DISTRIBUTION OF TRAFFIC ACCIDENTS IN RELATION TO PROBLEMS OF FULFILLMENT OF THE REQUIRED AND OVERTAKING SIGHT DISTANCES

Djordje Sokic[1]

Abstract: So far, the results of research in the world related to the recording of the causes of traffic accidents on the roads indicate the fact that in a large number one of the causes should be sought in inadequate sight distance. As part of this work, a spatial and statistical analysis of the distribution of traffic accidents was carried out in relation to the problems of fulfilling the required and exceeding sight distance with the idea of establishing correlations. The analysis was carried out on a part of the state road IB 22 in the Republic of Serbia, on which a detailed sight distance analysis was previously made, using innovative tools based on the movement of a virtual driver in a cloud of points created by mobile laser scanning.

Keywords: traffic accidents, sight distance, road safety

[1] Đorđe Sokić, B.Sc. traffic, Panpro team Ltd, Generala Rajevskog 1, Belgrade, Serbia, djordje.sokic@gmail.com

1. INTRODUCTION

Drivers in road traffic receive the largest amount of information through their sense of sight and based on them they make decisions about the use of various devices on the vehicle and approach the performance of various actions. By visually monitoring the traffic situation, drivers adapt their driving to the road and traffic conditions, that is, they perform certain actions and by changing the mode or path of the vehicle's movement, they react to potentially dangerous traffic situations. From the moment of perception to the moment of the driver's reaction and the response of the device on the vehicle, a certain amount of time elapses, during which the vehicle travels a certain distance without changing the mode of movement. For this reason, it is very important that road characteristics enable the driver to visually monitor traffic conditions in order to make timely decisions and change the mode of movement in case of need or a sudden potentially dangerous situation (Ivanović et all, 2014).

So far, the results of research in the world related to the recording of the causes of traffic accidents on the roads indicate the fact that in a large number of traffic accidents, one of the causes should be sought in the insufficient sight distances of the road. In this regard, road sections with sharp curves and larger longitudinal slopes, especially characteristic of difficult topographical conditions, are particularly unfavorable. Other reasons arise from visual obstacles and they usually do not have to be directly connected with the geometrical elements of the road of such dangerous sections.

Overtaking is an action that is characteristic of two-lane roads where traffic is allowed in both directions. These roads are the most common in almost all countries of the world. Sight distances when overtaking or overtaking sight distances is the distance that allows the driver of the overtaking vehicle to safely complete the action or to return to his right traffic lane in the event of the appearance of a vehicle from the opposite direction. On two-lane roads, safety and traffic conditions largely depend on the possibility of overtaking. Unlike highways where opposite directions are physically separated, on two-lane roads there is interaction between opposite traffic flows. In such traffic conditions, overtaking is possible only by using the traffic lane that is intended for the movement of vehicles from the opposite direction (NCHRP, 2008). Namely, overtaking is one of the most demanding and dangerous actions in traffic, which has a direct impact on traffic safety parameters. That is why it is the responsibility of the designers to define the zones of permitted and prohibited overtaking in accordance with the sight distances of the road. The percentage of permitted overtaking zones is a measure of the quality of traffic conditions on two-lane roads (Mathew et all, 2006).

In a real traffic flow, the need for overtaking arises in a situation when a vehicle, which has reached and tends to maintain a certain speed, begins to approach another vehicle moving at a speed lower than its own, as a result of which the following distance is reduced. Assuming that the oncoming vehicle wants to maintain or increase its speed, the following distance between this vehicle and the other vehicle is reduced to a safe minimum. The length of the overtaking path depends on the speed of the overtaking vehicle and the overtaken vehicle, that is, the relative difference between these speeds. In addition, the length of the overtaking path is influenced by the following distance at the beginning and at the end of the overtaking, as well as the speed of the vehicle coming from the opposite direction.

