Analiza razpoložljive pregledne razdalje na obstoječih cestah glede na teorijo in prakso v R. Srbiji

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Povzetek

Analiza obstoječe cestne pregledne razdalje in njena primerjava z zahtevano in pregledna razdalja pri prehitevanju je ključna dejavnost tako za ustrezno zasnovo prometne signalizacije in upravljanje hitrosti, kot za preverjanje prometne varnosti na obstoječih cestah. Obveznosti v zvezi s to dejavnostjo izhajajo iz domačih in tujih predpisov in normativov. Vendar je bila v dosedanji inženirski praksi analiza obstoječe cestne pregledne razdalje bodisi neustrezno obravnavana bodisi v celoti opuščena. Razlog za to je bilo pomanjkanje ustreznih orodij za izvedbo ustreznih analiz, ki temeljijo na zelo kompleksnih vizualizacijah voznikovega pogleda v tridimenzionalnem prostoru z vsemi možnimi ovirami. Takšne kompleksnosti tridimenzionalnega prostora ni mogoče predstaviti ali analizirati na podlagi klasičnih geodetskih posnetkov in meritev.

V prispevku je podan pregled teoretičnih in normativnih osnov, povezanih z analizo pregledne razdalje, pregled trenutne prakse, kakor tudi predlog inovativnih rešitev, ki temeljijo na simulaciji voznikovega pogleda, ustvarjenega v tridimenzionalnem modelu oblaka točk, pridobljenem z laserskim (lidarskim) skeniranjem ceste in okolice.

***Ključne besede**: Laserski (lidarski) sistemi, oblaki točk, vizualizacija, pregledna razdalja, obnova cest, preverjanje prometne varnosti.*

Analysis of available sight distances on existing roads with reference to theory and practice in R. Serbia

Abstract

Analysis of available sight distance and its comparison with the required and overtaking sight distance is a key activity for adequate operating of traffic signals and speed management, but also for checking traffic safety on existing roads. Obligations related to this activity arise from domestic and foreign regulations and norms. However, in the engineering practice so far, the analysis of available sight distance has been either inadequately treated or completely omitted. The reason for such a thing lies in the fact that there were no appropriate tools to conduct such analyzes since they are based on very complex visualizations of the driver's view in three-dimensional space with all possible obstacles that interfere with that view. Such complexity of three-dimensional space cannot be presented or analyzed on the basis of classical geodetic surveys and measurements.

This paper provides an overview of theoretical and normative bases related to visibility analysis, current practice and a proposal for an innovative solution based on simulation of the driver's view created in a three-dimensional model of point clouds obtained by laser (lidar) scanning of the road and its surroundings.

Keywords: *Laser (lidar) systems, point clouds, visualization, visibility, sight distance, road rehabilitation, traffic safety inspection.*

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1. INTRODUCTION

Although the theoretical basis of the concept of sight distances are relatively simple and precisely defined by norms, their determination and analysis is probably the most complex and almost impossible task for operatingers, even in today's highly developed information technologies. Although we distinguish, in theory, several types of sight distances such as: ***stopping***, ***required***, ***overtaking***, ***sharpened***, ***free***, among them, the ***available*** sight distance stands out because it should be the basis for adequate speed management, and operating of appropriate traffic signalization. However, the available sight distance is, at the same time, elusive for civil and traffic experts, especially on existing roads, unlike the newly operatinged ones. However, the fact is that every newly operatinged road will one day become existing, along which, vegetation and many other smaller or larger objects, that interfere with the driver's views, will sprout.

