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# EDITORIAL - Preface to Volume 9 Issue 2 of the Scientific Journal of Civil Engineering (SJCE)


## Marijana Lazarevska EDITOR - IN - CHIEF


Dear Readers,

**S**cientific **J**ournal of **C**ivil **E**ngineering (SJCE) is an international, peer-reviewed journal published bi-annually since December 2012. It is an open access Journal available at the web site of the Faculty of Civil Engineering in Skopje (www.gf.ukim.edu.mk).

This Journal is committed to publish and disseminate high quality and novel scientific research work in the broad field of engineering sciences. SJCE is designed to advance technical knowledge and to foster innovative engineering solutions in the field of civil engineering, geotechnics, survey and geo-spatial engineering, environmental protection, construction management etc.

As an editor-in-chief of the Scientific Journal of Civil Engineering, it is my great pleasure to present the Second Issue of Volume 9, an issue that is mainly devoted to **MARE**, the **M**acedonian **A**ssociation for **R**oads **E**ngineers.

MASE has been present in the engineering world for 50 years. Celebrating its 50th anniversary they organized the First Macedonian Road Congress in Skopje, in November 2019.

This congress gathered more than 300 participants from 16 different countries. Invited lecturers from Netherlands, Serbia, Croatia, Slovenia, Austria and North Macedonia had a unique opportunity to share their rich and valuable professional experience, contributing significantly for the great success of the Congress.

This general idea behind this Issue of SJCE is to acknowledge the importance of MARE for the professional growth of many road engineers and to support their enthusiasm for staring a new chapter in their scientific research and expert development. That is the reason why the editorial board invited the guest speakers of the First Macedonian Road Congress to participate in this Journal by publishing their recent scientific-research work.

This Issue of the Journal contains the most current research findings in the field of planning, design and construction of roads, risk management of major road projects and road safety. It includes the introduction part that gives a short overview of the First Macedonian Road Congress, followed by eleven papers written by the invited and selected speakers of the Congress and one paper in the field of geodesy.

I thank all the authors for contributing to this Issue and all the reviewers for providing detailed and timely evaluations of the submitted manuscripts.

It is a great challenge for the editor members to bring a new journal issue into the world, especially when the journal aims to publish high quality manuscripts. I would like to express my sincere gratitude to all of them for their excellent work, remarkable contribution, enthusiasm and support, especially during these tough times of COVID-19 pandemic.

Sincerely Yours,

Assoc. Prof. Dr. Marijana Lazarevska

December, 2020

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# Impressum


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# FIRST MACEDONIAN ROAD CONGRESS 2019

The First Macedonian Road Congress organized by the **M**acedonian **A**ssociation for **R**oads **E**ngineers (**MARE**), was held on 7- 8th November, 2019 in Skopje in the hotel "Double Tree by HILTON"

The co-organizers of the congress were:

- Public Enterprise for State Roads
- Faculty of Civil Engineering – Skopje
- University “S’s. Cyril and Methodius” - Skopje
- The Macedonian Chamber of certified architects and certified engineers
- Public Enterprise for the maintenance and protection of national and regional roads "Makedonijapat"
- Republic Council for Road Traffic Safety and
- The Engineering Institution of Macedonia.


The patron of the First Macedonian Congress for Roads 2019 was the Prime Minister of the Government of RN Macedonia, Mr. Zoran Zaev.

This First Macedonian Road Congress was organized in honor of several major anniversaries in RN Macedonia, as follows:

- 70 years since the founding of the University "S's. Cyril and Methodius" - Skopje
- 70 years since the founding of the Faculty of Civil Engineering in Skopje
- 50 years since the establishment of MARE

About 500 official guests were present at the opening ceremony of the congress, including representatives of the state leadership and the diplomatic corps from all participating countries in the country.

Although this was the first Congress, the Organizing and Scientific Committee can be satisfied with the number of participants - about 350, of which 130 from 16 European countries, with more than 70 peer-reviewed scientific papers. The Scientific Board was composed of eminent professors from 10 European countries.


According to the program, the congress had 7 invated lectures on actual topics by top professors and experts from Netherlands, Serbia, Croatia, Slovenia, Austria and Macedonia.

The topics of the congress were planning and design, management, construction and maintenance, road safety, environmental protection and sustainable development, infrastructure facilities, transport policy and financing, ITS and new technologies in traffic, free and related topics from area of roads and presentation of new projects.

In more than 50 years of existence of MARE some important events have been organized so far, but this was the first time to organize a congress, and therefore it presents an extremely important event. Not only because this is the first Macedonian Road Congress it is important because of the exceptional importance of the road network for society, as well as for the merits and challenges of Macedonian road engineers.

In that context, it is worth mentioning the fact that according to the Monograph "Roads in Macedonia from 1945 to 1988" published by the Republic Road SIU, there were only 5 km of roads with modern pavement construction in Macedonia after the liberation in 1945.


I will leave you to decide for yourself about the significance of my colleagues - road engineers and I will only mention the fact that today in Macedonia we have more than 300 km of motorways and more than 14.000 km of all road classes. It is the work of our road engineers of all generations.

This First Road Congress was held at a time when Macedonia is in an intensive investment cycle in the development of its road network, which not only completes the final look of the road map, but also acquires new knowledge and experience in the application of new technologies and materials, and modern construction trends are also implemented.

According to the opinion of many participants, the organization of this First Macedonian Road Congress will contribute in providing continuous education to its members - road engineers, to exchange experiences and knowledge with colleagues from abroad, in order to learn new technologies, which will results with benefit for our society also.

By organizing the The First Macedonian Road Congress we have affirmed not only the scientific-professional achievements in the field of roads in our country, but also our state.

It is our opinion, as well as of the participants that Macedonia needed such a congress in the field of roads even much earlier, and it is of great importance to strive for continuity.

In the end, as President of the MARE, I can say that I am especially proud that we organized this congress for roads, and accomplished the efforts of many generations of Macedonian road engineers.

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# MODERN SUBURBAN ROUNDABOUTS IN CROATIA - FLOWER AND TURBO ROUNDABOUTS

Turboroundabouts are specially designed multilane roundabouts with spiral circulatory roadway and physically separated traffic lanes. This roundabout layout was developed in the late nineties of the last century with the aim of increasing the traffic safety and capacity at classic multi-lane roundabouts. However, the experience has shown that turbo roundabouts have certain deficiencies - due to its complex geometry and large outer diameters, the reconstruction of existing less safe multi-lane roundabouts into turbo roundabouts is financially very demanding. In that case, a construction of so called flower roundabout is much better solution. Namely, unlike in the case of turbo roundabouts, it is possible to adjust the existing multi-lane roundabouts into flower roundabouts without moving any of the outer road curbs. Within the scope of this study, geometric design and performances of these two modern roundabout types are analyzed. Their advantages and disadvantages in regard to performances of classic multi-lane roundabouts are discussed, examples from Croatian design practice are presented, and recommendations for their planning and designing are provided.

Keywords: comparison, flower roundabout, geometry, performances, suburban roundabouts, turbo roundabout

## 1. INTRODUCTION

Roundabouts have become increasingly used all over the world over the recent decades [20]. This intersection type has curved fastest path and lower number of potential conflict points in respect to classic signalized and non-signalized road intersections which results in greater traffic safety and higher capacity [18]. Furthermore, at roundabouts queue lengths are significantly shorter and speed profiles are notably smoother which leads to lower fuel consumption and lower emission of harmful gases [27]. However, it is necessary to stress that traffic safety in roundabouts significantly decreases with an increase of traffic lanes on roundabout approaches and circulatory roadway, and that the capacity of such roundabouts is often lower than predicted [10, 13]. The reasons for this are high driving speeds and large number of potential conflicts at multi-lane entrances, exits and circulatory roadway (Figure 1) [9].

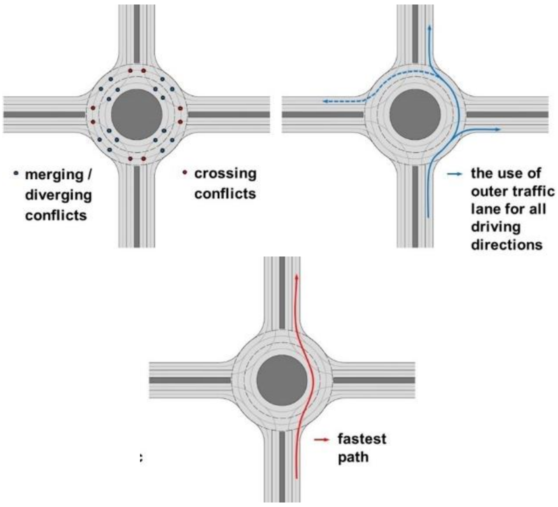


Figure 1. Disadvantages of multi-lane roundabouts

Following the above-mentioned findings, and the fact that several newer and safer types of multi-lane roundabouts (with significantly larger capacities and levels of traffic safety) were invented, in certain European countries (e.g. in Netherlands and Slovenia) the construction of classic multi-lane roundabouts is forbidden, and existing multi-lane roundabouts are being reconstructed [26].

## 2. SUBURBAN ROUNDABOUTS IN CROATIA

Roundabouts were not considered as a good traffic solution at the very beginning of their application in the Croatia. Namely, in the absence of domestic regulations and the lack of experience, foreign regulations (German, Austrian, and Swedish) were used and often misinterpreted, which resulted in a large number of improperly shaped roundabouts [1]. These first Croatian roundabouts had oversized circulatory lanes, and multi-lane approaches and circulatory roadways, which frequently led to previously described issues related with traffic safety and capacity.

However, an increasing number of roundabouts has been built in the Croatia in the last twenty years, and there is still a growing interest for them both by the investors and designers [1]. The reasons for this are numerous positive experiences of various Western European countries, including the neighboring Slovenia.

First Croatian guidelines for roundabout use and design [15] were published in year 2002. Main purpose of these guidelines was to achieve the commonality in the design and construction of all single- and multi-lane roundabouts at public roads in Croatia [21].

New Croatian guidelines for the design of roundabouts [16], published in year 2014, represent a significant upgrade of the first guidelines from 2002 in terms of the roundabout planning and designing i.e. the importance of swept path analysis for relevant design vehicle within the design process is emphasized [9]. Namely, the design of roundabouts is very specific due to the great variety of spatial and traffic factors, so it is not always possible to apply the optimal design elements and meet all the required criteria.

In the addition to above, according to these new guidelines [16] classic multi-lane roundabouts should be constructed only exceptionally i.e. special justification according to the criteria for checking the adequacy of the roundabout performance is required for the construction of such intersections. Moreover, separate guidelines for the design of newer and safer multi-lane roundabout, so called turbo roundabout, have been published in the same year [17].

Another alternative for classic multi-lane roundabouts are so called flower roundabouts. Unlike the turbo roundabout, these flower roundabouts are good traffic solution in the case of reconstruction of existing less safe multi-lane roundabouts. The reasons for this are as follows. When existing less safe multi-lane roundabout is converted into a flower roundabout all outer road curbs remain their positions (reconstruction costs are lower, and expropriation of surrounding land is not necessary). Contrarily, when existing multi-lane roundabout is converted into a turbo roundabout the position of all the kerbs of the circulatory roadway, splitter islands, and access roads needs to be changed, which is financially extremely demanding.

Flower roundabouts haven't been introduced to Croatian design practice, nor to design guidelines of this country. However, a number of classic single-lane roundabouts with bypass lanes for right turns, whose design elements and performances are quite similar to those of flower roundabouts, have. In the following text advantages and disadvantages of turbo and flower roundabouts in regard to performances of classic multi-lane roundabouts are discussed, examples from Croatia are presented, and recommendations for their planning and designing are provided.

## 2.1 TURBO ROUNDABOUTS

Turbo roundabout is a specially designed multi-lane roundabout with spiral circulatory roadway where the traffic flows at the entrance, circulatory roadway and exit are physically separated by raised mountable lane dividers [8]. Due to the physical separation of traffic lanes, driving speed is reduced, weaving conflicts are eliminated, and sideswipe collisions at roundabout entrances and exits are prevented (Figure 2) [9]. This roundabout type is recommended for use in the case of construction of new suburban multi-lane roundabouts due to its large outer diameters and multi-lane approaches.

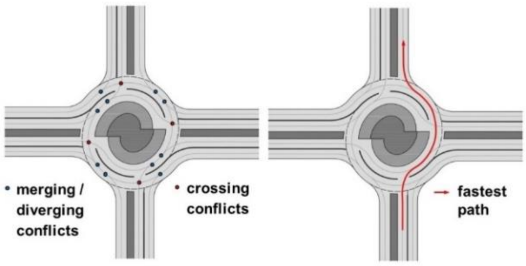


Figure 2. Conflicts and fastest path at turbo roundabout

According to Croatian guidelines [17], turbo roundabout planning and designing is an iterative procedure:

1. Selecting one of available turbo roundabout types (Egg, Basic turbo, Knee and Stretched-Knee - all these types should be used in the case of one dominant traffic flow) (Figure 3).
2. Defining a relevant design vehicle (truck with a semitrailer).
3. Creating one of given turbo block templates with inner radius from 10.45 m to 19.95 m (a turbo block is an auxiliary construction used in the design of spiral circulatory roadway) (Figure 4).
4. Designing the remaining turbo roundabout elements (circulatory lanes, central island, approaches, and lane dividers).
5. Conducting the required performance checks (design vehicle horizontal swept path analysis and fastest path vehicle speed analysis).

Iterativeness is reflected in the following: if analyses show that applied elements do not fulfil the swept path and/or speed requirements a redesign of roundabout elements is required.

It is necessary to stress that the design vehicle swept path should not be used not only as a performance check at the end of a design process, but also as a key parameter in geometric design of all turbo roundabout elements. Long term studies performed at the Department for Transportation of Faculty of Civil Engineering, University of Zagreb [8, 6, 7, 3, 22, 23] have shown that this design approach ensures the usage of optimal intersection element dimensions and an unhindered path for the design vehicle through the intersection.

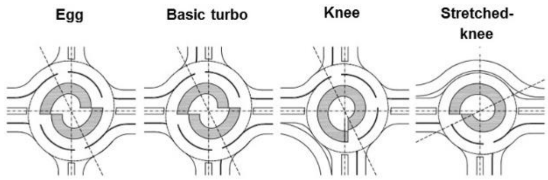


Figure 3. Turbo roundabout types given in Croatian guidelines [17]

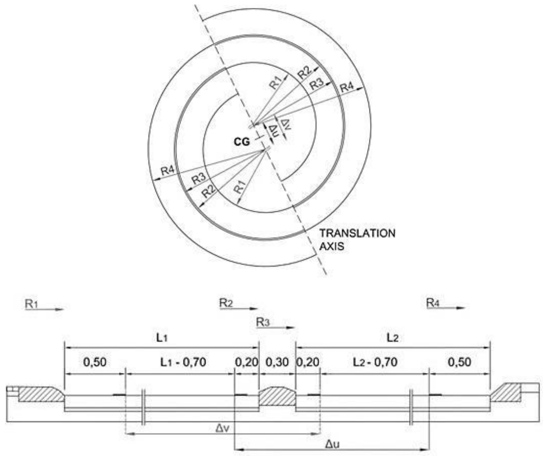


Figure 4. Turbo block design according to Croatian guidelines [17]

Studies involving turbo roundabouts show that this intersection type has a significantly lower number of traffic accidents in respect to classic multi-lane roundabouts. The use of this special multi-lane roundabout provides reductions of the number of total potential accidents between 40% and 50%, and reductions of the number of potential accidents with injuries between 20% and 30% [19]. In other words, traffic accidents at turbo roundabouts are extremely rare and usually result in material damage only [25]. Safety issues at this intersection type are mainly related to raised mountable lane dividers which represent a dangerous obstacle to motorcycles [4]. Moreover, these lane dividers hinder the maintenance and snow removal processes.

The capacity of turbo roundabouts is notably greater than the capacity of classic signalised and non-signalised road intersections [11]. However, if we compare them with classic multi-lane roundabouts, turbo roundabouts have greater capacity only in the case of one dominant traffic flow i.e. in the case of equal traffic volumes on all approaches capacity of turbo roundabouts is lower or equal to the capacity of classic multi-lane roundabouts [12].

Recent studies that have addressed the impact of traffic flow conditions on the environment have shown that in terms of emissions of harmful gases the turbo roundabouts are less favourable traffic solution than classic multi-lane roundabouts [14]. Namely, traffic in turbo roundabouts produces less carbon monoxide (CO) and hydrocarbons (HC), but more carbon dioxide ($CO_2$) and nitrogen oxides (NOx) [28]. Furthermore, studies have shown that fuel consumption and emission of harmful gases is lower at turbo roundabouts with bypass lanes than at those without bypass lanes [2].

Egg turbo roundabout located near the city of Osijek in Croatia is shown in Figure 5. This is a good example of a properly shaped suburban turbo roundabout: its approaches are aligned radially under the angles of 90°; heavy vehicles and intercity buses are passing smoothly through the circular roadway; lane dividers are positioned adequately.

Figure 5. Turbo roundabout near the city of Osijek

## 2.2 FLOWER ROUNDABOUTS

Flower roundabout is specially shaped roundabout with right turn bypass lanes [24]. In this roundabout, right turners have their own separate traffic lanes, and there is no need for them to enter the circulatory roadway i.e. circulatory roadway is used only by the vehicles that are driving straight through the roundabout, the vehicles that are turning left, and the vehicles that are making U-turn. As shown in Figure 5, flower roundabout has only 8 conflict points at circulatory roadway and neither of them is a crossing or weawing (Figure 6).

This type of roundabout is recommended for use in the case of reconstruction of existing less safe multi-lane roundabouts. As mentioned above, unlike in the case of turbo roundabouts, when reconstructing the existing two-lane roundabout into a flower roundabout all the curbs of the circulatory carriageway, splitter islands, and access roads remain in the same positions (Figure 7) [26].

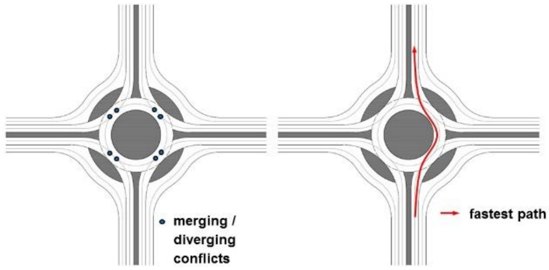


Figure 6. Conflicts and fastest path at flower roundabout

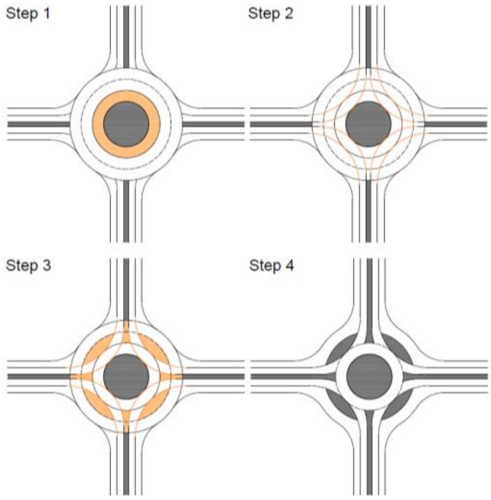


Figure 7. Reconstruction of classic two-lane roundabout to flower roundabout [26]

Flower roundabouts are rather simply a specific type of a classic single-lane roundabout with additional bypass lanes for right turns. These bypass lanes for right turns are separated from the outside edge of the circulatory roadway by a pseudo-elliptical traffic island, whose maximum width is equal to the circulatory lane width [5]. This roundabout solution can be implemented in four-lane as well as in two-lane roads. In the case of a two-lane road, an additional, sufficiently long entry/exit lane before the roundabout entry/exit should be planned [28].

In terms of traffic safety, the formation of these new entry/exit lanes at two-lane roads results in additional conflicts at roundabout approaches (8 new merging and emerging conflicts appear). However, the transfer of conflict points from the circulatory roadway to the road sections before and after the roundabout is considered as much safer traffic solution [25]. Generally, the bypass lanes for right turns can lead to speeding, and therefore, need to be used only at roundabouts in suburban areas, where number of non-motorized road users is reduced [24].

Recent studies have shown that flower roundabouts can be used whenever the circulating flow is below 1600 veh/h [5]. Up to that threshold they lead to higher capacities and lower delay than those in classic two-lane roundabouts. Contrarily, in the case of circulating flows higher than 1600 veh/h, the circulatory roadway tends to saturate and vehicles can't get onto it, and consequently entry flows reduce towards zero. It should be also noted that these roundabouts are advantageous compared to classic multi-lane roundabouts when a percentage of right turners reaches 60% of the total number of vehicles in roundabout [26].

Finally, there are no significant energetic and environmental benefits if existing classic multi-lane roundabout is replaced with flower roundabout at low traffic roads [5]. Moreover, if the traffic intensity is very high, two-lane roundabouts provide even better performances from this point of view. However, the use of flower roundabouts can lead to the potential reduction in fuel consumption and pollutant emissions only when the percentage of right-turns is higher or equal to 70% of the total traffic.

As mentioned before, flower roundabouts haven't been constructed in Croatia yet, but classic single-lane roundabouts with bypass lanes for right turns have. Such one classic single-lane roundabout with bypass lanes for right turns located near the city of Varaždin in Croatia is shown in Figure 8.

Figure 8. Classic single-lane roundabout with bypass lanes for right turns near the city of Varaždin [26]

## 3. CONCLUSIONS

A number of studies have shown that classic multi-lane roundabouts have poor traffic safety, and that the capacity of such roundabouts is often lower than predicted. The reasons for this are high driving speeds, and a large number of potential conflicts at roundabout multilane entrances, exits and circulatory roadway. In the past few years road designers are trying to solve these problems by introducing new roundabout layouts.

One such layout, which has been increasingly used in Croatian design practice in the last few years, is so called turbo roundabout. Because of its complex design, large outer diameters and multi-lane approaches, turbo roundabout is recommended for use in suburban areas. Furthermore, if existing multi-lane roundabout is converted into a turbo roundabout the position of all the kerbs of the circulatory roadway, splitter islands, and access roads needs to be changed, which is financially quite demanding. Turbo roundabouts have a significantly lower number of traffic accidents in respect to classic multi-lane roundabouts, but apparently their raised mountable lane dividers, which are important element of this road intersection, represent a dangerous obstacle for motorcycles. The capacity of turbo roundabouts is greater than the capacity of classic multi-lane roundabouts only in the case of one dominant traffic flow. Otherwise, their capacity is equal to or smaller than the capacity of classic multi-lane roundabouts. In terms of emissions of harmful gases this intersection is less favorable traffic solution compared to classic multi-lane roundabouts.

Flower roundabouts are much better alternative for existing less safe classic multi-lane roundabouts than turbo roundabouts - existing multi-lane roundabout can be replaced by a flower roundabout without movement of any of outer road curbs. In terms of traffic safety, fower roundabouts are much safer solution than classic multi-lane roundabouts. However, their bypass lanes for right turns might lead to speeding. Flower roundabouts should be used in the case of low traffic volumes, and in the case when a percentage of right turners reaches 60% of the total number of vehicles in roundabout. Contrarily, when the traffic intensity is high, and the percentage of right turners is lower than 60%, turbo roundabouts are notably better traffic solution. Finally, in terms of energetic and environmental benefits flower roundabouts are less favorable than classic two-lane roundabouts. Apparently, their use can lead to the potential reduction in fuel consumption and pollutant emissions only when the percentage of right-turns is higher or equal to 70% of the total traffic. In the light of above considerations, it would be advisable to provide the separate guidelines for the design of this particular roundabout type in further Croatian design guidelines.

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# RELATION BETWEEN SPEED AND CURVE RADIUS IN ROAD TRAFFIC SAFETY

Road safety, due to a large number of accidents and casualties, has become one of the most important issues of modern society. To achieve and maintain a continuous descending trend of traffic accidents, it is necessary to study the safety problem from the point of interaction of driver, vehicle and the environment (roadway). Previous studies have shown that the most important information perceived by the driver is provided by the road itself. According to these studies, the utmost effect on the driver, when making a decision about how to drive, is made by the elements of road horizontal alignment.

Keywords: road safety, curve radius, spot speed, vehicle path, technical regulations

## 1. INTRODUCTION

Large number of traffic accidents and above all large number of casualties have resulted in making the road traffic safety as one of the key issues to be tackled in today's modern society. In order to maintain continuous descending trend of accidental deaths and injuries it is relevant to approach the problem from many different angles in terms of interaction between the driver, vehicle and a roadway.

The essence of a so-called feasible approach to safety is best understood in the following saying: prevention is better than cure. The key question remains: how to incorporate safety requirements into the road planning and design process in a way to cause reduction in number of accidents and enhance general road traffic safety?

One can say with certainty that the road planning and design process represents the process which has to provide a high level of quality (high safety and maximal flow) while minimising investments, exploitation costs and environmental damage. In this paper is presented the relation between radius of horizontal curve, as a basic element of horizontal alignment, on one side, and boundary vehicle path and maximum spot speed in the curve, on another side. The emphasis is on the research of a passenger vehicle negotiating the shallow horizontal curve (with a small deflection angle and a radius less than 250 m) in free traffic flow conditions. The shallow curves are set aside to be particularly interesting, taking into account the high rate of road accidents that occur in them [6].

## 2. LITERATURE REVIEW

The two most important factors that can describe driver behavior in horizontal curves are speed and driven trajectory in those curves. This is particularly highlighted in numerous studies that dealt with driver behaviour in horizontal curves.

Lorenz (Lorenz H.) [10], who had been in the forefront in 1950, analyzed the vehicle movement through the curve of the so-called. "optimal" speed. The author defined this speed as the speed of a free wheel that occurs when driving through the curve. In this case, steering the vehicle through the curve is done exclusively by pressing the accelerator pedal. Analyzing the motion of the vehicle, the author noticed three characteristic vehicle trajectories: the moving vehicle with the optimal speed follows the axis of the conveyor belt; a vehicle moving at a speed greater than the optimal moves towards the outer edge of the conveyor belt; a vehicle moving at a speed less than optimal moves towards the inside edge of the conveyor belt. The author concluded that it is also necessary to use the steering wheel to prevent the vehicle from escaping from the curve. It was found that the driver is also affected by insufficient transparency, the transverse inclination of the car is not adjusted to the average speed of movement, the mismatch of the adjacent elements of the situation plan of the road, etc.

Krebs (Krebs G.H.) [9] was among the first (1973) to analyze the vehicle trajectory in horizontal curves. In his research, he found that in the curves there is a minor or greater deviation of the trajectory from the predicted one in theory. The driven radius is, as a rule, larger than the designed radius for the examined horizontal curve. He showed that the difference is significantly higher in horizontal curves whose radius and the distorted angle are smaller. The author also came up with analytical expressions that connect the driven and designed radius, taking into account the width of the lane and the width of the relevant vehicle. Finally, Krebs concludes that the speed of the curves should be determined by analyzing the radius of the driven trajectory, rather than by analyzing the radius of the designed trajectory.

Kopel (Koppel G.) [7] [8] (1980) showed that differences in the theoretical and actual behavior of drivers are particularly significant in the curvature of a small swivel angle and radius between 50 and 300 m. The author studied the relationship between speed and elements of the situation plan of the road. In his research, he found that there was no solid (unidentified) V-R connection, but this relationship should be viewed from a statistical point of view, with the radius of the curve being significant but not the only parameter that affects the driving speed in the curve. The slightest of the above research is that the connection between the speed and the designed radius is determined, but not between the speed and the driven radius. The author that the phenomenon of the variable value of theoretical (designed) speed as something that needs to be further explored in the future.

In 1993, Doncheva [2] concluded in her research that with the increase in curve characteristics, the number of traffic accidents is increasing. The most important conclusion of her research is that with the increase in the coefficient of dynamic homogeneity, the level of traffic accidents increases. This again stressed that in the modern road design the most important thing is to design a road in which homogeneous uncertainty would be achieved (according to the author, in the 20-40% of traffic accidents the main cause of the accident is exactly the way).

In 1998, Andjus and Maletin [1] investigated the trajectory of vehicles in horizontal curves, especially in radius curves of less than 250 m. The authors conclude that the trajectory in the circumference of the smaller radius curves is more comfortable than the designed trajectory. Such a trajectory, according to the authors, allows the driver to move faster than theoretical proposed speed, and at a higher speed the risk of traffic accidents increases. The authors conclude that the speed is the cause of 53.3% of traffic accidents on two-lane roads.

Spacek (Spacek P.) [11] [12] dealt with the tracing and typing of the vehicle trajectories at the end of the twentieth century. The author proceeded from the fact that when determining the dependence between the behavior of the driver on one side and the path characteristics on the other side, several parameters must be considered. The author emphasizes that it is often the case that research, based exclusively on the analysis of the impact of speed on driving safety, does not prove in its conclusions its starting assumption, since the speed of the cause of traffic accidents cannot be regarded as a mere speed. The author proceeded from the assumption that there is a connection between the geometry of the curve, the trajectory of the vehicle in the curve, and the events of traffic accidents. Experimental research was carried out under the conditions of free traffic flow, on 8 rural road curves of radius between 65 and 220 m. In each curve there were 12 measuring points (on the inside and on the outside of the curve), which enabled tracking of traffic in both directions of movement. During the experiment, the influence of local traffic characteristics on driver behavior in the curves was noticed, in terms of a good knowledge of the road and the prediction of the situations that can be expected on it. The author identified two behaviors as dominant: first, when the driver acted contrary to the applicable regulations and restrictions, and another, when the conduct of the driver was conditioned by the lack of adequate information from his environment. After the experiment was executed, Spacek isolated six different types of trajectories, which included "normal" and "extreme" behavior of the driver (for example, cutting curves).

