ESTIMATION OF SIGHT DISTANCE USING GIS

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Abstract - *Analyzing the distance visible to a driver on a highway is important for traffic safety, especially in manoeuvres such as emergency stops, when passing another vehicle, or when vehicles cross at intersections. A Software that calculates highway distances visible to a driver has been developed. This software is supported by a Geographic Information System (GIS) and can use a trajectory defined by points obtained with a Global Navigation Satellite System (GNSS) receiver instead of relying on project information. The software includes specific tools for studying shortcomings in three-dimensional (3D) alignment; mainly, this pertains to valleys. Advantages of using GIS in calculation of sight distances are also mentioned. A Microsoft .NET based algorithm is being made used to calculate the sight distances. Results are represented as sight diagram along with important details. In this review article, the software and its application to a case study are presented.*

***Key Words*: Sight Distance, Geographic Information System, Algorithm, Diving, Digital Terrain Model**

1.INTRODUCTION

1.1 Sight Distance

Among all design aspects of roads, geometric design is a relevant feature for traffic safety. Within road engineering, available sight distance along a vehicle trajectory is a significant parameter that enables alignment assessment. Available sight distance is defined as the section of roadway between the driver and the farthest target object on the roadway that can be seen by this driver without the line of sight being interrupted by the terrain or the road itself [4]. This distance is a feature for each position along vehicle trajectory, which enables engineers to check whether it is possible to perform emergency stops at any point, and overtaking or merging manoeuvers where required. Depending on project speed, required sight distance for such manoeuvers varies. Technical specifications all over the world actually fix minimum sight-distance values for each manoeuver. Therefore, available sight distances must be contrasted with required sight distances in order to check whether it complies with such specifications. In addition, shortcoming detection in road alignment can be done under this approach.

Fig. 1 shows the concept of available sight distance according to highway design standard. Consider a vehicle that will follow a trajectory (dotted line) along a horizontal curve, and an obstacle (gray color) exists to the right of the curve. When a vehicle is at point A, the obstacle prevents the driver from seeing farther than point B. Available sight distance is defined as the arc distance AB (continuous line of sight along the highway). The available sight distance calculation is important because if an obstacle (e.g., fallen tree, dead animal) is on the road at point B, available sight distance at A (arc AB) should be greater than the distance needed to stop the vehicle.

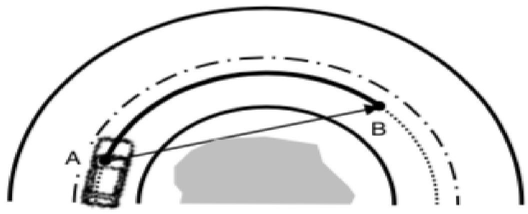

Fig. 1 Sight distance according to standards [2]

1.2 Relation between Sight Distance & Crash Rates

Fig. 2 shows the conceptual relationship between Available Sight Distance, ASD and crash rates (i.e., the ratio between the number of crashes per year and the average daily traffic volume) [1]. The figure shows that crash rates increase rapidly once ASDs fall below a threshold (ASDT), while they are relatively constant (i.e., insensitive) when the ASD is above the ASDT (Case A). Still conceptually, the threshold tends to increase (ASDT → ASDT') in road sections where additional hazards may occur (Case B in Fig. 2), thus shifting the curve to the right.

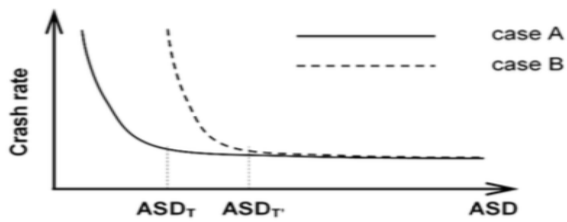

Fig. 2 Relation between ASD & crash rates [1]

1.3 Problem Arisen

Traditionally, analytical approaches have been utilized to calculate available sight distance in roads. However, the road and especially its environment are too complex to use available analytical approaches, which adjust poorly to reality. Therefore, a 3D approach is needed to represent reality more accurately.