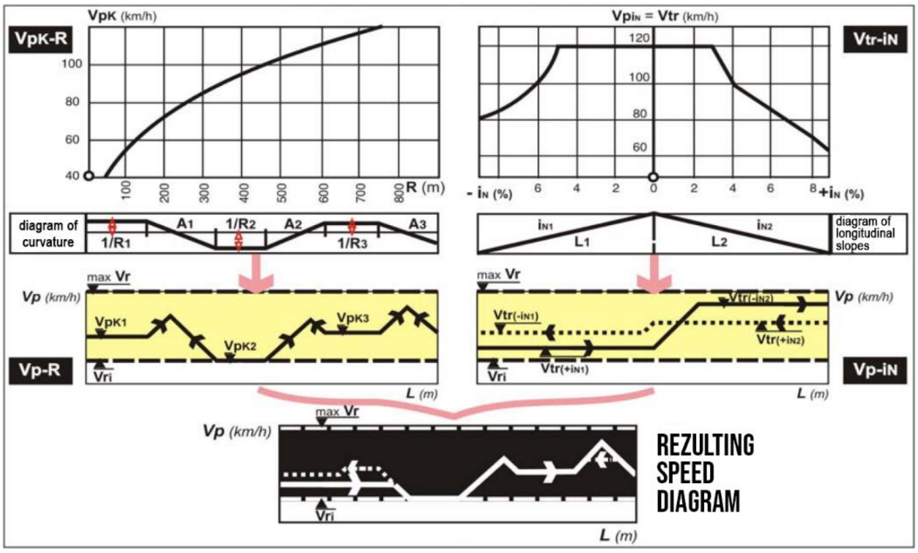
2. THEORETICAL BASIS, NORMS AND REGULATION

The simplicity of the theoretical basis related to the concepts of sight distance is reflected in the fact that all of them, except for available sight distance, are actually calculation or statistical values and directly dependent on speed, whether it is design, project, operating, exploitation or some other type of speed. Unlike them, the available sight distance does not represent calculation value, but, as its name suggests, measured sight distance that is really present / achieved / available on the road.

Since the theory related to the different type of the road sight distances is more or less the similar anywhere in the world, within this document, there is no need to specify each of them. However, we will single out the term **required** sight distance (**SD_r**), which is the most often determined as part of driving-dynamic-optical analyzes. This type of visibility is very often equated with the term **stopping** sight distance (**SD_s**), although there is an important difference. Required(stopping) sight distance is based on **operating** speed (**Vo**) that is **variable** along the road while stopping sight distance is based on **design** speed (**Vd**) that is **constant** on a certain road section.

The theoretical foundations, influencing factors, similarities and differences in the world, everything related to the problem of stopping(required) sight distance on roads are best described in the EUSight project (European Sight Distances in perspective[1]). Since the scope of this work is limited, it is not possible to present all the essential assumptions and results of the mentioned project, so those who want additional information are referred to the internet link given in the footer.

Figure 1 *Construction of the resulting profile of operating speed(current regulations in R.Serbia[2])*



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[1] https://www.cedr.eu/call-2013-safety

[2] Rulebook on conditions that must to fulfill by road facilities and other elements of public road from the aspect of traffic safety (Official Gazette of RS 50/11)

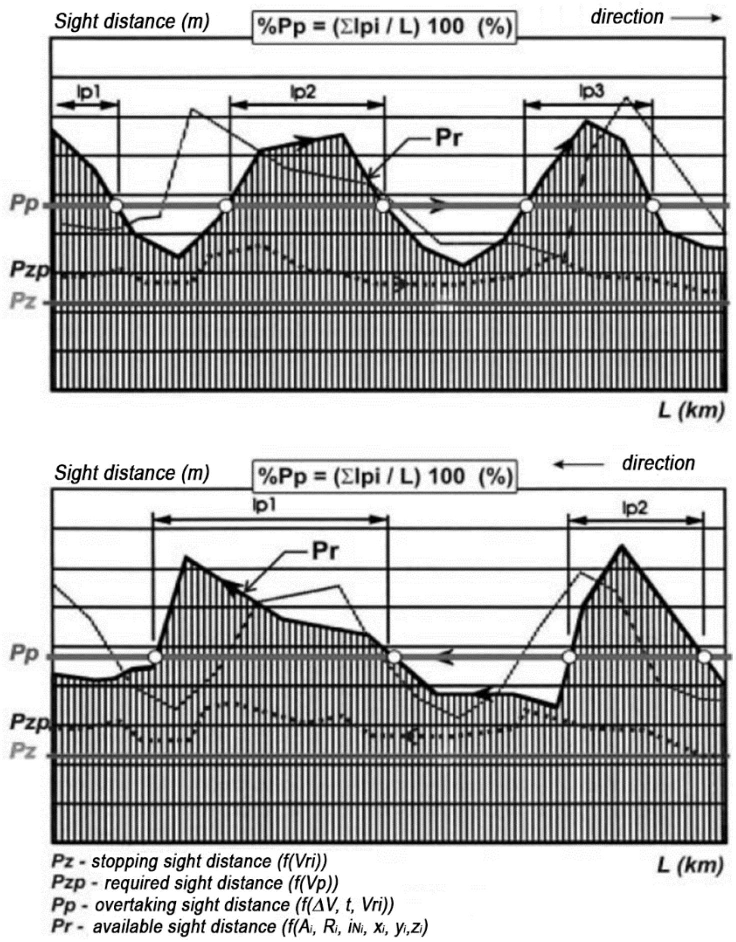


***Figure 2** Profile of stopping, required, overtaking and available sight distance (current regulations in R.Serbia[2])*