Fitzsimmons (Fitzsimmons, J. E.) [3] [4] [5] experimentally investigated by means of inductive loops housed in pavement, the vehicle speed and their lateral position in road profile (2012). The study included a one urban and one rural horizontal curve. The results of the study showed that the greatest impact on the trajectory of the motion through the curve has the speed at which the vehicle moves immediately before entering the curve. The author has found that in the horizontal curves of the smaller radius, he drives a significantly larger radius than designed one. In his conclusion, the author pointed to the complex connection between the geometry of the curve, the vehicle, the driver, and the surroundings, as well as that it is necessary to examine in more detail the relationship between the vehicle trajectory and the degree of traffic accidents in the curves.

## 3. ADEQUATE SPEEDS IMPLEMENTED IN ROAD DESIGN PROCESS AND THEIR IMPACT ON THE ROAD TRAFFIC SAFETY

Speed is one of the key parameters in modern road design process upon which all road elements depend: in cross profile, horizontal alignment and longitudinal profile. It also denotes the level of a road service amidst the familiar traffic load and it is the key indicator in the course of road design development, seeking out solutions and performing the assessment. The speed at the same time represents the initial parameter in defining the elements of a road cross profile.

The problem relating to adequate speeds in a road design process is closely associated with dynamic vehicle routing analysis. Dynamic vehicle routing analyses are of crucial significance when deciding the quality of proposed design solution and are in fact the first and key assessment from the standpoint of both comfort and safety on the roads.

Prevailing part of methods implemented in the course of assessment of dynamic vehicle routing is based on deciding the speed change in terms of implemented plan elements, road profile and traffic load for the provided level of service.

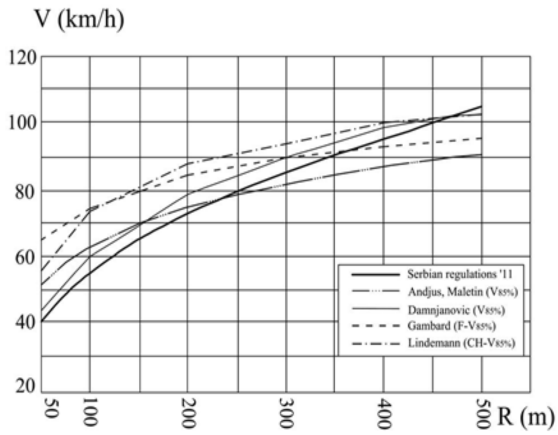


Figure 1. Vehicle speed dependence on a curve radius- research comparison

Source: [6]

In a radius of less than 250 m some significant departures from enforced theoretical speeds have been observed in operating speeds V85%, i.e., operating speeds are significantly higher. This is especially significant from the standpoint of road traffic safety given that the area of small radii is the one where traffic accidents occur the most.

One of the most common design mistakes is in fact application of unharmonised radii of adjacent horizontal curves. Flaws of such a solution are numerous. One of the key drawbacks is discovered in deterioration of change in gradual speed, which brings us to conclusion that road traffic safety is reduced. It is also common to apply the minimal curve radii after an extremely long direction, which brings about a sudden change in speed and quite frequently inability of a driver to adjust his/her speed to conditions prevailing on the road, therefore this suggests direct safety jeopardy on the road.

In the course of designing and formation of round curves it is necessary for a circular arc to be of a sufficient length so as to provide all needed information to the driver on how to navigate the said curve by implementing the adequate speed. As the driving around the curve directly depends on implemented radius and on curve deflection angle (i.e., curve length), for that reason deflection angles recommendable for application have been predefined.

One of the key problems arising in modern designing of roads is how to develop the adequate flow model which will describe in detail real conditions on site and at the same time be simple enough for efficient application in design development phase. Therefore, cibernatic model driver – vehicle – environment has been developed, which helps illustrate various possible situations in a more real fashion which may come up when steering the wheel [6].

## 4. VEHICLE PATH IN RURAL ROAD CURVES

The impact of these three factors (referred to as D-V-E) is inter-connected, thereby the driver, vehicle and environ make one cibernatic system in which each factor is with its clear defined role: the driver steers the vehicle, the vehicle is the subject of steering, while the environ is the valuable source of information which helps define general system condition.

Control over D-V-E (driver-vehicle-enviornment) is performed by feedback driver-vehicle in the following way: a driver will, owing to his/her senses (here we mean the sense of sight) receive numerous information from the surrounding area in the course of driving which he/she processes further and after which he/she makes a final decision on steps to be undertaken. As a result of such steps, and naturally in line with vehicle possibilities at the given moment of time, variation in vehicle travelling occurs which the driver both experiences and controls through its senses by means of a negative feedback. The theory behind all this is that a driver with the help of a feedback receives information on consequences of the action which he/she had previously taken. Driver's actions are not only affected by one element in the surrounding, but rather by many other elements from the same surrounding. In addition, time component changes as well in the system apart from spatial one, and for that reason the system is called a closed cibernetic system [6].

Term ideal vehicle path implies vehicle radius supported by the radius which fully meets the radius of the design path.

Previous researches have shown that in curves whose radius is less than 250 m and which are of small deflection angle, vehicles are manouvered at higher speeds when compared to ones obtained in analysis of theoretical dependence V-R (theoretical Vvd), which is presented in technical regulations.

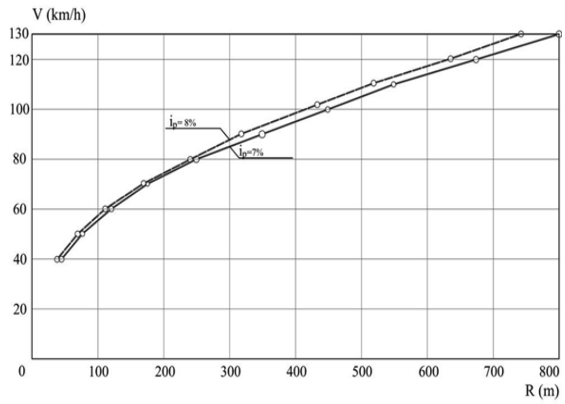


Figure 2. Theoretical dependence of variable design speed on horizontal curve radius

Source:[Serbian technical regulation]

Of special importance is the fact that the area of smaller radii is the one where large number of car crashes occurs - Ns. By analysing the aforementioned, the conclusion has been drawn that the design vehicle speed around the curve is to be decided based on vehicle path radius (expected), and not based on a radius of ideal (design) path.

## 5. CONCLUSIONS

The significance of analysing the spot speeds is best reflected in defining the connection between operating speed - driven radius, which shows that in the area of small radii (R<250 m) there are some significant deviations from the theoretical connection V-R, which is applicable in the most of the technical regulations. Some significant differences in values between vehicles spot speeds and those assumed in the theory have been established in the past. With reference to future research, in order for determining the methodology of broader significance from the standpoint of road traffic safety, the following recommendations can be emphasized [6]:

- perform experimental research with an aim to establish the impact of adjacent curves onto drivers' behavior around such curves;

- perform additional experimental researches with regards to speed under wet road conditions so as to eastblish in a more accurate manner the impact of the wet road onto the driving speed, which would be later implemented onto broader road network;

- incorporating conclusions drawn from these research into the process of Road Traffic Safety Audit, as an integral part of check lists used in the process.

Impelmentation of recommendations above could lead to the intended aim which is implementation of results of these researches into the technical regulation for designing of new road sections, reconstruction and rehabilitation (especially in the process of identifying black spots and "hazardous" road positions).

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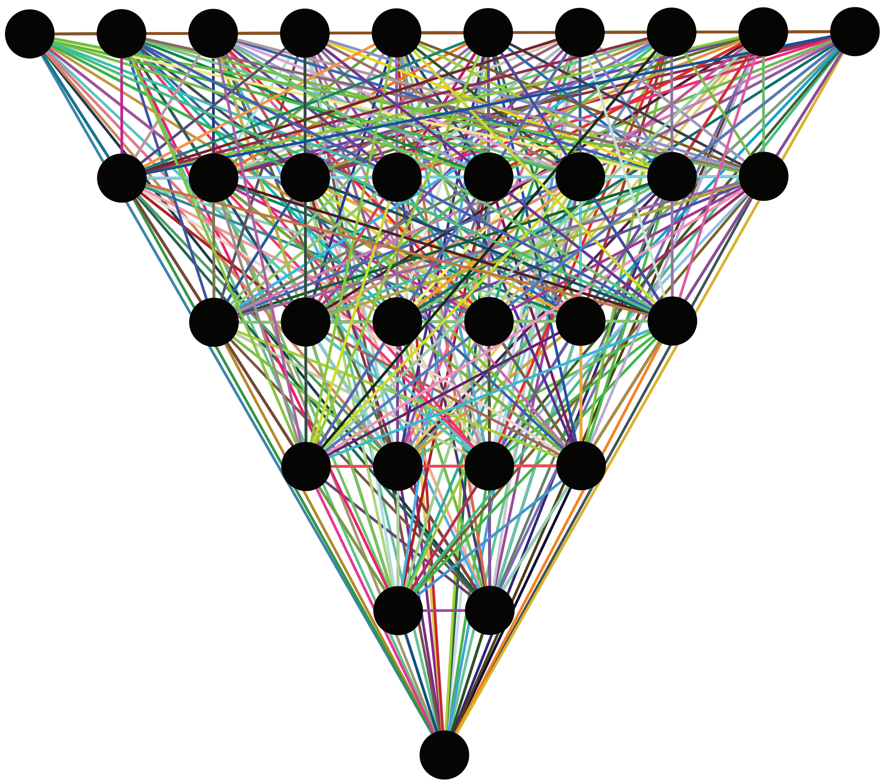

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# EXTERNAL COSTS OF ROAD ACCIDENTS IN THE REPUBLIC OF BULGARIA

The paper is developed following a scientific research, developed in the Department of Road construction and Transport Facilities at UACEG and successfully defended in October 2018. The problem of the economic impact of road accidents on the economies of the countries and in particular the Republic of Bulgaria is examined in detail. A detailed analysis of the situation in Bulgaria has been made, the system's positive and negative effects have been taken into account and a detailed model for calculating external costs due to road accidents of all time periods has been developed. The model can be used to calculate costs both globally - for the whole country as well as for a regional or a specific road or road section. Costs can also be calculated by other criteria, such as BGN (EUR) / vkm; BGN (EUR) / death ( or injured ); BGN (EUR) / accident and so on. At the end, the external costs of road accidents in the Republic of Bulgaria for 2017 are calculated. To achieve the objectives set at the beginning, a thorough analysis of the entire system related to road accidents, including the prosecutor's office, the police, the healthcare, the insurance business. To determine indirect costs, the largest sociological survey on the attitude of Bulgarian society towards road accidents was developed and conducted.

Keywords: External costs, internalization, road accidents, transport economics

## 1. INTRODUCTION

The external costs of transport are an actual topic on a world level. At European level, the European Union, in the face of the European Commission, has the ambitious goal of reaching a maximum accurate algorithm for identifying and internalizing external costs, with a number of studies being financed and even legislative changes initiated. Conclusions that have been made at the moment are united by the fact that transport together with its uncontested benefits also brings many damages (Figure 1), which are undervalued and unconscious by the users. It is for this reason that the European Union's clear decision is to define external costs and find a mechanism for transmitting information to consumers. In Bulgaria this theme is new and there is no common concept and understanding of the external costs of transport.

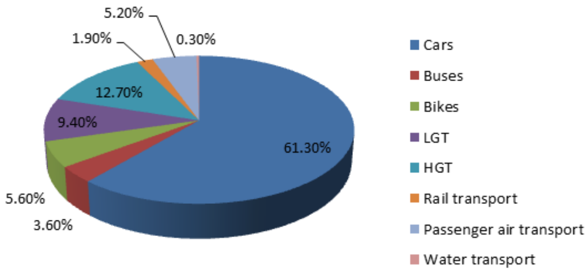


Figure 1 – external costs of transport ( by transport mode ), EU 2008

In order to clarify the situation, as in every aspect of our life, differences between the individual benefits (those of the individual user of transport) and those of society (which are formed by all other people, future generations and the state) must be made.

This task seems and it is impossible to solve by a purely scientific method. It is impossible to calculate real benefits for future generations of embarked journeys today, it is equally impossible to calculate the damage that this trip will bring to future generations. In this sense, it is sufficient to create a continuous process of monitoring and updating the costs and benefits suffered by the public and that it is clear to every user when making a decision to take a trip. Due to the origin of the problem, we will never get to the exact price and its accurate internalization, but it is absolutely essential to stick to it, update it regularly, and internalize properly. In conclusion, it is sufficient to create a permanent monitoring process for controlling and identifying external effects, to define them with maximum accuracy and information to be passed on to users accurately and clearly.

## 2. ANALYSING THE METHODS AND THE METODOLOGIES

Research [1] have found 6 methods After a detailed analysis, it has been decided to use a combination of two - the gross output approach and the risk-based approach, which is also the world practice.

**2.1. The gross output approach** includes the direct damage suffered by the state or the society, the costs of medical care and treatment, the administrative costs incurred by the police and the court for investigation and termination of the road accident, the material damage suffered by the users and the state and municipal administration for damaged property, as well as the indirect costs associated with the loss of contribution to the gross product ( GDP ) of the state. In this connection, correspondence was held with the bodies responsible for healthcare, police, judicial system, insurance companies, the road administration and municipalities for material damage to public property.

**2.2. The net output approach** is analogous to the gross output approach, taking into account that a person will consume much of what he produces. This method is very rarely used because there are several significant disadvantages. First, when a person retires, therefore, stops producing, and only consumes, his value will become negative. In addition, a person consuming goods generates a product for other people and therefore should not be consuming the entire value of consumption. However, this is in practice impossible to determine with sufficient precision.

**2.3. The life-insurance approach** determines the value of human life based on the sum insured that people choose for Life insurance. This method focuses exclusively on the subjective judgment of each person, giving value only to intangible costs. Considering that Life Insurance, according to data of the Financial Supervision Commission, was concluded by only 1 156 627 people, ie. about 15% of the population of the Republic of Bulgaria, and the fact that a large part of these insurances for compulsory mortgage loans are distorting the results - first the sample is too small and there are no statistics available to people who have entered into this insurance, and there are also accurate statistics on the number of insurances and premium income but there are no statistics on individual indemnities paid or statistics on insurance coverage. Secondly, as insurance is required by a large number of banking institutions, it can be assumed that the majority of mortgage lenders have concluded similar only because of the mandatory requirement of banks.

**2.4. The court award approach** determines indirect individual damages, based on the amounts determined by the court in case of death. Taking into account that the insurance system pays damages for death in crashes, these values depend exclusively on what insurers are willing to pay to the relatives of the death. Due to the lack of precise methodology for calculating damages, these costs are subjective and considered individually.

This method will not provide real data, but given the specificity of the problem, the values paid by insurance companies are internal and should be deducted from the total. Therefore, an analysis of the benefits paid by insurance companies has been made and thus the internal part of the Indirect Damage component is determined.

**2.5. The implicit public sector valuation approach** gives value based on the costs incurred for the prevention of crashes. The values obtained through it would also be unrealistic due to the subjective factors associated with prevention policies. In practice, the figures are based on the costs the state is doing to prevent road accidents. This method is not applicable.

**2.6.** The risk - based method **( The value of risk change or willingness to pay approach )** is the most preferred method of assessing human life on a European and global scale. It is based on the willingness to pay (WTP) probability approach, which is based on the willingness to pay a person, a group of people, the public, and the government to reduce the risk of crash. In practice, results are obtained through stakeholder questionnaires. Naturally, there are shortcomings in this method, which are mainly related to the preparation of the survey and the representative sample. Since the problem is specific in the specific case and the population does not have enough information, the questions need to be chosen very carefully so as to ensure that the answers that are received will provide the necessary information.

All the components have been identified and a detailed analysis of each of them has been made, whether they are external or internal. Accordingly, in the course of their work, they were calculated wherever possible. The problem in Bulgaria is the lack of statistics and information on the costs of hospitals, prosecution and police (direct costs) for costs incurred as a result of crashes. GDP data is available and updated on a regular basis, indirect costs are calculated in the specific research. The direct cost problem is solved by using translational ratios to match them to the indirect ones. Components in Bulgaria follow the logic of other countries with similar systems, with the exception of the cost of damage to public property. Analysis has shown that this component has an external part that is significant and it is necessary to complete a study to identify the specific problem and to seek a solution.

All global methodologies have been analyzed and a model (Figure 2) for calculating external costs as a result of crashes has been established.

The main element of the model is the road accidents statistics, including data on the number of crashes, deaths and injuries. Damages are divided into material and non - material (direct and indirect), and intangible include the economic value of the pain, suffering and grief of people involved in crashes and their relatives - most commonly expressed as "Value of Statistical Life". After the determination of the value of the statistical life, a reduction was made taking into account the effect of the insurance system.

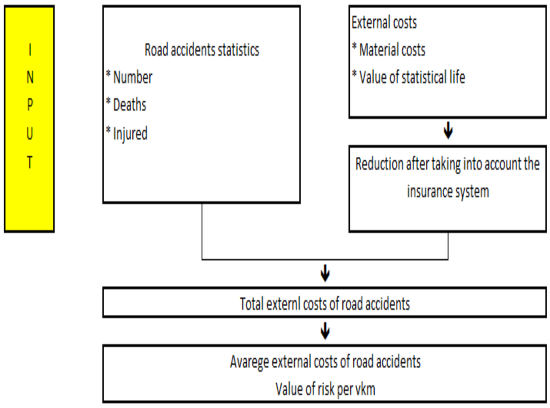


Figure 2 – Block scheme for calculating of external costs of road accidents

## 3. RISK BASED SOCIOLOGICAL STUDY

Risk-based methods are widespread [2]. They are based on the “Willingness to pay” approach.

The probabilistic approach of "willingness to pay", in this case to reduce the risk of fatal accidents, has become a standard method of assessing human life in economic theory. This approach begins with the following main question: Suppose that the user has the opportunity to buy an E reduction in his probability of dying. What is the maximum amount he will pay for the probability of increasing his life? If he / she will pay the most C for E, then we say that he / she assesses his / her life in C / E. Usually this is for very low values for E, in this case we put the respondents in a real environment with real data – 100 deaths per 1 000 000 inhabitants. We asked them to rate different reductions - 20%; 30% and 50%, which in practice means 20 / million; 30 / million and 50 / million. This gives the coefficient E = 0.00002. The model is simple enough, so much so that the "value of statistical life" will be decided as a simple function of the relative risk assessment.

The survey was conducted in December 2017, covering about 1,400 respondents, expecting about 800 real responses representing a representative sample of society.

The questionnaire contains four categories of questions:

• Personal experience with traffic accidents - Respondents are asked to respond to whether they personally and / or their relatives and friends have been in an accident involving victims or severely injured

• Used means of transport - this category allows to describe the most commonly used modes of transport by individuals, as well as the use cycles

• General socio-economic characteristics - this category collects information about gender, age, residence, family status and professional status and thus determines the social status of the respondent

• Payment Acceptance for Risk Reduction - This part is the essence of the contingency assessment. This requires the creation of a fictional scenario, albeit realistic and comprehensible, on which respondents will be called upon to think. They will then have to express how much they would like to pay to reduce the risk of death from a traffic accident. The level of risk reduction depends on a set of different questions and answers.

Respondents have the opportunity to contribute financially to the implementation of a regional and national projects aimed at enhancing the safety of road users. Since the participants themselves are residents of the respective region (in this case municipality) and of the country, they will feel directly concerned about the project. Participants are asked to determine how many BGN they are willing to pay monthly to the municipality or the government to implement the project. In addition, regardless of municipal or national policy, a control question was asked about individual risk-sharing costs, and it was also referred to relatives and friends.

In conclusion, the questions are selected so that they put the respondents in a real situation and to be easily assimilated by them. The main purpose of determining the individual risk assessment is achieved by asking questions in different hypothetical situations where respondents are asked to answer in exact amounts (in an open response without a frame ( as choose between answer a,b,c,d )), who are willing to pay monthly against a fixed percentage of risk reduction (which is considered to be guaranteed). This is used on the one hand to determine the value of the "cost of life" of each individual and hence the "value of statistical life" for the sample and secondly to eliminate the false answers. Example: If the same respondent evaluates a 20% risk reduction with a higher risk reduction of 50% then it is obvious that his/her judgment is not realistic and should be eliminated from the sample.

The questionnaire was assigned to 1406 people, with real answers being received by 755. This is in line with the goal of getting around 800 respondents. By comparison, such studies in other countries are considered valid. In France, this was done by 600, in Egypt by 400, by 210 in Sydney, Australia, by 342 in Chile, by 500 in Saudi Arabia and by 1,000 in Sweden.

To get real value, invalid results need to be removed. The methodology requires zero values to be removed as a first step. After they were removed, the data of 525 respondents remained. It is then necessary to examine and analyze the results of each respondent individually, the purpose here being to eliminate the invalid ones. Invalids are determined on the basis of the following principles: We assume that each person values their lives more than any other, so respondents who have given a higher risk to friends at their own risk are excluded from the survey - it is assumed that they are not correctly adopted the questions, therefore their results are invalid. On the same principle, the results of the questionnaire R7, which assess the risk in the same situation for the person as well as for the whole household (including him / herself) - if the respondent gave lower value to the whole household of your personal, then it is eliminated because the value of the remaining members of the household will be negative. The third check is based on the individual risk assessment. It has become clear that the questions are structured so that their correctness can be assessed after an appropriate analysis. A 20%, 30% and 50% reduction of individual risk is set if one of the respondents gives illogical answers - for example, a 20% reduction gives a higher value of 30% or 50% or a 30% reduction gives - a high 50% reduction, it is eliminated from the sample because it is assumed that he/she did not correctly take the matter and its answers are invalid.

After eliminating these respondents, the sample remained with 387 actual responses from which real information could be extracted.

The value of statistical life at a 50% reduction (E = 0.00005) obtained by two distinct questions - R5_2 and R9. Values vary by less than 4%, which is within the range of the statistical error. This means that the respondents reasonably assessed the small changes at their own risk and gave an additional positive assessment of the questionnaire and the results obtained.

Expectedly, the values obtained at 20% reduction are higher than those at a 30% reduction, respectively those obtained at a 30% reduction are higher than those obtained at a reduction of 50%. The difference between the highest and the lowest is 27.9% of the highest. However, the values are within reasonable limits, they are not extreme, and they are mostly in the order set in other countries. For determining the final value of the statistical life, we will calculate the weighted average of all, which is BGN 320,028.

The cost of damage to relatives and friends is received by two questions R7_2 and R10. Between BGN 267 093.48 and BGN 223 392.81 were received. Here again the values are in order and overlap with those in other countries. Again, the value for relatives and friends will be calculated as a weighted average of the two - 246 737.79 BGN

The final algorithm is the following:

$$\mathrm{TC} = \mathrm{A}(\mathrm{VSL} + \mathrm{C}_5) + \mathrm{dc} = \mathrm{A}(1.1\mathrm{VSL} + \mathrm{C}_5)$$

$$\mathrm{A} = 682 \cdot 1 \cdot 1.02 + 1943 \cdot 0.13 \cdot 1.50 + +6737 \cdot 0.01 \cdot 3 = 1276.63$$

$$\mathrm{VSL} = \mathrm{a} + \mathrm{b} - \mathrm{ins} = 320\,028.00 + 246\,737.79 - 122\,982.46 = 453\,783.33\ \mathrm{BGN}$$

$$\mathrm{C}_5 = \mathrm{GDP} \cdot \frac{(\mathrm{ww} \cdot \mathrm{dw} + \mathrm{wm} \cdot \mathrm{dm})}{(\mathrm{dw} + \mathrm{dm})}$$

$$\mathrm{C}_5 = 27{,}977.70 \cdot \frac{(8 \cdot 186 + 19 \cdot 496)}{(186 + 496)}$$

$$\mathrm{C}_5 = 447{,}643.20\ \mathrm{BGN}$$

$$\mathrm{TC} = 1\,276.63 \cdot (1.1 \cdot 453\,783.33 + 447\,643.20)$$

$$\mathrm{TC} = 1\,208\,719\,492.25\ \mathrm{BGN}$$

Where,

**TC** - Total cost

**A** - number of deaths following road accidents [3]. Data for 2017 was used. Corrected with correction factors for statistics deficiencies and unreported accidents. Coefficients have been used for equating the victims to the dead.

**VSL** - Value of statistical life. Where "**a**" and "**b**" are the respective values for the value of the own risk and the value of the risk for relatives and friends, **ins** is the reduction from the insurance system.

**dc** - direct costs, including the components ($c_1$, $c_2$, $c_3$, $c_4$) for health, police, judiciary and public property damage

**$c_5$** - losses on contribution to GDP.

**ww** - working years women - remaining years to a retirement for women in case they did not die in crashes

**wm** - working years men - remaining years until a retirement for men in case they did not die in crashes

**dw** - death women - women killed in crashes

**dm** - death men - men killed in crashes

Final values

• Serious crash – BGN 175 481.92

• Death – BGN 946 804.86

• Seriously injured – BGN 123,084.63

• Slightly injured - BGN 9 468.05

• External costs of road accidents in Bulgaria for 2017 - BGN 1,208,724,222.45

In conclusion, the value of one death person is compared to those obtained in other countries. A euro equivalent is approximately € 484,000.00. This value is comparable to those obtained in other European countries where a value of between EUR 275 000, Lithuania and Latvia and EUR 2 893 000 in Norway is obtained. The value obtained for the Republic of Bulgaria is close to the values obtained in the Czech Republic (EUR 495 000); Hungary (EUR 440 000); Estonia (EUR 352 000); Poland (EUR 341 000).

### *Acknowledgements*

I want to acknowledge the Transport infrastructure and costruction institute Ltd, Sofia, Bulgaria for financing and promoting the paper.


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# ASPHALT STRUCTURE FOR THE CIRCULAR ROADWAY

While driving through the roundabout, the thrust and frictional forces act on the asphalt pavement of the roundabout through the contact between the vehicle tires and the roundabout pavement. The circular roadways at roundabouts are exposed to special traffic loads due to cornering, namely friction and shear stresses, and in smaller roundabouts (mini roundabouts) also torsional stresses (turning of tires on the spot). Especially due to the high proportion of heavy traffic, damage to the asphalt pavement is often found, such as cracks, unevenness (indentations, ruts), etc.

Therefore, it is extremely important to counteract the development of asphalt road damage by selecting the right asphalt construction for the roundabout pavements. In order to avoid possible under dimensioning, it is recommended to generally choose the next higher load class - deviating from the RStOs (guidelines for standardization of pavements of traffic surfaces (GER)) in relation to the most heavily loaded section of the roundabout.

Keywords: roundabout, asphalt, bitumen, road construction

## 1. GERMAN RECOMMENDATIONS FOR THE ASPHALT STRUCTURE FOR THE CIRCULAR ROADWAY

According to [1] when dimensioning the roadway structure of the roundabouts, the calculated load class is increased by one load class in order to enable the absorption of the increased shear stresses (Fig.1) on the asphalt structure of the roundabout by appropriate road construction and building materials:


Figure 1. Shear stresses (Fig.1) on the asphalt structure of the roundabout [Hrapović K. 06.11.2015]

Bearing (base) course: AC 32 T S with 30/45

Binder course: AC 16 B S with 25/55-55

Asphalt surface course: AC 11 D S – Sp with 25/55-55

**Declaration:**

AC = Asphalt Concrete

11 = maximum particle size 11 mm

16 = maximum particle size 16 mm

32 = maximum particle size 32 mm

D = Asphalt surface course

B = Binder course

T = Bearing (base) course

S = special load

Sp = Asphalt concrete with crushed aggregate (chipping)

25/55-55 = Bitumen with penetration between (25 – 55) x $10^{-1}$ mm and softening point +55 °C (Ring and Ball method)

10/40-65 = Bitumen with penetration between (10 – 40) x $10^{-1}$ mm and softening point +65 °C

30/45 = Bitumen with penetration between (30 – 45) x $10^{-1}$ mm

SMA = Stone Mastic Asphalt

Sp = “Splitt” (germ.) = crushed aggregate (chipping)

Based on the damage analysis of asphalt circular roadways according to German guidelines and regulations, the following is recommended [1]:

a) Create paving plan / finisher plan
b) Avoid manual installation
c) No longitudinal seam in the circular carriageway, if possible, installation over the entire width of the circular carriageway
d) Building under traffic avoid as far as possible
e) No cover or manholes in the circular roadway
f) use hard binders e.g., PmB (polymer bitumen)
g) No Stone Mastic Asphalt as surface course, also recommendation of the relevant FGSV committees

Instead of SMA asphalt for the asphalt surface of the circular roadway use the chippy asphalt: AC 11 D S-Sp.

Technical characteristics of these asphalt mix are:

- Continuous grading with high chipping content (crushed/broken particle) and large cant (fig.2, fig.3)

- Good embedding of the aggregates in the large mortar phase with high strength.