On certain occasions, actual road alignment may differ from alignment defined on project or other available sources due to the fact that construction works might not have been executed exactly according to the geometry specified on project. Furthermore, restoration, rehabilitation or resurfacing works might have been performed on the roadway and its sides causing modifications on road geometry or on cut-side slopes. In addition, trees or buildings may exist alongside the road after it was built, reducing the available sight distance. That is why sight-distance estimation performed on project might have become obsolete.

In this sense, a need for tools capable of adapting to this complex reality arises if a precise analysis of sight distances is pursued. Although procedures based on ArcGIS have been produced for similar applications, it was necessary to develop an all new application so as to join all features required along the whole calculation process [3].

2. LITERATURE REVIEW

Kraemer et al. (2009) described that the increase in motorization accompanied with expansion of road network has brought with it the challenge of addressing the adverse influence of road traffic accidents. Road accidents are a global cataclysm with ever raising trend which pose a public health and development challenge and greatly affect the human capital development of every nation. Accident Black Spots are location on the road with higher severity of accident either in terms of numbers or injuries. In this paper, efforts have been made to identify the location of accident black spots on Barcelona-Las Palmas Highway. It faces huge traffic demands on daily routine. To carry out Black Spot analysis, IRS P-6 LISS-III data has been used. Mapping and geospatial analysis is done in freely available Quantum GIS (QGIS) software. Primary and secondary data of January 2013 to August 2015 are collected for the study and analyzed. GIS, an ingenious solution to this obstacle in mobility, can manage all attributes geographically and provides a suitable environment for compendious analysis of traffic safety problems. It can synchronize spatial and non-spatial data and can be used for visual analysis, data interpretation and information query. The conclusive goal is to identify and analyze accident black spots using QGIS, compare it with the most vulnerable segments from the method of Prioritization. This paper also discusses some suggestive which can be implemented on that particular segment which has been identified as stretch with maximum accidents. This study will showcase how to carry out black spot identification for urban areas of developing countries using open source GIS software [4].

Marco Bassani et al.(2019) described the available sight distance (ASD) is that part of the roadway ahead which is visible to the driver, and should be of sufficient length to allow a vehicle traveling at the designated speed to stop before reaching a stationary object in its path. It is fundamental in assessing road safety of a project or on an existing road section. Unfortunately, an accurate estimation of the available sight distance is still an issue on existing roads, above all due to the lack of information regarding the as-built condition of the infrastructure. Today, the geomatics field already offers different solutions for collecting 3D information about environments at different scales, integrating multiple sensors, but the main issue regarding existing mobile mapping systems (MMSs) is their high cost. The first part of this research focused on the use of a low-cost MMS as an alternative for obtaining 3D information about infrastructure. The obtained model can be exploited as input data of specific algorithms, both on a GIS platform and in a numerical computing environment to estimate ASD on a typical urban road. The aim of the investigation was to compare the performances of the two approaches used to evaluate the ASD, capturing the complex morphology of the urban environment [1].

Castro M. (2012) stated that because of the high number of crashes occurring on highways, it is necessary to intensify the search for new tools that help in understanding their causes. This research explores the use of a geographic information system (GIS) for an integrated analysis, taking into account two accident-related factors: design consistency (DC) (based on vehicle speed) and available sight distance (ASD) (based on visibility). Both factors require specific GIS software add-ins, which are explained. Digital terrain models (DTMs), vehicle paths, road centerlines, a speed prediction model, and crash data are integrated in the GIS. The usefulness of this approach has been assessed through a study of more than 500 crashes. From a regularly spaced grid, the terrain (bare ground) has been modeled through a triangulated irregular network (TIN). The length of the roads analyzed is greater than 100 km. Results have shown that DC and ASD could be related to crashes in approximately 4% of cases. In order to illustrate the potential of GIS, two crashes are fully analyzed: a car rollover after running off road on the right side and a rear-end collision of two moving vehicles. Although this procedure uses two software add-ins that are avail- able only for ArcGIS, the study gives a practical demonstration of the suitability of GIS for conducting integrated studies of road safety [2].