According to legislative and norms in R.Serbia, the required sight distance must be achieved at each point of the road so that a lone vehicle can stop in front of a sudden obstacle in the conditions of a wet road. In order to confirm whether the required sight distance has actually been achieved, it must be compared with the actual **available** sight distance (**SD_a**).

3. CURRENT PRACTICE RELATED TO DETERMINATION AND VERIFICATION OF SIGHT DISTANCE

Current practice in the field of sight distance analysis can be divided into:

- the period before and after the advent of modern computers,
- issues related to existing roads, in relation to newly operatinged roads

Within this paper, the focus is on the problems of sight distance on existing roads, since their problems are much more complex than the newly designed ones. That is, in the case of newly designed roads in modern times, the whole problem is reduced to the analysis of clean surfaces (triangulated digital models - **DTM**[3] or **DSM**) of roads and roadbed (cuts, fills, embankments) unencumbered by various vegetation and objects that are created over time along the road or possibly planned horticulture and again, objects that we can quite convincingly model and show. Therefore, in the case of newly operatinged roads and its surroundings, the problem is mainly reduced to the analysis of whether the driver's vision penetrates through the wire model of the terrain and accompanying facilities or not.

3.1. Practice before the advent of personal computers

One of the simplest methods for analyzing visibility does not require computers at all. Namely, for the simplest analysis of sight distance, two people are needed, with the first being on the road in the driver's

[3] DTM-Digital terrain model, DSM-Digital surface model. The difference between these two models is that the DTM is a network-wired model terrain without vegetation and facilities and DSM is a terrain model that includes vegetation and other facilities. In this paper, we will collectively call them the wire model.

position and the second also on the road, away from the first one, for the length of the required sight distance vision. In addition, they need to have ordinary measuring rods for the purpose of adjusting the driver's view height, and an obstacle height. If person 1, from the position of the driver's eye, sees an obstacle at a distance of the required sight distance vision, then the required visibility is fulfilled and inversely. After that, the persons, operators move along the road according to a predetermined step. Of course, this method is not only inefficient and irrational, but it is also unsafe since it requires the presence of an operator on the road.

In addition to this field method, before the advent of personal computers, it was possible to work on sight distance analysis on drawings of layout plans and longitudinal profiles. Such a method meant that different projections (horizontal - layout plan and vertical - longitudinal profile) were independently assessed by manually drawing sight distances along the route at a certain step, and then creating a visibility sight distance envelope. After the advent of modern computers, this method only experienced automation. The disadvantages of this method are reflected primarily in the impossibility of three-dimensional perception of the problem, but the analysis is conducted in mutually independent two-dimensional planes.

3.2. Practice after the advent of personal computers

For many years, the usual operating process, whether of newly designed roads or rehabilitation of existing roads, involved creating design bases, based on classical geodetic measurements using the tachymetric method or recording points according to predetermined profiles. Based on a large number of recorded points, it was possible to create wire models through which longitudinal and transverse profiles were cut. Classical geodetic surveys, in addition to recording data on the position of the point and terrain level, also included many other phenomena along the road, but always with a limited amount of data, that did not allow their adequate three-dimensional representation in space. Therefore, it was not possible to conduct any detailed visibility analysis, which would include a spatial representation of tree canopies and shrubs, various billboards, fences, parked vehicles, containers and all other various obstacles to the driver's vision.

With the development of technology, meanwhile, various photo and video cameras have appeared, which are, nowadays, integrated into mobile phones that almost everyone owns. This has enabled very cheap and efficient photography and video recording of the routes of existing roads with an incredible level of detail. The only deficiency to these affordable and cheap devices and data is that they cannot provide depth (distance) measurement.