The simplicity of the theoretical foundations related to sight distances concepts is reflected in the fact that all of them, except **available** sight distances, are actually calculation values and directly dependent on speed, whether it is design, inferred, exploitation or some other type of speed. In contrast to them, the available sight distances does not represent a calculated value but, as the name suggests, the measured sight distances that is actually present/achieved/available on the road. The nature and differences in the seasons make the problem of available sight distances even more complex. Even in plain conditions, with roads in low embankments where no particular problem with sight distances is expected, conditions can drastically differ in the summer months with the presence of agricultural crops along the road compared to winter conditions (Sabo et all, 2022).

In accordance with the theory and the valid regulation, the required sight distances is the sight distances that is directly dependent on the inferred design speed, which, on the other hand, is directly dependent on the horizontal and vertical geometry of the road. In fact, since when designing roads, engineers tends to use more conformal elements than the limit ones defined by the design speed, it follows that the conditions on the road are variable and that speeds that are higher than the deisgn speed can occur and be achieved. Speeds obtained by calculation in relation to the projected or existing horizontal and vertical geometry are called inferred design speeds. In relation to it, the required transverse slopes are calculated and the required sight distances is determined, which differs from the stopping sight distances insofar as the stopping sight distances refers to the calculated value obtained on the basis of the design speed. Therefore, at every point of the road, the required sight distances must be achieved so that alone vehicle can stop in front of a sudden obstacle in wet road conditions. In order to confirm whether the required sight distances are really achieved, they must be compared with the actual available sight distances (Sabo et all, 2022).

As part of this paper, a spatial and statistical analysis of the distribution of traffic accidents was performed in relation to the problems of fulfilling the required and overtaking sight distances with the idea of establishing correlations. The analysis was carried out on a part of the state road IB 22 in the Republic of Serbia, on which the Elaborate[2] was previously prepared, using innovative tools based on the movement of a virtual driver in a cloud of points created by mobile laser scanning.

2. THE METHODOLOGY OF THE CONDUCTED RESEARCH REGARDING THE CORRELATION BETWEEN TRAFFIC ACCIDENTS AND SIGHT DISTANCE PROBLEMS

For the purposes of this paper research was carried out, which can roughly be divided into three steps:

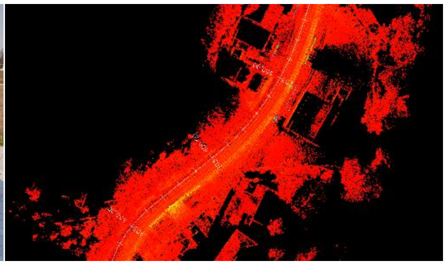
- taking over of data and results of Elaborate[2] with a focus on road segments in which the required and overtaking sight distances in relation to the posted speed limits are not met;
- taking over and systematization of data on traffic accidents from the database of the Traffic Safety Agency;
- creation of a database from the elements obtained from the previous steps and its analysis with a focus on the spatial distribution of traffic accidents.

During the creation of Elaborate[2], point clouds were recorded with measuring equipment installed on the vehicle (picture 1) and consisting of a lidar (laser) device that records point clouds of high density and an INS (inertial) device that is connected to GNSS antennas and an RTK modem , whose role is to georeference the points recorded by the lidar device (picture 2).

[2] Elaborate analysis of the available sight distances with a proposal for measures to eliminate deficiencies on the part of SR IB No. 22, from node 2223 to node 2225, Kraljevo (Jarcujak)-Usce (Investor: PE Roads of Serbia)

Based on a detailed analysis of the points obtained in this way and an additional analysis of the recording of the spherical video camera, in addition to defining the horizontal and vertical axis of the road, the following was created:

- diagrams of posted speed limits along the route for both driving directions;
- inferred design speed diagrams based on the recognized horizontal and vertical geometry of the road;
- diagram and required sight distances for both driving directions calculated on the basis of posted speed limits;
- measurement of available sight distances for both driving directions and creation of a diagram based on the movement of the virtual driver in the cloud of points;
- analysis of speed management;
- sight distances analysis (required and overtaking);
- definition of measures to eliminate deficiencies;
- sight lines and envelopes of required sight distances;
- sight lines and envelopes of available sight distance;

Picture 1*. Measuring equipment on the car* ***Picture 2****. Lidar captured point cloud*

Finally, it should be noted that the entire described system (recording the cloud of points and measurement of available sight distances and), developed as an author's work by the company Panpro Team ltd, represents an invaluable aid to designers when determining zones where overtaking is allowed.

