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# IMPACT OF VEHICLE MOVEMENT SIMULATION ON THE SIZE OF FOREST ROAD TRAVELED WAY WIDENING IN SMALL RADIUS CURVES

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**Abstract:** Smooth movement of vehicles on forest roads necessarily requires widening of the traveled way in small radius curves. This paper presents the results of a comparison of two methods for determining the required widening of a forest road traveled way in small radius curves: the traditional method based on formulas and the traces curve method, obtained by simulating the movement of vehicles. Both methods were applied in the preparation of the Main project of reconstruction of the forest road "Rasadnik - Pustinac" with a length of 5.285 km in the teaching base of the Faculty of Forestry "Majdanpečka domena". In the project which determined the traveled way widening by the traces curve method, the total area of the surfacing was by 2.79% smaller than the area of the surfacing in the project which determined the widening using a formula. The width of the traveled way directly affected the scale of earthworks. In the first case, the volume of the cut was by 4.17% lower than in the second one. The volume of the filling decreased by 7.05%, and the amount of material needed for making the surfacing decreased by 2.94%. A smaller volume of earthworks and material required for pavement construction in the preparation of the Main project of reconstruction, in which the size of widening was calculated by the traces curve method, influenced the estimated value of reconstruction is lower by 3.34% than the total cost of reconstruction obtained in the preparation of the Main project of the same forest road reconstruction that calculated the widening size using the traditional method.

**Key words:** forest roads, circular curves, traveled way widening, vehicle movement simulation, earthworks

## INTRODUCTION

Design and construction of forest roads in the hilly and mountainous areas of Serbia is based on the principle of economy, while alignments are adapted to local conditions of the relief. Analyzing 50 implementation projects of forest roads in the territory of Serbia, Stefanović (1996) argues that forest roads are designed and built exclusively with circular horizontal curves with radiuses of up to 100 m are represented in 85.93% of cases, with the curviness index of 44.6%, the average distance between the intersection points of 74.6 m and the average straight line between curves of 43.3 m. The adjustment of forest road alignment to local orographic conditions reduces the volume of earthworks that significantly contribute to the costs of construction (Akay, 2006). In fact, as pointed out by Robek and Klun (2007), more than one half of the costs of forest road construction consists of earthworks. In addition, Pičman and Pentek (1998) state that in the cost structure of forest road construction, the greatest impact on reduction can be achieved on the cost of earthworks, which represent the greatest burden to the cost of road construction.

The volume of earthworks is directly affected by roadway width, i.e. traveled way width of a forest road. In order to reduce the volume of earthworks as much as possible, forest roads in the hilly and mountainous areas of Serbia are most often constructed as single-lane roads, with a surfacing width of 3.0 m, and passing places designed and built at a distance of 300 to 500 m (Aćimovski, 1997).

Forest roads are designed and built with circular horizontal curves with a minimum radius of 20 m (Stefanovic, 2001), while smooth and safe movement of vehicles in curves necessarily requires widening of the traveled way in curves. According to Butulija (2000), traveled way widening is necessary in all horizontal curves with a radius of less than 70 m. The size of traveled way widening in curves is determined in several ways: using the formula for calculating the required widening, nomograms, traces curve, etc.

Considering that forest roads represent the most expensive infrastructure facilities in forestry (Rankovic, 1996), whose price of construction, among other things, depends on the width of the traveled way, determination of the required traveled way widening in curves requires selection of a method that requires minimum volume of work and, at the same time is harmless in terms of traffic safety and driving comfort. In case of insufficient traveled way width in curves, trailer wheels of trucks move beyond the traveled way, leading to damaged traveled way and shoulders of the forest road. On the other hand, if the width of the traveled way in curves is too large, the volume of earthworks is increased, i.e. the cost of road construction is higher (Schiess and Whitaker, 1986).

