is calculated as follows:

$$d_1 = 0.278 t_i \left[v - m + \left(a t_i / 2 \right) \right] \quad (1)$$

where;

t_i = time of initial maneuver, ranges from (3.6 to 4.5) sec,

a = average acceleration, ranges from (2.25 to 2.41) km/h/s,

v = average speed of passing vehicle (km/h),

m = difference in speed of overtaken vehicle and passing vehicle (km/h).

2) d_2 = Distance traveled while the passing vehicle occupies the left lane, and is determined as follows:

$$d_2 = 0.278 v t_2 \quad (2)$$

where;

t_2 = time passing vehicle occupies the left lane, ranges from (9.3 to 11.3) sec,

v = average speed of passing vehicle (km/h).

3) d_3 = Distance between the passing vehicle at the end of its maneuver and the opposing vehicle (the clearance length), ranges from (30.0 to 90.0) m.

4) d_4 = Distance traversed by an opposing vehicle for two-thirds of the time the passing vehicle occupies the left lane, or 2/3 of d_2 above, and ranges from (97.0 to 209.0) m.

Table 1 shows the minimum values of PSD required for the design of two-lane highways based on AASHTO Green Book of 2018.

Each passing zone along a length of roadway with sight distance ahead should be equal to or greater than the minimum passing sight distance as long as practical. The criteria for marking passing and no-passing zones on two-lane highways are established by MUTCD [9]. Passing zones are not marked directly. Rather, the warrants for no-passing zones are set by MUTCD, and passing zones merely happen where no-passing zones are not warranted. Table 2 shows the MUTCD PSD warrants for no-passing zones. These criteria are based on prevailing off-peak 85th-percentile speeds rather than the design speeds.

Table 1. Minimum PSD values for design of two-lane highways.

Design Speed (km/h)	Assumed Speeds (km/h)		Minimum Passing Sight Distance (m)
	Overtaken Vehicle	Passing Vehicle	
30	11	30	120
40	21	40	140
50	31	50	160
60	41	60	180
70	51	70	210
80	61	80	245
90	71	90	280
100	81	100	320
110	91	110	355
120	101	120	395
130	111	130	440

Source: AASHTO Green Book, 2018.

Table 2. MUTCD warrants for NPZs.

85th percentile speed Limit (km/h)	Minimum Passing Sight Distance (m)
40	140
50	160
60	180
70	210
80	245
90	280
100	320
110	355
120	395
130	440

Source: MUTCD, 2009, 2012.

MUTCD uses a minimum passing zone length of 120 m to 240 m (400 ft to 800 ft) depending on the 85th percentile speed limit, (*i.e.*, where two no-passing zones come within 120 m to 240 m of one another, the no-passing barrier stripe should be continued between them). Table 3 shows the minimum passing zone Lengths to be Included in marking of PZs and NPZs [4].

2. Methodology

Viewshed analysis in GIS calculates the visible surface from a given observer point over a digital elevation model. The viewshed analysis in a GIS environment

Table 3. Minimum lengths of PZs.

85th Percentile Speed Limit (km/h)	Minimum Passing Zone Length (m)
40	140
50	180
60	210
70	240
80	240
90	240
100	240
110	240
120	240

Source: MUTCD, 2009, 2012.

typically evaluates raster-based elevation data, such as digital elevation model (DEM), to determine which cells are visible from a particular location. Digital elevation models are used to represent topographic surfaces in digital form, specifically to a raster or regular grid of spot heights. The resolution, or the distance between adjacent grid points, is an important parameter of any DEM. The best resolution commonly available is 30 m. Each raster cell is denoted by its column and row number, relative to a reference X and Y coordinate. Each raster cell is associated with a single attribute, such as elevation in the case of a DEM. The width of the raster cells denotes the spatial resolution of the dataset. To create a viewshed for determining the visibility between an observer location and a target point on the Earth's surface, all cells along the line-of-sight (LOS) from an observer's location and a target's location must be identified. Once the raster cells along the line-of-sight have been determined, the elevation value of each cell is loaded into an array, which holds the elevation values of the terrain profile between the two points. However, the LOS does not necessarily cross each cell at its center, with the exception of the beginning and end cells. Therefore, the terrain profile may be further refined by interpolating the elevation value at the approximate location at which the LOS enters and leaves each cell. After the cells underneath the LOS are selected and the elevation values are determined in a chosen geographic coordinate system, these values can then be used to create the terrain profile needed for determining visibility of the target from the observer, and a viewshed is created [10]-[28]. In order to conduct the assessment of the sight distance analysis of locations along two-lane highways, DEMs are needed as well as a representation of the road network to provide information on the trajectories that vehicle must follow when traveling along a highway. DEMs are often publicly available online in a variety of formats and spatial resolutions for most areas within the U.S. The following steps are used to generate viewsheds:

- Derive a set of observer points along a roadway from which passing sight distance will be evaluated.