With the further development of technologies, lidar (laser) devices have appeared, which have the ability to record a huge number of points every second, which practically enables mobile scanning of the road and its surroundings. Today, such devices can be mounted on cars, as well as on drones that can shoot from the air. Since each recorded point records data on the distance of the reflected laser ray, it is possible to measure lengths, unlike images taken with cameras or video cameras. In fact, technology has advanced so much today that even photogrammetric methods, that is, overlapping images taken from different locations, make it possible to scan space and form point clouds, similar to lidar devices, and very often, the images made with these different technologies are combined. According to such advances in technology, it is now possible to obtain a visual representation of scanned space within point clouds with a very high point density.

Nowadays, there are a large number of software, operatinged for road design or GIS oriented, that have the capability of point cloud processing and automatic visibility analysis, and very few have the ability to calculate operating speed and consequently required sight distance visions. However, all of them, or at least those with whom authors of this paper had contact (Civil3D, ArcGIS, Global Mapper), have one insurmountable flaw that will be discussed later, and that is that they are based on the analysis of the penetration of the line through the wire model. Also, another significant flaw of those software is that they treat the required sight distance as a constant, and not as a variable value along the route.

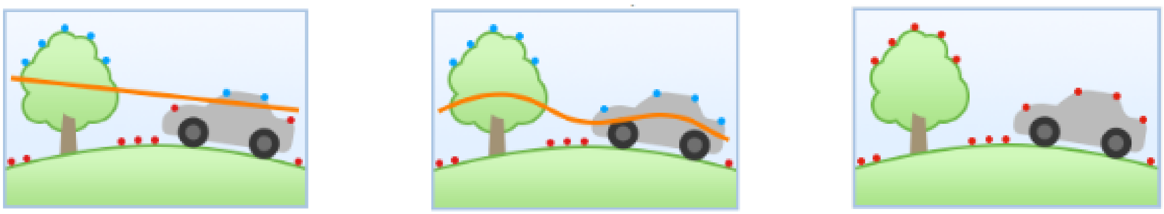
An example of the application of Civil3d software in sight distance analysis is the simulation of vehicle movement and obstacles in the cloud of points, which can be seen at link[4].

[4] https://drive.google.com/file/d/1TJuwigJRak9SlW1GM0O78MbxZ9VCqo-X/view?usp=sharing

In the subject simulation, a yellow line in the depth of the image represents an obstacle at a height of 0.1 from the road surface and at the distance of the vision of the required sight distance. The eye height of the driver in the simulation is set at 1.1m relative to the pavement surface. The driver's eye and obstacles move along the trajectory of the traffic lane. The lack of tools (Analyze / Drive) embedded into the Civil3d software is that the distance of the required sight distance is treated as a constant value and that can not return data on the length of available sight distance. However, even such a tool is indicative enough and can indicate problematic places on the route of the existing road. For the purposes of visualization, the length of the required sight distance of 100m is defined as a constant value, while the realistically variable length of the required sight distance on the subject road section varry from 68 to 108m.

In addition to this tool, Civil3d also has a special tool (Analyze / Visibility Check / Check Site Distance). This tool can really analyze the visibility and as a result give the sight distance envelope, ie the difference between the required and available sight distance envelope. However, this tool analyzes the penetration of the view through the wire model, which was previously stated as an unacceptable deficiency. What does this deficiency look like?

It is reflected in the fact that a triangulated digital model cannot form a wire model that will have two sections in one vertical. That is, if we take the example of a tall tree with a large canopy, the wire model will be formed in one of the following three ways:



Planar Avarage method — Kriging Interpolation method — No Filter method

Figure 3 *Different methods of creating a triangulated digital model (Civil3d User Guide)*

Without going into the description of any of these three methods, it is clear that the first two are only an approximation, while the third is also unusable because instead of a three-dimensional representation of a tree with a canopy in the shape of a wine glass, the tree will be presented as a barrel. Similar like when a table or chair is covered with a sheet that falls to the floor. In fact, the transparent part under the canopy will be opaque in such a model, because the model will form along the outer edge of the most protruding parts of the canopy, and connect them with points on the ground. This is a big problem because there will be points of vegetation which rises above the road, along its outer circumference, connect with the points on the road, so that the part of the road below the canopy will be covered with a wire model, as is the case in the following pictures where the same view is shown wit, and without a wired model.