The paper presents results of a comparison of two methods for determining the required traveled way widening of a forest road in small radius curves: the traditional method based on formulas and the traces curve method, obtained by simulating the movement of vehicles. The simulation of vehicle movement was performed using the software system SURVEY – Trasa – Modul za projektovanje saobraćajnica. The aim of this paper was to determine the effect of the above methods of determining the required traveled way widening of a forest road in curves on the volume of works in the construction of forest roads, and therefore also on the cost of road construction. The basic hypothesis is that the application of the method of traces curve obtained by simulating the movement of vehicles in curves on the forest road provides lower construction costs of the observed forest road than the construction costs obtained by the traditional method of widening calculation.

## MATERIALS AND METHODS

In the fifties of the last century intensive construction of forest roads started in Serbia, although their structural elements have not changed substantially since then (Kadović, et al., 2008). In accordance with that, as Simonović (1949) argued, in forest road design radiuses of curves are chosen depending on the situation in the field, by calculating the minimum curve radius and roadway width of a forest road depending on its importance, or according to the type of reference vehicle operating on that road. Using this assumption, Butulija and Rađenović (1993) developed internal guidelines for forest road design within SE "Srbijašume" which supplies limit values of the geometric and structural forest road elements. These guidelines were used as the basis for this study. According to Butulija (2000), the size of traveled way widening in curves on single-lane forest roads is determined by the formula:

$$\Delta B = \frac{40}{2R} \, [m]$$

where ΔB is linear widening of a forest road in a curve; R – radius of the horizontal curve.

The calculated value of the traveled way widening is applied to the circular arc part (L), and transition from the unwidened part of the traveled way to the widened one is realized on the

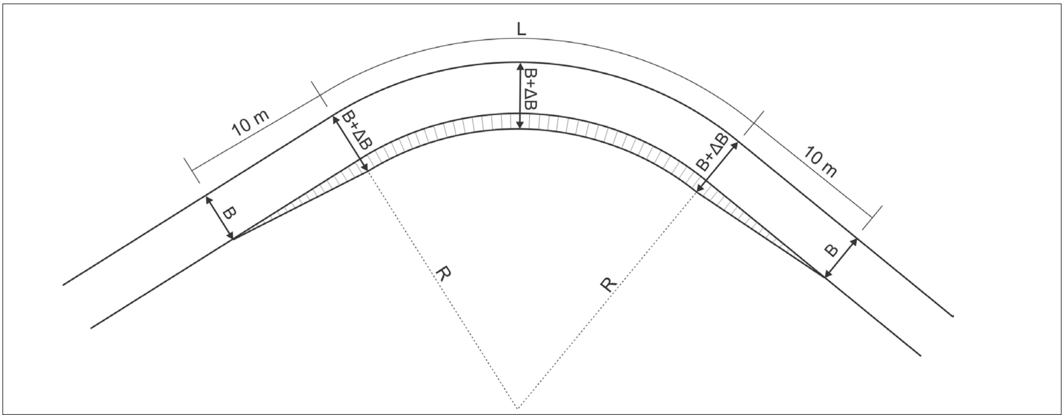


**Figure 1.** Traveled way widening using the traditional method with transitional ramps

part of the transition lenght, which is usually 10 m long. Traveled way widening is implemented from the inside of the curve towards the center of the curve.

The software system SURVEY – T*rasa* – *Modul za projektovanje saobraćajnica* was used to determine the traces of curves left by the vehicle during movement through horizontal curves. The traces curve can be produced for any vehicle and is provided by simulating the movement of a vehicle along the given route. The simulation is performed in two directions, from the beginning to the end of the route (Figure 3a) and from the end to the beginning of the route (Figure 3b), while each characteristic point on the vehicle leaves a trail in a different color. Due to a large number of traces left by the outermost points of the vehicle, software is used to determine the leftmost and rightmost traces (Figure 3c). Due to difficulty of driving, especially in curves, the ultimate right and left traces cannot be adopted as the final width of the traveled way, and it is necessary to widen the traveled way. Final edges of the traveled way are obtained by adding safety belts on both sides of the outermost traces (Figure 3D).

The traces curve was obtained by simulating movement of a truck Kamaz 5511 with a Goša FP14 trailer along a predetermined route. By its dimensions, this truck is a representative vehicle operating on forest roads in Serbia (Figure 2).