    - Densification of road segments: for each segment of the roadway, vertices are added such that the distance between each vertex and the next one is not more than the AASHTO recommended passing sight distance, as shown in **Figure 1**. For instance, given a road segment that is 1050 m long, with a speed of 70 km/h and an AASHTO passing sight distance of 210 m, 5 vertices (*i.e.*, 1050/210) would be added to the line so that there is at least one vertex every 210 m.
    - Convert segment vertices to points: for each road segment, all vertices are extracted and rendered as point features. The resulting points are then used as possible locations from which drivers may view the landscape while driving.
- Determine the roadway analysis region: the region around each road to be analyzed should be sized according to how it is assumed features off the roadway are expected to impact visibility. For instance, it could be assumed that features more than 200 m from a road segment likely would not have a large impact on sight distance, etc.
    - To obtain this analysis region, the road segments can be transformed into polygons through a buffer transformation using a GIS. For example, the segments could be buffered by 200.0 m so as to define the areas of interest.
- Extract portions of DEMs within the analysis region: given that, DEMs can be large and present a computational burden, only those portions of the DEMs corresponding with the analysis region are retained for analysis. This can be done by clipping the DEMs by the road buffer.
- Combine the portions of the DEMs within the analysis region: in cases where more than one DEM is needed to evaluate roadway sight distance, all of the portions of the DEMs falling within the analysis region can be combined together into a single seamless DEM termed a Mosaic that can minimize the abrupt changes along the boundaries of the overlapping raster.
- Creating viewsheds: using the mosaicked DEMs, the observer points, and assuming the heights of the driver and an object on the road, viewsheds can be generated. In particular, the following parameters must be specified before creating the viewsheds, as shown in **Figure 2** and **Figure 3**.

1) Observer Height = represents the height of the driver's eye above the road surface for each observer point. AASHTO recommends 1.08 meter as an observer height for the passing sight distance.

2) Object Height = represents the height of a visible object above the road surface. AASHTO recommends 1.08 meter as an object height for the passing sight distance.

3) Start Azimuth = represents the start horizontal angle of the scan range for the observer. A 0.0 degree is used in this paper for passing sight distances.

4) End Azimuth = represents the end horizontal angle of the scan range for the observer. A 180.0 degree is used in this paper for passing sight distances.

5) Upper Vertical = represents the upper vertical angle of the scan for the observer. A 90.0 degree is used for passing sight distances.

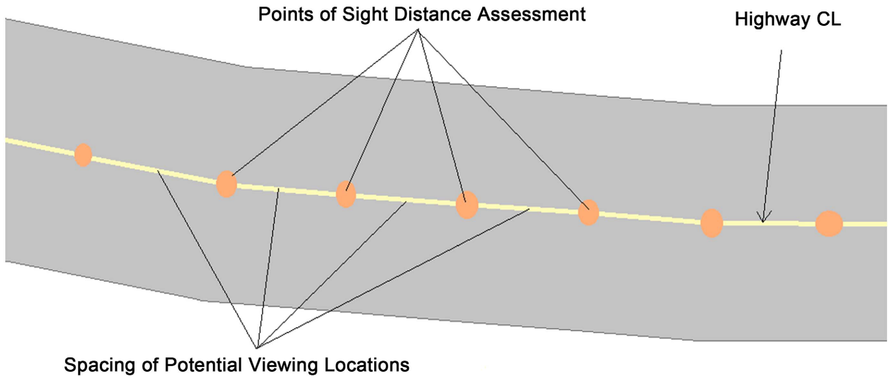

Figure 1. Observer points in viewshed analysis.