Castro M. et al.(2011) studied that analyzing the distance visible to a driver on a highway is important for traffic safety, especially in manoeuvres such as emergency stops, when passing another vehicle, or when vehicles cross at intersections. Software that calculates highway distances visible to a driver has been developed. This software is supported by a geographic information system (GIS) and can use a trajectory defined by points obtained with a global navigation satellite system (GNSS) receiver instead of relying on project information. The software includes specific tools for studying shortcomings in three-dimensional (3D) alignment; mainly, this pertains to divings. In this article, the software and its application to a case study are presented. The results are compared with those obtained using an existing validated procedure [3].

3. SOLUTION DEVELOPED

An all new application has been developed for ArcGIS environment, implemented in .NET and conceived to join the tasks needed for the analysis. This add-in gathers all ArcGIS capabilities required for the sight-distance calculation process. Once installed, the application could be added to any toolbar as a button.

3.1 Required Inputs

Both a Digital Elevation Model (DEM) of the land around the road and the trajectories that a vehicle follows along the road on each way are essential to carry out the calculation.

First, the DEM could be obtained either from photogrammetry or, preferably, from other technologies such as LIDAR (Light Detection and Ranging), which enables more accurate results. The use of Digital Surface Models (DSM) instead of Digital Terrain Models (DTM) entails the advantage of analysing sight-distance taking vegetation and buildings into account. Triangular Irregular Networks (TIN) is the digital mean to be used when representing surfaces on ArcGIS environment since DEM available are usually point grids saved as ASCII files. The transformation from ASCII to TIN is easily carried out by ArcTool Box.

Next, vehicle trajectories must be imported as a sequence of points which could be obtained through cartography, orthophotos or axis data from project. Otherwise, trajectories could be obtained by a GNSS device mounted on a car if project data are not available or reliable [2]. Whatever be the method used to produce the trajectory, the resulting points can be evenly spaced or not and are saved as a shape file or in a feature class of a geodatabase. However, a new attribute for each entity must be created containing the distance to the fixed point of beginning for each trajectory. This task is performed by the add-in from a polyline if these distance values are not available initially [2].

3.2 Algorithm

The application developed utilizes the "GetLineOfSight" tool from 3D Analyst toolbox. This function draws the longitudinal profile of the terrain below a line of sight that stretches between two desired points, determining whether the target point, besides all intermediate points of the terrain just below that line of sight, is seen from the observer position (Fig. 3). It can be observed that, in the example depicted on Fig. 3, the "Get Line of Sight" will determine that the target point is actually seen by the observer since the line of sight is not intercepted by the terrain surface.

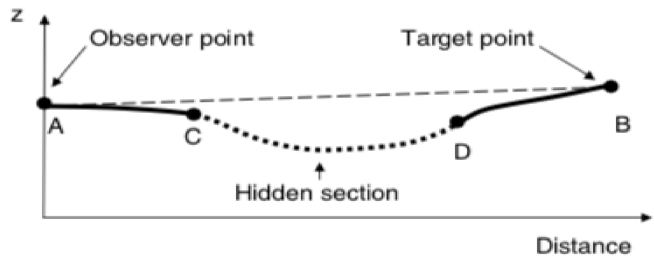

Fig. 3 Get Line Of Sight Function [2]

For sight-distance calculation it is necessary to define the height of the observer above the roadway as well as the height of the target object. Actually, technical specifications in many countries fix them.

Fig. 4 shows the trajectory of a vehicle modeled through a set of points (i ....k). To calculate the sight distance of a driver located at point i, the software should check whether point i + 1 is visible from point i. If this is the case, then it should check whether point i + 2 is visible from point i, and so on. When this checking fails at point n, sight distance at point i is the difference in stations between point n − 1 and point i. Then, the software should continue checking whether or not the remaining points (n+1…k) are visible from point i. In this way, all the points that are visible, plus those that are not visible, from point i are determined. So, the existence of an obstacle means that from point i, a driver who could see a first highway section (from point i to point n − 1) would not be able to see a second highway section (from point n − 1 to point m), but could see a third highway section (from point m to point k).