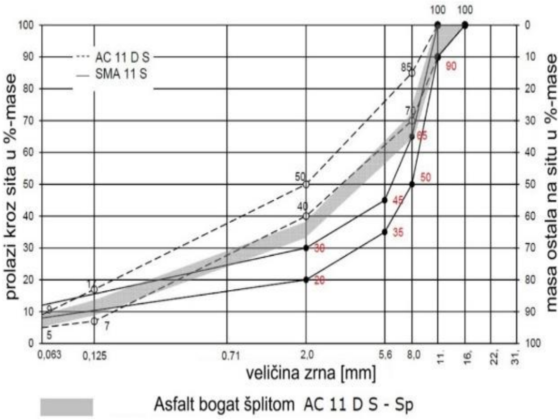



Figure 2. Grading envelope of the asphalt mix: AC 11 D S and SMA 11 [1]

| gradjevinski materijali | jedinica mjere | uslovi |
|---|---|---|
| zrna agregata | - | gruba zrna agregata, fina drobljena zrna agregata, krečnjački filer (kameno brašno) |
| udio drobljenih zrna | - | min. $C_{95/1}$ udio potpuno drobljenih zrna min. 60 %-mase |
| najmanji udio finih zrna agregata $E_{CS}35$ | % | 100 |
| otpornost protiv sitnjenja pri udaru | - | $SZ_{18}/LA_{20}$ |
| otpornost protiv habanja PSV | - | 51 |
| vezivo, vrsta i sorta veziva | - | 25/55-55 A ili tvrdji bitumen |
| **mješavina zrna agregata** | | |
| udio grubih zrna agregata | M.-% | cilj: 65 |
| **asfaltna mješavina** | | |
| udio šupljina ispunjenih vazduhom MPK | Vol.-% | 2,5 do 3,5 |
| veličina deformacije asfaltnog cilindričnog uzorka pod dejstvom pritiska i toplote prema TP A-StB, Dio 25B sa $\delta_o$ = 0,35 N/mm² | $10^{-4}$ ‰/n | ≤ 3 |
| **sloj** | | |
| debljina ugradjivanja | cm | 3,5 do 4,0 |
| sadržaj šupljina u cilindričnom uzorku asfalta | Vol.-% | 2,5 do 4,5 |

Figure 3. Technical characteristics of the asphalt mix AC 11 D S-Sp [1]

The characteristics of these asphalt mix are:

- Very high shear strength
- Good processing properties
- Temperature susceptibility reduces
- Very high internal friction

## 2. AUSTRIAN RECOMMENDATIONS FOR THE ASPHALT STRUCTURE FOR THE CIRCULAR ROADWAY

Based on the empirical recommendations of asphalt circular roadways in Austria, the following is recommended (Fig.4):

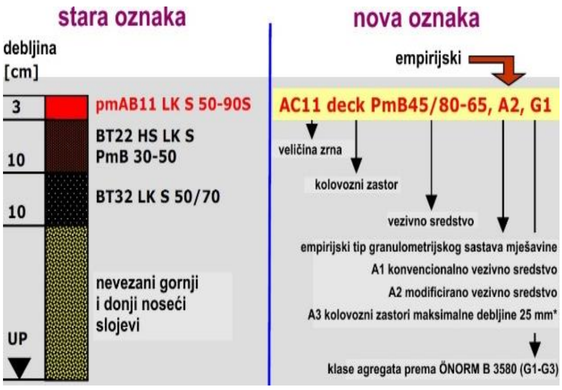



Figure 4. Asphalt pavement according to empirical recommendations in Austria [2]

**Declaration:**

**3 cm AC11 deck PmB 45/80-65 A2, G1, LA15:**

3 cm = Asphalt layer thickness

AC11 = Asphalt Concrete with a maximum particle size 11 mm

11 = maximum particle size 11 mm

deck = name for the top layer (here is surface course)

PmB 45/80-65 = polymer bitumen with penetration between (45 – 80) x $10^{-1}$ mm and softening point +65 °C (Ring and Ball method)

A2 = asphalt type produced exclusively with modified binders (e.g. PmB) aggregate class of the asphalt mix according to Austrian standard (OENORM B 3580-1, 2018)

G1 = aggregate class of the asphalt mix according to Austrian standard (OENORM B 3580-1, 2018)

LA15 = Los Angeles value

**10 cm AC32 binder PmB 25/55-55 H1, G4:**

10 cm = Asphalt layer thickness

AC32 = Asphalt Concrete with a maximum particle size 32 mm

binder = binder

PmB 25/55-55 = polymer bitumen with penetration between (25 – 55) x 10-1 mm and softening point +55 °C (Ring and Ball method)

H1 = highly stable base layer (binder)

G4 = aggregate class of the asphalt mix according to Austrian standard (OENORM B 3580-1, 2018) for binder and base courses as well as base and surface courses with low requirements or no requirements for skid resistance.

20 cm = unbound upper road base, with a maximum particle size 45 mm, C90/3, 20 cm thickness

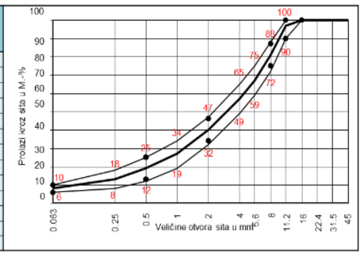
C90/3 = Categories for the percentage of crushed particle surfaces (including the percentage of totally crushed (90%) and totally rounded (3%) particles) (EN 13043, 2015)

30 cm = unbound subbase with a maximum particle size 63 mm, 30 cm thickness

The empirical recommendations of asphalt mix AC11 deck PmB 45/80-65 A2, G1, LA15 according to Austrian guidelines are:

- Minimum binder content 3% percent by mass
- Siev sizes: 0,063-0,5-2-8-11-16
- Air voids content of aggregate: $V_{min}$ = 2 %, $V_{max}$ = 4 % percent by volume
- Minimum temperature $_{min.}$T = +150°C and maximum Temperature $_{max.}$T= +190°C of this asphalt mix.
- The proportional rut depth $PRD_{air}$ =7% according to the European Standard EN 12697-22: bituminous mixtures - test methods - part 22: wheel tracking

| Vel. sita mm | Prolaz kroz sita u M.-% | | |
|---|---|---|---|
| | **ispitana M.-%** | ÖNORM M.-% | BB LE M.-% |
| 45 | **100** | 100 - 100 | - |
| 31,5 | **100** | 100 - 100 | - |
| 22,4 | **100** | 100 - 100 | - |
| 16 | **100** | 100 - 100 | 100 |
| 11,2 | **97** | 90 - 100 | 90 - 100 |
| 8 | **81** | 72 - 88 | 75 - 87 |
| 5,6 | **67** | 59 - 75 | - |
| 4 | **57** | 49 - 65 | - |
| 2 | **40** | 32 - 47 | 34 - 46 |
| 1 | **27** | 19 - 34 | - |
| 0,5 | **19** | 12 - 25 | 13 - 25 |
| 0,25 | **13** | 8 - 18 | - |
| 0,063 | **8,0** | 6 - 10 | 6,0 - 10,0 |




| Vel. sita mm | Prolazi kroz sita u M.-% | | |
|---|---|---|---|
| | **ispitana M.-%** | ÖNORM M.-% | BB LE M.-% |
| 45 | **100** | 100 - 100 | - |
| 31,5 | **100** | 100 - 100 | - |
| 22,4 | **100** | 100 - 100 | - |
| 16 | **100** | 100 - 100 | 100 |
| 11,2 | **95** | 90 - 100 | 90 - 100 |
| 8 | **53** | 45 - 68 | 48 - 60 |
| 5,6 | **40** | 35 - 52 | - |
| 4 | **34** | 25 - 43 | 28 - 40 |
| 2 | **25** | 20 - 33 | 20 - 32 |
| 1 | **18** | 14 - 29 | - |
| 0,5 | **14** | 10 - 25 | 10 - 22 |
| 0,25 | **11** | 8 - 20 | - |
| 0,063 | **8,0** | 5 - 10 | 6,0 - 10,0 |

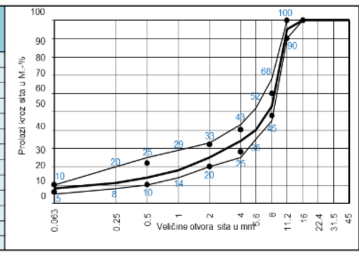



Figure 5. Direct comparison of grading curves of the asphalt mix AC11 deck PmB 45/80-65 A2,G1 (top) and asphalt mix SMA 11 PmB 45/80-65,S2,GS (below) [3]

On the figure 5 is shown direct comparison of grading curves of the asphalt mix AC11 deck PmB 45/80-65 A2,G1 and asphalt mix SMA 11 PmB 45/80-65,S2,GS according Austrian guidelines and regulations.

In Austria, similar to Germany (Fig.122), it is also very noticeable that AC11 asphalt concrete contains considerably finer fraction than SMA11 (Fig.6). the sieve with an opening width of 2 mm in the AC11 allows between 32-47 M-% (Fig.120) to pass through, while the SMA11 only has between 20 and 33 M-%. In the case of AC 11, as much as 72-88 mass percent passes through the 8 mm sieve, and in the case of SMA 11 it is only 45-68 M-%.

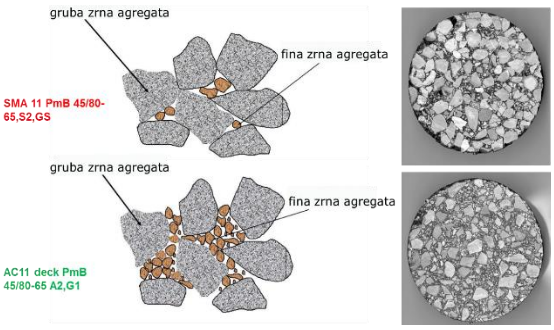



Figure 6. Direct comparison of the asphalt mix AC11 deck PmB 45/80-65 A2,G1 and asphalt mix SMA 11 PmB 45/80-65,S2,GS [4]

Tab.1 shows an initial test report for asphalt mix AC11 PmB 45/80-65, A2, G1 from an Austrian asphalt laboratory. The aggregate for this mix is made of basalt and a special fine crushed aggregate (EBK). E.g. 4/8 mm fine crushed aggregate contains 23.7 mass percent in this mix. The polymer modified bitumen PmB 45/80-65 is included in the mix in 5.4 mass per cent (Tab.1).

The designation 45/80-65 means that the penetration of the bitumen at +25°C is between 4.5 and 8 mm and the ring and ball softening point is +65°C.

Table 1. Initial test report for asphalt mix AC11 PmB 45/80-65, A2, G1 [5]

| Dijelovi i sastav | | | | | | Dodatak – potreban sastav u M.-% | |
|---|---|---|---|---|---|---|---|
| Zrna agregata | Nr. | oznaka | Postrojenje za proizvodnju asfalta | Broj sertifikata | napomena | | |
| | 1 | EBK 0/2 | Appel /fabrika Mühldorf | 1159-CPR-0062/04 | bazalt | 35,0 | **33,1** |
| | 2 | EBK 2/4 | Appel /fabrika Mühldorf | 1159-CPR-0062/04 | bazalt | 15,0 | **14,2** |
| | 3 | EBK 4/8 | Appel /fabrika Mühldorf | 1159-CPR-0062/04 | bazalt | 25,0 | **23,7** |
| | 4 | EBK 8/11 | Appel /fabrika Mühldorf | 1159-CPR-0062/04 | bazalt | 25,0 | **23,7** |
| Reciklirani asfalt | Nr. | oznaka | porijeklo | | Sadržaj VS M-% | | |
| | 1 | - | - | | - | - | - |
| Vezivo | Vezno sredstvo=VS (vezivo) | | Elastična deformacija % | Broj sertifikata | TRPK °C | suma 100 | |
| | Reciklirani asfalt | | - | - | - | | - |
| | PmB 45/80-65 | | - | - | ≥ 65 | | **5,4** |
| | - | | - | - | - | | - |
| | Rezultirajuće vezivo | | - | - | - | | **5,4** |
| | | | | | | | **100,0** |

| dodaci | Oznaka, vrsta i porijeklo | Udio u M.-% |
|---|---|---|
| - | - | - |

1) odnosi se na masu asfaltne mješavine
2) odnosi se na sumu zrna agregata
3) odnosi se na masu dodatog bitumena

in the Tab.2 can be seen the Declaration of performance for the Austrian wearing course AC11 deck PmB 45/80- 65, A2, G1 with the limits values of all relevant parameters according to European and Austrian standards as well as the declared parameters on the basis of the manufacturer's test.

Table 2. Declaration of performance for the Austrian wearing course AC11 deck PmB 45/80- 65, A2, G1

| AC11 deck PmB45/80-65, A2, G1 | | | | | granične vrijednosti po ON B 3584-1 | | deklarisane vrijednosti prema atestu proizvodjača | |
|---|---|---|---|---|---|---|---|---|
| parametri | standard | ozn. | jedinica | rezultat ispitivanja | min. | max. | min. | max. |
| Rastvoreni sadržaj veziva | EN 12697-1 | $S$ | M.-% | **5,2** | 3,0 | - | 4,9 | 5,5 |
| Gustina asfaltne mješavine | EN 12697-5 | $r_{mv}$ | Mg/m³ | **2,552** | - | - | - | - |
| Gustina zrna agregata | računski | - | Mg/m³ | **2,780** | - | - | - | - |
| Gustina probnog tijela | EN 12697-6 | $r_{bssd}$ | Mg/m³ | **2,472** | - | - | - | - |
| Sadržaj šupljina probnog tijela | EN 12697-8 | $V_m$ | V.-% | **3,1** | 1,5 | 5,0 | 2,5 | 4,5 |
| Sadržaj šupljina skeleta agregata | EN 12697-8 | $VMA$ | V.-% | **16** | - | - | - | - |
| Stepen ispune šupljina | EN 12697-8 | $VFB$ | V.-% | **80** | - | - | - | - |
| Stabilnost po Marshall-u | EN 12697-34 | $S$ | kN | **13,4** | - | - | - | - |
| Tečenje po Marshall-u | EN 12697-34 | $F$ | mm | **4,2** | - | - | - | - |
| Odnos stabilnosti i tečenja po Marshall-u | EN 12697-34 | $S/F$ | kN/mm | **3,2** | - | - | - | - |
| Proporcionalna dubina kolotraga | EN 12697-22 | $PRD_{vazd}$ | % | **5,0** | - | 7,0 | - | 7,0 |
| Oticanje veziva | EN 12697-18 | $D$ | M.-% | **0,0** | - | - | - | - |
| Dubina prodiranja | EN 12697-21 | $I_{min}$ | mm | **-** | - | - | - | - |
| Maksimalni gubitak zrna | EN 12697-17 | $PL$ | M.-% | **-** | - | - | - | - |
| Ponašanje prilikom požara | EN 13501-1 | - | V.-% | **12,6** | - | 16,9 | - | - |
| Afinitet | EN 12697-11 | - | % | **98** | 80 | - | 80 | - |
| Prolaz kroz karakt. grubo sito 8 mm | EN 12697-2 | - | M.-% | **81** | 72 | 88 | 75 | 87 |
| Prolaz kroz sito 4 mm | | - | M.-% | **-** | - | - | - | - |
| Prolaz kroz sito 2 mm | | - | M.-% | **40** | 12 | 47 | 34 | 46 |
| Prolaz kroz karakt. fino sito 0,5 mm | | - | M.-% | **19** | 10 | 25 | 13 | 25 |
| Prolaz kroz sito 0,063 mm | | - | M.-% | **8,0** | 6,0 | 10,0 | 6,0 | 10,0 |
| Djelimično drobljena zrna agregata | EN 933-5 | $C_c$ | M.-% | **100** | 100 | - | - | - |
| Potpuno drobljena zrna agregata | | $C_{tc}$ | M.-% | **100** | 90 | - | - | - |
| Potpuno okrugla zrna agregata | | $C_{tr}$ | M.-% | **0** | - | 0 | - | - |

According to the European Standard EN 12697-22: bituminous mixtures - test methods - part 22: wheel tracking, the proportional rut depth $PRD_{air}$ (germ. $PRD_{Luft}$) of the tested material (asphalt specimen) it amounts 5 %.

In Tab.2 it can also be seen that the limit value for the asphalt type AC11 deck PmB 45/80-65 A2, G1, LA15, $PRD_{air}$ =7 %.

## 3. CONCLUSIONS

Based on the damage analysis of asphalt circular roadways, the following is recommended:

a) Create paving plan / finisher plan
b) Avoid manual installation
c) No longitudinal seam in the circular carriageway, if possible installation over the entire width of the circular carriageway
d) Building under traffic avoid as far as possible
e) No cover or manholes in the circular roadway
f) use hard binders e.g. PmB (polymer bitumen)
g) No Stone Mastic Asphalt as surface course, also recommendation of the relevant FGSV committees
h) Instead of SMA asphalt for the asphalt surface of the circular roadway use the

chippy asphalt in German: AC 11 D S-Sp

i) Instead of SMA asphalt for the asphalt surface of the circular roadway use the chippy asphalt in Austria: AC11 deck PmB 45/80-65 A2, G1, LA15

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# INFLUENCES OF NATURAL AND MAN - MADE HAZARDS ON ROAD NETWORK AND ELEMENTS OF RISK MANAGEMENT STRATEGY

Natural and man-made hazards are causing in average yearly damage of more than 40 billion US dollars worldwide. Among them, landslides and floods are the most frequent. In order to improve management of such hazards, many studies focus on the different topics related to qualitative and quantitative flood and landslide risk assessment from global to national scales.

With aim to underline again the importance of these hazards for Macedonian road infrastructure, here we are presenting some analyses, connected with influences of floods and landslides to the Macedonian trunk road network. The analyses are mainly based on own experiences for several case histories in the country. Authors believe that these findings can help in improvement of legislative in line with the flood and landslide risk management strategies to be developed on national scale.

Keywords: Floods, landslides, road infrastructure, risk management, legislation

## 1. INTRODUCTION

It is well known that the conditions for rational and successful design of infrastructure facilities, as well as their exploitation and maintenance, are highly dependent on the impacts of different geohazards. Among them, the most significant are the impacts of landslides and floods, as they annually cause damages in the amount of over $ 40 billion or an equivalent of over 40,000 human lives [1].

Such phenomena, as elsewhere, are also of great importance to our country. Moreover, due to the complex geological-tectonic, geomorphologic, climatic and other conditions, parts of the territory of the Republic of Macedonia belong into the category of terrains with natural predispositions for development of instabilities. So far, there have been a number of floods and over 300 landslides that have directly or indirectly endangered the infrastructure. Variety of damages were caused: disruption of road and railway traffic, damage to and demolition of individual and collective residential buildings, damage and interruptions to water, utility, gas, telecommunication and electrical installations, destruction of natural terrain and agricultural arable land, endangering entire settlements etc. In some cases, even human lives were lost.

It is characteristic that at present, directly or indirectly, to a certain degree of risk are exposed more and more routes from the national road network, with frequent traffic interruptions and redirections. In our country, the economic losses from these adverse events are measured in tens of millions of Euros annually. Due to urgency, in such cases, additional costs may arise due to the necessity for urgent design and execution of extensive remedial measures, such as retaining structures, anchor structures, installation of protective meshes, drainage systems and other remediation measures. The constant and necessary monitoring of these unstable phenomena also entails "permanent" costs.

In this context, beside presentation of the impacts of these hazards on infrastructure, one of the aims of this paper is to provide guidance on addressing these aspects with specific proposals for improving the legislation and developing a floods and landslides risk management strategy on national level.

## 2. OVERVIEW OF ACHIEVEMENTS IN THE FIELD OF IMPACT OF NATURAL AND MAN-MADE HAZARDS ON INFRASTRUCTURE

Considering the importance of this problem, a large number of papers, designs, conferences and more have been prepared on worldwide and national level. Specifically, for the issues addressed in this paper, of great importance are the papers dealing with classification and definition of landslide types, laboratory and field investigations of rock and soil materials, methods for stability assessment, impacts of groundwater and earthquakes on the occurrence of instabilities, methods for formation of landslides cadastre, methods for vulnerability, hazard and risk mapping, methods of mathematical statistics, various analytical and numerical procedures, etc. Details can be found in Peshevski, 2015 [12]. Therefore, in this paper will be mentioned some of the more important papers.

For example, there are over 200 different landslides classifications, but the actual ones in worldwide use are those of Varnes D.J. (1978); IAEG (1990); Cruden D.M. (1991), Hungr O. et al. (2014) and others [12]. The concepts for determining the stability of the slopes and the measures for their stabilization have been elaborated at different times and by different authors, Fellenius W. (1927), (1936); Taylor D.W. (1937); Janbu N. (1954), (1968), (1973); Bishop A.W. & Morgernstern N.R. (1960); Morgerstern N.R. & Price V.E. (1965); Spencer E. (1967); Skempton A.W. & Hutchinson, J.N. (1969); Corps of Engineers (1970), (1982); Chowdhury R.N. & Xu, D.W. (1994); Bishop A.W., (1955). Methodologies for stability assessment of slopes build of solid rock masses have been developed by Hoek E. Bray J.W., & Boyd J.M. (1973); Sarma S.K. & Bhave M.V. (1974); Hoek E. & Bray J. (1977), Goodman E. (1976), (1980). Formation of databases and statistical analysis of landslides have been developed by Malamud et al. (2004); Guzzetti F. et al. (2012); Eeckhaut M.V.D & Hervas H. [12]. At the moment, for preparation of maps and cadastres for instabilities, the most actual are the data by Eeckhaut M.V.D & Hervas H. (2012); Guzzetti F. et al. (2012) [12]. In terms of landslide hazard and risk assessment and zoning, the papers by Varnes D.J. (1984); Westen Van C.J. (2004); Cascini L. et al. (2005); AGS (2007); Fell R. et al. (2008); Gokceoglu, C., & Sezer, E., (2009), and others [2], are considered especially important.

It is important to be mentioned that scientific and expert meetings on this topic are regularly organized worldwide, such as World Landslide Forums (2008, 2011, 2014 and 2017), regional symposia and workshops being organized by the International Consortium for Landslides-ICL.

Here, in the past, several methodologies and procedures dealing with some of these aspects have been developed. The first landslide database was established at the time of the Former Yugoslav Federation in 1960-1970. During this period, the Basic Geological Map of the Republic of Macedonia (BGM) was prepared in scale of 1:100000 and all observed landslides were applied on it. In the period 1990-2012 several landslide data collection programs have been developed, which have been relatively successful. There are also numerous significant papers related to this topic in Macedonia. Details can be found in the references [8], [9], [10], [11] and [12].

The following projects are important on internationaland national level [1], [2], [3], [4], [5], [6], [7] and [8]:

- SafeLand
- Horizon 2020 Transport Advisory Group – TAG;
- FEHRL Vision 2025 for Road Transport in Europe;
- Sendai Framework for Disaster Risk Reduction (2015-2030);
- UNDP- implemented EU Recovery Program to support Macedonia recovery efforts after 2015-floods;
- European Union Program for overcoming the consequences of floods, reconstruction and rehabilitation of transport and water supply infrastructure after the floods in 2015;
- Technical assistance for designing of climate resistant constructions, Manual for the needs of Public Enterprise for State Roads in Macedonia (2019) and others.

Particularly noteworthy is the SafeLand international research project (FP7) supported by the European Commission that was implemented in the period 2009-2012. The project involved 27 institutions from 13 European countries and was coordinated by the Norwegian Geotechnical Institute (NGI). Another important project also funded by the European Commission and JRC is INSPIRE (Infrastructure for Spatial Information in Europe) launched in May 2007, where a special thematic working group on natural risk zoning has been set up. This group considers the landslides as a natural hazard and gives recommendations for further activities in this field to EU Member States [2].

In this context, and bearing in mind the significance of this problem, this paper presents some examples of drastic impacts of floods and landslides on Macedonian roads [9], [10], [11], [12]. The analyzes are presented mainly on the basis of the authors' experiences, and are in context of the recommendations of the Study concerning the construction of so-called "climate" resistant structures. This Study is prepared for the needs of the Public Enterprise for State Roads - PESR [8]. One of the goals of this study, among other things, is to integrate the data on landslides, floods and other hazards into the so-called system RAMS (Road Asset Management System) introduced for the purposes of road management under the authority of PESR.Another purpose of the Study is to provide comprehensive recommendations to all involved in the design of road infrastructure in our country, to take them into account in the projects and the expected effects of climate changes.

It is worth to mention a few significant conferences specifically devoted to the problem of the influence of natural and man-made hazards. Here are just a few examples: 16th European Danube Geotechnical Conference: "Geotechnical Hazard and Risks, Experiences and Practices" held in the Republic of Macedonia in June 2018 [1], "Seventh International Conference on Debris-Flow Hazards Mitigation" in Golden, Colorado 2019, ResyLab 4 - Sarajevo 2019 and many more.

## 3. BASICS OF METHODOLOGIES FOR HAZARD AND RISK ASSESSMENT OF NATURAL AND MAN-MADE HAZARDS ON THE INFRASTRUCTURE

In the world practice, it is generally known that any analysis dealing with natural and man-made hazards should be based on an analysis of susceptibility, hazard and definition of the risk of their occurrence.

Landslide susceptibility zoning covers the classification, size (volume) and spatial distribution of existing and potential landslides in one area. Susceptibility zoning usually involves the formation of cadastre of landslides that have occurred in the past, together with an assessment of areas with potential for future landslides, but without estimating the frequency (annual probability) of landslides occurrence.

Landslide hazard zoning can be performed by taking into account the results of the susceptibility mapping and estimating the frequency of the potential landslides. It should consider all the landslides that may affect the analyzed area, including the landslides above that can reach the area, and landslides below it that can move regressively (retrograde) therein.

Landslide risk zoning can be done by taking into account the results of hazard mapping, assessing the potential for harm to people (annual probability of loss of life), to property (annual value of lost property), and aspects of endangering the environment.

In order to generally illustrate the core of the preceding paragraphs, the following figures show some recent cartographic examples for definition of landslide susceptibility, hazards and risks, also prepared for the needs of PESR. Some of these maps have been adapted for different rainfall scenarios according to some forecasts of climate scenarios developed worldwide [8], and are based on the knowledge gathered trough the landslide database from the past 50 years. In general the following analysis sequence is applied *(Figure 1):*

*1. Defining the landslide susceptibility*
*2. Defining the basic level of hazard*
*3. Defining design hazard for a certain period.*

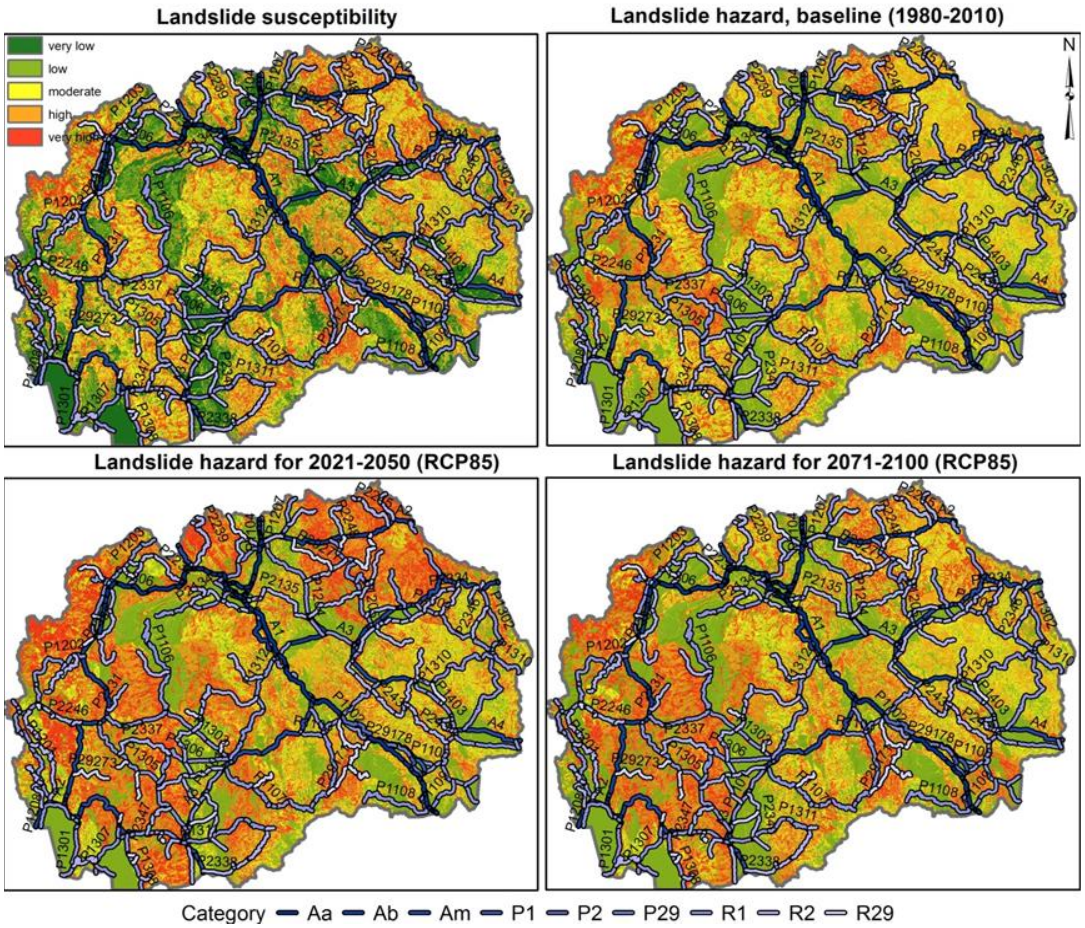


Figure 1. Presentation of models for defining landslide susceptibility and hazard of the Macedonian road infrastructure for certain periods [8]

The essence of preparing such models for forecast of the landslide hazard (LH) is, besides the impacts of lithological settings (L), slope inclination (S), land cover (LC) and earthquake impact (E), to define also the effect of the rainfalls (R) by changing their influence based on certain climate scenarios and introducing a rainfall impact factor (RF). This factor is normalized to a value of 0 - 1. For certain scenarios for the periods 2021-2050 and 2071-2100, using the worst case scenario for RCP85 emissions, the following formulas are obtained:

LH = 0.3 x L + 0.175 x (S + LC + E_100 years return period + R) (1)

For rainfalls scenarios the following factors are adopted: RF1 = 90th percentiles of rain x expected annual amount for 2021-2050 and RF2 = 90th percentiles of rain x expected annual amount for 2071-2100. Thus, the prognosis of the landslide hazard is based on the following formulas:

LH1 = 0.3 x L + 0.175 x (S + LC + E_100+ (1+RF1) * R) (2)

LH2 = 0.3 x L + 0.175 x (S + LC + E_100 + (1+RF2) * R) (3)

An example of prognosis of the hazard, vulnerability and risks of the roads in Polog region is shown in Figure 2.