In the second step, it was necessary to take over and systematize the data on traffic accidents that occurred on the observed part of the state road IB-22. Data on the characteristics of traffic accidents were taken from the database available on the Internet portal of the Traffic Safety Agency for the observed period 2016-2022.

Finally, a database was formed from the elements obtained from the previous steps and its analysis was carried out with a focus on the spatial distribution of traffic accidents, in order to reach conclusions to what extent problems with the fulfillment of the required and overtaking sight distances affect the occurrence of traffic accidents.

3. RESULTS OF EXPRESSION

The concept of security analysis is based on temporal and spatial distribution of traffic accident. Spatial distribution is most often at the level of the municipality, region or republic, if we look at the broader aspect, i.e. micro locations such as settlements, roads, streets, intersections, etc. For the temporal distribution, certain ones are taken time intervals usually hours during the day, days in during the week , months during the year and year for a certain period of time. Traffic accidents as traffic events are mass character and in all respects they represent statistical sets whose study is based on application of appropriate statistical methods.

3.1. Temporal distribution of traffic accidents

The temporal distribution of accidents is basically different in time and space due to the effect of various factors which affect the time rhythm (frequency) of accidents. The temporal distribution of accidents by month is not the same in all regions. So, for example, in agriculture most accidents occur during the period intensive agricultural autumn work, while in most accidents occur in tourist regions tourist season when the intensity of traffic is the highest. In the summer months, the volume of traffic increased by all roads due to the increased mobility of the population due to departure and arrival from annual leave locals and tourists alike. Multi-year monitoring and analysis temporal distribution of accidents allows to they notice the trends in the movement of these phenomena and in that way acquire general knowledge about them for the purpose of planning and implementation of appropriate activities for minimization of them as a general social goal. In this paper, the analysis covers the period of seven years from 2016 to 2022. in which year analyzed temporal (monthly) distribution of the total number traffic accidents as well as the number of traffic accidents with the dead.

Tabela 1. *Number and type of traffic accidents for the observed years*

	2016	2017	2018	2019	2020	2021	2022	Σ
TA with the dead	0	2	3	0	1	2	2	**10**
TA with the injured	30	16	22	20	21	17	16	**142**
TA with mat. damage	37	28	34	20	20	25	30	**194**
In total	**67**	**46**	**59**	**40**	**42**	**44**	**48**	**346**

A total of 346 traffic accidents were recorded on the relevant part of the state road IB-22 Kraljevo-Usce in the observed period, of which 10 were traffic accidents with fatalities, 142 with injured persons, while 194 were other traffic accidents. It can be seen from Table 1 that the highest number of accidents occurred in 2016 and 2018, respectively. The lowest number of traffic accidents was recorded in 2019.

The monthly temporal distribution was made with the aim of determining how different periods of the year affect the occurrence of traffic accidents.

Tabela 2. *Number and type of traffic accidents for the observed months*

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
TA with fatalities	0	0	1	2	0	2	1	1	1	1	1	0
TA with the injured	12	9	10	12	10	11	10	16	16	19	8	9
TA with mat. damage	24	16	18	19	12	20	15	14	13	20	13	10
In total	**36**	**25**	**29**	**33**	**22**	**33**	**26**	**31**	**30**	**40**	**22**	**19**

Based on this analysis, it can be seen that the months of January, April and June lead with the number of traffic accidents compared to other months. If we look at the total number of accidents, we can see that they reach their maximum in October. Often, as a reason for this distribution of accidents, months before and in connection with reinforced by seasonal agricultural work increased intensity of traffic and other movements, however, since the part of the state road in question passes through a gorge that cannot be linked to agricultural activities, this may indicate an increased impact of sight distances disturbances from vegetation, which is significantly more pronounced in those periods. If we look at the month of January, the reason for the increased number of traffic accidents should be sought in the conditions of the road and the surrounding area, that is, in the slippery pavement that is characteristic for this period of the year.

