Sight distance for road safety analysis using GIS

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Abstract

Sight distance is of major importance for road safety either when designing new roads or analysing the alignment of existing roads. It is essential that available sight distance in roads is long enough for emergency stops or overtaking manoeuvres. Also, it is vital for engineers/researchers that the tools used for that analysis are both powerful and intuitive. Based on ArcGIS, the application to be presented not only performs an exhaustive sight distance calculation, but allows an accurate analysis of 3D alignment, using all new tools, from a Digital Elevation Model and vehicle trajectory. The software has been successfully utilised to analyse several two-lane rural roads in Spain. In addition, the software produces thematic maps representing sight distance in which supplementary information about crashes, traffic flow, speed or design consistency could be included, allowing traffic safety studies.

1. Introduction

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 (Kraemer et al., 2009). 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 (AASHTO, 2011; FGSV, 2012; Harwood et al., 1995; Ministerio de Fomento, 2000). 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.

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2. Problem arisen

Traditionally, analytical approaches have been utilised 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 (Castro et al., 2011; Leroux, 2004), it was necessary to develop an all new application so as to join all features required along the whole calculation process.

3. Developed solution

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) (ESRI, 2013) 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 (ESRI, 2008) 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 (stations) 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 (Castro et al. 2013). Whatever the method is used to produce the trajectory, the resulting points can be evenly spaced or not and are saved as a *Shapefile*

(ESRI, 1998) or in a feature class of a *Geodatabase* (ESRI, 2009a). 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 (Castro et al., 2013).

3.2. Software's inner working

The application developed utilizes the "GetLineOfSight" tool (ESRI, 2010) 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 (Figure 1). It can be observed that, in the example depicted on figure 1, 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.
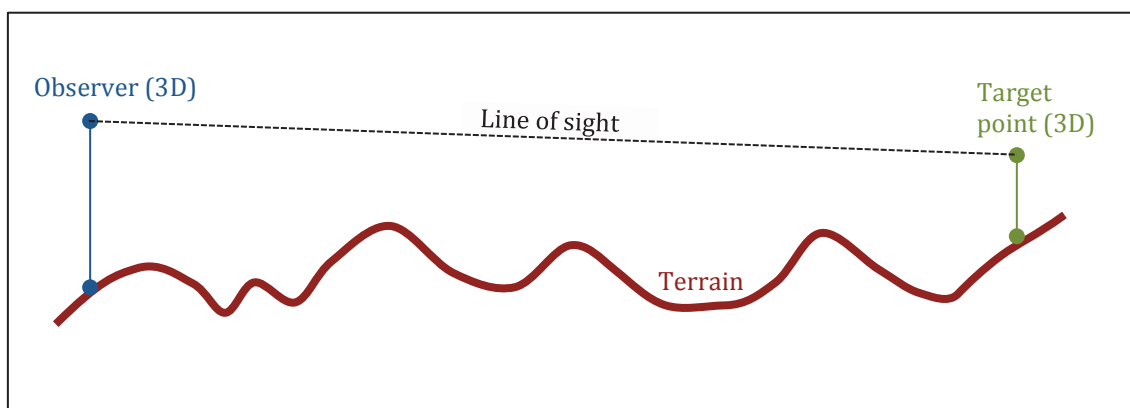

Figure 1. Profile of a line of sight above the terrain.

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 two (AASHTO, 2011; FGSV, 2012; Harwood et al., 1995; Ministerio de Fomento, 2000).

The algorithm programmed executes a loop in which the observer is successively placed along all vehicle trajectory stations. From each station, another loop launches "GetLineOfSight" function from the fixed observer to the stations ahead where the target object is successively placed up to a distance chosen by user. When the observer is placed at station i, it is checked if stations from $i+1$ to $i+n$ are seen or not from observer's position. After that, the observer moves forward to the succeeding station $i+1$ and the same launching process takes place until station $i+1+n$ is reached. Loops at each station are executed until point m, where trajectory ends (Figure 2). Usually, arrows for seen points are represented in green while arrows for non-seen points are in red.