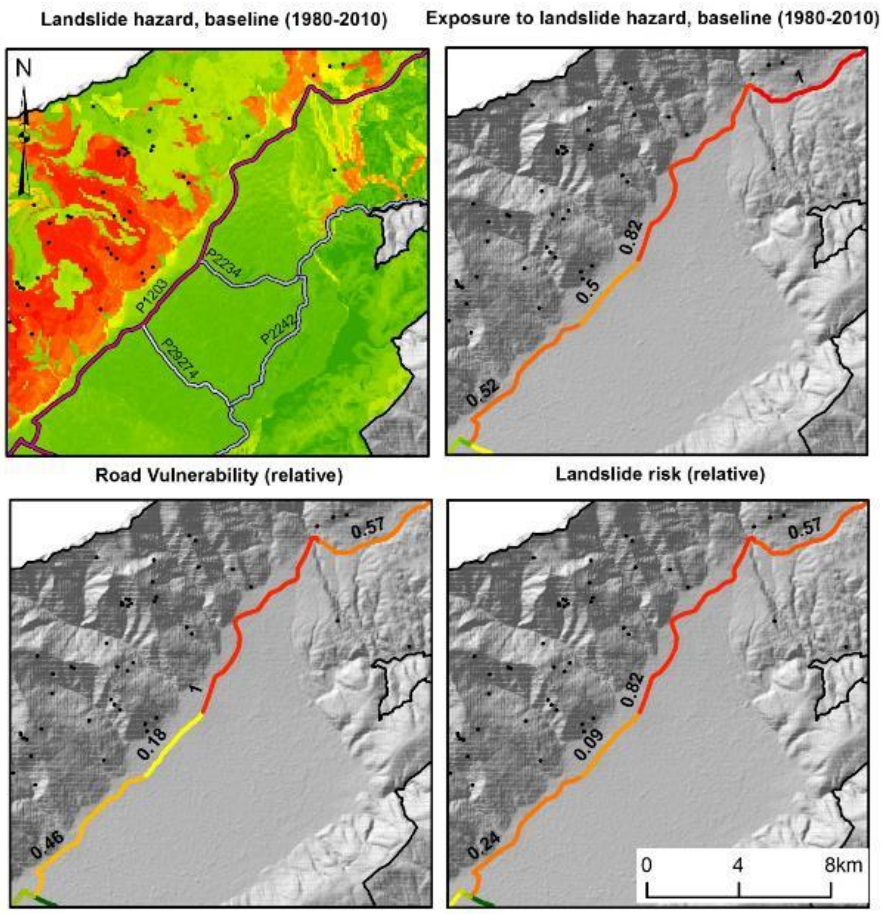


Figure 2. Presentation of models for defining landslide susceptibility and hazard, vulnerability of the road and landslide risk of the road infrastructure in Polog region for certain periods [8

Of course, these models can be subject to discussion and eventual changes, as some of the input factors are not fully predictable, but they can certainly be helpful in defining the current state of the infrastructure and certain forecasts that will help to manage the risks in the future. Successful realization of this aspect of course requires a general state management strategy.

## 4. SOME EXAMPLES FOR DAMAGE OF THE INFRASTRUCTURE

Every year, the landslides and floods in the Republic of Macedonia cause losses that are measured in millions of Euros. Most of these funds are usually spent on rehabilitation and cleaning of roads and railways. This is confirmed by the fact that 60% of the registered landslides have obstructed or blocked the traffic on the highways, regional and local roads. In order to get impression where the largest number of landslides is registered in our country, Figure 3 shows a cadastral map of unstable phenomena.

Statistics show that about 70% of the landslides are triggered by the effects of intense or prolonged rainfalls, which in turn are the cause of floods.

The usual period for floods in the country is November – January, and they are caused by the outflow of the major rivers Vardar, Crna Reka, Treska, Strumica and Bregalnica. To illustrate some of the effects, it will be mentioned that the floods in 2004 affected 26 municipalities with an estimated damage of about 15 million Euros. The floods in January and February 2015 affected 43 of 80 municipalities in the Republic of Macedonia (Mogila, Zrnovci, Petrovec, Novaci, Bosilevo, Demir Kapija, Strumica, Vinica, Radovish, Bitola). This has caused enormous damages to roads, bridges, culverts, irrigation canals and systems, industrial facilities, schools and individual dwellings. The floods in August 3, 2015, and the landslides triggered by them, caused the loss of 6 people and a lot of damage to the municipal and state infrastructure in the north western region Polog. The total estimated damage from these floods is 21.5 million Euros. The occurrence of

intense rainfall in the night between August 6 and August 7, 2016 is very indicative, as a result of which the Northern bypass of the city of Skopje was affected, with a tragic loss of 23 human lives and an estimated damage of over 30 million Euros. According to official data from the Hydro Meteorological Institute, rainfall of 92.9 mm/m$^2$ fell during a few hours, which is considered as an event with a return period of 1000 years.

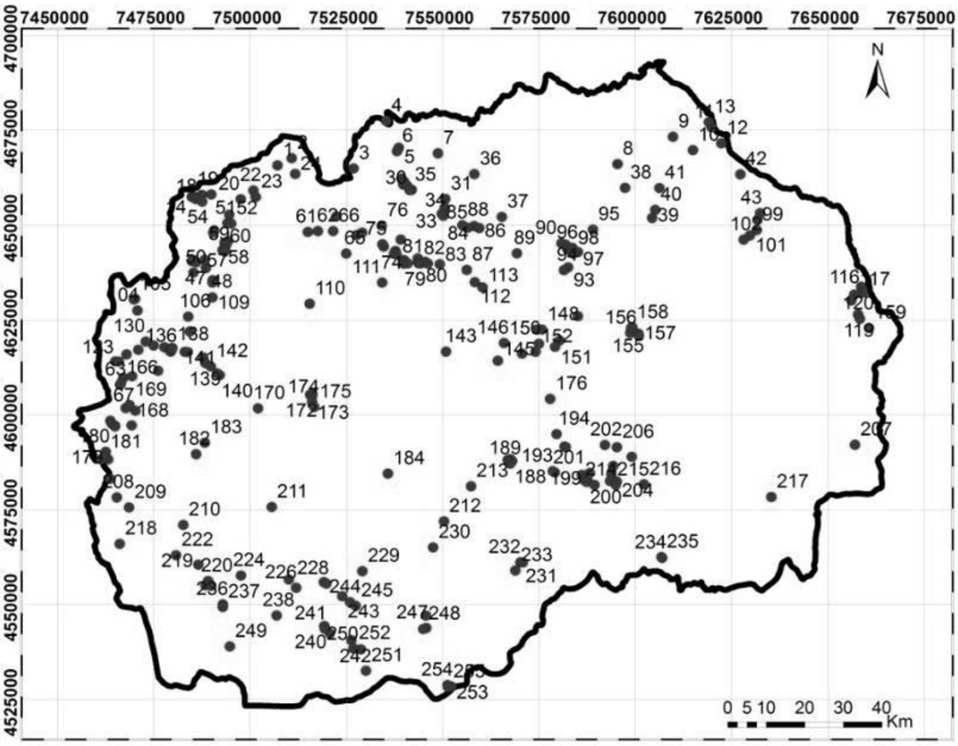


Figure 3. Cadastre of occurred landslides on the territory of R. Macedonia, for the period 1970-2015 [12]

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Having in mind these numbers, according to data from the Centre for Research on the Epidemiology of Disasters (CRED), between 2015 and 2016, Macedonia is among the 10 countries most affected by the impacts of floods and landslides. For example, according to the economic damages suffered or the mortality, our country ranks 6th in 2016 (1.06/100,000) by mortality, then 3rd in 2016 (0.55% of GDP) and 8th in 2015 (0.85% of GDP) according to occurred damage.

An illustration of the damage caused by landslides and floods is given in the following figures (Figure 4). The figures are undertaken from the authors' personal archive, colleagues in the profession and daily newspapers.

A) Rockfall on the road Istibanja – Makedonska Kamenica (2015 year)

B) Mudflow on the road Tetovo - Jazince triggered by flash flood of Poroj river (2017 year)

C) Landslide on national road Bitola-Resen (2010 year)

D) Total deformation of the pavement of the northern bypass of the city of Skopje, due to the flood in 2016

E) Snow and debris avalanche on the road Mavrovo-Debar (2010 year)

F) Rockfall on the road Kochani-Shtip (2013 year)

G) Landslide on the road Resen – Greece Border, place Markova Noga, in 2017

H) Rockfall on the road Veles-Gradsko in 2013

Figure 4. Some examples of impacts from occurred landslides, rock falls and floods on the road infrastructure [most examples are from authors' archive]

In order to see the value of the costs to be spent on remediation of some of the cases shown, Table 1 shows some data by design bill of quantities or by already finalized remediation.

Table 1. Some examples for remediation costs for landslides and rockfalls (reference – design documentation)

| Location | Costs for remediation (EUR) |
|---|---|
| Road R-2433, Resen – Greece Border, place Markova noga | 1.700.000,00 |
| Veles, road R-1102, km 49+300 | 894.000,00 |
| Kratovo, road R-1205, km 18+125 | 305.000,00 |
| Kratovo, road R-1205, km 18+165 | 850.000,00 |
| Road for the ski center Kozuv R-1105, seven landslides | 3.500.000,00 |
| Bitola bypass | 600.000,00 |

All this is a sufficient alarm, in the near future, to adopt a certain integrated Hazard and Risk Management Strategy for the environment, in order to prevent a great part of the problems and not to act after the disaster.

## 5. BASIC ELEMENTS IN THE RISK MANAGEMENT STRATEGY

It should be noted that there is no unique procedure in the world capable of estimating the land-sliding potential for each individual type of landslide and the expected displacement of the material, but the risk management scheme shown in Figure 5is considered suitable.

The particular steps in the risk management scheme should be all performed consistently, in order to achieve the final goal. As it can be seen from the figure 5 the risk management strategies predict continuous monitoring, review of input data and drawing conclusions for future studies. The process of landslide hazard and risk assessment is therefore repetitive, with average period of repetition (in developed countries) from 5 to 10 years.

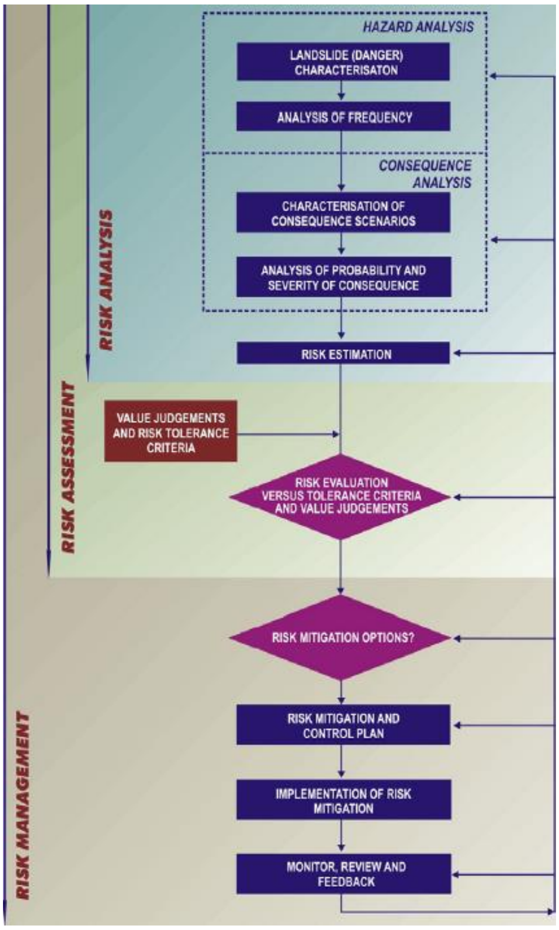


Figure 5. General scheme for landslide risk management according to Fell R. et al. Engineering Geology, vol. 102, (12)

The quality of the input data for landslide hazard and risk assessment is essential to the reliability of the results. Quality data enables the preparation of precise hazard and risk models, which is the basis for making the right decisions in terms of spatial planning and development of the country's infrastructure. Figure 6 below shows the general structure of the proposed national body for landslides where specific teams will work on various aspects related to landslides, such as: teams for technical documentation collection, teams for field mapping and investigation, teams for data bank preparation and maintenance and teams for preparation of landslide hazard and risk maps.

The ultimate goal of all activities of this body (institution) is: to propose appropriate construction methods depending on the landslide susceptibility of a certain area, to propose protection and remediation measures in endangered areas, cooperation with the Ministry of Environment and Physical Planning and Ministry of Transport and Communications. All these aspects contribute for proper development of the infrastructure, both at regional and local level. This set-up also requires a quite number of changes to the legislation, in particular the Law on Construction and the Law on Public Procurement, where the natural disaster management is scarce, and legislation itself in such cases is often a limiting factor in overcoming the consequences, if any challenge appears.

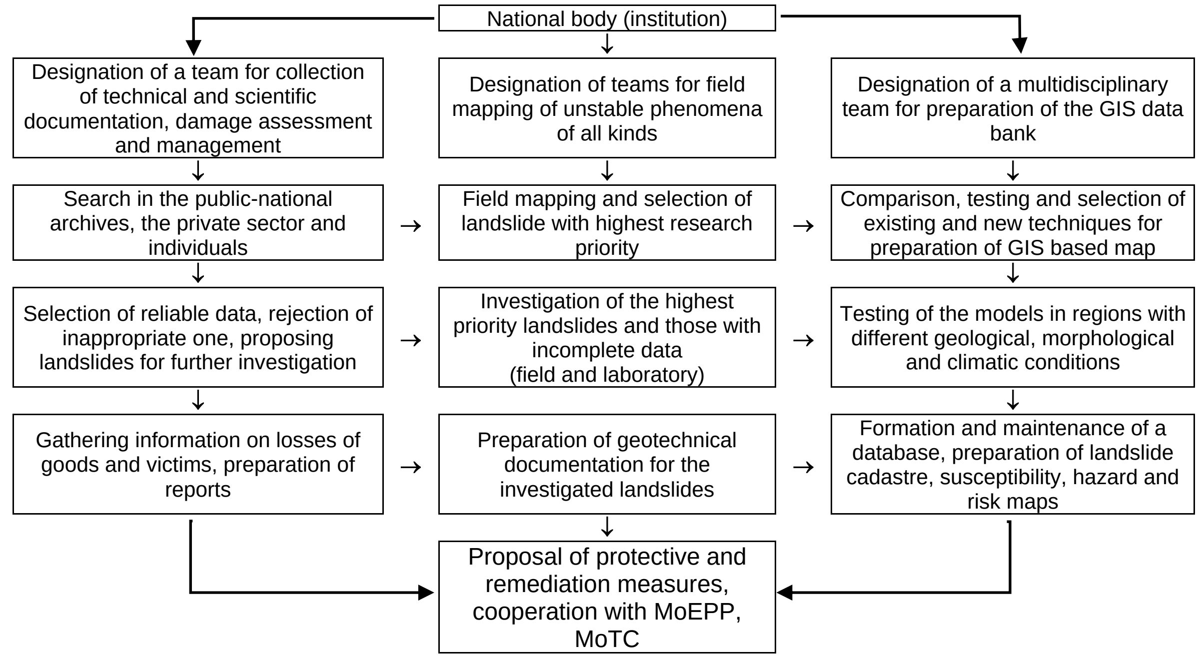


Figure 6. Strategic plan for establishing a landslide database in the Republic of Macedonia

## 6. CONCLUSION

From the realized work and all the conducted analyses, it is clear that there are many activities in this scientific and practical field that have yet to be planned and implemented. Here the priority steps would be: adapting the legislation in line with the positive experiences from around the world to enable it to deal successfully with the risks from the natural and man-made hazards; defining the developer and holder of the proposed GIS database, selection of appropriate landslide susceptibility/hazard and risk assessment methods following the example of the latest study prepared for the necessities of PESR, preparation of hazard and risk zone maps and their inclusion in the legislation on construction and environmental protection, preparation of recommendations for citizens and construction companies on how to reduce the vulnerability of already constructed structures in areas of high flood and landslide hazard, defining areas that restrict or prohibit the construction of buildings of different categories and more. All of these activities can be performed at national level, or for certain priority regions. Since landslides and floods are considered as main hazards to roads in the country, the hazard/risk management strategy should be focused around them.

For the realization of the proposed activities, it is necessary to involve more experts from the fields of geology, geotechnics, climatology, hydrology, agriculture and forestry, spatial planning etc., but above all, state assistance and coordination of a number of institutions that in one way or another have points in common with these problems.

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# FROM IDEA TO NEW TECHNOLOGY IN ROAD NOISE PROTECTION

In the past 20 years, Croatia has experienced an intensive development of its transport infrastructure. If referring to road infrastructure, then the region is considered, and Croatia leads in the quantity of constructed highways, as confirmed by data from the European Commission. For any modernization to be successful, it must be closely linked with research and development performed by the scientific community. The Faculty of Civil Engineering – University of Zagreb has been actively involved in all such projects, not only in the process of their creation, but also in the application of innovative solutions and technologies. This paper present successful environmental and innovative product that the Faculty of Civil Engineering - University of Zagreb, in cooperation with its industrial partners, has applied successfully in regular engineering practice. The quality of this product has been recognised by the European Commission through co-financing of environmental programs and innovative products by the EU that have increased European added value and also by the international associations in the field of transport infrastructure, like International Road Federation.

Keywords: transport infrastructure, innovation, new technologies, noise protection, RUCONBAR

## 1. INTRODUCTION

Today, we live in a world of digital communications and digital networks. However, life today would be unthinkable without the transport infrastructure, i.e. roads and railways. The changes that are now occurring in this area are happening very quickly, and the reason for this is the increasing use of innovation, new technologies and materials. Selecting certain technologies and innovative solutions leads to a more efficient and faster construction of transport infrastructure, and subsequently of course better quality management. Naturally, these changes are inconceivable without innovative engineers, because only they are able to create something new or make something better. Future social and economic trends will impose new challenges for civil engineers. The role and importance of civil engineers in creating something new is well described in the following view: "It is a great profession. There is the fascination of watching a figment of the imagination emerge through the aid of science to a plan on paper. Then it moves to realization in stone or metal or energy. Then it brings jobs and homes to men. Then it elevates the standards of living and adds to the comforts of life. That is the engineer's high privilege." Herbert Hoover, President of the United States.

When observing the creation of something new, attention should be given to the important fact that there are no innovations and new technologies without cooperation and dissemination of knowledge. Innovation is not only based on the individual knowledge of researchers in narrow fields, but today it incorporates interdisciplinarity and exchanging knowledge and experience. This fact has been recognised particularly in Europe and consequently, cooperation between universities and industry is increasing encouraged, especially cooperation from small and medium enterprises. Here, big companies are not mentioned since they tend to have their own highly developed laboratories, and very often a department or institute involved in development, which means that they are able to independently commercialise a new product or production process that has been developed. For small companies that also possess a research potential, this becomes much harder to achieve. Nonetheless, cooperation that is scientifically based and which exists in the academic community (universities, institutes), this can be achieved a lot easier since there exists a developed research infrastructure in most countries. Only through such cooperation can a particular sector become competitiveness. However, such cooperation is often difficult to come by in southern and eastern Europe. The reasons can be found in the following:

- Scientists often think that business entities should be the first to approach with their ‘problem’, which requires solved or with their ‘idea’ that needs to be further developed.
- Business entities often have an attitude that universities are mainly engaged in the research which provide impractical and inapplicable results.

These attitudes results in distrust, and therefore quite poor cooperation between industry and universities. The reasons for poor cooperation and the lack of trust can be explained by the fact that a very small number of engineers from industry enrol into postgraduate studies organised at universities. If this number were to increase, there would be a greater convergence of the business sector and the academic community, communication would become easier and greater trust would be acquired leading to better teamwork. This scenario could lead to improvements in certain technologies, technological processes, and to the creation of new technologies, new products and innovations. It is precisely this fact that can greatly help in boosting the competitiveness of business entities, which in today's market is most important.

The application of road traffic noise barriers began more than 50 years ago in both the USA and Europe [1, 2]. The noise wall exploitation behavior, repair, and/or replacement frequency of aged or deteriorated wall panels became an important issue in the last decade. However, despite the long-term experience in the application of noise walls (and research on the sustainability of noise barriers as well as other noise abatement measures [3–7]), when deciding on the panel material to be used in the design phase, designers still encounter numerous uncertainties associated with the exploitation behavior of noise walls constructed with panels made from different materials [8], including their stability, durability, and resistance to fire, impacts, and atmospheric influences. The main question is how the imminent degradation of panels will affect the efficiency of the wall structure, its life-cycle costs, and its long-term sustainability in specific locations and conditions [9].

The Department of Transportation Engineering at the Faculty of Civil Engineering in Zagreb has been striving for many years to link the academic community and industry in order to develop innovative products, new materials and technologies in the area of transport infrastructure. When research is conducted, it is necessary to keep in mind that results do happen immediately, but it is often much time-consuming and hard work is required to achieve a specific result and improve a particular process or create a new product. This paper will present an innovative product RUCONBAR - noise protection barriers with recycled rubber added that have been developed under research project RUCONBAR – Rubberised Concrete Noise Barriers funds of the EU CIP ECO-INNOVATION fund.

Absorbing concrete barriers with the addition of recycled rubber called RUCONBAR, were entirely developed at the Faculty of Civil Engineering, University of Zagreb. The whole idea behind the new product occurred at the Department of Transportation Engineering, but product development was done in close collaboration with the Department of Materials. Development, from the idea to the new product lasted about one and half years. After conducting all the necessary laboratory tests, the optimal mix for the new product was obtained and then followed transferring the technology to a company's production facilities for the purpose of manufacturing precast elements. The first samples of the product were produced at the factory, which were then subjected to comprehensive testing, confirming that this is a new, innovative, and in this case, the environmentally friendly product, since it produce from recycled products. In order to obtain verification that it indeed is an environmentally friendly and innovative product, and for it to received encouragement to market the product on the international market, the project was registered for the tender 2010 CIP ECO-INNOVATION. Selection of the project for funding from the EU CIP ECO INNOVATION programme, where the annually only approximately 15-20 % of proposals submitted are co-financed, is a confirmation that this is indeed a valuable environmentally friendly and innovative product.

Initiating the research and discovering something new in this area was driven by the state of the economy. During 2006-2007, the Department of Transportation Engineering at the Faculty of Civil Engineering in Zagreb had already made a similar product for the market (absorbing concrete barriers with expanded clay), which was also a new product in Croatia at the time. The product was then, completely accepted by the profession after only two years, and quickly took approximately 50 % of the market for noise protection barriers, Figure 1. The figure shows the percentage of types of noise protection barriers in use in Croatia after the introduction of absorbing concrete barriers with expanded clay to the market. Prior to this period, this type of barrier did not exist on the Croatian market.

This experience relating to the commercialisation of the product has helped in developing the environmentally friendly and innovative RUCONBAR barrier. The development of the RUCONBAR barriers and its commercialising sought different requirements on the Croatian market for this product, so it was necessary to prepare the product for much wider market acceptance. The construction of road infrastructure in Croatia in 2011 was at an end, with the railway infrastructure sector only beginning to awaken. The situation on the market indicated to us that we had to find an appropriate way to commercialise a completely new product and find a way to make it distinctive and interesting for the market, especially the regional market. This was the development team's goal, to find the appropriate EU fund for branding the product and facilitating its commercialization.

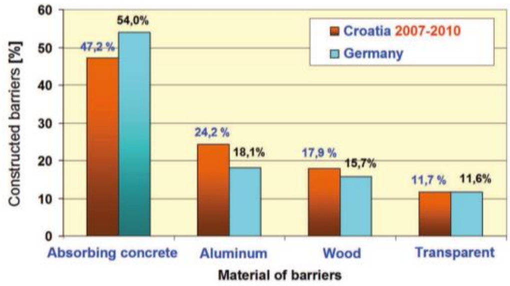


Figure 1. Percentage of the type of particular noise protection barriers on motorways in Croatia after 2007

Since this was an innovative and environmentally friendly product, the decision was made to apply to the CIP ECO-INNOVATION programme. When applying for this EU programme, besides the product being environmentally friendly, innovative, replicative and able to provide European added value, which is the case for the RUCONBAR product, when preparing for the EU project we prepared the material very carefully in order to answers several important facts:

a) Why should the EU Commission allocate funds for co-financing the proposed RUCONBAR product?

b) What makes the RUCONOBAR product stand out and what makes it different?

c) How will the project become recognisable in a large group of projects from many major EU countries?

d) How will the completely new product be commercialised on the international market.

To register at all for the tender against a large number of projects coming from EU member states, the RUCONBAR project had to be different. The next step was systematic preparation of the tender documentation in order to obtain a well defined, clear, interesting, easy to understand project possessing a good vision and purpose. With the vision defined, the required path was determined: obtaining finance from the EU funds, improving the quality of the manufacturing plant and systematic work on the market. This implies a good market analysis, identification of any problems and obstacles that can occur when commercialising new products, answering the question of why would the market want this new product, analysing how to confront a competitive product(s) , in what ways is our product better and more competitive. When looking at the product RUCONBAR, 21 countries are already interested in the stated product, providing proof that you can create a distinctive EU product. It is important to keep in mind one thing when referring to product innovation and new technologies: innovation without application in business is useless.

As noted previously, the Department of Transportation Engineering at the Faculty of Civil Engineering in Zagreb in 2006/2007 with industrial partner, developed absorbent noise protection concrete barriers. This product, which was then a completely brand new product in Croatia, had the absorbing barrier layer made from expanded clay (Fig. 2).

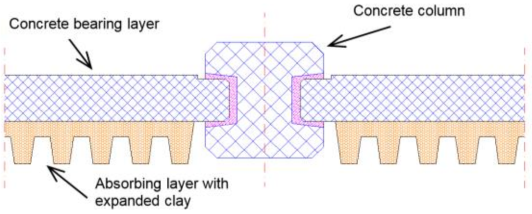


Figure 2. Cross-section of the absorbing concrete panel and bearing column

After the first use of the product on the test section and complete laboratory and field tests, market penetration began. In the beginning, this was very difficult. Since most infrastructure projects were in areas exposed to strong hurricane gusts, the proposed concrete barrier due to their greater weight and stability, proved to be the optimal solution. It was also aided by the fact that it was an entirely domestic product. Figure 3 shows the first absorbing concrete barrier in Croatia.

Figure 3. Absorbing concrete barrier at the entry to the City of Zadar (2007), [10]

By obtaining a stable barrier with the necessary absorptive properties, the product was ensured a rapid success on the market and already next year (2008) it was fully in use on the Split-Ploče motorway and the Šestanovac-Zagvozd and Zagvozd-Ravča sections. The corresponding sections had a total of approximately 15,000 m2 of noise protection barriers installed, ensuring the product's primacy on the market, as shown in Figure 1. Very quickly, other designers began fully implementation of the noise protection solutions by applying absorbent concrete barriers.

Excavation of clay

Thermal treatment

Granules of expanded clay

Environment following excavation of clay

Figure 4. Process of producing expanded clay

Forest cutting

Sawing

Wood fibres

Forest after cutting

Figure 5. Process of producing wood fibres

The important element in absorbent concrete barrier is primarily the absorbent layer made of a porous lightweight concrete. The first products that were marketed, as shown in Figure 2, were made of lightweight concrete with expanded clay granules that were imported. Since two Croatian companies had already adopted the production of these barriers, the desire was to produce the stated part of barriers from local materials. Today, manufacturers of absorbing noise protection concrete barrier use two materials, expanded clay and wood fibres. Were the production of these materials commenced in Croatia, it would not be in line with sustainable development. Namely, the production of expanded clay requires the excavation of clay in the environment, followed by thermal treatment to form the required granules for the production of lightweight concrete. Besides the irrecoverable consumption of natural resources for the production of expanded clay granules, it creates a stripped and devastated environment (Figure 4). Another material used for the production of porous lightweight concrete is wood fibres. The lack of such barriers is also an exploitation of natural resources, forests, for the purpose of producing the absorbent layer, Figure 5.

Due to these shortcomings in existing solutions for concrete barriers, the Faculty of Civil Engineering at the University of Zagreb continued its research into the field of noise protection for developing solutions compliant with sustainable development. The goal was to find a material for the production of lightweight concrete, which would have the appropriate absorption properties. The new material posed a number of requirements for its production and use in a new product [10-12]:

a) That it be produced from recycled waste

b) That the waste to be recycled is found on roadways

c) That it contributes to waste management

d) That its application produces an environmentally friendly product,

e) That sustainable production is achievable,

f) That work be done on innovative products

e) That a completely domestic product be obtained.

To respond to such demands placed at the start of developing new products is not simple. The development of the barrier RUCONBAR commenced from the first presumptions, and that is, that the absorbing lightweight concrete be produced from materials obtained from recycling waste found on roadways. The analysis of transport equipment and transport infrastructure confirmed the assumption that the recycling of used tires can provide granules for the production of lightweight concrete, Figure 6.

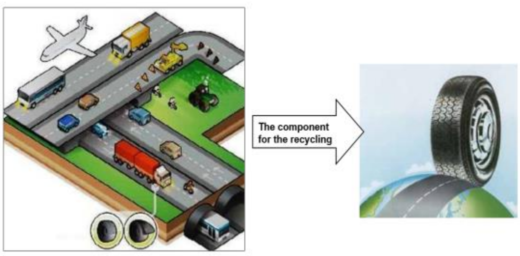


Figure 6. Transport resources and transport infrastructure – seeking suitable components for recycling following its lifetime of use

The use of tires in concrete was done before. There are studies that have dealt with the application of rubber in concrete, but from the point of view of improving the mechanical properties. Data and information on the use of recycled rubber for the production of concrete mixes for achieving absorption properties was not previously investigated. This fact prompted the development team at the Faculty of Civil Engineering in Zagreb to focus research into these new materials in this direction. A test program was defined in order to obtain an optimum mixture that would fully meet the set requirement, i.e. to obtain a lightweight concrete with the addition of recycled rubber that has absorptive properties. In addition to absorption properties, also investigated were other mechanical properties such as strength, fire resistance, freezing/thawing, compressive strength, tensile, impact resistance.