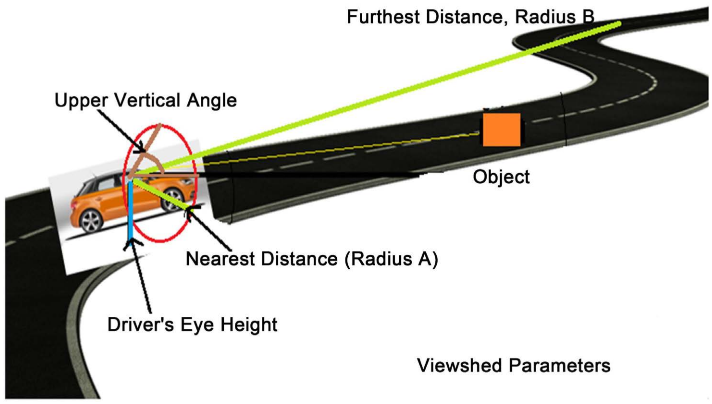

Figure 2. Viewshed analysis parameters.

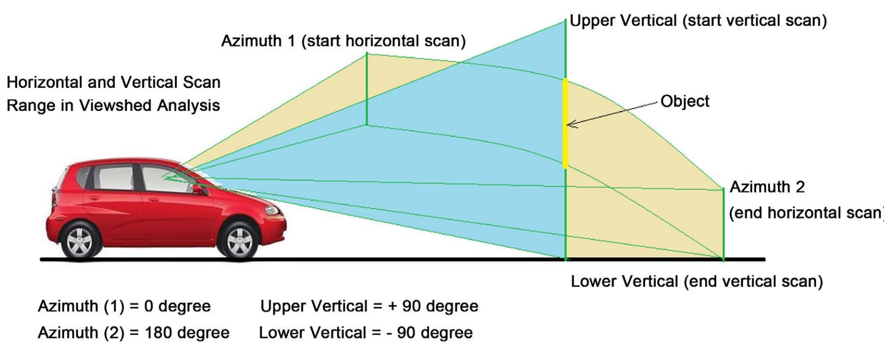

Figure 3. Driver's viewshed horizontal and vertical scans.

6) Lower Vertical = represents the lower vertical angle of the scan for the observer. A negative 90.0 degree is used for passing sight distances.

7) Nearest Distance = represents the closest location that can be viewed by the observer. A 0.0 meter is used in this paper for passing sight distances.

8) Furthest Distance = represents the farthest location that can be viewed by the observer. This value could be infinity or any reasonable number that the driver's eye can see at farthest possible point. A value of 1000 meter is used for passing sight distances.

- To incorporate the passing sight distance in the methodology, the viewsheds created in the previous steps were classified into segments that conform to AASHTO passing sight distance (*i.e.*, Passing Zones PZ) and segments that may not conform to AASHTO passing sight distance (*i.e.*, No-Passing Zones NPZ). PZs are those with available sight distances that are equal or greater than the AASHTO passing sight distance criteria, and the NPZs are those with available passing sight distance that are less than the AASHTO passing sight distance, as shown in **Figure 4**.

3. A Case Study: Missouri Route-5

Since the passing sight distance is only applied in practice on two-lane highways, therefore Missouri Route-5 (MO Route-5), a two-lane highway, is used to assess the PSD as a study site. MO Route-5 is the longest two-lane, two way highway in the state of Missouri, USA with a total length of 571 km (355 mile) that traverses the entire state from north to south, as shown in **Figure 5**. The GIS MO Route-5 data were obtained from Missouri Spatial Data Information Service (MSDIS). The Digital Elevation Models were used to assess passing sight distance and locating the passing and no-passing zones along the MO Route-5. The resolution of the DEMs was 30 m × 30 m (with 2100 row by 2100 column). There were thirteen DEMs that covered the length of MO Route-5. The number of observer points generated for passing sight distance (using a maximum point spacing of 320 m) along MO Route-5 was 2104. Vertices are added to MO Route-5 segments such that each vertex is no more than 320.0 m from the next vertex. This distance represents the recommended AASHTO passing sight distance, which corresponds to an average speed limit of 100 km/h (60 mph) along MO Route-5.