When storing calculation results, it was taken into account that sight distance between the two involved stations must be measured along the road axis, not along the correspondent line of sight.
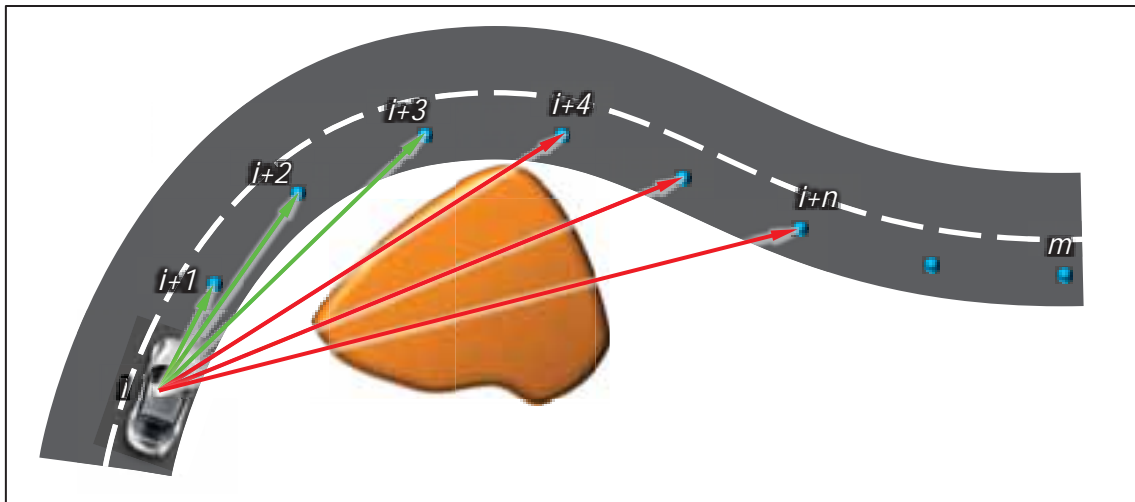
Figure 2. Line-of-sight launch from a generic station *i*.

3.3. Commands

The application described operates embedded in ArcGIS environment. Figure 3 shows the Add-in interface where three different panels can be distinguished. The first one enables visual configuration of calculation results (green frame on figure 3), the second one (red frame on figure 3) manages calculation inputs and the third one (blue frame on figure 3) shows the menu bar as well as calculation results once it has been completed.
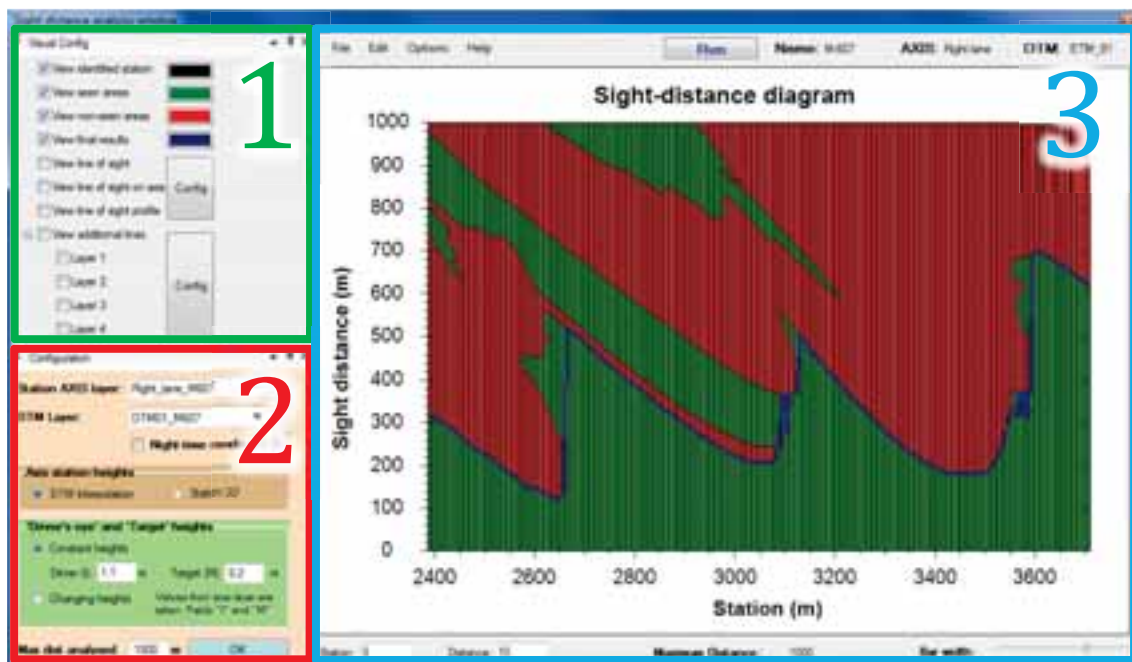

Figure 3. Software interface within ArcMAP environment.