Waste tyres in the environment

Recycling waste tyres

Rubber granules

Clean environment

Figure 7. The process of producing rubber granules – from a polluted to a clean environment

During research, most of the attention was given to the fact whether it was possible to improve or reduce certain mechanical properties of concrete, which contains in its composition a certain percentage of rubber granules. Another important piece of information that was to be kept in mind was that if satisfactory properties of lightweight concrete were obtained, and whether there are enough of used tires on the market from which to obtain the necessary raw materials. If taking into consideration the used tires sector, then about 12% of used tires are used for the retreading purposes, 54% are recycled in the form of rubber granules, and the remaining are used for burning in cement making facilities and recycled in the form of rubber thread, rubber powder and some other specially requested products [13]. Furthermore, this innovative product does not only allow noise protection, but contributes to the disposal and management of waste tires in an appropriate, effective, innovative and economically efficient manner - with the development of new products. if we consider the barriers RUCONBAR in terms of sustainable development, then this widely used product is environmentally acceptable since waste tires creates a value added product, and also contribute to a cleaner environment (Figure 7).

RUCONBAR contains in the structure of its absorbent layer 40 % rubber granules (Figure 8), obtained by recycling waste tyres and as such represents an innovative solution to the production of noise protection barriers. A patent has been taken out for the product at the State Intellectual Property Office of the Republic of Croatian (P20100483A) and the trademark (Figure 9).

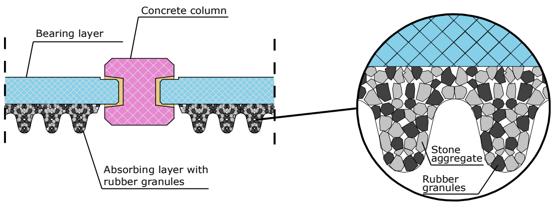


Figure 8. Cross-section of the innovative solution – RUCONBAR noise protection barrier

Figure 9. Visual mark for the product RUCONBAR, [14]

According to data [12, 15], only 5 % of waste tires are uncontrollably disposed of in Western Europe, whereas in the area of the new member states and candidate countries 29 % of the resulting waste tires about 450 000 t, or about 42.5 million units) are uncontrollably disposed of, Figure 10. According to Directive 1999/31/EC as of 2006, any kind of disposal of waste tires in the environment is completely prohibited; hence, this decision has brought about an increase in the available quantity of waste tires used for recycling. This is the answer to the question of whether we have a sufficient amount of this type of waste for the production of rubber granules and what is the potential market for these barriers. These facts are rightly the reason for the high interest in this product. Two environmental components are related, noise protection, which is achieved with the product and the manufacturing of products with recycled material, whereby we have prevented its unauthorized disposal into the environment. A great interest in barrier RUCONBAR is currently expressed in the following countries: Bosnia and Herzegovina, Slovenia, Serbia, Romania, Lithuania, Bulgaria, Australia, Canada, Switzerland, India, Ukraine, Qatar, Turkey, France, Iran, Russia, USA, Canada, Germany, Hungary. Agreements on the transfer of technology with some companies are in the phase of being signed.

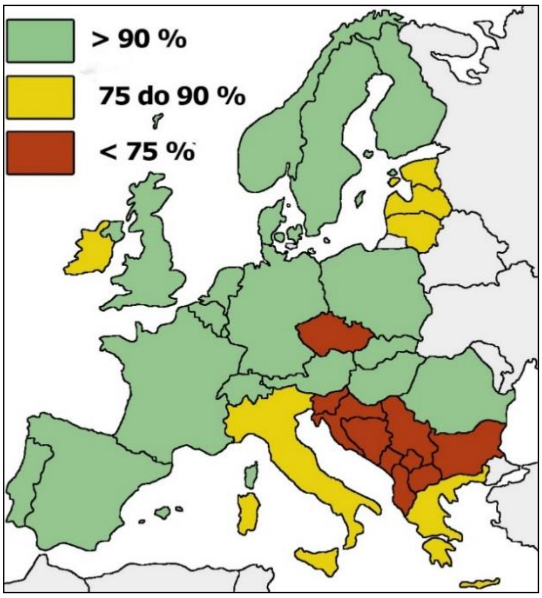


Figure 10. Percentage of recycling waste tyres in the area of Europe [3, 4]

## 2. FIRST APPLICATION OF THE RUCONBAR NOISE PROTECTION BARRIER

Given that the developed barrier meets the requirements relating to the reduction of noise levels set governed regulations and standards, each innovative solution seeks also a first application. Selecting the first application for any product is always the hardest. Since the Department of Transportation Engineering at the Faculty of Civil Engineering in Zagreb conducted a large number of surveys, and a large number of main and detailed design projects on noise protection, finding the first applications was somewhat easier. The settlement of Scott was chosen for the first noise protection application, near the toll station on the Krk Bridge. The stated application will be co-financed from the EU RUCONBAR project. To facilitate selection of a visual solution for the stated barriers, and its position illustrated in space, the first application of RUCONBAR noise barriers (Figure 11).


Figure 11. First application of RUCONBAR noise barriers on road section (noise road protection of the settlement Scott)

The first application of this novel innovative noise protection barrier was made on a road section near toll booths for Krk Bridge in Croatia. Following this example, RUCONBAR walls are being constructed on different road and railway sections.

Application of the RUCONBAR barriers was also realized at the Croatian Railways network. The first application of this innovative noise protection barrier was made on Perušić-Gračac railway line, Figure 12. Application of the RUCONBAR barrier on a railway line is interesting since this is a first noise protection implemented along a railway line in Croatia and on account of announced major investments in the future of this sector in the Republic of Croatia, [15].

Figure 12. First application of RUCONBAR noise barriers on railways line (noise protection of the settlement near railways station Gospić)

## 3. INTERNATIONAL RECOGNITION OF THE INNOVATIVE PRODUCT RUCONBAR

The simple design makes absorbent concrete barriers a very practical application not only for new roadways (road or railway lines) but also along existing roads. It is actually the area of existing roads that the issue of noise protection is being increasingly investigated. If we consider current practice in Croatia, then noise protection is applied only to new highway sections. However, existing motorways should not be forgotten. In fact, many sections of motorways in Croatia were constructed 30 years ago or more, and in some parts of these roads there are frequent complaints from the local population relating to increased noise due to an increase in the number of vehicles. A particular application of this kind of barrier can be found in urban areas, where its ease and speed of construction but also very simple possibility architecture make it appealing. Application of the RUCONBAR noise protection barrier is very practical for aesthetic, economic and architectural reasons. Using a product made from recycled type waste in the absorption layer helps protect the environment by solving the problem of disposing of tyre waste, the consumption of natural resources, and compared with similar solutions reduces CO2 emissions and the actual price of ready-made barriers. These benefits were anticipated by the EACI Commission (European Agency for Competitiveness and Innovation) which accepted the project RUCONBAR for financing through EU funds based on the 2010 ECO-INNOVATION tender. Project RUCONBAR and its final product – the noise barrier – have been widely recognized as an excellent example of academic-professional cooperation to tackle major environmental challenges. This has been acknowledged by:

ARCA 2012, 10th International innovation exhibition - Grand prix (Zagreb, Croatia, 2012)

GREENOVATION Award for best technology of Croatian green business (Croatia, 2012)

CEMEX – Building award 2015 (Sustainable building) - Noise protection of settlement Scott near toll stop for Krk Island (Croatia, 2015)

Inventions Geneva 2016 – Golden medal with the congratulations of the jury (Geneva, Switzerland, 2016)

Innova 2016 - Golden medal with the congratulations of the jury (Brussels, Belgium, 2016)

Silicon Valley International Invention Festival 2018 – Silver medal (Santa Clara, USA, 2018)

IRF Global Road Achievement Award 2018 in category “Research” (Las Vegas, USA, 2018), Figure 13

RailTech 2019 Innovation Award in category "Infrastructure" (Utrecht, Netherlands, 2019), Figure 14

The Awards are recognized as a prestigious industry accolade in their own right, but they also serve to remind a much wider audience that the mobility everyone takes for granted would not be possible without the talent and commitment of our industry. Faculty of Civil Engineering University of Zagreb now joins an elite group of scientific institutions whose exemplary projects have been recognized by their peers for their excellence, innovation, and societal impacts [16]. This project and innovation will continue serving as a model and inspiration for others in the road and transport sector.

Figure 13. Crystal Globe for RUCONBAR in category "Research", IRF Global Road Achievement Award 2018


Figure 14. RailTech 2019 Innovation Award for RUCONBAR in category "Infrastructure"

## 4. CONCLUSION

The economic development of a country is inconceivable without a properly developed transport infrastructure. In Croatia, intensive work on the construction of road infrastructure was carried out in the previous period, while very little attention was given to railway infrastructure. Today, all attention of builders is focused on the construction and modernisation of the railway infrastructure. Industry activities in both sectors of the Department of Transportation Engineering have been successfully monitoring this and through participation in a number of preliminary, main and detailed design projects and supervision of construction and testing of materials. A significant step forward has been made in developing new products and technologies which are recognised by the profession and which are increasingly find their place in daily engineering practice. The reason for this is the fact that most of the innovative products developed in collaboration with industry certainly facilitate market penetration. The direction in which today new trends move in the field of transport infrastructure is certainly the use of new products and technologies that contain a certain proportion of recycled material and in turn contribute positively to waste management, and thereby protection of the environment.

The innovative product RUCONBAR is designed to be replicable on any market in need of end-of-life tire recycling and quality noise protection on road and railway infrastructure. Technology transfer has been ensured through prepared procedures for production plant assembly and staff training documentation.

RUCONBAR concept is an economical, easy to implement, and environmentally sound noise protection solution. For orientation, 46.4 t of recycled rubber granules, obtained by recycling 7.800 waste car tires, can be used for manufacturing 1 kilometer of noise barriers 3 m in height (3,000 square meters of barriers). Major environmental benefits of using RUCONBAR are:

- 31% reduction in GHG emissions compared to similar solutions available on the market [11],
- reduced consumption of non-renewable resources (gravel or crushed stones, natural clay and tree felling),
- protection of natural environment against uncontrolled clay excavation and tree felling practices,
- recycling end-of-life car tires.

Desired sound absorption properties can be achieved by varying the thickness and shape of absorbing layer of the noise protection panel. Absorption properties have been tested according to HRN EN ISO 354 and HRN EN 1793-1. Class of A2 and A3 is expected for standard applications of RUCONBAR. Class A1 can be achieved for special purpose applications. Aside from noise mitigation properties, product certification and compliance has been established through rigorous testing resulting in CE label (Conformite Europenne) issued by Notified Body in 2014.

Innovative and environmentally friendly concept of Ruconbar is applicable in all EU and beyond but it is most applicable in those countries that have need for waste tyres management and demand for noise protection barriers due to underdeveloped traffic infrastructure. With the introduction of EU Directive in SEE, which bans landfilling of whole (July 2003) and shredded (July 2006) tyres, it is clear that there is need to increase recycling capacities and develop markets for utilising recycled tyres. Ruconbar provides an opportunity to accelerate transit and adoption period of SEE countries and reduce the gap between them and other EU countries in the field of noise pollution and waste tyres management, [14]. Ruconbar production in each country of these contributes jointly to the implementation of the Waste Management which yields significant ecological benefits in reduction of noise pollution and waste tyres disposal.

## AUTHOR'S NOTE

This paper is based on the manuscript prepared for the chapter in the book Future Trends in Civil Engineering (eds. Cerić, A., Lakušić, S.), Zagreb, 2014. Due to the importance of the topic covered, chapter in the book was for the purpose shorted and connected with the research performed at the Faculty of Civil Engineering University of Zagreb.

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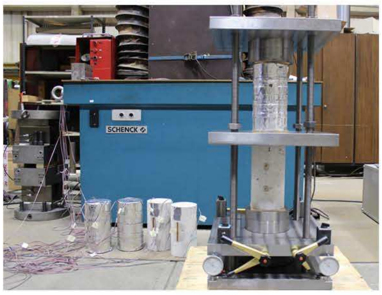


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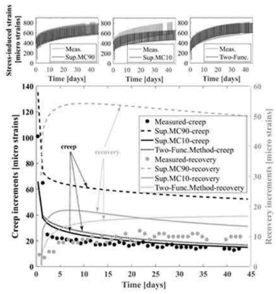


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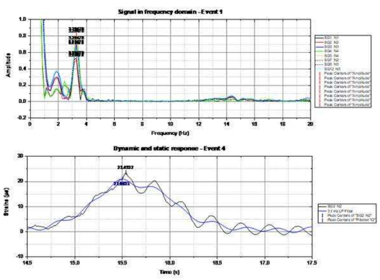

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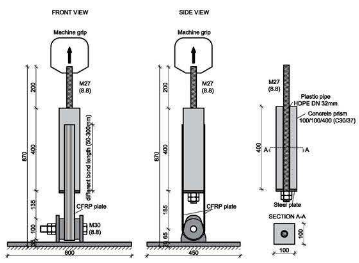


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# IMPACT OF DIFFERENT PAVEMENT REHABILITATION TYPES ON DRIVING SURFACE ROUGHNESS QUALITY

There are more factors from bond vehicle - road condition that have significant impact on driving comfort on the road. One of indicators in this bond is roughness of roadway surface (smoothness), and with this indicator safe and comfortable driving at designed speed on particular roadway is ensured.

One of the most important surface parameters of every roadway is longitudinal roughness which is functionally connected with maximum allowed driving speed. Longitudinal roughness, expressed through International Roughness Index (IRI) is significant parameter which have to be achieved on pavement surface.

The occurrence of excessive plastic deformation, fatigue and the appearance of cracks in the pavement structure are factors that require on-going quest for a technical solution in order to obtain high quality flexible road construction especially for highways and roads with very heavy traffic load. Applying a design solution by overlaying or one-layer upgrading of pavement structure, is usually limiting factor in achieving of the required roughness.

Keywords: longitudinal roughness, pavement structure, reconstruction, rehabilitation

## 1. INTRODUCTION

In this paper, main attention is paid to pavement surface longitudinal roughness expressed through the International Roughness Index (IRI), as one of the most important surface characteristics of each road. It is evident that roughness has a great impact on driving comfort and safety, but this pavement surface factor is variable during the exploitation of roads and depends on many influential factors.

To determine the impact of different types of rehabilitation in the road construction on road surface roughness quality, the International Scientific Project "Application of PmB in the base asphalt layers of the pavement construction at the roads with the heavy traffic loading and motorways " [1] determines the so-called "Zero / initial" measurement of the roughness index (IRI) on a specific section of the Motorway A1 (E-75): "Negotino - Demir Kapija" (left motorway) from km 121 + 800 to km 115 + 224.

## 2. CHARACTERISTICS OF THE EXPERIMENTAL SECTION

The section subject to this measurement was constructed in accordance with the project Reparing and Rehabilitation of Motorway A1, section: "Negotino - Demir Kapija" in the period July/2018 to November/2018 by the contractor GD GRANIT AD Skopje. The installation of the final wearing course was completed with an electronically guided spreader supported by large MultiPlex skis, covering the full width of the road (approximately 11 m), an ideal technology that levels out any uneven road surface, undulations and irregularities. MultiPlex skis operate on the principle of non-contact scanning of the values in relation to the surface, with three laser sensors placed on both sides of the spreader at a height ranging from 250 mm to 650 mm.

The experimental section is divided into 3 subsections that differ in terms of type of rehabilitation performed:

**Sub-section 1 – New motorway construction – (section where reconstruction was performed by replacement on capping layer, sub base (base course) and three layers of asphalt pavement):** complete rehabilitation of the subgrade, sub base (base course) and asphalt pavement were performed on section from km 115+040 to km 116+990, at 195m length. Total thickness of pavement structure is 89 cm with following structure and dimensions:

- **Embankment of stone material** in depth of min 30 cm
- **Improved capping layer** in depth of 40 cm
- **Sub base (base course)** in depth of 30cm

Total asphalt pavement on this section is 19 cm, three layer asphalt pavement type:

**I layer**: Asphalt base type BNS 32sA, at 7cm thickness,

**II layer**: Asphalt base BNS 22sA at 6cm thickness,

**III layer**: Asphalt wearing course AB 16s with polymer modified bitumen PmB (45/80-65) at 6cm thickness.

**Sub-section 2 – Rehabilitation – (section where rehabilitation was performed with a single-layer upgrade, e.g. overlaying on asphalt wearing course and local repair of asphalt base was performed):** it's consist of two sections – section from km 116 + 990 to km 119 + 881, at 2.891 m length and section from km 120 + 228 to km 122 + 984, at 2.756 m length. The overlay on asphalt wearing course was performed with asphalt mixture type AB 16s polymer modified bitumen PmB (45/80-65) at 6 cm thickness. Total asphalt pavement on this subsection (new and existing asphalt pavement) is ≈17 cm;

**Sub-section 3 – Existing pavement structure – (on this sub-section, no intervention was made):** Due to planned construction of a Toll station on the section from km 119 + 881 to km 120 + 228, at 347 m length, construction activities weren't performed.

Concerning the total thickness of all asphalt layers in the road construction, the sections are categorized in one group.

## 3. IN SITU MEASUREMENT OF THE SURFACE ROUGHNESS OF THE LEFT MOTORWAY OF THE SECTION: "NEGOTINO – DEMIR KAPIJA" (LEFT MOTORWAY) FROM KM 121 + 800 TO KM 115 + 224

In order to notice the differences in the quality of driving surface roughness among different types of interventions, the roughness of approximately the entire section on which construction activities took place from km 115 + 040 to km 122 + 984 was measured. The measurement of the section was performed on 9/11/2018 on a stretch from km 121 + 800 to km 115 + 224 in the direction from Demir Kapija to Negotino, at 6,576 km length. It was conducted with Dynatest Road Surface Profilometer ® 5.051 Mark II, a high speed inertial profile measuring device owned by the PE for State Roads (Figure 1).


Figure 1. Initial chainage for measuring evenness

The criterion for expressing the longitudinal road surface roughness of the motorway is the International Roughness Index IRI - International Roughness Index [m / km], which is applied in the most European countries and worldwide.

In the interest of laser beam reflection accuracy, the roughness measurement was performed on a clean and dry surface, according to the standard EN 13036-5 *Road and Airfield Surface Characteristics - Test methods - Part 5: Determination of Longitudinal Unevenness Indices (EN 13036-5: 2019*). The measurement was performed with three laser units, each measuring one longitudinal profile, while these three profiles covered 3 positions (left, middle and right) of a traffic lane. Both the driving and the fast traffic lane, were individually measured.

## 4. ANALYSIS OF THE INITIAL AND EXPLOITATION ROUGHNESS OF THE DRIVING ASPHALT SURFACE ON THE LEFT MOTORWAY ON SECTION: "NEGOTINO - DEMIR KAPIJA" (LEFT CARRIAGEWAY) FROM KM 121 + 800 TO KM 115 + 224

In the Republic of Macedonia, measuring of the roughness through the International Roughness Index is not foreseen in the existing technical regulations, whereby the roughness is measured with 4 meter-long measuring laths. At the same time, no distinction is made between assessments of driving surface roughness of the exploited roads, new constructions, as well as different types of rehabilitations. For that reason, the assessment of the condition of the driving area is conducted according to Croatian regulations, taking into account the size of the traffic load, the category of the road, the type of intervention and the projected driving speed, enlisted under Table 1.

Table 1. Evaluation criteria for longitudinal evenness

| **Asphalt pavement category** | | **Scope of construction works** | **Designed roughness index $IRI_P$ *[m/km]*** | **Tolerance limit as per roughness index $IRI_T$ *[m/km]*** | **Unacceptable roughness index $IRI_N$ *[m/km]*** |
|---|---|---|---|---|---|
| **Motorway** | New motorway construction | Newly constructed asphalt pavement within new contraction of the motorway (without structures) | $IRI_{DMN} \le 0,90$ | $IRI_{TMN} = 1,05$ | $1,35 \le IRI_{UMN}$ |
| | Overlay | Newly constructed asphalt courses within overly of the motorway (without structures) | $IRI_{DMO} \le 1,10$ | $IRI_{TMO} = 1,30$ | $1,70 \le IRI_{UMO}$ |
| | Structures | Newly constructed asphalt surface on structures as a part of a motorway (new construction and overlay) | $IRI_{DMS} \le 1,65$ | $IRI_{TMS} = 2,10$ | $2,45 \le IRI_{UMS}$ |
| **National road** | New construction | Newly constructed asphalt pavement within new construction of the national road | $IRI_{DNN} \le 1,15$ | $IRI_{TNN} = 1,35$ | $1,65 \le IRI_{UNN}$ |
| | Strengthening/ Reconstruction | Newly constructed asphalt courses within reconstruction of the national road | $IRI_{DNR} \le 1,40$ | $IRI_{TNR} = 1,70$ | $2,30 \le IRI_{UNR}$ |
| | Overlay | Newly constructed asphalt courses within overlay of the national road | $IRI_{DNO} \le 2,15$ | $IRI_{TNO} = 2,55$ | $3,00 \le IRI_{UNO}$ |
| **City roads** | | Newly constructed asphalt courses within new construction and reconstruction of the city roads | $IRI_{PC} \le 2,00$ | $IRI_{TC} = 2,45$ | $2,85 \le IRI_{UC}$ |

The driving and the fast lane roughness index was evaluated for the entire section, at 6,576 km length, and the evaluation criteria are taken for 2 road categories: motorway reconstruction (rehabilitation) and new construction (complete reconstruction).

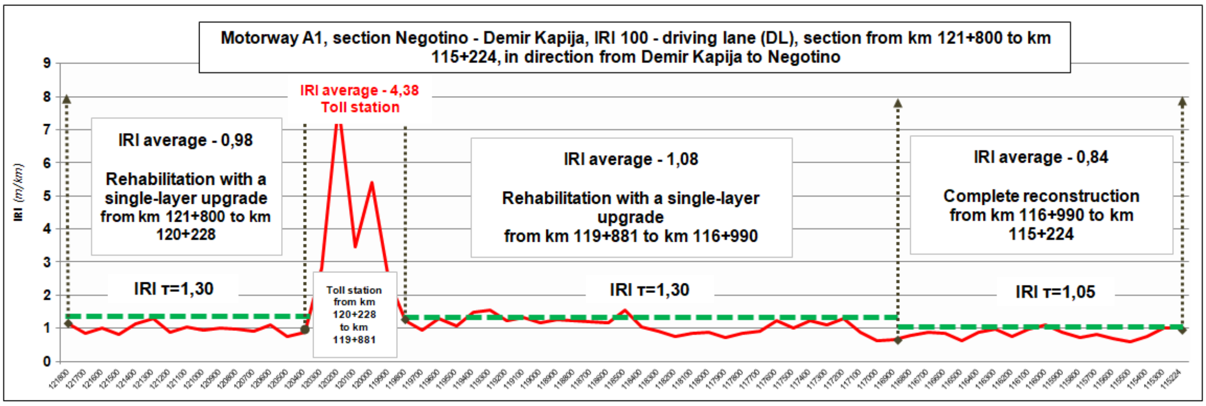


Figure 2. Measured values of $IRI_{100}$ for the section on driving lane (DL) – section from km 121+800 to km 115+224

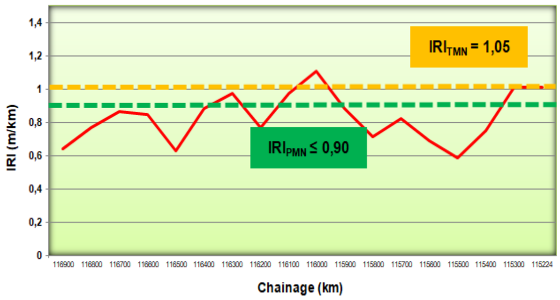


Figure 3. Measured values of IRI100 (IRI100AVG = 0,84 *(m/km);* IRI100max = 1,11 *(m/km);* IRI100min = 0,59 *(m/km))* for the section on driving lane (DL) – section where complete reconstruction has been performed – from km 116+990 to km 115+224

Figure 2 and Figure 5 show the $IRI_{100}$ exploitational roughness of the entire measured section of the driving lane and the fast lane from km 121 + 800 to km 115 + 224, according to the criteria for tolerance limits as per roughness index enlisted under Table 1, for a new asphalt construction as part of new motorway construction ($IRI_T$ = 1.05) for the section where complete reconstruction was performed (from km 116 + 990 to km 115 + 224) and in accordance with the criteria for tolerance limit as per roughness index for newly constructed asphalt courses within reconstruction of the motorway ($IRI_T$ = 1.30) for the section where rehabilitation was performed with a single-layer upgrade (from km 121 + 800 to km 120 + 228 and from km 119 + 881 to km 116 + 990).

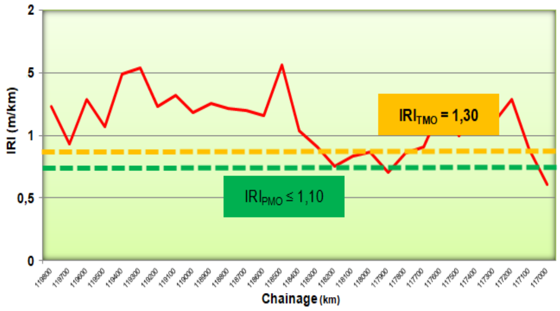


Figure 4. Measured values of $IRI_{100}$ ($IRI_{100AVG}$ = 1,08 *(m/km);* $IRI_{100max}$ = 1,56 *(m/km);* $IRI_{100min}$ = 0,61 *(m/km))* for the section on driving lane (DL) - section where rehabilitation was performed with a single-layer upgrade – from km 119+881 to km 116+990

The statistical calculation was performed on all measured values of $IRI_{100}$ on both lanes, in terms of the type of rehabilitation, separately by subsections and for the entire section, and the characteristic statistical data are presented in Table 2 and Table 3.

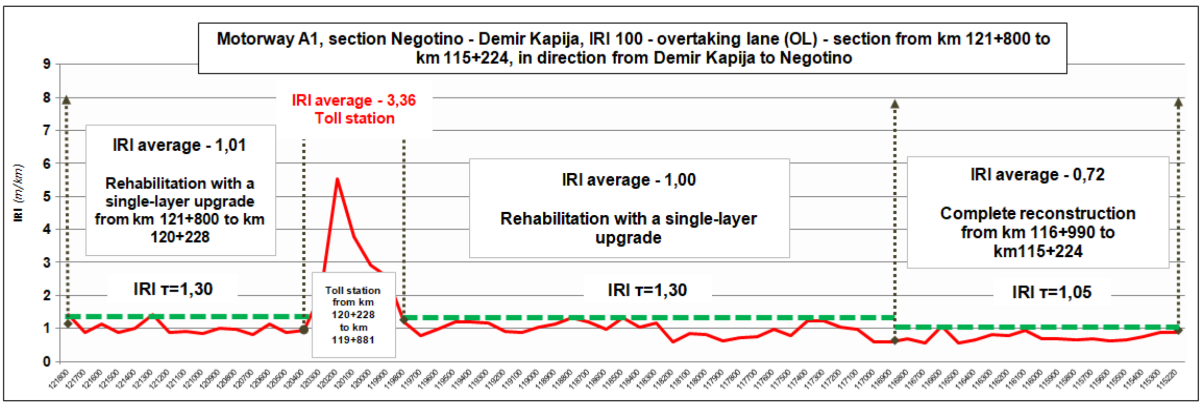


Figure 5. Measured values of IRI100 for the section on fast lane (OL) – section from km 121+800 to km 115+224

Table 2. Statistical data for $IRI_{100}$ for the entire section and separately by subsections – DL

| $IRI_{100}$ for sub-section: | min. | max. | Average $IRI_{100AVG}$ [m/km] | St. Dev. | Criteria |
|---|---|---|---|---|---|
| **Complete reconstruction** Section km 115+224 to km 116+990 | 0.59 | 1.11 | **0.84** | 0.14 | $IRI_{PMN} \le 0,90$ $IRI_{TMN} = 1,05$ (motorway – new construction) |
| **Rehabilitation with a single-layer upgrade** Section km 116+990 to km 119+881 | 0.61 | 1.56 | **1.08** | 0.25 | $IRI_{PMO} \le 1,10$ $IRI_{TMO} = 1,30$ (rehabilitation of a motorway) |
| **Rehabilitation with a single-layer upgrade** Section km 120+228 to km 121+800 | 0.77 | 1.30 | **0.98** | 0.14 | $IRI_{PMO} \le 1,10$ $IRI_{TMO} = 1,30$ (rehabilitation of a motorway) |
| **Existing asphalt pavement – part for Toll station** km 119+881 to km 120+228 | 2.46 | 7.76 | **4.38** | 2.20 | / |
| **Entire section** Section km 121+800 to km 115+224 | 0,59 | 7,76 | 1,25 | 1,08 | $IRI_{PMO} \le 1,10$ $IRI_{TMO} = 1,30$ (rehabilitation of a motorway) |

Table 3. Statistical data for $IRI_{100}$ for the entire section and separately by subsections – OL

| $IRI_{100}$ for sub-section: | min. | max. | Average $IRI_{100AVG}$ [m/km] | St. Dev. | Criteria |
|---|---|---|---|---|---|
| **Complete reconstruction** Section km 115+224 to km 116+990 | 0.54 | 1.07 | **0.72** | 0.14 | $IRI_{PMN} \le 0,90$ $IRI_{TMN} = 1,05$ (motorway – new construction) |
| **Rehabilitation with a single-layer upgrade** Section km 116+990 to km 119+881 | 0.60 | 1.34 | **1.00** | 0.21 | $IRI_{PMO} \le 1,10$ $IRI_{TMO} = 1,30$ (rehabilitation of a motorway) |
| **Rehabilitation with a single-layer upgrade** Section km 120+228 to km 121+800 | 0.81 | 1.43 | **1.01** | 0.19 | $IRI_{PMO} \le 1,10$ $IRI_{TMO} = 1,30$ (rehabilitation of a motorway) |
| **Existing asphalt pavement – part for Toll station** km 119+881 to km120+228 | 2.01 | 5.54 | **3.36** | 1.37 | / |
| **Entire section** Section km 121+800 to km 115+224 | 0.54 | 5.54 | 1.10 | 0.76 | $IRI_{PMO} \le 1,10$ $IRI_{TMO} = 1,30$ (rehabilitation of a motorway) |

Based on driving and fast lanes roughness assessment for the entire section, including all subsections, it can be concluded that only the tolerable limit as per index of roughness for the criterion of road reconstruction - rehabilitation is met. If the assessment excludes the section on which no intervention was made and each sub-section is analyzed separately in terms of rehabilitation type, then the results change/improve drastically, whereby all criteria are met. Notably, the section Complete Reconstruction meets the criteria for Motorway – New Construction (new motorway construction), while for section Rehabilitation meets the criteria for Motorway - Reconstruction.