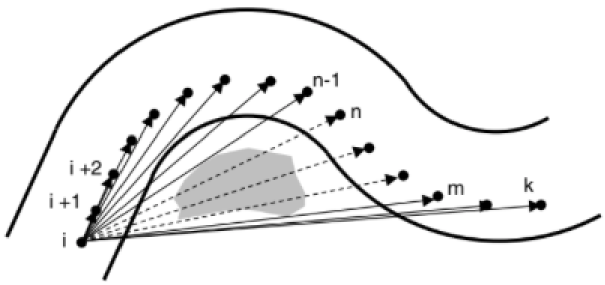

Fig. 4 Algorithm that searches for visible points along vehicle trajectory [1]

As shown in the pseudo code, the software could store not only the available sight distance information, but also what sections could or could not be seen from point i. This is an important difference from highway design software and previous studies by the authors [3]. In these, only sight distance (distance measured along the highway up to the first point that is not visible) is stored.

In addition, nighttime conditions could be considered. At night, only the portion of space illuminated by vehicle headlights can be seen. Vehicle headlights illuminate a cone with its vertex on the vehicle at a certain height above the highway and an orientation defined by vehicle azimuth and highway grade at this point. This cone has a horizontal aperture around vehicle azimuth and a vertical aperture around highway grade. The height of the cone is the head-light's range.

The software thus determines what points of the DTM are illuminated by these headlights when a vehicle is located at point i. Then, using the same procedure as in daytime conditions, visible and nonvisible highway sections are determined, and from them, sight distance.

3.3 Application

Software based on ArcGIS and implemented in Microsoft .NET Framework has been developed for the calculation and analysis of sight distances. An add-in is created in the ArcGIS Desktop when installing this software. This add-in is of the button type and could therefore be dragged to any ArcGIS toolbar, where it appears as another button.

When this button is clicked on, three dockable windows appear over the GIS main window. Two of them are used to configure the application, and the other displays the results. These three windows can be hidden, minimized, or moved inside the Windows environment.

Window 1 is used to configure the elements that will be shown in the results window (3), in the main GIS window (0), or in additional windows. Initial data are given in window 2. Parameters such as height of driver point of view, obstacle height, and maximum distance that will be considered are defined in this window.

As indicated in the previous section, using the Get Line Of Sight function and the algorithm that searches for visible points along the vehicle trajectory, the software determines which trajectory points can be seen from any other point. Sight results are shown in a sight diagram (Fig. 5) by means of thematic maps layered on top of the highway's horizontal layout or by means of reports.

The pseudo code for the computation of sight distance based on C++ programming is shown below. The code uses a nested for loop and also a nightcalculus function to check night visibility, i.e head light sight distance.

```
for(i=0,i<howmany(mstationlist)-1;i++)

{ Number: stationbase=mstationlist[i].pk;

Point XYZ: pntobs=mstationlist[i].point;

//Processing Z coordinate of pntobs. Own DTM, modify
taking into account observer height

if(NightCalculus)

{ Get Values }

mstationlist[i].stdy=null;

mstudylist=newList<StationStudy>();

for(j=i+1;j<howmany(mstationlist);j++)

{ Number: stationlooked=ccgeneral.mstationlist[j].pk;

point XYZ: pntlooked=ccgeneral.mstationlist[j].point;

if(stationlooked-stationbase)>maxdistance)

break;

if(nightcalculus)

{nighvisible=nightcalc();

}

if(nightvisible==false)

break; }

mstationlist[i].stdy=mstudylist;}
```

The sight diagram is a chart in which stations are on the x-axis and sight distance (measured along vehicle trajectory) is on the y-axis. Consequently, from point A, there is a first highway section that is visible (section AC in Fig. 3 and 5), a second section that cannot be seen (section CD in Fig. 3 and 5), and a third section that is visible once again (section DB in Fig. 3 and 5). For each point, the sight diagram shows all of the sections that are visible using a color (e.g., green or light gray) to distinguish them from the sections that could not be seen (e.g., red or dark gray).