Within visual configuration panel it is possible to select features to be displayed either in panel 3 or on the map. The upper four options manage visual features of the sight-distance diagram without any further information: "View identified station", View seen areas", "View non-seen areas" and "View final results". The three following options enable the user to depict a selected line of sight on the map or to produce a longitudinal profile of the terrain just below a line of sight within a new window (Figure 4). Finally, "View additional

lines" enables to show up to four extra auxiliary features in the sight-distance diagram area that are not depicted directly after calculation, such as point heights, required sight distance, etc.
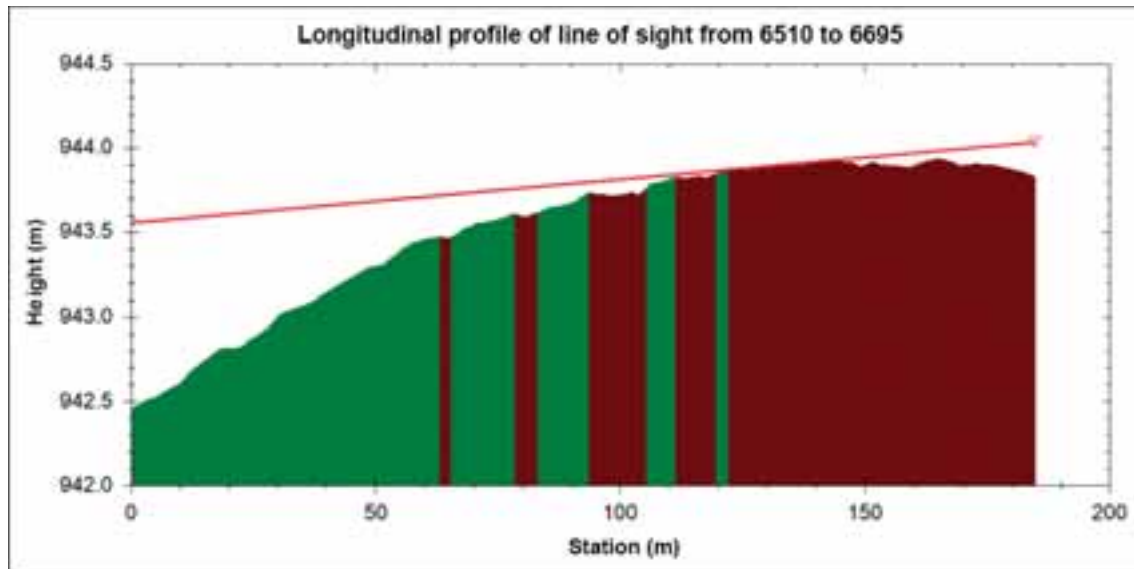
Figure 4. Example of a longitudinal profile of a line of sight.

Within calculation configuration panel, data for the calculation are selected. The first step is to select the TIN surface and the correspondent vehicle trajectory. It is also possible to select the height of the virtual observer and the height of the target object above the surface or above the point heights if the opportune attribute has been previously defined. Furthermore, an option to perform calculation dynamically or, on the contrary, saving every sight-distance profile is available. An additional feature enables sight-distance calculation under night-time conditions. The last parameter to be fixed is the maximum distance to analyse at every station. Before calculation starts, it is necessary to save configuration changes.

Panel 3 includes a menu bar and the graphic area where sight-distance diagrams are depicted. The menu bar offers additional options that aid in defining the *Shapefile* for vehicle trajectory and tools to filter and debug calculation results, besides the usual saving and printing options. The button "Run" that starts calculation is also located in this bar.