The average value for $IRI_{100AVG}$ for the section where complete rehabilitation has been performed is 0.84 *[m/km]* for the driving lane and 0.72 *[m/km]* for the fast lane, which according to the evaluation criterion for Motorway - New Construction, classifies within the projected roughness index **$IRI_{PMN} \le 0,90$** which is the highest roughness level.

In addition to this, the average value for **$IRI_{100AVG}$** for the section where rehabilitation was performed with a single-layer upgrade falls within the framework of 0.98 to 1.08 *[m/km]* for the driving lane and 1.01 *[m/km]* for the fast lane, which according to the evaluation criterion for Motorway - Reconstruction, can be classified within the projected roughness index **$IRI_{PMN} \le 1,10$,** the highest roughness level.

This statement imposes the need to draft regulations with gradation of the road (traffic load) and the type of intervention on the road.

## 5. CONCLUSION

The roughness of the road is one of its main features and one of the first features that users notice during driving.

It is important to note that roughness - or unevenness of the roads has an impact on travel comfort and on road safety also.

Based on the results of driving surface longitudinal roughness measurements expressed through the IRI, the following can be concluded:

- The analysis of the measured results indicates the conclusion that there is a significant difference in the value of the evaluated roughness, between the measured average value for **$IRI_{100AVG}$** for the whole section and by sections, visible from fig. 2 and 5.
- The results of the examination showed that there is a difference in the achieved level of roughness depending on the type of intervention of the pavement construction. It is concluded that the highest level of roughness was achieved during new pavement construction (**$IRI_{100AVG}$** for the part where complete rehabilitation was performed is **0.84** *[m/km]* for the driving lane and **0.72** *[m/km]* for the fast lane), and then at single-layer rehabilitation (**$IRI_{100AVG}$** ranges from **0.98** to **1.08** *[m/km]* for the driving lane and **1.01** *[m/km]* for the fast lane), while on the

section of the existing pavement construction, we have the lowest roughness level (**$IRI_{100AVG}$ = 3.36** *[m/km]).* (Tab.2 & Tab. 3)

- Measurements were made on the two driving lanes of the motorway (driving and fast lane), in order to monitor the further condition of the roughness of the pavement surface in relation to the impact of traffic load, in the phase of exploitation.
- The evaluation of the longitudinal roughness in the absence of domestic, is made according to foreign regulations. Although Republic of Macedonia has modern equipment for this purpose, has not yet adopted its own regulations in this area. The need for preparation of appropriate Macedonian regulations for roughness is imposed to the authorities, respecting all influential factors and specifics such as: road class, traffic load, the type of road intervention (rehabilitation, reconstruction, new construction), road in operation or new construction, etc

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# STRUCTURAL ANALYSIS OF FLEXIBLE ROAD PAVEMENTS

The focus of most road agencies around the world, and even in developing countries, is shifting nowadays from construction of new road sections to maintenance, rehabilitation and improvement of the existing road networks. Having accurate information about the condition and remaining service life of pavements is fundamental for their efficient maintenance. The objective of this paper is to present review of different approaches available for analysis of pavement structural condition, both at network and project levels. Paper presents review of the most widely used deflection measuring devices with focus of newly developed devices for continuous network level measurements at highway speeds and provides review of available tools and techniques for assessment of pavement structural capacity.

Keywords: pavement structural capacity, deflection, deflection basin parameters, Backcalculation

## 1. INTRODUCTION

The focus of most road agencies around the world, and even in developing countries, is shifting nowadays from construction of new road sections to maintenance, rehabilitation and improvement of the existing road networks which deteriorate due to the combined influences of traffic and environmental loads.

Having accurate information about the condition and remaining service life of pavements is fundamental for their efficient maintenance. Pavement evaluations are conducted to determine functional and structural conditions of a road sections either for purposes of routine monitoring or planned corrective action. Functional condition is primarily concerned with the ride quality or safety aspects of a road section (longitudinal and transverse evenness, surface texture and skid resistance, cross slope, splash and spray, etc.). Structural condition is concerned with the structural capacity of the pavement as measured by deflection, layer thickness, and material properties. In addition, visual condition surveys are used to assess both pavement functional and structural condition, but generally serve as a qualitative indicator of overall condition.

The pavement surface condition can be readily observed. However, subsurface information concerning the base and subbase courses and subgrade is costly to gather and interpret with destructive testing (i.e. coring, boring, trenching); this is why non-destructive (NDT) methods, particularly deflection testing are commonly used for pavement structural evaluation. Use of NDT also minimizes disruption to traffic, which is essential for heavily trafficked roads and airports. NDT can also be used as a screening tool to determine locations where selective material sampling should be conducted to evaluate other material properties in the laboratory. As such, its focus is to assess in situ properties that can be used to evaluate the need for further "destructive" testing, location of that destructive testing, and the current structural capacity of the highway as related to layer stiffness and strength.

The objective of this paper is to present review of different approaches available for analysis of pavement structural condition, both at network and project levels.

## 2. ANALYSIS METHODS

Although deflection measurements are relatively standard for pavement monitoring, improving the quality of the measurements and the interpretation of the test results is still an important issue.

The deflection analysis methods may be categorized in one of the following categories:

- Maximum deflection and deflection basin parameters (shape factors),
- Surface, composite, or pavement modulus approaches, including AASHTO '93 procedure [1], and
- Backcalculation of pavement layer moduli.

### 2.1 MAXIMUM DEFLECTION AND DEFLECTION BOWL (BASIN) PARAMETERS

The maximum (central) pavement deflection represents the overall bearing capacity of the pavement structure and subgrade and it is still used as the most important parameter for pavement rehabilitation design and for delineation of homogeneous sections (Figure 1). The limits between homogeneous sections are defined as locations where chart of cumulative differences changes slope.

Figure 2 presents an example of pavement rehabilitation criteria based on maximum deflection.

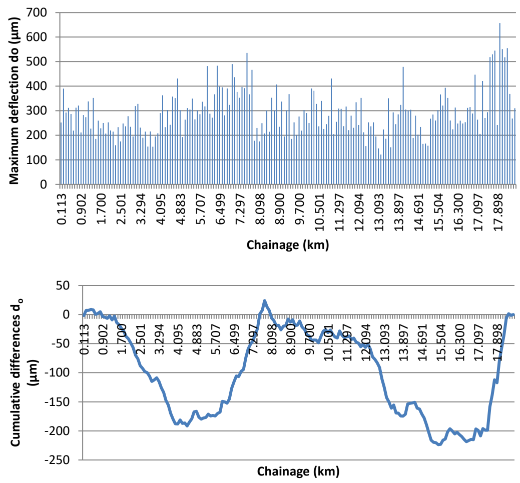


Figure 1. Chart of maximum deflections and homogeneous sections based on cumulative differences approach

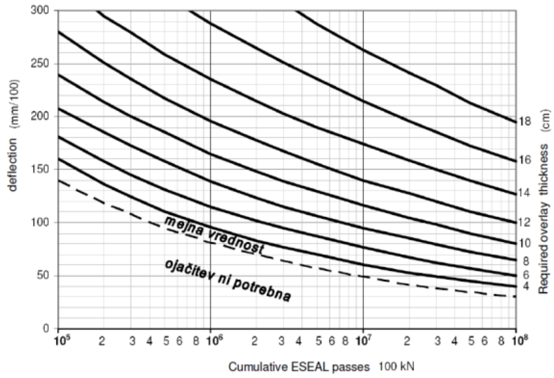


Figure 2. Overlay thickness criteria based on maximum deflection [5]

However, deflection basins, typically obtained by FWD, provide more useful information for better understanding of pavement condition and structural capacity. If maximum deflections are same, the higher curvature of the deflection basin in the vicinity of load indicates the weaker bound layers on the top of the pavement. Similarly, lower outer deflections are obtained on pavements on stiffer subgrades.

Horak [2] has defined three zones that characterize deflection bowl measured under a loaded wheel (Figure 3). In Zone 1, which extends to up to 300 mm from the loading, the deflection basin has a positive curvature. Zone 2 is called inflection zone where the deflection bowl switches from positive to negative curvature. This zone typically lies between 300 mm and 600 mm from the loading, but exact limits depend on pavement type and structure. Zone 3 includes the furthest part of the deflection basin from the loading, till approximately 2000 mm, which depends on the pavement structure and subgrade. The deflections within these three zones are related to various depths (layers) within the pavement structure.

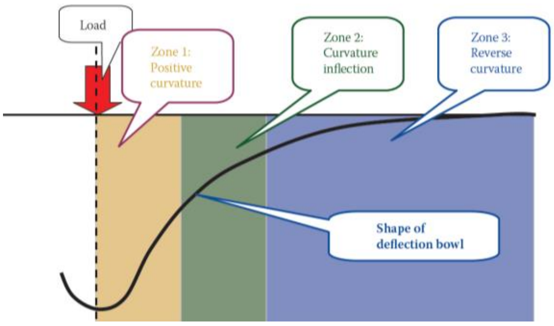


Figure 3. Summary of deflection bowl parameters [2]

Several deflection bowl parameters may be used to characterize pavement surface deformation under the loading. Table 1 presents some of most frequently used parameters.

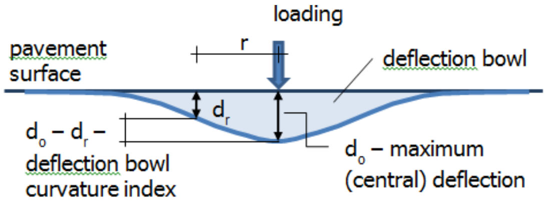


Figure 4. Deflection bowl parameters

Table 1. Deflection bowl parameters

| Parameter | Designation/ Expression | Unit | Indication |
|---|---|---|---|
| Maximum deflection | $d_0$ | µm | The overall pavement condition |
| Other deflections | $d_r$ | µm | Layer condition at equivalent depth r |
| Radius of Curvature, RoC | $RoC = \frac{200^2}{2 \cdot d_o \cdot \left(1 - \frac{d_{200}}{d_0}\right)}$ | µm | Fatigue of asphalt layers |
| Surface Curvature Index, SCI | $d_0 - d_{300}$ $(d_0 - d_{200})$ | µm | Fatigue of asphalt layers |
| Base Damage Index, BDI | $d_{300} - d_{600}$ | µm | Base condition |
| Base Curvature Index, BCI | $d_{600} - d_{900}$ | µm | Subbase condition |
| Deflection basin Curvature Factor, CBF | $(d_0 - d_r) / d_0$ | - | Layer condition at equivalent depth r |
| Deflection Ratio, DR | $d_0 / d_r$ | - | Layer condition at equivalent depth r |

In addition to definitions presented in Table 1 that are mostly used in the literature, there are additional definitions of these parameters, sometimes under different names, or using different deflections. For example, Talvik and Aavik [9] define BCI as difference between deflections at 1200 and 1500 mm from the point of loading, and use this indicator to assess the subgrade condition. Therefore, it is critical to understand the physical meaning of each parameter and to consider it in the context of particular pavement structure, because they may have different importance for thick or for thin pavements.

For Do, RoC, SCI, BSI and BCI, Horak and Emery [3] determined benchmark classification for various flexible pavement sections.

In addition, AREA parameters that present the surface of deflection basin are widely used in the pavement structural capacity analysis. $AREA_{36}$ is widely used for analysis of rigid pavements, while $AREA_{12}$ is used for flexible pavements.

$$AREA_{36} = 6 \cdot \left(1 + 2 \cdot \frac{d_{300}}{d_0} + 2 \cdot \frac{d_{600}}{d_0} + \frac{d_{900}}{d_0}\right) \quad (1)$$

$$AREA_{12} = 2 \cdot \left(2 + 3 \cdot \frac{d_{200}}{d_0} + \frac{d_{300}}{d_0}\right) \quad (2)$$

Deflection basin parameters provide simple and sound way to assess the pavement structural capacity that is not dependent on the knowledge of pavement structure, which is often not available. They can easily be used for network level assessment, but also represent a valuable tool that can be used for project level assessment.

## 2.2 SURFACE, COMPOSITE, OR PAVEMENT MODULUS APPROACHES

The surface modulus is the “weighted mean modulus” of an equivalent half space of a material with uniform modulus. It is calculated using Boussinesq’s equations:

$$E_o(0) = 2 \cdot (1 - \mu^2) \cdot \sigma_o \cdot \frac{a}{d(0)} \quad (3)$$

$$E_o(r) = (1 - \mu^2) \cdot \sigma_o \cdot \frac{a^2}{r \cdot d(r)} \quad (4)$$

where:
$E_o(r)$ -surface modulus at a distance r from the center of the loading plate
µ - Poisson's ratio (usually set equal to 0.35)
$\sigma_o$ - contact stress under the loading plate
a - radius of the loading plate, and
$d_r$ - deflection at the distance r.

The surface modulus plot ($E_o$ versus r) provides:

i. An estimate for subgrade modulus (or CBR)

ii. Immediate determination of whether the subgrade modulus is linear elastic or non-linear, giving an indication of likely soil type, and
iii. Confirmation of the adequacy of the geophone settings (as shown in Figure 5)

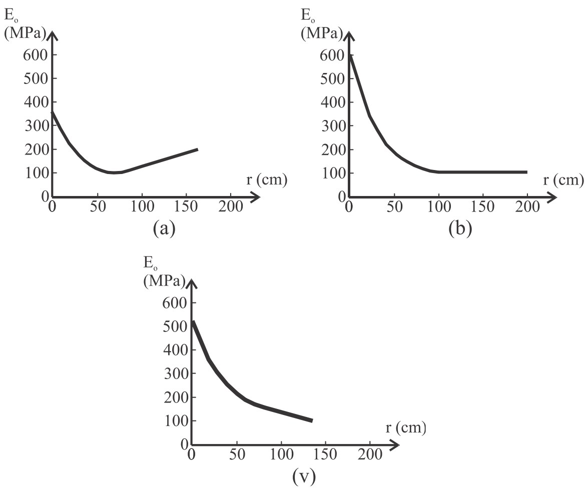


Figure 5. Surface modulus plot (a) with non-linear elastic subgrade modulus, (b) with linear subgrade modulus and (c) where geophones are too close

At relatively large distances (generally more than 600 mm) from the loading plate, all compressive strain will occur in the subgrade rather than in the pavement layers which lie outside the stress bulb. For this reason the outer deflections will be uninfluenced by the pavement structure, i.e. the surface modulus will tend to the modulus of the subgrade alone.

When outer deflections show an apparently increasing modulus (case a), this is indication of non-linear subgrade. Case (b) presents the linear subgrade performance, where subgrade modulus does not depend on the distance to loading. Finally, case (c) is related to thick, stiff pavement, where geophones are located too close to loading plate and there may be softer soils beyond the range of geophone assembly. In this case the geophone spacing should be increased so that at least the three outer geophones define a linear segment on the surface modulus plot.

AASHTO/93 Guide [1] includes three approaches for determination of existing pavement structural capacity. The first two approaches, that are less used, include analysis of distresses and past traffic loading. The mostly used approach is based on deflection measurements, and analysis of two layered structure, composed of pavement considered as a composite layer, and subgrade, as presented in Figure 6.

The subgrade resilient modulus $M_R$ is first determined based on one of outer deflections, which should be ideally located at distance $r$ larger than the radius of stressed zone on the surface of subgrade $a_e$. The subgrade resilient modulus is equal to the surface modulus calculated from outer deflections and the approach typically includes determination of surface modulus minimum value, and check if that value is determined from deflection sensor located outside of the stressed zone in pavement.

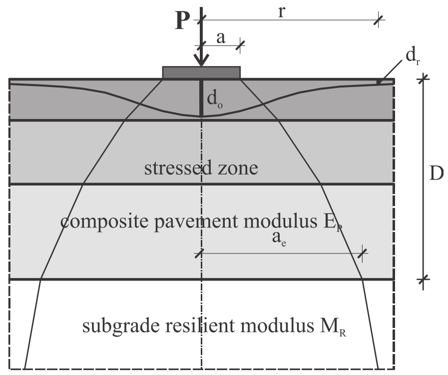


Figure 6. Parameters of pavement structure and deflection basin used in the AASHTO/93 approach

When the subgrade resilient moduli is known, the composite pavement modulus $E_p$ and pavement effective structural number $SN_{xeff}$ can be calculated from maximum deflection $d_o$ using equations (5) and (6).

The AASHTO approach provides relatively simple way for determination of pavement structural capacity and overlay design, since it is consistent with AASHTO procedure for design of new pavements. In addition, the overlay thickness can be easily calculated for all deflection points if pavement total thickness is reasonably available and homogeneous sections may be defined based on overlay thickness, using the method of cumulative differences. On that way, the approach would account for spatial variability of data.

$$SN_{xeff} = 0.0237 \cdot D \cdot \sqrt[3]{E_P} \tag{5}$$

$$d_o = 1.5 \cdot \sigma_o \cdot a \cdot \left[ \frac{1}{M_R \sqrt{1 + \left( \frac{D}{a} \cdot \sqrt[3]{\frac{E_P}{M_R}} \right)^2}} + \frac{1 - \frac{1}{\sqrt{1 + \left( \frac{D}{a} \right)^2}}}{E_P} \right] \tag{6}$$

where:

$d_o$ – maximum deflection (mm), corrected to 20°C
$\sigma_o$ – contact stress (kPa)
P – deflectometer loading (kN)

D – pavement total thickness (m)
a – radius of contact plate (0.15 m for Dynatest FWD, 0.225 m for KUAB FWD)
$M_R$ – subgrade resilient modulus (MPa)
$E_p$ – pavement composite modulus (MPa).

## 2.3 PAVEMENT AND SUBGRADE MODULI BACKCALCULATION

The mechanistic empirical approach, that is based on calculation of moduli, stresses and strains in pavement layers and relating them to past experience of pavement performance, is being used more and more instead of empirical methods based on bowl parameters for evaluation of pavement structural capacity.

A major advantage of analytical or mechanistic structural design methods over more empirical methods is that the former may be used with any type of material and structure, and under all climatic conditions (provided that fatigue criteria are established for each material type). The latter, on the other hand, may be applicable only under the conditions for which the empirical relationships were developed.

Pavement layers and subgrade modulus backcalculation is the most sophisticated approach to assess pavement structural capacity based on deflection testing. This is an iterative procedure in which the initially presumed layer moduli are adjusted until the best match is achieved between the predicted and measured surface deflection values. A straightforward linear elastic approach is generally favored in routine FWD analysis [9], although this procedure can also take into account non-linearity of materials in subgrade and subbase, history of loading and pavement surface deflection, material anisotropy etc.

The approach may include manual iterations, when the backcalculation is begun by making a surface modulus plot, then calculating the subgrade modulus, then the unbound base modulus and finally the modulus of asphalt layers. These values can then be manually adjusted based on engineering judgement, in an iterative manner until predicted and measured deflections match acceptably. The iterative process can be automated, and in that case may start from a set of layer moduli which may or may not be user defined (seed moduli). Finally, there are approaches that are based on soft computing methods (artificial neural networks and genetic algorithms) and use databases with large number of deflection bowls. In addition to static backcalculation, there is option to use time history of loading and deflections and perform dynamic backcalculation since FWD test in inherently dynamic. This approach takes advantage of more information provided by the test, which allows for backcalculating more parameters such as layer thicknesses or the modulus versus frequency curve of the HMA layer.

For static backcalculation approach, knowing accurate pavement layer thicknesses is of critical importance, since minor variations of layer thickness during construction, if not accounted for, can result in major errors in backcalculated layer moduli [4]. Because most of the measured deflections is dominated by the nature of the subgrade, it is important that its stiffness is accurately modelled. Otherwise backanalysis would result in disproportionately large errors of upper layers moduli [6]. Procedure is not sensitive to the values of Poisson's ratio, and values between 0.35 and 0.45 are typically used in the analysis. Generally, it is recommended that the model should contain only one asphalt layer (all asphalt layers are combined in one) and that moduli decrease significantly with depth (an Ei/Ei+1 ratio of greater than two is sometimes recommended).

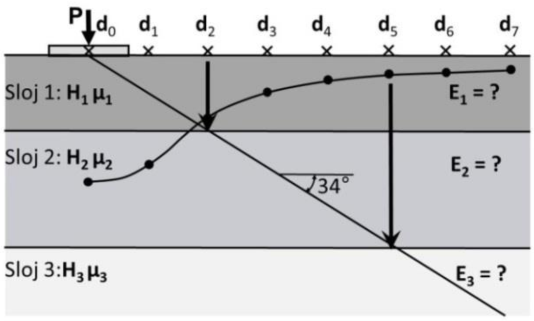


Figure 7. The principle of pavement layer moduli backcalculation

A large number of computer programs for doing automated backcalculation have been developed. Among the more widely used programs are the following:

- ELMOD (Dynatest)
- EVERCALC (Washington State DOT)
- MODCOMP (Cornell University)
- MODULUS (Texas A&M University)
- PADAL (University of Nottingham)
- WESDEF (U.S. Army, Waterways Experiment Station)

Most of the automated backcalculation programs rely on an elastic layer program, except ELMOD which is based on Odemark's Method of Equivalent Thicknesses [11]. The FHWA report [7] provides more extensive overview of the available backcalculation software.

Most of these programs involve the use of numerical integration subroutines that are capable of calculating FWD pavement deflections and other parameters, if stiffness (or moduli) and thicknesses of the various pavement layers are known. If all assumptions are correct, meaning each layer is an elastic layer, is isotropic and homogeneous, and all other boundary conditions are correct, then it is possible to iterate various combinations of moduli until there is a sufficiently close match between measured and theoretical FWD deflections.

A major drawback to this approach is the fact that one or more of the many input assumptions mentioned above may be incorrect and therefore do not apply to the actual in situ pavement system. Despite this, the procedure reaches very reasonable and rational moduli values in most cases. This conclusion appears to be especially true when relatively intact, well-defined, and un-distressed pavement sections are tested with FWD. However, it is critical that the engineer using a backcalculation program of choice should be very well versed in its proper use and inherent limitations. Accordingly, backcalculation is arguably more of an art than a science [9].

## 3. CONCLUSION

The paper summarized the available approaches for analysis of pavement structural capacity and provided review of deflection basin parameters and approaches based on calculation of surface, or subgrade and pavement composite moduli. These approaches provide simple way to assess the pavement structural capacity, especially in case when limited other information on pavement construction history, structure and past traffic are available.

If sufficient information is available, mechanistic approach that assumes backcalculation of subgrade and pavement layer moduli is the most advanced and recommended for evaluation of pavement structural capacity and several computer programs are available for pavement moduli backcalculation.

Several important issues, like spatial and seasonal variations, including variations of layer thicknesses, temperature and moisture conditions, material non-linearity, and depth to stiff layer have also been addressed in the paper. They illustrate how important it is to be aware on all limitation of theory and to have deep understanding of material and layer properties and stress and strain conditions within the pavement and the subgrade in order to achieve reasonable assessment of layer moduli.

“The backcalculation is more art than science” used to say two gurus of backcalculation, prof. Lynne Irwin and Richard Stubstad. This should always be kept in mind!

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# RISK ASSESSMENT OF ROAD CONSTRUCTION PROJECTS USING EXPECTED VALUE MODEL

Risks can occur during any phase of road construction project, they cannot be completely avoided, but with proper risk management model they can be put to minimum. Risk assessment enables proper project management and helps the road construction managers in the decision-making process in order to avoid or decrease the negative effects and/or outcomes of any possible negative risks.

The Expected Value Model refers to risk assessment by determining the severity of the consequences caused by the risk itself. This paper presents the benefits of risk assessment for achieving a quality realization of road construction projects. The main goal is to show the application of The Expected Value Model (EVM) and its implementation on a road construction project.

Keywords: risk assessment, expected value model, road construction project

## 1. INTRODUCTION

Road construction projects are affected not only by minor risks, but also by risks which can cause a scenario that can be critical in terms of creating a negative impact onto any project objective. Therefore, it is necessary to assess the risk, regardless of when, how and in which form or phase it occurs. Risk assessment enables proper project management and helps the road construction managers in the decision-making process in order to avoid or decrease the negative effects and/or outcomes of any possible negative risks. It is highly important to understand that proper risk management is based on an adequate risk assessment, especially during the first phases of the project life-cycle, and it is essentially the most important component for a successful realization of a any road construction project.

### 1.1 RISK ASSESSMENT AS PART OF THE RISK MANAGEMENT PROCESS

Risk management is mostly defined as a cycle process with a returning character. This means that regardless of the phase in which the risk can happen, it has to be analyzed with a simultaneous consideration of all other phases of the project life-cycle. The returning character clearly expresses the cyclicality, in sense that no phase of the risk management process can be passed without re-analyzing a previous one or without perceiving the effects and impacts on a subsequent one. And this is because the risk usually comes suddenly and incidentally, so it is necessary to take into consideration the road construction phase during which the risk can occur. Such a vigilant monitoring requires abilitis and skills in order to find an appropriate way to assess the risk properly and manage it after, correctly.

When it comes to a risk management of road construction projects, the cycle process is based on a platform that consists of several phases. The size of the platform depends on the extent of the risk that is subject of interest in for a certain road construction projects. So, it is always said that the greater the risk, the bigger the platform. This means, that the risk can affect on the platform size by developing phases more and more. The phases are generally independent of each other in terms of what they are intended to address in risk management. But, in some cases they are tightly connected to each other, in terms of its smooth reduction. Such a platform, based not only on a few phases, helps road construction managers to correctly solve the risk, by reducing its negative consequences in terms of creating a minimum harmful impact.


Figure 1. Cycle character of the risk management process

Figure 1 shows the cyclical risk management process which can be related to a road construction project [1]. It mainly consists of five phases, depending on the severity of the risk and its influence to the project. In order to properly manage the risk, the first step is to properly identify all possible risks that can occur during the road project life-cycle. The risk assessment, as a next phase of the risk management process, depends on the type and nature of the risk, the probability of occurrence, the extent of the consequences on the project objectives and the way it affects the road construction project as a whole. Risk assessment is crucial for planning of the management decisions regarding the further risk responses. It is quite important that risk assessment gives a distinctive note in the complete annulment of the risk, especially in finding a model for its management. And the importance of the management model is that it helps fulfilling the project objectives, effectively and efficiently. Risks can occur during any phase of road construction project, they cannot be completely avoided, but with proper risk management model they can be put to minimum.

## 1.2 OBJECTIVES OF RISK ASSESSMENT

To define the objectives of the risk assessment the sources that can cause future risks must be identified. Examples of some risk sources that are typical for road construction projects are:

- complexity of the project and its uniqueness;
- numerous participants and various project stakeholders;
- capacity and ability to respond to a wide range of project activities;
- high project costs;
- environmental impact;
- location conditions (geomechanical, hydrological, climate, meteorological etc.);
- safety and health at work, as an inevitable concept for successful execution of the road construction project;
- expropriation;
- cultural, socio and economical level of development of the area in which the road is being constructed;
- political situation;
- poor designs;
- not sufficient or not correct geotechnical investigations;
- lack of qualified staff in both design and construction stage etc.

The above-mentioned risk sources do not always act separately. They usually act as combination of two or more in case of creating the risk that affects the road construction project in its own specific way. Such an issue abounds in having a complex background, according to what the risk assessment itself should be performed.

The risk assessment can be simply defined as: *"The process of quantifying events that affect the formation of risk, based on previous documentation that primarily provides information about the origin of the risk, and the origin is nothing but the source of which arose from the risk itself."* [2] This approach to defining risk assessment offers the possibility of distinctively separating the assessment phase from the risk identification phase. Therefore, the basic objectives of risk assessment can be considered from two most important aspects:

1. ***Determining the probability of occurrence of the risk.***

The occurrence of the risk can be interpreted as the probability of occurrence of an adverse event that causes negative effects on the road construction project. According to this, from the aspect of probability and statistics, the risk can be quantified in the continuum, so that it can get values from 0 to 1. Of course, when assessing the risk, there should always be a tendency to reach 0, which is theoretically achieved, but practically in almost no case can it be achieved at all.

2. ***Determining the impact of risk.***

If the value of the frequency of the risk exceeds the limit value 0.5, then the risk has a significant impact on the construction project. The impact of risk, as an aspect, treats risk in a way that gives a quantitative and qualitative assessment of the severity of the consequences caused by the risk itself. The term definition of severity assessment implies whether the risk can or must be treated in the further management process. For that purpose, a risk assessment model is developed, ie. a model that assesses the severity of the consequences caused by the risk itself. Depending on the results of the analysis, an appropriate conclusion is further drawn as to whether the risk can be reversed or it should be treated, by defining a management model, as the next phase or even a next step in the whole process of risk management.