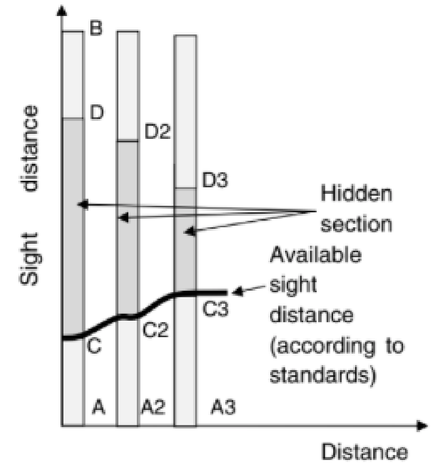

Fig. 5 Sight Diagram [1]

3.4 Identification of Divings

The sight diagram is a chart in which stations are on the x-axis and sight distance (measured along vehicle trajectory) is on the y-axis. Consequently, from point A, there is a first highway section that is visible (section AC in Fig. 3 and 5), a second section that cannot be seen (section CD in Fig. 3 and 5), and a third section that is visible once again (section DB in Fig. 3 and 5). For each point, the sight diagram shows all of the sections that are visible using a color (e.g., green or light gray) to distinguish them from the sections that could not be seen (e.g., red or dark gray).

In a highway section composed of a tangent with a crest, a sag, and a crest in the vertical alignment, an observer located at point A sees highway section AC and does not see highway section CD, but sees highway section DB (Fig. 3). This information is provided by the sight diagram. Analyzing the vertical bar corresponding to point A (column ACDB of Fig. 5), highway sections AC and DB are visible, but highway section CD is not visible. The location (station) of this phenomenon is shown on the x-axis of the sight diagram. In the example shown in Fig. 5, the phenomenon occurs at several highway locations (when the driver is at points A, A2, and A3). The y-axis of the sight diagram provides numerical data about the lengths of the highway sections involved. In this example, when the driver is at point A, the hidden section starts at distance AC from A, and the length of this hidden section is CD meters.

In the sight diagram, the available sight distance, according to the standard highway design definition, could also be shown. It is the line joining each point studied up to the beginning of the first hidden section (line C, C2, C3) (Fig. 5).

3.5 Identification of Vertical Obstructions

In the GIS main window, a plan view of the highway with visuals could be shown. In another window, the longitudinal profile of the terrain defined by a vertical plane containing the sight line could be shown (Fig. 6). This longitudinal profile of the terrain could be analyzed to deter- mine its influence on available sight distance values. Longitudinal profile generation between observation and observed points, in which visible and hidden sections are shown, helps to analyze the causes of reduced sight distance on the highway. In this way, it is possible to identify what zone of the longitudinal profile is responsible for a section with low sight distance (the zone ST for the sight line shown in Fig. 6).

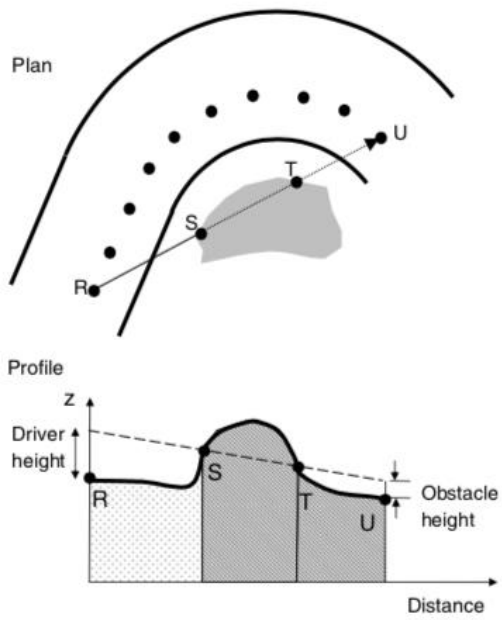

Fig. 6 Plan and profile of sight line [2]

4. CASE STUDY

The software was applied to the M-325 highway located in Madrid, Spain. It is a two-lane rural highway with a lane width of circa 3m. The terrain is rolling. This highway has been chosen because it has a defect (diving) in its 3D alignment that allows the software to be tested. A GNSS GR-3 receiver antenna was mounted on the top of the vehicle and threaded into a robust magnetic base.