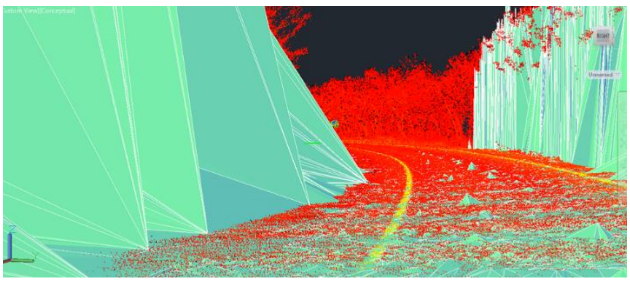


Figure 4 *View of point clouds overlapped with a wired model*

Figure 5 *View of point clouds without folded wire model*

In the previous pictures, it can be seen that the visibility from this position of the observer is satisfactory, ie the yellow line at the distance of the required sight distance is visible in the display of point clouds without a wired model. However, it is not visible in the combined view with the wire model because the points at the top of the tree canopy connected to the points on the road, creating triangles that hide everything below them.

4. MODERN METHODS OF VISIBILITY ANALYSIS

Given the previously described deficiency of determining the penetration of the sight distance vision through the wire models, modern methods are more based on the analysis of the penetration of the vision of visibility through ***voxel.*** What is voxel? The easiest explanation for voxel is that it is a three-dimensional pixel. In fact, since a point is a dimensionless quantity (it has no dimensions) its representation in the plane must be visualized by a square of a certain dimension called a pixel. In the same way, the size of a certain point in space can be visualized with a sphere or a cube of a certain dimension. Such an object in space will be called a voxel instead of a pixel. By replacing the points in the point cloud with spherical or cube-shaped bodies of certain dimensions, a set of bodies in space is obtained that can touch and overlap, as shown in the figure below.

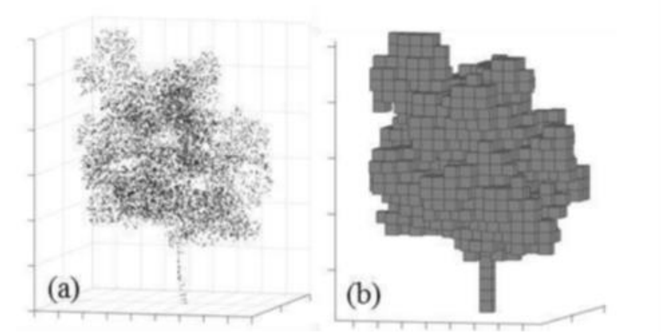


Figure 6 *A tree represented as a point cloud (left) and the same tree represented as a set of voxels (right) (3D VIRTUAL SIGHT DISTANCE ANALYSIS USING LIDAR DATA 5 [1])*

This means that each body in space, instead of a wired model, is represented by a set of building cells (voxels) whose cross sections with rays from driver's eye can be calculated by a computer. This actually means, that the problem of sight distance analysis is summarized in searching for the line penetration through the voxel. It remains to give dimensions to a voxel, which is again a special kind of problem, in terms of precision and in terms of consumption of computer resources, the both. Since, theoretically, the verification of the required sight distance is reduced to a single ray of light reflected from an imaginary obstacle, located on the driving path, and the distance from the driver's eye along that path equal to the length of the required sight distance, it looks like the problem is simple and solvable. If that ray does not pass through a single voxel on its way, the length of the required sight distance is achieved. If it cuts a voxel, then it is not achieved. However, that again does not say how much visibility is actually available. On the other hand, the question is how big is the object that was blocked by the ray that travels to the driver's eye. Is it a voxel in a set of voxels that build a slim pole of traffic signals and is it a real obstacle to visibility or not?

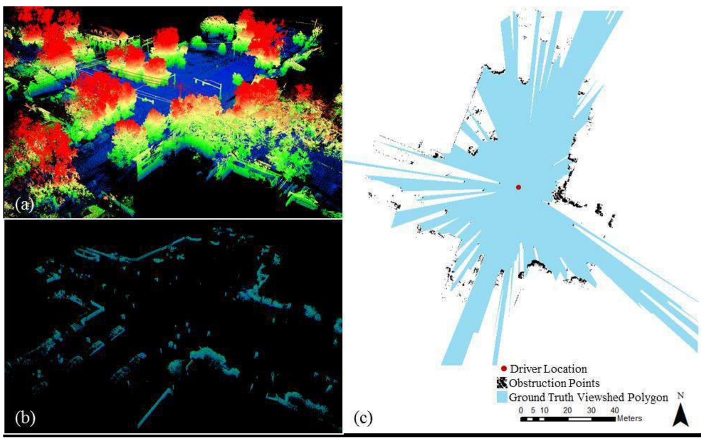


Figure 7 *Analysis of visibility triangles at intersections with obstacle detection (3D VIRTUAL SIGHT DISTANCE ANALYSIS USING LIDAR DATA Error! Bookmark not defined.)*