# 2. RISK ASSESSMENT MODEL – EVM (EXPECTED VALUE MODEL)

## 2.1 DESCRIPTION OF EVM

The Expected Value Model (EVM) refers to risk assessment by determining the severity of the consequences caused by the risk itself. Target consequences that are being considered in this model are: **time** and **cost**. Of course, road construction projects can be affected by many other risk consequences, but these two have the most significant contribution in defining the severity assessment. In order to define the severity assessment, a separate assessment should be given for the quantitative and the qualitative aspect of the risk on the project as a whole. Finally, depending on these two assessments, a description is given of the complete condition of the road construction project, affected by the effects caused by the risk. All this provides an answer for the extent of the negative consequences that risk can cause during the road construction project.

EVM must be based on a previously developed and resolved network plan. The need to solve a network plan is due to determining the total time period from the start of the construction project until its implementation. It is common knowledge that every network plan must have at least one critical path, ie. a path that is composed of critical activities. The critical path always starts with the first and ends with the last project activity, which are always critical indeed. And critical project activity means that the activity has an equal earliest and lowest start or end. After determining the critical path, EVM can be applied for risk assessment. If there are more than one critical paths in the network, the EVM should be applied separately on each of the critical paths.

## 2.2 METHODOLOGY OF EVM

After completing of the network plan composed of all project activities and determining the critical paths, critical activities $(N_j)$ should be marked. Each critical activity is marked as a $j-$activity, where $j=1,2,...,n$. The sources $(M_i)$, that cause the risk, which in turn directly affect the critical activities, are marked as $i-$ sources, where $i=1,2,...,m$.

Variables in EVM are:

$L_{ij}$ – probability of occurrence of the $i-$ source, on the $j-$ activity;

$I_{ij}$ – probability of impact of the $i-$ source, on the $j-$ activity;

$W_{ij}$ – weight coefficient of probability of the $i-$ source, on the $j-$ activity;

Variables are quantities which are determined empirically in the analysis or they are based on a current survey or research. Namely, if it is a matter of experiential definition of the values of the variables, it means that a the range in which they move should be defined. This method, although is a quite skeptical, still offers a great accuracy in terms of end results. Defining the values of the variables with a currently conducted survey or research can lead to inaccurate data, due to inaccuracy and unpreparedness of the surveyed or inappropriately located sources in the research. In that case, it is proposed that the respondents should be experts and professionals who have participated in similar or the same road construction projects. With their experience, the survey turns into an empirical definition of the values of the variables, which also offers certainty in the analysis.

Constants in EVM are:

$(BTE)_j -$ basic parameter for estimating the time of the $j-$ activity;

$(BCE)_j -$ basic parameter for estimating the cost of the $j-$ activity;

The parameter for estimating the time of the the $j-$ activity $(BTE)_j$ is determined from the beginning with the solution of the network plan. It clearly shows the duration of each critical activity, necessary for its full execution. The value of this parameter is constant and unique for each road construction project separately.

The parameter for estimating the cost of the $j-$ activity $(BCE)_j$, is determined depending on the budget available for the road construction project management. This parameter varies greatly due to unforeseen costs that can arise during project implementation. However, it is due to the unity in defining the seriousness of the consequences. This means that the risk assessment should define an average value which, like the previous parameter, will have a constant character.

Results in EVM are:

The results are the essential part of the risk management model. They are usually interpreted as an amount of the assessment, whether it is a quantitative or a qualitative one. The interpretation of the results is based on three different characteristics, which are shown below. Precisely, they are two composite factors and a factor which can not be define as a quantity of something, so it is the quality of the risk assessment, at all.

$(CLF)_j -$ composite factor of probability of occurrence on the $j-$ activity;

$$(CLF)_j = \sum_{i=1}^{m} L_{ij} \cdot W_{ij} \qquad (1)$$

where: $0 \le L_{ij} \le 1$ and the sum of all weight coefficients is 1.

$(CIF)_j -$ composite factor of probability of impact on the $j-$ activity;

$$(CIF)_j = \sum_{i=1}^{m} I_{ij} \cdot W_{ij} \qquad (2)$$

where: $0 \le I_{ij} \le 1$ and the sum of all weight coefficients is 1.

$(RS)_j -$ severity of consequences (risk assessment)

**QUANTITATIVE ASSESSMENT:**

$$(RS)_j = (CLF)_j \cdot (CIF)_j \qquad (3)$$

**QUALITATIVE ASSESSMENT:** (Table 1.)

Table 1. Risk quality assessment

| No. | Values | Severity of consequences |
|---|---|---|
| 1 | $0.00 \le (RS)_j \le 0.10$ | **low** |
| 2 | $0.11 \le (RS)_j \le 0.20$ | **medium** |
| 3 | $0.21 \le (RS)_j \le 0.25$ | **high** |
| 4 | $0.26 \le (RS)_j \le 1.00$ | **dangerous** |

## 2.3 APPLICATION OF THE EVM

The application of the EVM requires a specific database that meets the requirements of the model itself. By specific database, it means subsets whose values are obtained according to the methodology of the model itself. In this paper, the model is implemented on a road construction project, for which, depending on the results obtained, appropriate conclusions are made. Table 2. gives the basic characteristics of the road, ie. the road construction project that is subject to elaboration [3].

During the implementation of the EVM, there are separated twelve (12) most significant risks that affect the road construction project. For a clearer presentation, they are divided into three groups which refer to the different phases that the construction project goes through. They are presented in Table 3 with an appropriate explanation.

Table 2. Base char acteristics of the road construction project

| No. | Base characteristics | |
|---|---|---|
| 1 | Category | A |
| 2 | Length | 80 km |
| 3 | Construction period | 24 months |
| 4 | Cost | 10 milions € |
| 5 | Assessment model | EVM |

Table 4 shows the calculation model, made of mathematical relations between the data base [3]. The final results are obtained for the three basic characteristics in defining the severity of the consequences, caused by the risks that affected the road construction project. These parameters, previously defined in the methodology of the EVM, can only receive values from 0 to 1. The first two parameters are only an opportunity to define the third, which in turn is considered from two aspects: **quantitative** and **qualitative**. This way of defining offers the possibility of risk assessment with a high degree of accuracy. Errors of course exist, but they are negligibly small compared to the accuracy of the obtained results, so it can be conclude that the EVM represents the risk assessment at all.

Table 3. Risk classification

| No. | Risk Classification Nomenclature | Risk Description |
|---|---|---|
| 1 | **FPR** | Feasibility Project Risk |
| 2 | **DPR** | Design Project Risk |
| 3 | **TPR** | Technology Project Risk |

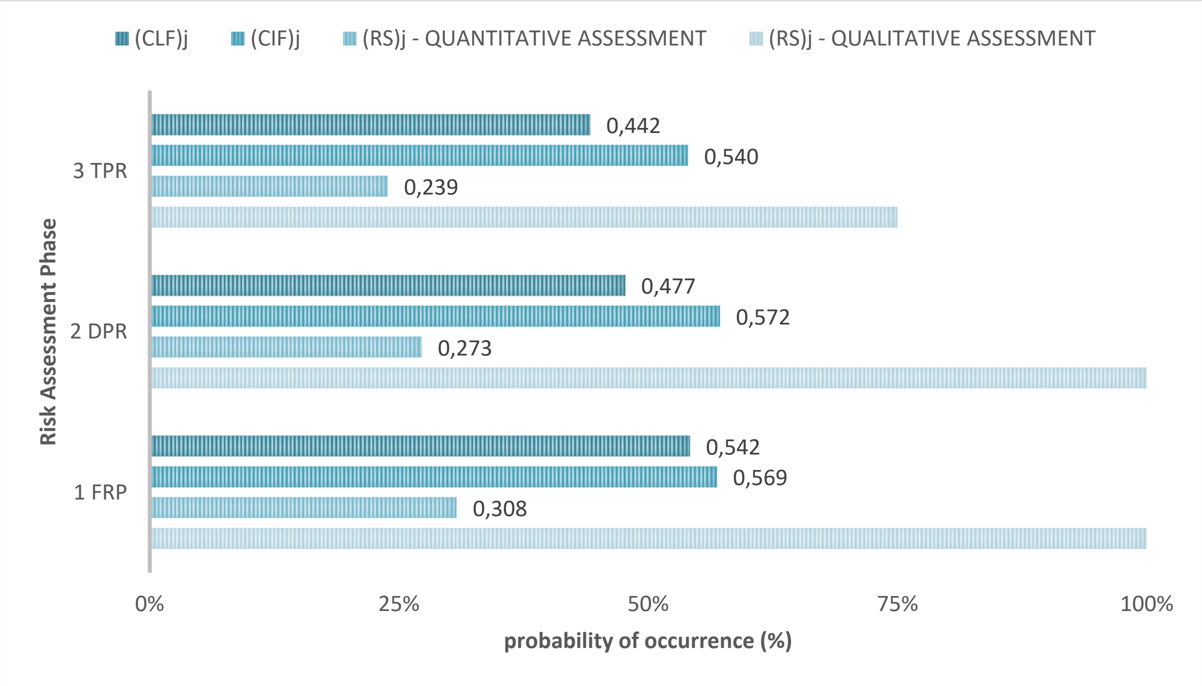


Figure 2. Results of the EVM

Table 4. EVM calculations for Risk Assessment

| No. | | Risk Classification Nomenclature | Risk Description | SEVERITY Risk Assessment | | | |
|---|---|---|---|---|---|---|---|
| | | | | $(CLF)_j$ | $(CIF)_j$ | **QUANTITATIVE ASSESSMENT** $(RS)_j = (CLF)_j \cdot (CIF)_j$ | **QUALITATIVE ASSESSMENT** |
| 1 | 1.1 | **FPR** | Political interference | 0.050 | 0.065 | **0.308** | **dangerous** |
| | 1.2 | | Interference of the environment | 0.085 | 0.085 | | |
| | 1.3 | | Delay due to interdepartmental issues | 0.058 | 0.058 | | |
| | 1.4 | | Delay in clearance from environmental and forest departments | 0.170 | 0.164 | | |
| | 1.5 | | Lenders not comfortable with project viability | 0.047 | 0.044 | | |
| | 1.6 | | Cancellation of project after bidding | 0.041 | 0.058 | | |
| | 1.7 | | Review of technical specification and Bill of quantities | 0.090 | 0.094 | | |
| | Σ | | | **0.542** | **0.569** | | |
| 2 | 2.1 | **DPR** | Design error and omissions | 0.128 | 0.159 | **0.273** | **dangerous** |
| | 2.2 | | Design process takes longer than anticipated | 0.113 | 0.144 | | |
| | 2.3 | | Failure to carry out work in accordance with contract | 0.117 | 0.159 | | |
| | 2.4 | | Request late changes | 0.118 | 0.112 | | |
| | Σ | | | **0.477** | **0.572** | | |
| 3 | 3.1 | **TPR** | Unqualified staff for managing risks | 0.160 | 0.225 | **0.239** | **high** |
| | 3.2 | | Unqualified staff for using mechanization | 0.282 | 0.325 | | |
| | Σ | | | **0.442** | **0.540** | | |

## 3. CONCLUSION

During the risk management process, when it comes to a road construction projects, there are undoubtedly a number of risks that affect the project itself. But it is not the number of risks that matters, but the severity of the consequences, which are caused by the risks. For that purpose, in this paper is shown the importance of determining the seriousness, ie. the risk assessment itself. And all this leads to the process of defining a model for further risk management in the risk management process. Best interpretation of the EVM results is a graphical representation of the severity – risk assessment both quantitative and qualitative assessment. So, it can be concluded that regardless of the phase of the road construction project, the risk is involved, it is quite important to act quickly and correctly. In order to avoid many possible risks that can cause a negative impact, it is necessary to hire a professional staff, led by a road construction manager, who will both strive for the most efficient and better implementation of the road construction project as a whole.

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# RELIABILITY PROBLEM AND FAILURES OF TECHNOLOGY OR SYSTEM USED IN RAILWAY TRAFFIC FOR TRAFFIC REGULATION AND MANAGEMENT

Many travelers avoid rail out of frustration with unreliable train services. Trains are often late or canceled. From 10% to 25% of European passenger rail trains suffer delays, depending on the operator. About a third of those delays are caused by poorly maintained trains.

Lately new technologies have been developed. Driverless trains and maglev trains are the most important technologies developed in the railway industry. Maglev trains are faster, more efficient, and more environmentally friendly than modern wheeled trains. Driverless is the future technology, and there are many benefits and advantages of the system over conventional technologies.

Keywords: railways, transportation system, reliability problem, maglev trains, driverless trains, accidents

## 1. INTRODUCTION

Railway transport is energy efficient, comfortable, fast, provides a larger carrying capacity, is safe and reliable, and emits a low percentage of $CO_2$ (less than 2%), making the railway industry one of the most efficient and environmentally friendly transportation systems globally [1].

Railways had reached their peak in the nineteenth century when they became essential in the transport of passengers and goods [2].

Railways are massive infrastructures and are the prime mode of transportation in numerous countries. Given that it is associated with cargo and passenger transportation, transport contains a high risk of asset costs and human lives. Even though better safety standards and new technologies continuously introduce, accidents still occur. Derailment and collision risks will always be present. However, the elimination of fundamental causes can reduce them.

## 2. RELIABILITY PROBLEMS IN RAILWAY TRAFFIC FOR TRAFFIC REGULATION AND MANAGEMENT

Reliability in transport relates to the absence of incidents, which relates to the risk factor. The latter is caused by technical failures and the physical environment, in which the human element is decisive [4]. Technical problems can occur in the track, rolling stock, or safety installations. Issues with the trail can be due to excessive speed or the failure of one or more of its components; those with rolling stock are caused by deterioration, with missing wheel flanges and suspension failure being the most frequent derailment causes.

Other incidents can relate to engines, which can cause the train to stop, or faults with couplings, whose failure can cause it to break apart. As for safety installations, their absence or defective operation can cause accidents.

The physical environment can affect trains in various ways, such as the slippage of a cutting or embankment, torrential rain, or earthquakes, and authorities can do little about them. Only railway construction on land where such events cannot occur can prevent such accidents or lessen their impact on train services.

Lastly, problems with the environment can include the human factor. Many incidents are caused by railway staff through incorrect action or failure to take the necessary action [5].

When railway accidents happen, regardless of the causes or the safety measures in place, we can't help but wonder about train travel safety. When a vehicle as huge and heavy as train crashes, the resulting injuries and life loss can be tragic and extensive.

## 3. TRAINS DRIVEN BY COMPUTER SYSTEM – DRIVERLESS TRAINS

Train reliability is an infamous sore point for commuters who have been caught in the middle of a system failure. With an automated system, this issue can be reduced significantly.

Driverless is the future technology, and there are many benefits and advantages of the system over conventional technologies.

First of all, it is a fully grade-separated driverless automated system. The Operation Control Centre automatically controls trains, and adjustments can be made quickly to meet demand changes. Before the regular operation starts in the morning, trains are automatically positioned for service. All is done automatically with little to human intervention [6].

In 2018, the International Association of Public Transport found 42 cities worldwide run 64 fully automated lines, with over 50 % of them in Asia.

In China alone, 32 fully automated metro lines will be entering service across 16 cities by 2022 [7].

## 4. MAGLEV TRAINS

In the 21st century, a few countries use powerful electromagnets to develop high-speed trains, called maglev trains. These trains float over guideways using magnets basic principles to substitute the old steel wheel and track trains. There is no rail resistance to speak of, meaning these trains can reach speeds of hundreds of km per hour [8].

Yet high speed is just one significant benefit of maglev trains. Because the trains rarely touch the track, there is significantly less vibration and noise than the conventional trains, resulting in considerably less mechanical breakdowns and weather-related delays.

The distinction between a conventional train and a maglev train is the lack of a traditional engine in the maglev trains. The engine that maglev trains use is rather inconspicuous. Rather than using fossil fuels, they create a magnetic field generated by the electrified coils in the guideway walls, which combine with the track to drive the train [9].

Maglev trains are eliminating friction as they hover on a cushion of air, which, combined with the trains aerodynamic design, enables them to reach unprecedented ground transportation speeds of more than 500 km/h, or twice as fast as Amtrak's fastest commuter train [10]. Developers say that maglev trains will ultimately connect cities that are up to 1,609 kilometers apart. You could travel from Paris to Rome at a speed of 550 km/h in just over two hours [11].

Some maglev trains can achieve even higher speeds. In October 2016, a Japan Railway bullet train blazed to 601 km/h during a short spell. Those kinds of speeds give engineers hope that technology will prove useful for routes that are hundreds of miles long [12].

## 5. TRAIN ACCIDENTS STATISTICS

Train accidents are not as frequent as other transportation accidents, so they are not viewed as a significant threat. Although railroads are not used as frequently as they were in centuries past, they remain considerably active. Regrettably, when train accidents occur, they usually result in severe injuries and fatalities.

In the EU-27, 1 666 significant railway accidents were reported in 2018. In these accidents, 853 persons were killed, and another 748 persons were severely injured. At the EU level, the number of fatalities in railway accidents decreased gradually from 1 245 in 2010 to 853 in 2018. Suicides occurring on railways were reported separately. With 2 379 reported incidents in 2018, suicides outnumber the victims of railway accidents [13].

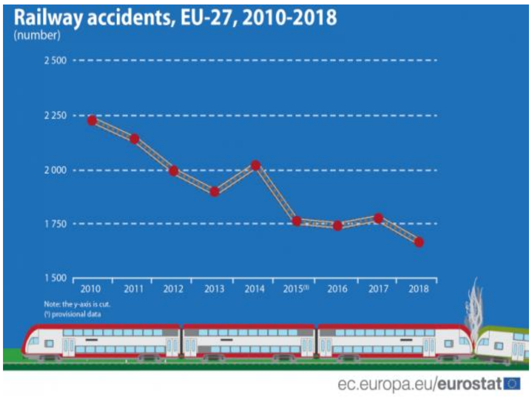


Figure 1. Railway accidents, EU – 27, 2010 – 2018, Source: Eurostat (trans_sf_railac)

Most fatalities from railway accidents happen at level crossings or involve unauthorized persons on the tracks [14].

On August 11, 2006, a maglev train chamber caught fire on the Transrapid Shanghai airport line. There were no injured passengers, and investigators believed that the fire was caused by an electrical problem [15].

On September 22, 2006, in Emsland, Germany, a Transrapid test train crashed into a repair car unintentionally left on the track during a test run. The train was going at least 193 km/h at the time. There were twenty-three casualties and eleven injured. A tribunal ruled that the incident was caused by human error, which could have been avoided if employees had followed established regulations and procedures.

Since 2006, no further maglev accidents have been reported [15]. Despite this, the test trains in Germany were eventually suspended while the Shanghai maglev train still operates.

**Persons killed in railway accidents by type of accident, 2018**
(number)

| | TOTAL | Collisions | Derailments | Level crossing accidents (incl. pedestrians) | Accidents to persons by rolling stock in motion (excl. suicides) | Fires in rolling stock | Other accidents |
|---|---|---|---|---|---|---|---|
| EU-27 | 853 | 11 | 3 | 254 | 584 | 0 | 1 |
| Belgium | 13 | 0 | 0 | 9 | 4 | 0 | 0 |
| Bulgaria | 18 | 0 | 0 | 4 | 14 | 0 | 0 |
| Czechia | 28 | 0 | 0 | 21 | 7 | 0 | 0 |
| Denmark | 6 | 3 | 0 | 3 | 0 | 0 | 0 |
| Germany | 128 | 2 | 0 | 35 | 91 | 0 | 0 |
| Estonia | 5 | 0 | 0 | 2 | 3 | 0 | 0 |
| Ireland | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Greece | 17 | 1 | 0 | 4 | 12 | 0 | 0 |
| Spain | 16 | 1 | 0 | 7 | 8 | 0 | 0 |
| France | 58 | 3 | 0 | 16 | 39 | 0 | 0 |
| Croatia | 18 | 0 | 0 | 8 | 10 | 0 | 0 |
| Italy | 73 | 0 | 3 | 4 | 66 | 0 | 0 |
| Latvia | 12 | 0 | 0 | 5 | 7 | 0 | 0 |
| Lithuania | 12 | 0 | 0 | 3 | 9 | 0 | 0 |
| Luxembourg | 2 | 0 | 0 | 2 | 0 | 0 | 0 |
| Hungary | 93 | 0 | 0 | 20 | 72 | 0 | 1 |
| Netherlands | 16 | 0 | 0 | 13 | 3 | 0 | 0 |
| Austria | 16 | 1 | 0 | 6 | 9 | 0 | 0 |
| Poland | 195 | 0 | 0 | 49 | 146 | 0 | 0 |
| Portugal | 18 | 0 | 0 | 4 | 14 | 0 | 0 |
| Romania | 60 | 0 | 0 | 17 | 43 | 0 | 0 |
| Slovenia | 5 | 0 | 0 | 1 | 4 | 0 | 0 |
| Slovakia | 30 | 0 | 0 | 15 | 15 | 0 | 0 |
| Finland | 5 | 0 | 0 | 4 | 1 | 0 | 0 |
| Sweden | 9 | 0 | 0 | 2 | 7 | 0 | 0 |
| United Kingdom | 30 | 0 | 0 | 4 | 26 | 0 | 0 |
| *Channel Tunnel* | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| Norway | 5 | 0 | 0 | 1 | 4 | 0 | 0 |
| Switzerland | 11 | 0 | 0 | 1 | 10 | 0 | 0 |
| Montenegro | : | : | : | : | : | : | : |
| North Macedonia | 6 | 0 | 0 | 3 | 3 | 0 | 0 |
| Turkey | 76 | 9 | 25 | 15 | 25 | 0 | 2 |

(:) Not available
*Source:* Eurostat (online data code: tran_sf_railvi)

eurostat

Figure 2. Persons killed in railway accidents, by type of accident, 2018, Source: Eurostat (trans_sf_railac)

## 6. CONCLUSION

We must be aware of the reciprocity between human interactions and technology and how each will proceed to underlie many causes and contributing factors of future incidents.

As a civil engineer who researches transportation infrastructure, dangerous goods, and risk, I see several changes to the policy that can help reduce future accidents.

Companies must perform everything they can to achieve safety for railroads and railways to ensure the passengers, operators, pedestrians, and society.

When a train crash occurs, the black box should be recovered as it will provide essential details of what has caused the accident, such as the train's speed and direction. The black box is crucial in determining if there was any oversight on the part of the railway.

Fortuitously, the safety of everyone involved in railway transport is more important than ever for the railway industry. Operators go through rigorous training, and solely the ones who meet strict requirements are accepted. State inspectors also work with the Macedonian Railways - Transport to ensure all railroad tracks and buildings across the country are safe, secure, and updated according to safety regulations.

From the above, I can conclude that maglev trains exceed other rapid transit rail systems in the areas of travel comfort and safety. The design of the guideway ensures that the trains are safe from the derailment. Today, maglev trains are considered to be among the safest and most comfortable rapid transit systems globally. Even concerning earthquakes, maglev trains are considered to be very secure fast transit systems, which will make them the rail transportation of the future.

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# THE PAVEMENT MANAGEMENT SYSTEM ON CROATIAN MOTORWAYS - EXAMPLE FROM PRACTICE

The pavement management system, as an integral part of the RoNeAna- Road Network Analyser of the Croatian Road Asset Management System, is implemented in managing pavements on Croatian motorways. This paper provides a brief overview (using the example of the A3 motorway) of pavement management procedures, from the collection of basic network and pavement construction data, to data processing aimed at determining performance indicators, to predicting the future behaviour of pavement, the required repair treatments with lists of priorities and expected costs, and various scenarios for multiannual maintenance planning. The condition of the A3 motorway, the most loaded highway in Croatia covering 300 km from the Slovenian to the Serbian border, is completely identified by visual inspection (cracking and surface defects) and other measured parameters (longitudinal and transverse evenness, skid resistance, macro-texture and bearing capacity).

Keywords: Croatian motorways, road management system, RoNeAna, pavement condition

## 1. INTRODUCTION

The structure management system (SMS) has been under development by the Institute IGH Inc. for the needs of Croatian Motorways Ltd since 2007. Upon completing modules for managing bridges, drainage and tunnels, a module for managing pavements using the RONeANa-Road Network Analyser,[3] a project developed by the company Geoexpert-project Ltd. Zagreb, has been implemented on the SMS platform. The system was tested in 2013 on sections of the A3 motorway, covering a length of approximately 100 km (from the Slovenian border to the town of Kutina). During 2015 and 2016, visual inspections were conducted and technical parameters measured on the remaining 200 km of the A3 (from Kutina to the Serbian border). Visual inspections and measurements were performed to collect data on damages to the surface, longitudinal and transverse evenness, skid resistance, macro-texture and bearing capacity of the pavement. The data was processed and the results, together with the system settings and management procedures are outlined below.

## 2. A3 MOTORWAY (BREGANA - ZAGREB - LIPOVAC)

The A3 motorway runs from the border with the Republic of Slovenia to the border with the Republic of Serbia over a total length of 306 km. It was built in stages over some 25 years and consists of a total of 25 sections, i.e. road parts between the traffic junctions. To simplify, this paper shows the condition of eight representative parts of the A3, grouped by the year of construction, pavement structure design and the average annual daily traffic (AADT). The grouped sections are shown in Table 1

Table 1. Grouped sections of the A3 Motorway

| Section no. | Length [km] | | $CPI_c$ | Operational since | AADT |
|---|---|---|---|---|---|
| 1 | 0,0 | 13,7 | | 2001 | 3.04 |
| 2 | 13,7 | 41,7 | | 1981 | 3.05 |
| 3 | 41,7 | 118,2 | | 1980 | 2.81 |
| 4 | 118,2 | 161,5 | | 1985/1986 | 2.00 |
| 5 | 161,5 | 222,3 | | 1988 to 1991 | 1.94 |
| 6 | 222,3 | 250,1 | | 1996 to 1999 | 1.97 |
| 7 | 250,1 | 276,0 | | 2002 | 2.71 |
| 8 | 276,0 | 306,4 | | 2006 | 1.80 |

Section no 1. Slovenian border-Jankomir
Section no 2. Jankomir-Ivanja Reka
Section no 3. Ivanja Reka-Lipovljani
Section no 4. Lipovljani-Prvča
Section no 5. Prvča-Slavonski Brod
Section no 6. Slavonski Brod-Velika Kopanica
Section no 7. Velika Kopanica-Županja
Section no 8. Županja-Serbian border

It is apparent that the most loaded section of the A3 is the grouped section 2- Jankomir-Ivanja Reka (also known as the Zagreb bypass), followed by the adjacent sections. Figure 1 shows a GIS display of the A3 motorway from RoNeAna [3]. The different colours represent the condition of the pavement by performance indicators.

## 3. TECHNICAL PARAMETERS AND PAVEMENT PERFORMANCE INDICATORS

Visual inspections and other measurements to pavements form the basis for establishing the technical parameters and determining performance indicators. Technical parameters obtained by visual inspection and measurements, and the corresponding performance indicators, are in accordance with the settings and recommendations of the COST Action 354, Performance Indicators for Road Pavements.[1] Damages to the final layer (cracks and surface defects) are established by visual inspection, and data is collected on the longitudinal and transverse evenness, skid resistance, macro-texture and bearing capacity via a range of measurements. These data create the technical parameters of pavement condition ($TP_i$). Using transformation functions, the technical parameters are translated into individual pavement performance indicators ($PI_i$). The individual indicators, adjusted by the weighting influences ($W_i$), create the combined performance indicators ($CPI_i$), determined from the perspective of $CPI_c$- traffic comfort, $CPI_s$- traffic safety and $CPI_b$- bearing capacity.

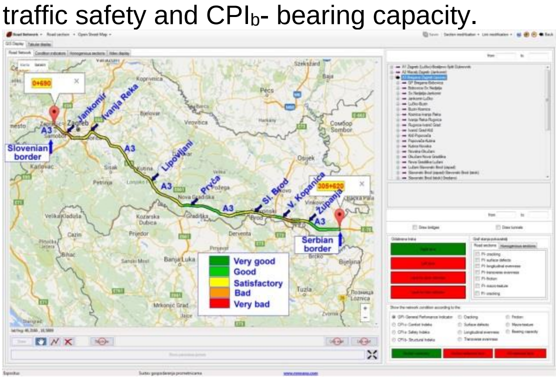



Figure 1. RoNeAna GIS display)

The combined performance indicators ($CPI_i$), adjusted by the weighting influences, forms the general performance indicator (GPI). The weighting influence values $W_i$ ($W_c$-traffic comfort, $W_s$-traffic safety and $W_b$-bearing capacity) are used to determine the general performance indicators (Table 2).

Table 2. Weighting influences for the General Performance Indicator (GPI)

| Combined Performance Indicators ($CPI_i$) | | |
|---|---|---|
| $W_{cpi\ c}$ | $W_{cpi\ s}$ | $W_{cpi\ b}$ |
| **$W_i$ – weighting influences for GPI** | | |
| 0.7 | 1 | 0.65 |

The value range of the performance indicators ranges from 0 to 5, as shown in Table 3.

Table 3. Pavement performance indicators

| Very good | Good | Satisfactory | Poor | Very poor |
|---|---|---|---|---|
| 0 - 1 | 1 - 2 | 2 - 3 | 3 - 4 | 4 - 5 |

# 4. TECHNICAL PARAMETERS AND PAVEMENT PERFORMANCE INDICATORS

## 4.1 PAVEMENT PERFORMANCE INDICATORS

After processing the results of the inspections and measurements, the management system calculates individual, combined and general performance indicators. The performance indicators are continuously calculated every 10 m, individually for each traffic lane. The results are shown in tabular and graphic form for each lane of pavement. Figure 2 shows the performance indicators for the driving lane on the left pavement of the section Velika Kopanica - Babina Greda (listed as Section 7. Velika Kopanica-Županja in Table 1). The critical technical parameters for this section are the cracks and the macro-texture. Medium severity alligator cracking determines pavement bearing capacity as very poor, and the general performance indicator as poor. Cracks have the greatest influence on the indicator of pavement bearing capacity, which is within the limits of the very poor condition ratings. The performance indicators for the driving lane of that section are shown in Table 4.