The distribution of the number of accidents with injured persons has similar distribution as the total number of accidents with the difference that they grow from August, and reach their maximum in October. This fact tells us that the largest number the accident with injured persons happened exactly in this period. There is a decline in all distributions after October number of accidents and injuries until January after which they start to grow again. Only for traffic accidents with fatalities cannot be claimed to match the rest distributions due to the fact that the death toll is evenly distributed throughout the year with two extremes, the months of April and June, in which there were 2 traffic accidents with fatalities.

In addition to the already mentioned fact that the conditions can differ drastically in the summer months with the presence of vegetation along the road compared to the winter conditions, this kind of analysis is not able to show that, therefore the use of adequate equipment and tools is necessary.

Figure 3*. An example of the influence of vegetation on sight distances*

3.2. Spatial distribution of traffic accidents

This survey covers two sections of the state road IB-22, namely, Kraljevo (Jarcujak) - Mataruska banja and Mataruska banja - Usce. The total length of the sections is 45.84 km, with the second section being significantly longer.

Tabela 3. *Characteristics of the relevant sections of the state road IB-22*

Share	The start	The end	Length [m]	Perc. route length [%]
02224	157+870	164+640.28	6770.28	14.77
02225	164+640.28	203+709.38	39069,10	85.23
		Σ	45839.38	100

For the purposes of this research, the term urban area was used, which does not refer to urban places (traffic sign III-23) and settlements (III-24), but represents the driver's experience of the road sorroundings. This was done for the reason that the marking of the points where settlements start and end (traffic signs III-24 and III-24.1), often does not correspond to the real situation on the ground.

Taking the above into account, we come to the parts of the route that pass through urban areas.

Tabela 4. *The length of the route through urban areas*

Rb	The start	The end	Length [m]	Perc. route length [%]
1	157+870	167+410	9540	20.81
2	168+050	169+300	1250	2.73
3	174+500	175+300	800	1.75
4	194+750	196+230	1480	3.23
5	203+100	203+709.38	609.38	1.33
		Σ	13679.38	29.84

Looking at the previous table, we come to the conclusion that 29.84 percent of the route passes through the urban areas, while 70.16 percent of the route passes outside the them. Based on the available data on the number of traffic accidents for the period 2016-2022. through spatial analysis, we arrive at the result that of the total number of traffic accidents, 167 occurred in urban areas, that is, 179 traffic accidents outside them. It should be noted that all traffic accidents that occurred on the sections in question were positioned along the route based on their coordinates, which were then converted into chainages.

Tabela 5. *The length of the route and the number of traffic accidents in urban/non urban areas*

	Route length [m]	Perc. route length [%]	TA number	Percentage TA[%]
Urban areas	13679.38	29.84	167	**48,27**
Non- urban area	32160	70,16	179	**51.73**
In total	**45839.38**	**100**	**346**	**100**

It follows from Table 5 that the concentration of TA in urban areas is significantly higher than outside them if the distribution along the route is observed, although the length through urban areas is significantly shorter than outside. This is probably logical since there is more influence in urban areas than outside, and also that the intensity of traffic and other movements is greater in urban areas than outside them.

The available data on traffic accidents did not offer information on how much influence insufficient sight distances had on the occurrence of traffic accidents, because it is very difficult to assess without adequate equipment and tools, that is, in a large number of accidents, sight distances was not recognized as an influential factor. Accordingly, it is necessary to determine the problem zones of required and overtaking sight distances. The following pictures show the method of determining sight distances problem zones based on diagrams taken from Elaborate[2].

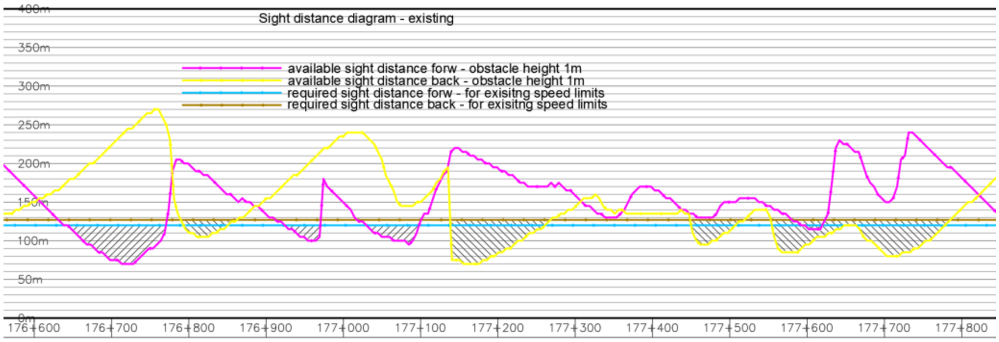


Figure 4*. An example of sections of the route where the required sight distances for the posted speed limits is not met*