In order to determine the really available sight distance using a voxel, one ray directed at an imaginary obstacle at a certain distance is not enough, but a beam of ray is, with the ray intersecting the voxel which is angularly closest to the direction occupied by the vehicle in space. If it is planned to release a beam of rays, one must think about how small or big the change of angle in that beam should be. All these issues are very nicely described in the document[Error! Bookmark not defined.] which is recommended for those who want to get additional information. The introductory part of the document states that the US federal state of Oregon has applied this methodology on all its state roads in order to identify locations that have problems with sight distance and take measures to eliminate those problems, as well as to check locations of the highest priority once a year.

This method can give excellent results when checking the sight distance triangles at intersections. However, the mentioned document does not explain whether the variability of sight distance length along a section is taken into account. Also, this method does not give an answer whether there are additional obstacle behind the detected interference that need to be detected. In fact, if we remove the first obstacle in the driver's vision, it doesn't mean that we have removed all the others that are behind the first one.

According to the above, the question is whether there are other models that will, anyhow, enable the determination of zones of available and required sight distance, and their overlap for comparison. A similar innovative method was devised by the authors of this paper. The method envisioned is described in the following paragraphs.

5. PROPOSED INNOVATIVE METHOD

The description of the author's method begins with the question of who could benefit from the sight distance analysis and what would be the final result that could have the greatest use value of such an analysis.

Undoubtedly, various participants in planning, designing, safety inspection, road maintenance, expertise processes, insurance, etc. can benefit. Apart from the fact that they could benefit, considering the impact on traffic safety, the preparation of the available sight distance analysis is also their obligation in accordance with the laws and bylaws. However, the author's orientation is mostly directed towards the road managers, and if his role is analyzed, the desired final result would be as follows.

The road manager needs to detect obstacle in the driver's vision, so that he could remove obstacles or regulates speed limits if obstacles couldn't be removed.

Accordingly, the road manager needs a layout plan of the overlapping envelopes of the available and required sight distance, with the detected objects in that overlap that represent obstacle. Namely, not all the objects, that fall into the fold of the sight distance envelope, need to be obstacle at the same time. These are objects that are below or above the two visibility **fan** that are created at each point of the road, or are small and slim enough as pole of traffic signs that they do not really represent visibility disturbance. The first mentioned fan starts from the driver's eye and aims at a point on the road. The end point along these fans is located at a distance of the required sight distance from the driver's eye along its trajectory. The second fan targets points that are raised above the road by a specific size. In fact, the fan step and the height of the obstacle will be the input parameters that will be defined by the operator, which gives the possibility for different scenarios of visibility checking (for a passenger vehicle, truck, etc.).

The mentioned fans are the key to the proposed method. Instead of looking for penetration of rays that start from the driver's eye with wire model triangles or voxels, all the point cloud points between the two fans will stand out. Neither a wire model, nor the creation of a voxel, ie assigning dimensions to points, is required to recognize these points. The visual representation of the previously described fans is shown in the following figure, but due to the better visual representation, the height of the obstacle is set at 1.5 m.

Moving the complex geometric body, which for simplicity will be called the ***pyramid*** of sight distance, which is formed by the two fans along the trajectory, will create the possibility to select all points within the entire cloud of points that interfere with sight distance. The step of moving the pyramid of sight distance, the height of the driver's eye above the road, and the position within the traffic lane, will also be the input parameters that will be left to the operator.

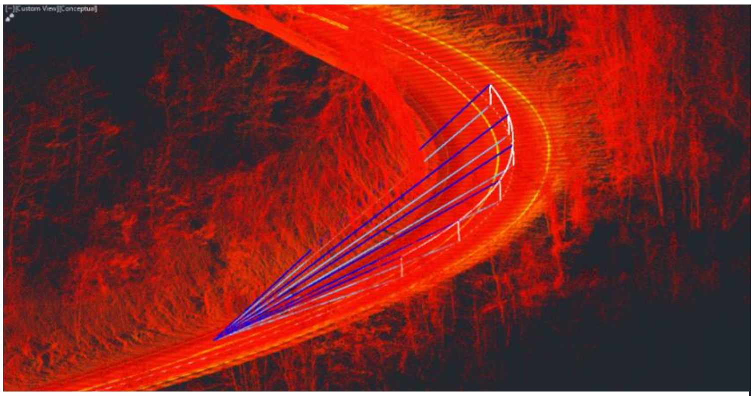


Figure 8 *Demonstration of creating a fan (pyramid) of transparency*

When all the points are separated, in the pyramid of sight distance, determining the available sight distance is reduced to determining the marginal point that is angularly closest to the direction that defines the position of the vehicle in space.