4. Results and Discussion

The basic output for viewshed analysis is a visibility map, in raster format, which classifies the terrain surrounding an observation point into visible and not visible (true/false or 1/0). Thus, the viewshed analysis resulted in two classifications of segments regarding the PSD. The length of each classification is measured from the latitude and longitude of a start point till the latitude and longitude of an end point. The two classification segments are as follows:

1) segments having passing sight distance that conform to the AASHTO PSD standards throughout MO-5 (*i.e.*, Passing zones, PZs); and

2) segments that might not conform to the AASHTO PSD standards and may have visibility issues (*i.e.*, No-passing zones, NPZs).

Table 4 shows the longitude, latitude, and the lengths of the no-passing zones (NPZs) throughout MO Route 5. **Figure 6** shows PZs and NPZs along MO Route-5 as generated in the viewshed analysis.

There are many software's and applications that can be used to further explore the circumstances of the NPZs at MO Route-5 using the start point and end point with their latitudes and longitudes, such as Google Earth, and the instant Google Street View. For example, looking at the start location (37.308944,

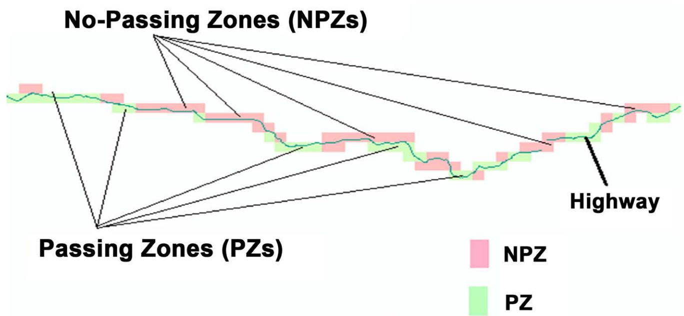

Figure 4. Passing and no-passing zones generated in GIS viewshed analysis.

Figure 5. MO Route 5, State of Missouri, USA.

Table 4. The longitude, latitude, and lengths of NPZs at MO Route-5.

Segment	From		To		Length, km
	Longitude	Latitude	Longitude	Latitude	
1	−93.004359	40.484525	−93.039366	40.429639	6.78
2	−93.095767	40.370752	−93.103407	40.352586	2.11
3	−93.104301	40.238526	−93.108841	40.220032	2.20
4	−93.143679	40.163192	−93.151739	40.144075	2.39
5	−93.153424	40.106560	−93.154823	40.086905	2.22
6	−93.167665	39.955366	−93.167010	39.917416	4.22
7	−93.173719	39.822029	−93.175213	39.777525	4.95
8	−92.948035	39.712250	−92.960232	39.538017	19.40
9	−92.924321	39.519018	−92.931916	39.431446	9.76
10	−92.849713	39.405615	−92.850153	39.368578	4.24
11	−92.848705	39.273705	−92.848248	39.254711	2.37
12	−92.737894	39.008679	−92.738758	38.998677	1.32

Continued

13	−92.776593	38.934922	−92.788225	38.913645	2.88
14	−92.826733	38.875756	−92.839573	38.857380	2.61
15	−92.852559	38.803348	−92.858902	38.671686	14.65
16	−92.783911	38.651579	−92.789150	38.592526	6.58
17	−92.804933	38.501483	−92.809033	38.460242	4.60
18	−92.828179	38.444716	−92.840909	38.440861	1.29
19	−92.852193	38.421307	−92.852686	38.336142	9.47
20	−92.841158	38.327190	−92.828479	38.317812	1.79
21	−92.783003	38.043133	−92.780999	38.030541	1.48
22	−92.766330	38.023961	−92.757785	38.016843	1.39
23	−92.695300	37.834654	−92.686848	37.812360	2.85
24	−92.677993	37.777665	−92.663442	37.680213	10.91
25	−92.649409	37.664414	−92.592571	37.540851	14.62
26	−92.590049	37.475200	−92.593311	37.392065	9.25
27	−92.546268	37.308944	−92.521418	37.264932	5.36
28	−92.571119	37.135156	−92.605843	37.077511	7.11
29	−92.637784	37.021681	−92.650352	37.002673	2.32
30	−92.662056	36.983856	−92.666214	36.940981	5.27
31	−92.680214	36.888024	−92.667394	36.878627	1.63
32	−92.653373	36.868902	−92.643354	36.863384	1.38
33	−92.626141	36.850418	−92.620128	36.847817	1.22
34	−92.604948	36.831432	−92.596547	36.825270	1.25
35	−92.557487	36.774156	−92.547966	36.755395	2.66
36	−92.538684	36.736304	−92.522083	36.698760	4.92
37	−92.512340	36.679130	−92.503572	36.671346	1.46
38	−92.479960	36.666402	−92.503176	36.670698	1.15
39	−92.466909	36.641292	−92.456152	36.632850	1.33
40	−92.439636	36.622524	−92.431578	36.600425	3.22
41	−92.474234	36.565489	−92.492366	36.546843	2.84
42	−92.481389	36.512929	−92.482681	36.499052	2.10