Table 4. Section Velika Kopanica-Babina Greda - performance indicators

| No. | From [km] | To [km] | CPI$_c$ | CPI$_s$ | CPI$_b$ | GPI |
|---|---|---|---|---|---|---|
| 7.1 | 250.1 | 263.7 | 2.86 | 1.54 | 4.16 | 3.03 |

Figure 2. Performance indicators for the section Velika Kopanica-Babina Greda (left pavement, right lane)

The state of this section surface layer is shown on Figure 3.

## 4.2 HOMOGENEOUS SECTIOS

For practical purposes, in order to determine the necessary repairs, the combination of technical parameters and status indicators are grouped into homogeneous sections, i.e. parts of the section with similar performance indicators and requiring the same kind of repair. Input data for determining homogeneous sections are a combination of technical parameters on the defined part of the pavement lane. Figure 3 shows the state of the surface layer of this section.

Figure 3. Alligator cracking on the section Velika Kopanica- Babina Greda (left pavement)

These combinations are included in the decision- making procedures such as "if the technical parameter $TP_1 > n_1$ and/or technical parameters $TP_2 > n_2$ and/or … and/or technical parameters $TP_i > n_i$, then the repair that covers all of those damages is the standard repair "REPAIR$_i$". The decision-making procedures of the management system regarding homogeneous sections and standard repairs can be called the “Decision Tree”. In the calculation module of the application, it is possible to set a minimum length for calculation of homogeneous sections.

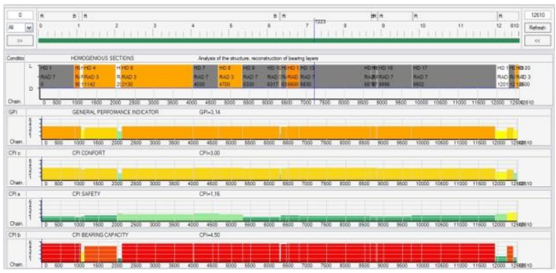


Figure 4. Alligator cracking on the section Velika Kopanica- Babina Greda (left pavement)

The most accurate calculated condition is for homogeneous sections of shorter length (since it takes all local damages into account), though this approach may be impractical and unprofitable during repair works. Testing different variants and, ultimately, manual adjustment, leads to an accurate and technologically reasonable model. Figure 4 shows the graphical representation of homogeneous sections and standard repairs with related costs for the driving lane of the left pavement from the previous example.

## 5. PERFORMANCE INDICATORS ON THE A3 MOTORWAY

Table 5 shows the performance indicators on grouped sections of the A3, the average value for all lanes on the left and right pavement. This gives some general insight into the overall condition. The specific condition, in the example of the characteristic section for each of the groups from the table, with the proposed repairs, will be outlined later.

Table 5. Pavement condition on the grouped sections of A3

| Section no. | Length [km] | $CPI_c$ | $CPI_s$ | $CPI_b$ | GPI |
|---|---|---|---|---|---|
| 1 | 13.7 | 1.65 | 2.91 | 1.21 | 3.04 |
| 2 | 28.0 | 1.24 | 2.96 | 0.95 | 3.05 |
| 3 | 76.5 | 0.86 | 2.76 | 0.75 | 2.81 |
| 4 | 43.3 | 1.28 | 1.90 | 0.91 | 2.00 |
| 5 | 60.8 | 1.17 | 1.84 | 0.89 | 1.94 |
| 6 | 27.8 | 1.45 | 1.59 | 1.53 | 1.97 |
| 7 | 25.9 | 2.50 | 1.62 | 3.34 | 2.71 |
| 8 | 30.4 | 1.23 | 1.68 | 0.89 | 1.80 |
| Aver./km | 306.4 | 1.28 | 2.17 | 1.14 | 2.37 |

The average combined performance indicators of the A3 motorway per kilometre are good (traffic comfort and pavement bearing capacity) or satisfactory (traffic safety). The overall performance indicator is satisfactory.

### 5.1 SECTION 1 (SLOVENIAN BORDER – JANKOMIR)

The grouped sections of the motorway listed under the number 1 shows that the macro-texture and skid resistance have the greatest impact on traffic safety (CPIs), which approaches the limit of poor condition, and the general performance indicator (GPI) is already in the zone of poor condition. The performance indicators of a characteristic section on that part of the A3 (Bregana-Bobovica, driving lane of the right pavement) are shown in Figure 5.

Values of the technical parameters of macro-texture and friction are considered in the decision-making procedures to determine homogeneous sections and the required standard repairs. As a result, the proposal is final layer replacement or coating with micro-asphalt, Figure 6.

Figure 5. Performance indicators for the section Bregana-Bobovica (right pavement, driving lane)
Figure caption

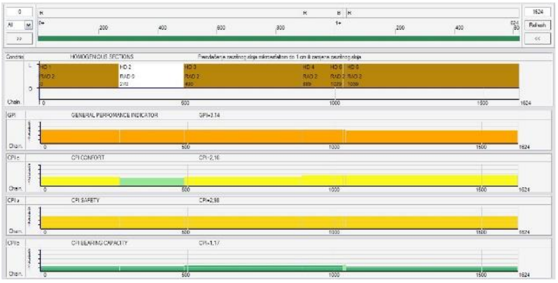


Figure 6. Homogeneous sections on the section Bregana-Bobovica (right pavement, driving lane)

### 5.2 SECTION 2 (JANKOMIR – IVANJA REKA)

On this section of the A3 motorway, skid resistance and macro-texture of the pavement and, in places, longitudinal unevenness have the highest impacts on pavement condition. These technical parameters have the greatest influence on the traffic safety indicator CPIs, which approaches the limit of poor condition, and the general performance indicator GPI, which is already in poor condition.

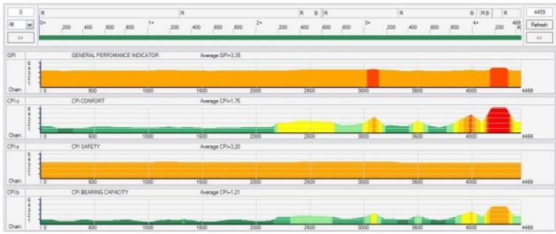


Figure 7. Performance indicators for the section Jankomir-Lučko (right pavement, right lane)

Performance indicators of a characteristic section on that part of the A3 (Jankomir-Lučko, driving lane of the right pavement) are shown in Figure 7. Near the end of the section, longitudinal unevenness has an effect on the homogenous section, with the recommendation for replacement of the final layer. Over the whole section, friction values are very near the limit values that represent the “trigger” for deciding on the repairs as defined in the decision-making procedures (“Decision Tree”).

## 5.3 SECTIONS 3 TO 5 (FROM IVANJA REKA TO SLAVONSKI BROD)

Part of the highway that encompasses section groups 3 to 5 has an overall satisfactory or good condition, according to all the performance indicators. The repairs to homogenous sections generally predict the filling of cracks and the replacements of the final asphalt layer.

## 5.4 SECTION 6 (SLAVONSKI BROD – VELIKA KOPANICA)

This part of the A3 motorway has an overall good condition according to all performance indicators, though unlike the section of the motorway in paragraph 5.3, it has some parts with extremely poor condition. This primarily refers to the left pavement (direction towards the border with Serbia). The greatest influence on the performance indicators of the left pavement are cracks, mostly alligator cracks of low and medium intensity. The performance indicators of the characteristic section on that part (Slavonski Brod east-Sredanci, right driving lane of the left pavement) are shown in Figure 8.

Homogenous sections with estimated repairs depend primarily on the type and quantity of cracks. For homogenous sections with alligator cracks of medium intensity which, corrected with weighting influences, extend over 20% of the surface area, an analysis of the structure of the pavement and the reconstruction of layers is estimated. For the remainder of the homogenous sections with cracks of lesser intensity and quantity, repairs to the asphalt layers (from replacement of the final layer to larger repairs) are estimated. Those repairs cover both the poor condition of friction and the macro-texture.

Figure 8. Performance indicators for the section Slavonski Brod-Velika Kopanica (left pavement, right lane)

## 5.5 SECTION 7 (VELIKA KOPANICA – ŽUPANJA)

This part of the A3 motorway characterizes the combined performance indicator of bearing capacity on all sections of that part of the A3, ranging from poor to very poor. A characteristic section of this part is shown and described in paragraphs 4.1 and 4.2.

## 5.6 SECTION 8 (ŽUPANJA – SERBIAN BORDER)

This part of the A3 motorway is in good condition with respect to every performance indicator. No pavement repairs are estimated for the majority of the section (with the exception of the boundary area with the preceding section).

# 6. LISTING PRIORITIES AND MULTIANNUAL MAINTENANCE PLANNING

After determining the condition and necessary repairs, the Pavement management system lists the maintenance priorities, and predicts the future condition as a function of time, thus enabling the creation of different scenarios and for multiannual maintenance plans.

## 6.1 MAINTENANCE PRIORITIES

The process of determining the priorities, i.e. the order of section maintenance, is performed done with a mathematic multi-criteria analysis that calculates the strengths and weaknesses of the decision to repair each section relative to all other sections, based on the established criteria and their weighting influences. The difference between the advantages and disadvantages for each observed parameters give the list of priorities. The importance criteria include the category of roadway, ability of bypass, average annual daily traffic (AADT), combined (CPIi) and the general performance indicator of the pavement (GPI).

## 6.2 MULTIANNUAL MAINTENANCE PLANNING

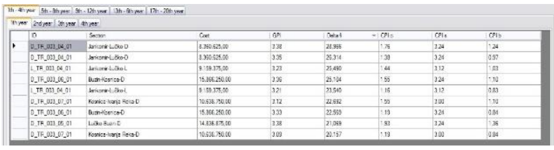
The acquired data on roadways (traffic loads, pavement structure, completed pavement renewal, etc.) and information on the current condition, forms the basis for the drafting of multiannual maintenance plans.

### *6.2.1 Prediction of future condition*

For the needs of multiannual planning and the creation of the maintenance strategy, models of pavement behaviour as a function of time are an integral part of RoNeAna. These models predict the progress of certain type of damages over time, depending on the type of pavement construction and the traffic loads. Models have been implemented from the MDOT pavement management system report, Prediction Models and Feedback System, Final Report[2], a study conducted by the Department of Civil Engineering, University of Mississippi (October 2000). The models are created on the basis of data collected through the years on approximately 20,000 km of roads and on expert opinions.

### *6.2.2 Development of multiannual maintenance plans*

During the life cycle of roads, the level of service is reduced by the curve, dependent on the progression of damage over time, as outlined in paragraph 6.2.1. Reduction in the level of service can be slowed, delayed, or remedies by returning the road to satisfactory condition through the application of certain maintenance strategies. The Road management system, RoNeAna, allows for the creation of different maintenance scenarios over a 20-year planning period, leaving the road administration to select the most favourable model. The input parameters are the annual budgetary resources through the planning period and the limitation of the allowable levels of pavement performance indicators. The output results for each scenario are annual, 4-year and 20-year maintenance plans with yearly and total costs, as well as the values of the performance indicators at the end and in each period within the planned timespan.


1th - 4th year | 5th - 8th year | 9th - 12th year | 13th - 16th year | 17th - 20th year
1th year | 2nd year | 3rd year | 4th year

| ID | Section | Cost | GPI | Delta 6 | CPI c | CPI s | CPI b |
|---|---|---|---|---|---|---|---|
| D_TR_003_04_01 | Jarkomir-Lučko-D | 8.360.625,00 | 3.38 | 28.966 | 1.76 | 3.24 | 1.24 |
| D_TR_003_04_01 | Jarkomir-Lučko-D | 8.360.625,00 | 3.35 | 26.314 | 1.38 | 3.24 | 0.97 |
| L_TR_003_04_01 | Jarkomir-Lučko-L | 9.159.375,00 | 3.23 | 25.490 | 1.44 | 3.12 | 1.03 |
| D_TR_003_06_01 | Buzin-Kosnica-D | 15.866.250,00 | 3.36 | 25.104 | 1.55 | 3.24 | 1.10 |
| L_TR_003_04_01 | Jarkomir-Lučko-L | 9.159.375,00 | 3.21 | 23.540 | 1.16 | 3.12 | 0.83 |
| D_TR_003_07_01 | Kosnica-Ivanja Reka-D | 10.638.750,00 | 3.12 | 22.692 | 1.55 | 3.00 | 1.10 |
| D_TR_003_06_01 | Buzin-Kosnica-D | 15.866.250,00 | 3.33 | 22.569 | 1.19 | 3.24 | 0.84 |
| D_TR_003_05_01 | Lučko-Buzin-D | 14.836.875,00 | 3.38 | 21.069 | 1.93 | 3.24 | 1.36 |
| D_TR_003_07_01 | Kosnica-Ivanja Reka-D | 10.638.750,00 | 3.09 | 20.157 | 1.19 | 3.00 | 0.84 |

Figure 9. Maintenance scenario with fixed annual budget

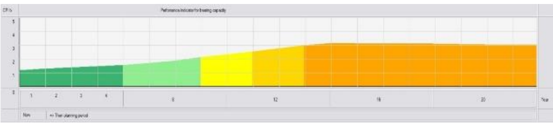


Figure 10. Fixed annual budget- graphic representation through the years

With regard to the selected input requirement, two general groups of possible scenarios can be distinguished:

For certain budget resources, possible projects are planned and the scenario calculates the performance indicators during and at the end of the planning period (as shown in the example in Figures 9 and 10).

For previously defined limit values of the performance indicators during and at the end of the planning stage, the necessary budget resources are being calculated.

## 7. CONCLUSIONS

Management procedures and different maintenance scenarios allow road authorities to compare the relationships between total costs and achieved performance indicators, thereby selecting the most favourable scenario as the maintenance strategy for the multiannual planning period. This should be a scenario which uses the lowest budgetary resources to return the desired pavement performance indicators.

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# ACCURACY ASSESSMENT OF UNSUPERVISED LAND COVER CLASSIFICATION

This paper shows the importance of combining remote sensing techniques and GIS tools to quantify the quality of unsupervised classification in addition to determining the land cover classes. In order to quantitative understanding of the allocation of different types of land, it's necessary to perform validation or assessment of the accuracy of the classification.

The validation of the unsupervised land cover classification for the valley of river Treska (SJCE vol 9, issue 1) is performed by comparing the corresponding points placed on the reference surface (satellite image), from which the classification is obtained and the thematic map. The validation results showed an overall accuracy of the classification of 89%, while based on the Kappa coefficient - 85% which is an indicator of high compatibility of the classified thematic map with the actual ground information.

Keywords: remote sensing, GIS tools, validation, reference points, accuracy assessment, unsupervised classification

## 1. INTRODUCTION

Accuracy assessment is an essential and key part of any classification project. The accuracy assessment actually reveals the degree of correspondence between the actual ground data and the classification results and provides the user with more information about where the errors occurred. Depending on the acceptable level of errors, the user will determine if the classified map is useful or needs to be reclassified. Thereby, two data sources are compared: the classified thematic map and ground reference test data, which is considered accurate or contains the "true" values for the land cover classes. Ground truth values can be collected in the field or extracted from the interpretation of high-resolution images or existing classification maps. [10] The level of (mis)match between the two sets of data is a measure of the accuracy of the classified land cover map.

The relationship between the classified map (Figure 1) and the reference data is summarized in a confusion matrix.

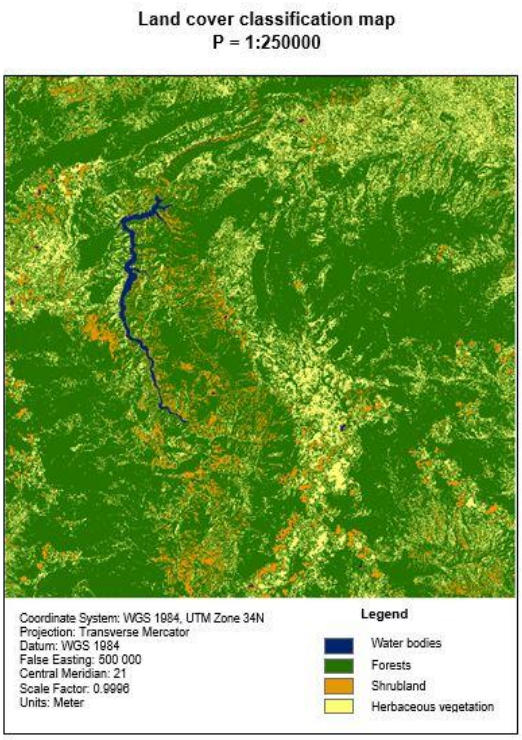


Figure 1: Land cover classification map

## 2. ACCURACY ASSESSMENT

Accuracy assessment is useful for checking the validity of the classification approach for error assessment. The accuracy report includes confusion matrix, commission error, omission error, producer's and user's accuracy for each information class individually, as well as the overall accuracy and statistics of the Kappa coefficient.

The pixels that are correctly assigned to each information class are represented in the diagonal fields of the matrix. Non-diagonal fields show classification errors given the ground reference information.

The commission error determines the probability by class that the test point on the classified map does not belong to the same class on the ground and occurs when the ground cover class is included in an incorrect class category. It is obtained when the sum of incorrectly classified pixels for each class is divided by the number of actual (true) values for each class.

The omission error, in contrast to the commission error, refers to reference locations that have been left out or omitted from the correct class of the classified map, providing the probability by class that the class sample is classified in another class on the map. The right type of land cover is excluded from the class it really belongs to. It is obtained when the number of incorrectly classified pixels in a column is divided by the number of reference pixels of that class - the sum of the column.

Statistics that shows the probability that a reference pixel is correctly classified and is a measure of the omission error, or how well the analyst has classified a particular area, is called producer's accuracy. Producer's accuracy is obtained by dividing the number of correctly classified pixels of a given class by the column of total reference points for the class in question. The low producer's accuracy implies a high error of omission.

User's accuracy, on the other hand, represents the probability that a pixel classified in a given class actually represents that ground class. It is calculated by dividing the number of correctly classified pixels by the total number of pixels of the class and indicating what percentage of a certain type of land cover on the map is really that type of land cover in reality. Low user's accuracy entails a high commission error.

In general, overall classification accuracy is obtained when the number of correctly classified reference points is divided by the total number of reference points. [2]

Another indicator of the overall accuracy of a classified map is the Kappa statistics which also compares two sets of data to see if they differ significantly (classified map and the reference data are considered). Unlike overall accuracy, Kappa statistics is a more reliable indicator of classification accuracy because it uses all the data in the confusion matrix, not just the diagonal ones, and it is calculated by the equation:

$$k = \frac{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} * x_{+i})} \qquad (1)$$

where:

k = Kappa value of the coefficient

r = number of inputs (for example, land cover classes) in the matrix

$x_{ii}$ = number of observations in row „*i*“ and column „*i*“

$x_{i+}$ and $x_{+i}$ = marginal amounts for row „*i*“ and column „*i*“

N = total number of observations (test points)

 

The Kappa coefficient can take values from 0 to 1. A value close to 1 indicates a perfect match between the ground land cover and the classified map, while 0 indicates a complete discrepancy between the two sets of data. If the value of Kappa is greater than 0.80, a large match or accuracy can be found between the classification map and the ground reference values, the value of Kappa between 0.40 and 0.80 is considered moderate, while the value of Kappa less than 0.40 indicates a weak correspondence between the two data sets. [2]

## 3. RESULTS OF THE ASSESSMENT

In order to determine to what extent the thematic map corresponds to the current situation on the ground and for what needs and purposes it can be used, a validation process is performed: test points are compared with their corresponding locations on the classified map.

The test points should be evenly distributed on the map because if they are concentrated on only one part of it, the accuracy will only be relevant to that part. Also, the location of the samples must be chosen randomly without bias, as any bias can affect the statistical analysis of the confusion matrix and may result in an error or inaccurate assessment of the actual accuracy of the thematic map. [7]

Figure 2: Allocation of test points

Moreover, in addition to the location, it is important to determine their optimal number in order to further obtain a quantitative indicator of the accuracy of the classification performed. The number of reference points is an important factor in assessing the accuracy of any classified map. A good guide is to use a minimum of 30 test points for each information class to obtain a statistically valid sample. Approximately, more than 250 pixels are needed to estimate the average accuracy of a class within ± 5%. [2] Or, in this case, ten times more test points are used than the number of classes - 40 test points for each class. That is, the validation of the land cover map was performed with a total of 160 test points (Figure 2).

The test points are placed on the reference surface used to perform the classification - satellite imagery. Each test point is compared to the pixel size of the map and it should fall inside the pixel.

After placing and labelling the test points, the next step is to calculate the results of the comparison which are presented in a confusion matrix. The confusion matrix is a central element of the assessment and provides a specific number of individual and total parameters for each of the classes and compares, category by category, the relationship between the known reference data ("true" values) and the corresponding results of the automatic classification procedure [8]. The columns of this matrix represent the information about the reference test points, the rows correspond to the classes generated by the unsupervised classification, and the diagonal fields represent the pixels assigned to the exact class.

However, in order to ensure thematic consistency between the map data and the "true" values, it is useful to define a protocol or document in a recognizable and understandable format. The most common way to express the accuracy of the classification is by means of a contingency table that presents the errors by class and the match between the map classification data and the reference data.

Table 1 summarizes the parameters of the correspondence between the entities on the map and the satellite image, as follows: out of a total of 160 test points in the respective class belong 142 (diagonally) as follows: for class 1 and 2 all test points placed on the reference surface match with the classified values, while for classes 3 and 4, 32 or 30 out of a total of 40 test points are correctly classified. Furthermore, in the next column the total number of points is given, i.e. the "true" values that belong to each class individually. Of the placed test points, 42 belong to the class of water bodies, 40 points

Table 1: Results of the accuracy assessment

| Number and class name | Class 1 | Class 2 | Class 3 | Class 4 | Row total (ground truth values) | Commission error (%) | Omission error (%) |
|---|---|---|---|---|---|---|---|
| Water bodies | **40** | 0 | 2 | 0 | 42 | 4.8 | 0 |
| Forest | 0 | **40** | 4 | 7 | 51 | 21.6 | 0 |
| Shrubland | 0 | 0 | **32** | 3 | 35 | 8.6 | 20 |
| Herbaceous vegetation | 0 | 0 | 2 | **30** | 32 | 6.2 | 25 |
| Column total | 40 | 40 | 40 | 40 | **160** | | |
| Producer's accuracy (%) | *100* | *100* | *80* | *75* | Number of correctly classified pixels 142 | | |
| User's accuracy (%) | *95.2* | *78.4* | *91.4* | *93.8* | | | |
| *Total accuracy 88.8%* | | | | **Kappa 85%** | | | |

from the class itself and 2 which during the validation are assessed that they belong to the class of shrubland, and during the classification are assigned to class 1. Probably, these are the pixels on the river bank or the shadows of clouds whose small parts based on the spectral structure were assigned to class 1. Consequently, in the forest class, instead of only the 40 pixels assessed when positioning the points belonging to that class, there are another 4 points of shrubland and 7 which during the validation process are marked as herbaceous vegetation. Next, the points that are estimated to correspond to shrubland on the ground, compared to the classified map, only 32 correspond. Additionally, in this class are classified 3 points which during the validation are marked as herbaceous vegetation. Finally, the number of "true" values for class 4 is 32, of which 30 belonging to the class itself and two from shrubland.

The next column presents the commission errors for each class individually. This percentage is the highest, or the majority of the test points are placed in the wrong class forest - 21.6%, followed by the classes of shrubland and herbaceous vegetation with 8.6%, and 6.2% respectively and finally the water bodies with 4.8%, which has the lowest number of test points (2) that do not belong to this class.

The last column represents the omission error, which, in contrast to the commission error, shows how well the reference pixels of the particular ground cover are classified. The biggest omission error is present in herbaceous vegetation - 25%. The pixels marked as herbaceous vegetation on the classified map were supposed to belong to forests (7) and shrubland (3). Next is class shrubland with 20% of the pixels excluded from the class to which they really belong. The omitted pixels are distributed in the remaining three classes: 2 belong to water bodies, 4 are assigned to forests and 2 to herbaceous vegetation. While in water bodies and forests there are no pixels that are excluded from the classes and therefore the omission error rate is 0%.

To summarize, the source of errors in land cover classes: forests, shrubland and herbaceous vegetation can be caused by the foliar coverage. The energy reflected and measured by Landsat-8 sensors is based on the interaction of electromagnetic radiation with plant components and bare soil. Density and foliar coverage are particularly affected within forests, where some grasses may affect the reflection response.

Moreover, as already mentioned, one of the prerequisites for validation with the confusion matrix is that each entity on the map and each sample taken are assigned to one class and they represent the same spatial extension. This can be more or less difficult to achieve depending on a number of factors such as: the structure of the scene, the spatial resolution of the pixels, the minimum mapping unit, the positional accuracy of the map and the size of the sample. For example, in a homogeneous scene with huge ground cover samples and mostly "clean" pixels, it is unlikely that positional errors, e.g. some meter displacements between the position of the ground sample and the map, or classification problems will affect the accuracy rate. However, they can have an impact in areas with heterogeneous fragmented areas where "mixed" pixels are common and where a small change in spatial position will transfer the sample to another class of land cover.

When the area of interest is composed of two or more entities that differ significantly in brightness and spectral response, the pixel is composed of several, very different values of digital numbers, so the average of the values of different land cover classes is calculated. That unique value of the digital number that represents the pixel can not accurately represent any of the present categories. "Mixed" pixels are common in data with rough spatial resolution and along the edges of entities and can sometimes lead to misclassifications. [10] Using a satellite image with a spatial resolution of 30x30 meters, it is normal to have "mixed" pixels, whose presence affects the sorting of different types of land cover in the appropriate class.

In addition, the accuracy of the placement and labelling of the test points in the appropriate class should be taken into account. Although Google Earth is used to allocate the reference pixels, in order to identify the ground cover in a certain area, as well as the previous knowledge of the relief and geography of the scene, still the eventual placement of the test points exactly on "mixed" pixels or some oversight in the setting, as well as the influence of the degree of accuracy of the chosen mathematical model and algorithm can not be completely eliminated.

Furthermore, the producer's and user's accuracy for each class is also calculated. According to Table 1, the first two classes are absolutely correctly classified, while the percentage of the producer's error for shrubland is 80% and for herbaceous vegetation this percentage is slightly lower and is 75%. Based on the presented percentages, it can be concluded that all four classes are characterized by a high degree of classification accuracy.

According to the user's accuracy as well, we can notice a high correspondence, over 91% for class 1, 3 and 4, while this percentage is the lowest for class 2 and is just over 78%, which is to be expected given the largest commission error for this class. Nevertheless, based on this parameter, all four classes are characterized by a high degree of classification accuracy.

After calculating the individual errors for each class, it is necessary to determine the overall accuracy of the thematic map. In this regard, there are two ways to evaluate the confusion matrix of validation: descriptive statistical and analytical-statistical method. [7]

1. The descriptive statistical method evaluates the total accuracy of the classified map, i.e the percentage of correctly classified land cover. Determining the degree of total accuracy of the thematic map can be simplified by dividing the total number of correctly classified pixels (sum of the main diagonal) and the total number of test points (samples) and in this case is high 88.8%.

2. Analytical-statistical methods are used to statistically evaluate the accuracy of classified maps obtained from remote sensors and the confusion matrix. [4] These methods are suitable for analyzing data from remote sensors, because such data are discrete, with binomial distribution. These methods involve a k-coefficient, also called Kappa Analysis.

Unlike total accuracy, which takes into account only the number of total and accurately classified test pixels, the Kappa coefficient, in addition to these parameters, includes in its calculation the number of test points for each class individually, as well as the number of pixels that belong to each class ("true" values) and is therefore a more reliable indicator of the accuracy of the unsupervised classification.

As already mentioned, the values of the Kappa coefficient range from 0 to 1 and if the value of Kappa is greater than 0.80, a large match or accuracy can be found between the classification map and the country reference. For the land cover classified map in this master thesis, based on the calculation expression given in section 3.3, the Kappa coefficient is 0.85 which means high classification accuracy, or expressed as a percentage - 85% (Table 1) for better visual presentation and interpretation.

## 4. CONCLUSION

In order to perceive the quality of the classification, accuracy assessment is inevitable. The accuracy assessment was performed by comparing the values of the corresponding points on the satellite imagery used as a reference for the classification and the classified map. The results are summarized in different groups of errors for each class individually (commission error, omission error, producer's accuracy and user accuracy), but the total accuracy of the map, which is high 89%, is also determined. However, a better indicator of the accuracy of the performed classification is the Kappa coefficient because it takes into account several parameters and is 85%, which is a high degree of coincidence of the map with the current situation in reality.

In this context, it is logical to ask the question of the cause of these errors. The source of errors in the classes: forests, shrubland and herbaceous vegetation, can be found in the density and foliar coverage that particularly affect within forests, where some grasses may affect the reflection response. Also, considering the heterogeneity of the scene and the spatial resolution of the satellite image (30 meters) the presence of "mixed" pixels, which affects the sorting of different types of land cover in the appropriate class is unpreventable.

Of course, the precision of the placement of test points in the appropriate class should also be taken into account. Although an open source such as Google Earth was used to allocate the reference pixels, in order to identify the ground cover of a certain area, as well as the previous knowledge of the relief of the scene, still the possible placement of the test points on "mixed" pixels or some oversight in the placing, as well as the impact of the degree of accuracy of the chosen mathematical model and algorithm should not be completely neglected.

However, although this study discussed about validation of land cover classification, limitations in terms of data sources made this study to not be more specific. This study depends only on satellite imagery to identify different features of the earth. All results are generated by remote sensing products. The accuracy of the methods for classifying the images can be tested more rigorously using terrestrial measurements. Also, land cover and land use change can be studied with increased spatial and temporal resolution.

In future studies, more time and effort should be spent on improving accuracy (including the accuracy of mathematical models and algorithms), as classification accuracy is extremely important for the final output and areas of application of the classification. Improving classification accuracy will improve the quality of land cover detection results, and land resource change statistics will also be more accurate.

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