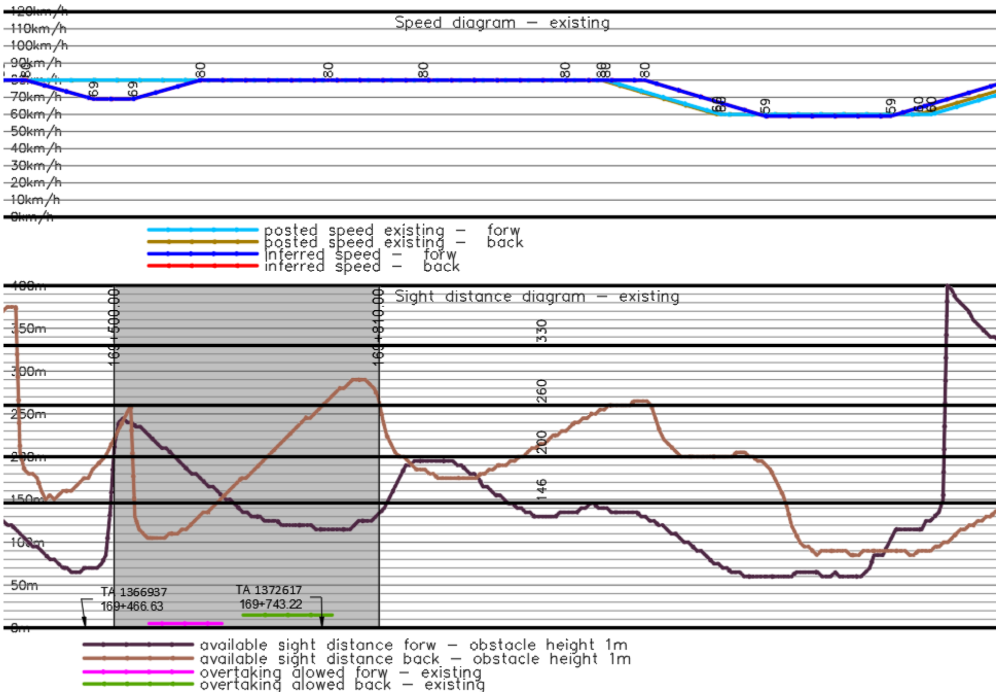


Figure 5*. Example of a zone, from km 169+500 to 169+810, in which overtaking sight distances of 330m is not satisfied for the speed ratio 80-60-80 km/h, in accordance with the posted speed limits*

On the basis of these diagrams, problem zones of required and overtaking sight distances, as well as combined problem zones, were identified. It should be noted that the combined problematic zones do not represent the strict sum of the lengths of the required and overtaking sight distances, but the sum of the overlapped lengths of the mentioned sight distances.

Tabela 6. *Length of problematic zones of required, overtaking and combined sight distances*

	Problems of required sight distances [m]	Problems of overtaking sight distances [m]	Combined sight distances problems [m]	Percentage in relation to the total length of the section [%]
Urban areas	926	995	1921	**4.19**
Non-urban area	12447	4059	15961	**34.82**
In total	**13373**	**5054**	**17882**	**39.01**

This indicates that sight distances problems are not dominant in urban areas and that the analysis of the impact of sight distances on the occurrence of traffic accidents should be devoted only to those outside them.