6. APPLICATION IN PROCESSES OF RSI IN SERBIA

Until the time of writing this paper, the software tools developed by the team of authors have been applied in the processes of traffic safety inspection (RSI) on several sections of state road nertwork of the first order in the Republic of Serbia.

The tools developed and used in RSI are:

- preparation of diagrams of posted and operating speed based on horizontal and vertical elements of the road alignment
- preparation of diagrams of required sight distances based on posted and operating speed diagrams
- visualisation of moving of driver eye and obstacles in front of the driver at the distance of required sight distance within the point cloud generated by lidar's equipment

As an example of the application of these tools, we cite the results obtained during the traffic safety check on the section 02334 (Pakovraće-Kratovska Stena) of the state road IB23.

On section in subject, which total length is 17.745km, conducted inspection determined that the required visibility was not met on:

- 7050m, for ahead direction (based on operating speed);
- 2825m, for ahead direction (based on posted speed);
- 7724m, for backward direction (based on operating speed);
- 2495m, for backward direction (based on posted speed).

Beside previous, during inspection of section in subject also was determined that on over 70% of segments where overtaking is alowed not only the overtaking sight distance wasn't met but required sight distance as well.

Example of above mentioned simulation and minutes from presentation of such innovative metodology to the representatives of PE Road of Serbia, interested can found on the link[5] in footer. The yellow cylinder that moves through the point cloud together with the driver's location movement represents a virtual obstacle that the driver's gaze must reach in order to meet the required sight distance.

7. CONCLUSION

According to the data taken from the database[6] available on the Internet portal of the Traffic Safety Agency in Republic of Serbia, in the period 2016-2020., there were 2520 traffic accidents with fatalities. Out of those 2520 accidents, 192 are classified in the group of influential factors *"Driver's omissions due to inadequate visibility and sight distances, ie complete experience and vision of the road and traffic"*. Of these 192 accidents, 71 are classified as influential factors: *"Impact of a stopped or parked vehicle", "Impact of vegetation", "Impact of road layout on driver visibility", "Impact of buildings, billboards, traffic signals".* If the mentioned figures are converted into percentages, it can be concluded that 7.6% of all accidents with fatalities are classified as causes related to inadequate visibility and sight distances, while 2.8% directly have inadequate sight distance as the cause.

The mentioned values would probably be even higher if we take into account the fact that the impact of visibility on the occurrence of a traffic accident is very difficult to assess without adequate equipment and tools, ie that in many of them visibility is not recognized as an influential factor. For example, the authors of this paper did not find in the mentioned database the term "overtaking" as an influential factor, but if from the group of influential factors *"Wrong performance of traffic by the driver"*, selected is the influential factor "*Inadequate assessment of the route or speed of another traffic participant"*, there is an additional 94 traffic accidents with fatalities which most likely have inadequate visibility in the cause.

[5] https://drive.google.com/drive/folders/1zSpOekU0I4rHoG4bZHTa-Ez4aAC0rhqg?usp=sharing
[6] https://www.abs.gov.rs/%D1%81%D1%80/analize-i-istrazivanja/baza-podataka

In any case, such values can be considered unacceptably high if we take into account that they are possible to prevent by the preventive action of the profession, regardless of the actions of the environment, ie the wider social community.

In accordance with all the above, the authors of this paper present the following conclusions:

- visibility problems each year cause traffic accidents with fatalities consequences that are unacceptable considering that they can be prevented;
- with today's development of technology, there is no justification for not conducting activities related to the analysis of visibility at any stage and procedure of planning, designing, safety revision and maintenance of roads, defined by law and bylaws regulations;
- considering the observed contradictions, it is necessary to reconsider the measures proposed for the purpose of improving traffic safety, but also a comprehensive review of the elements defined by the norms relating to the movement and stopping of vehicles, in accordance with modern development in technology and vehicles.

8. LITERATURE

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