Because vehicle speed was between 30–40 kmph, data were registered with a minimum interval of 0.5 s, which means that the points recorded were 5m apart. This distance is larger than the grid spacing (1m, see subsequent information), but not too coarse to get accurate enough results.

To evaluate the scalability of the software, calculations were also made using only the first 3 km of the vehicle trajectory and a coarser DTM (5-m grid spacing). Full calculations (15 km trajectory and DTM with 1-m grid spacing) take 1,948 s. If the trajectory is reduced to 3 km but the DTM is the same, calculations take 346 s. If the DTM is coarser (5-m grid spacing) but the whole trajectory (15 km) is used, calculations take 487 s. If both the coarser DTM and the shorter trajectory are used, calculations take 78 s. All calculations were made on the same computer, an i73610QM with 16 GB of RAM. It can thus be seen that calculation time increases almost linearly when either the number of points in the trajectory or the size of the DTM increases.

According to the Spanish standard, the height of the eyes above the road surface was taken as 1.1 m, and the height of the observed object as 0.2 m. Fig. 7 shows the sight diagram of this highway section. Diving begins at station P and ends at station Q. At station Q, the sight distance value will jump abruptly (black line in the diagram). The length of diving is the difference between stations Q and P. In this case, the length of diving is 75 m. Between stations P and Q, there are highway sections hidden to a driver, and highway sections that reappear. The hidden sections are plotted in dark gray, and those that reappear in light gray.

Fig. 8 shows a thematic map of the zone corresponding to the sight diagram shown in Fig. 7. Available sight distance has been represented on an orthophoto. The highway sections in which available sight distance is less than 100 m, over 200 m, and between 100 and 200 m are shown.

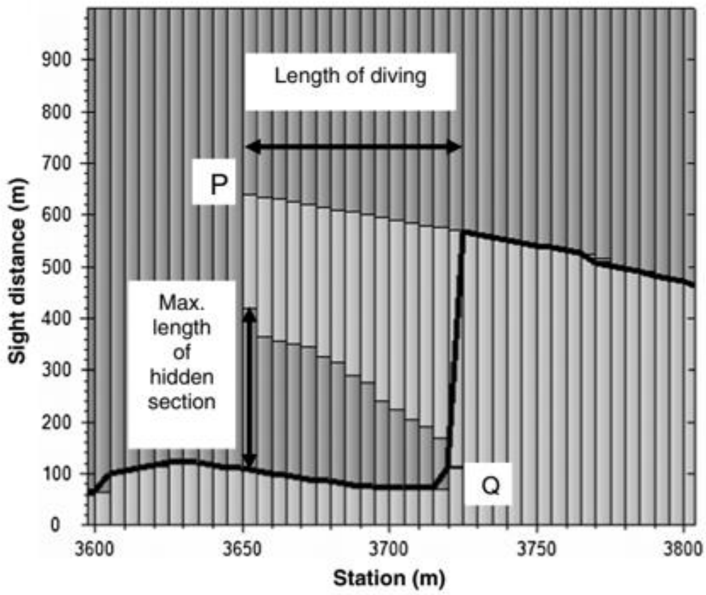

Fig. 7 Case study: Sight diagram of diving [2]

Fig. 8 Thematic Map [2]

5. CONCLUSION

5.1 Summary

Software developed for ArcGIS that calculates available sight distances on a highway is proposed. This software could make calculations based on the usual information (DTM and highway alignment) or on other sources [such as cartography, digital surface model (DSM), and vehicle trajectory data obtained with a GNSS]. This second possibility makes it very useful when highway design information is not available.

5.2 Results

The software developed shows available sight distance and allows a graphical comparison with required sight distance. The software also determines visible and hidden highway sections from each station. In this way, diving can be easily detected. In addition, the software helps to identify the causes of low sight distance because it can show sight lines in the plan view and generate longitudinal profiles along sight lines. It also produces thematic maps. In these maps, additional information such as crashes, speeds, or design consistency could be included. This possibility increases the usefulness of this tool in traffic safety studies.

5.3 Future Research

In future research, following shortcomings will be analyzed. The effect of DTM resolution (grid spacing) on the results will be addressed. In this sense, the use of DSM instead of DTM will be considered.

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