A tool has been programmed to calculate vehicle trajectories from the road axis through the function "Copy parallel" from ArcGIS (ESRI, 2009b). A lateral displacement is performed towards the chosen side and the desired distance, keeping up the original *Shapefile*. Similarly, based on the tool "Creating new points along a line" (ESRI, 2011), a series of evenly-spaced points are created to define the stations along vehicle trajectory.

Gross errors can be also debugged using a tool specially designed for the task. This tool has been designed keeping in mind that DEM could include isolated errors that may influence in the outcome. The TIN could include an apparent dip due to a vertex whose height is demonstrably false compared to the surrounding vertices. Such errors must be analysed and corrected if necessary using the tools designed for this purpose. These error corrections could be performed either manually or automatically.

To check whether gross errors have to be corrected or not, longitudinal profiles of lines of sight play an important role. These charts are where users are more likely to find the

cause of the isolated seen/non-seen station (usually non-seen). If the cause of a particular weird result remains unclear, TIN and vehicle trajectory could be imported to ArcSCENE where such causes will be finally identified and cleared up (Figure 5).

Figure 5. Visualization of TIN and vehicle trajectory on ArcSCENE.

Calculation results may be saved as a text file, besides four different sorts of reports depending on which aspect the user of the software wants to focus in: maximum sight distances, maximum distance from which a station is seen, sections with partial roadway disappearances, etc. These exported data can be certainly used in other software.

If results are exported to the axis layer (or vehicle trajectory layer), it is possible to produce thematic maps. Such coropleth maps could represent any variable desired among the ones calculated by this Add-in. In this sense, areas are coloured or patterned in proportion to available sight distance, required sight distance, algebraic difference between available and required sight distance, etc. On such maps, not only safety-critical sections can be detected quickly but also additional information may be added such as traffic flow data, speed maps, crash locations and design consistency.

Figure 6. Thematic map representing available sight distance along a short section of a rural road.

Also, sight-distance analysis enables detection of perspective shortcomings for driver's view such as sight-hidden dips. A sight-hidden dip occurs whenever a driver is able to see the section of road immediately ahead and another section further, but not the section in between (Kraemer et al, 2009). In the sight-distance diagram (panel 3 on figure 3) it happens where a vertical bar comprises two green stripes and a red one in between.

This application and all its features have been tested on four rural roads within the Region of Madrid and could be used to perform safety studies on a complete road network.

4. Advantages of using GIS

One of the most important features is that ArcGIS enables a 3D approach. The power of ArcGIS makes easier big data management, especially MDE, a key element in sight-distance calculation. Moreover, the fact that it is possible to use different sorts of MDE, such as DTM and DSM, makes ArcGIS highly attractive for this task. This versatility also extends to the possibility of choosing the most suitable road axis. Additionally, accurate results can be achieved using this software within relatively short computing time. They can be as accurate as the DEM and the GNSS precision allow. As an example, sight distance calculation for a 15-kilometer stretch (a trajectory of 3 000 points and a TIN created from over 14 millions of points) was performed within 33 minutes using a conventional computer (Castro et al., 2013).

Also, the graphic power of ArcGIS must be highlighted for several reasons. First, diagrams displayed are very versatile and intuitive for interpretation and analysis. Thematic maps can be created to illustrate safety-critical sections of the route and simplify research into the relationship between sight distance and crashes, traffic flow, speed and alignment consistency data, or even perform road safety audits. As a result, safety studies could be easily carried out from such analysis. The features that enable reports productions facilitate further studies when exporting results is needed.

5. Conclusions

An ArcGIS Add-in software capable to calculate available sight distance on roads has successfully been developed. The tool created is very versatile since it can perform the analysis of available sight distance for either from road project or from field data gathered from roads where there may be significant differences or modifications compared to the project. Estimating available sight distance for either case, it is possible to locate safety-critical spots along the road alignment. Combining this information with data traffic flow, speed maps, crashes and alignment consistency is possible to carry out road safety studies on a platform as powerful as ArcGIS in an integrated manner.

Working on ArcGIS with georreferenced data, it is possible to depict driver's lines of sight directly on cartography, a fact that enables 3D analysis from any point of view. It is easy to locate safety-critical spots on alignment since the software is able to depict longitudinal profiles where hindrances can be identified. Even if there is any doubt left, ArcSCENE allows the user to identify such hindrances definitely.

6. Acknowledgements

7. References

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