−92.546268) of segment number 27 in Google Earth, we can see that the surrounding area is hilly with a downgrade and upgrade ahead, as shown in Figure 7. This implies that the existence of the grades could be the reason for the inadequate AASHTO passing sight distance at this location, which was marked as NPZ in the viewshed analysis.

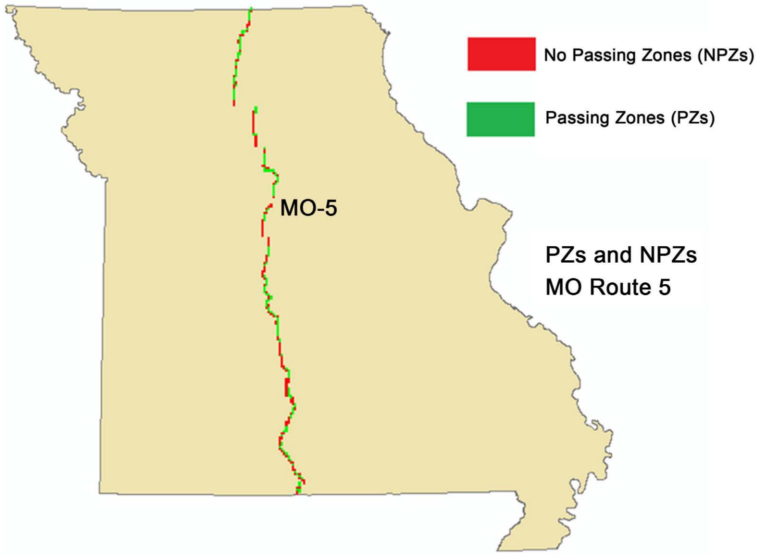

Figure 6. PZs and NPZs along MO Route-5.

Figure 7. The Google Earth start location of segment 27 at MO Route-5.

Another example is by looking at the end location (38.317812, −92.828479) of segment 20 in Google Earth. We can see that the highway is comprised of a horizontal curve, as shown in Figure 8. This implies that the existence of the curve could be the reason for the inadequate AASHTO passing sight distance at this location, which was marked as NPZ in the viewshed analysis.

5. Conclusion

A new approach was presented in this paper to assess the existing passing sight distance on two-lane, two-way way highways by utilizing the GIS capability of analyzing the visibility through creating viewsheds. The minimum recommended passing sight distance (PSD) ahead is always considered as an important factor in the marking of passing zones and no-passing zones along two-lane highways. This new approach is extremely beneficial in that passing sight distance can be rapidly estimated for highways over a large geographic extent without using the traditional vehicle methods or putting personnel at risk. In this approach the Digital Elevation Models (DEMs) were utilized for the viewshed analysis. The steps used to generate the viewsheds were: densifying the highway

Figure 8. The Google Earth end location of segment 20 at MO Route-5.

DEMs by appropriate distance; converting the feature vertices of the DEM's alignment from lines to points; buffering the highway alignment of the DEMs by adequate distance; clipping the DEMs by the road buffer; connecting the buffered-clipped DEMs by Mosaic tools; adding new parameters to the attribute table of the point's layer that control the visibility analysis in the viewsheds; creating viewsheds for all points of the highway alignment; and classifying the viewsheds into visible and invisible categories along the road alignment. On two-lane, two-way highways faster vehicles frequently overtake slower moving vehicles. The developed method was implemented in a GIS viewshed analysis and applied to evaluate the passing sight distance on Missouri Route-5, a two-lane highway in the state of Missouri, USA. The results indicated that the developed approach provides a very precise tool of rapidly assessing passing sight distance, and effectively locating the passing zones and no-passing zones along two-lane highways.

Conflicts of Interest

The author declares no conflicts of interest.

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