Tabela 7. *Number of traffic accidents for different types of sight distances and their percentage in relation to the total number of traffic accidents non-urban areas (179 TA)*

	Requested sight distances [TA number]	[%]	Overtaking sight distances [TA number]	[%]	Combined sight distances [TA number]	[%]
Zone of problematic sight distances	70	**39,10**	19	**10.61**	85	**47,49**
Zone of problematic sight distances + 50m	100	**55.87**	28	**15.64**	111	**62.01**

Observed for any type of sight distances or their combination, there is a significant increase in the number of traffic accidents if the beginnings and ends of those zones are extended by 50m, which leads to the conclusion that some traffic accidents are the result of sight distances problems, but due to the required reaction time of the driver and the distance traveled during those reactions actually happen immediately before or after the registered zones of problematic sight distances. Based on the results obtained, a very alarming is the fact that out of the total number of traffic accidents that occurred outside of urban areas, as many as **62%** of accidents occur in problematic combined (required and overtaking) sight distances zones, although such zones are only **34.82%** in length.

After the results obtained in this way, a more detailed analysis of traffic accidents that occurred in zones with combined problematic sight distances was carried out. The division was made according to Kind of TA, Groups of types of TA, according to Type of TA and Groups of influencing factors.

Tabela 8. *Kind of TA*

Kind of TA	TA number
TA with fatalities	4
TA with an injured face	41
TA with material damage	66

Tabela 9. *Groups of types of TA*

Tabela 9. Group of types of TA	TA number
TA with one vehicle	68
TA with at least 2 vehicles - without turning	34
TA with at least 2 vehicles - turning or crossing	8
TA with pedestrians	1

Tabela 10. *Types of TA*

Type of TA	TA number
Accident with one vehicle - leaving the road in a curve	20
Accidents involving one vehicle and obstacles on or above the roadway	20
Other accidents with at least two vehicles - opposite directions without turning	9
One vehicle rollover accident	9
At least two vehicles - head-on collision	9
Accident with one vehicle on the road	8
At least two vehicles moving in the same direction - catching up	7
At least two vehicles moving on the same road in opposite directions turning left in front of another vehicle	6
Accident with one vehicle - going off the road to the left	6
At least two vehicles moving in the same direction - overtaking	5
Other traffic accident	12

Tabela 11. *Groups of influential factors of TA*

Groups of influential factors TA	TA number
Taking reckless actions by the driver	45
The influence of the road and the road environment	34
Wrong performance of actions in traffic by the driver	16
He missed the driver due to poor psychophysical condition, inattention, distraction	9
Falt of the driver due to inadequate visibility, sight distances, that is, the complete experience of seeing the road and traffic	3
Impact of vehicle malfunction	2
Special cases	2

From table 8, it can be seen that out of 111 traffic accidents that occurred in zones of combined problematic (required and overtaking) sight distances, 4 accidents resulted in fatalities and 41 accidents resulted in injuries. Having in mind that 10 traffic accidents with fatalities occurred on the entire section in question, it comes to the conclusion that 40% of the total number of traffic accidents with fatalities occurred in these zones.

When it comes to Groups of types of traffic accidents, traffic accidents with one vehicle lead here, as many as 68 of the 111 that happened in these problematic zones. The second dominant Group of types is TA with at least two vehicles - without turning, which includes head-on crash, crash when overtaking vehicles, etc. in which 34 such accidents were recorded. With this Group of types of accidents, insufficient sight distances can have a big impact on the occurrence of traffic accidents. Also, in traffic accidents with one vehicle, one of the reasons for the occurrence of a traffic accident can be problems with sight distances, because drivers often react incorrectly or make a wrong assessment due to reduced sight distances.

The analysis of traffic accidents also included the Types of traffic accidents that occur in the observed zones of problematic combined sight distances. Based on table 10, it can be seen that there are two most numerous types of TA - "traffic accidents with one vehicle - leaving the roadway in a curve" and "accidents with the participation of one vehicle and obstacles on or above the roadway". These accidents in this distribution take 36% of all accidents that happened outside of urban areas in zones of problematic combined sight distances. We should not ignore the number of accidents that almost certainly depend on the sight distances of the road, such as overtaking accidents, head-on crash, left-turning accidents in front of another vehicle and overtaking accidents.

The last analysis of traffic accidents related to Groups of influential factors of traffic accidents. The obtained results show that the main influencing factor for the occurrence of a traffic accident is "taking reckless actions by the driver". These influencing factors appear in 45 out of 111 traffic accidents. The second dominant influence is the influence of the road and the road environment. The fact that, based on everything shown, only 3 traffic accidents are in the group "missed by the driver due to inadequate sight distances, sight distances, that is the complete experience of seeing the road and traffic" is very problematic. Influential factors should be given more attention, because almost certainly in both of the most numerous influential factors in a large number of accidents, the problem with sight distances is hidden as an influential factor, just it is not recognized.

4. CONCLUSION

The required sight distances is the sight distances that is directly dependent on the inferred design speed, which on the other hand is directly dependent on the horizontal and vertical geometry of the road. Since when designing roads, engineers tends to use more conformal elements than the limiting ones defined by calculated speed, it follows that road conditions are variable and that speeds that are higher than calculated can occur and be achieved. Speeds obtained by calculation in relation to the designed or existing horizontal and vertical geometry are called inferred design speeds. In relation to it, the required transverse slopes are calculated and the required sight distances is determined, which differs from the stopping sight distances insofar as the stopping sight distances refers to the calculated value obtained on the basis of the design speed and zero longitudinal slope. Therefore, at every point of the road, the required sight distances must be achieved so that a lone vehicle can stop in front of a sudden obstacle in wet road conditions. In order to confirm whether the required sight distances has really been achieved, it must be compared with the actual available sight distances.

During the research, it was determined that 29.84 percent of the route passes through the urban area, while 70.16 percent of the route passes outside them. Based on the available data on the number of traffic accidents for the period 2016-2022. of the total number of traffic accidents, 167 occurred in urban areas, while 179 traffic accidents occurred outside them. Based on the diagram of the required and overtaking sight distances, the problem zones of the mentioned sight distances , as well as the combined problem zones, which represent the sum of the overlapped lengths of the required and overtaking sight distances, were identified. The percentage of such zones in non-urban areas amounts to almost 35% of the total length of the entire observed route, so further analysis looked only at traffic accidents that occurred in these zones, non-urban areas. A worrisome fact is the fact that of the total number of traffic accidents that occurred in non-urban areas, as many as **62%** of accidents occur in problematic combined (required and overtaking) sight distances zones. Finally, an analysis of traffic accidents that occurred in problematic combined sight distances zones was performed according to the Kind of TA, according to the Group of TA types, according to the TA type and according to the Group of influencing factors. Out of a total of 10 traffic accidents with fatalities that occurred on the entire section in question, as many as 4 traffic accidents with fatalities occurred in these zones. Of the 111 traffic accidents that occurred in these problem areas, 68 were accidents with one vehicle. Another dominant Group of types are TA with at least two vehicles - without turning. The two most numerous Types of traffic accidents - "traffic accidents with one vehicle - leaving the roadway in a curve" and "accidents with the participation of one vehicle and obstacles on or above the roadway". In this distribution, there are 40 of these accidents out of the total number of accidents that occurred outside urban areas in problematic combined sight distances zones.

This paper is probably the first in the Republic of Serbia that deals with the issue in detail and as such can represent a good basis for further research. The presented results can be most useful to road managers and decision-makers, to find appropriate mechanisms for their elimination after the identified problems with the fulfillment of the required and overtaking sight distances. In order to obtain even more reliable and precise results, it is necessary to carry out similar research on a larger number of sections that differ from each other in terrain, geometric, functional, urban, traffic and other characteristics.

Also, the obtained results indicate a significant impact of inadequate sight distances on the occurrence of traffic accidents, which is inconsistent with the data from the Table - Group of influential factors, which speaks of only 3 accidents in the group ***„Falt of the driver due to inadequate sight distances, sight distances, that is, the complete experience of seeing the road and traffic“.*** This in turn indicates insufficient studing and knowledge of sight distances as an influencing factor, which can be partially understood if we take into account that this influence is very difficult to prove if there are no tools for measuring of avaialble sight distances.

In any case, the numbers of traffic accidents shown in this paper, which can be linked to sight distances problems, could be considered unacceptably high if it is taken into account that they can be prevented by profession independently of wider social influence.

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