During development of the main reconstruction project, the forest road was designed as a single-lane road with a traveled way width of 3.0 m. The width of trucks and trailers operating on forest roads is usually about 2.5 m, which means that the traveled way is by 0.5 m wider than the truck and trailer. For this reason, edge traces obtained by simulating the movement of vehicles along a given route, were further widened by 0.25 m on both sides (a total of 0.5 m) (Figure 3D).

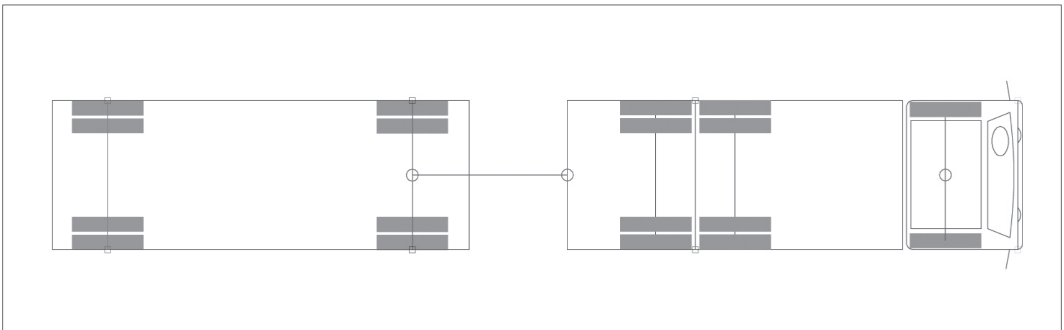

**Figure 2.** Dimensions of the truck Kamaz 5511 and a Goša FP14 trailer

Unlike in the case of the traditional method, where widening was made in curves of radiuses of less than 70 m, the traces curve method applied widening of all curves with radiuses of less than 100 m. In large radius curves the required widening is slightly below 10 cm, so that it is not necessary to perform it. Otherwise, according to the *Regulations on the conditions that must be met by road structures and other elements of public roads from the safety aspect*, if the widening is smaller than 0.20 m, it will not be performed (Fig. RS, 50/2011). In addition, Kuonen (1983) argues in favour of the rule that forest roads with curvature radiuses greater than 100 m should not be widened.

## RESEARCH AREA

The method of traces curve obtained by simulating the movement of the vehicle when determining the required traveled way widening of a forest road in small radius curves was applied in the preparation of the Main project of the "Rasadnik – Pustinac" forest road reconstruction in the teaching base of the Faculty of Forestry "Majdanpečka domena".

The forest road "Rasadnik – Pustinac" is located in the management unit "Crna reka" and belongs to the slope road type. The total road length is 10.380 km and it ends with a circle turning.

The forest road "Rasadnik – Pustinac" was built in 1989 and since then there have been no major investments in its maintenance. Poor condition of the forest road, which is characterized by small radiuses of horizontal curves and particularly of serpentines, small roadway width, dysfunctional drainage channels and culverts and almost complete lack of pavement structure, were the reasons for the reconstruction project for this road. Reconstruction of the road section from the beginning of the route to the beginning of the station km 5+285.00 was planned for 2014. This part of the forest road was built on category III and IV soil. In preparing the detailed design, the size of traveled way widening in curves was determined on the basis of the width of traces obtained by simulating the movement of a truck with a trailer. For the purpose of comparison, a project of traveled way widening in curves was also developed by the traditional method using the formula for calculating the widening width.

## RESEARCH RESULTS

In preparing the main project of reconstruction of the forest road "Rasadnik - Pustinac" the size of the traveled way widening in curves was initially determined by the traces curve method, and then by the traditional method using the formula for calculating the widening width.

When determining traveled way widening in curves by simulating the movement of vehicles, it was observed that when moving through a circular curve the vehicle requires not only a traveled way widening on the inside, but also on the outside of the traveled way. The traveled way widening on the outside is certainly smaller than the widening on the inside.

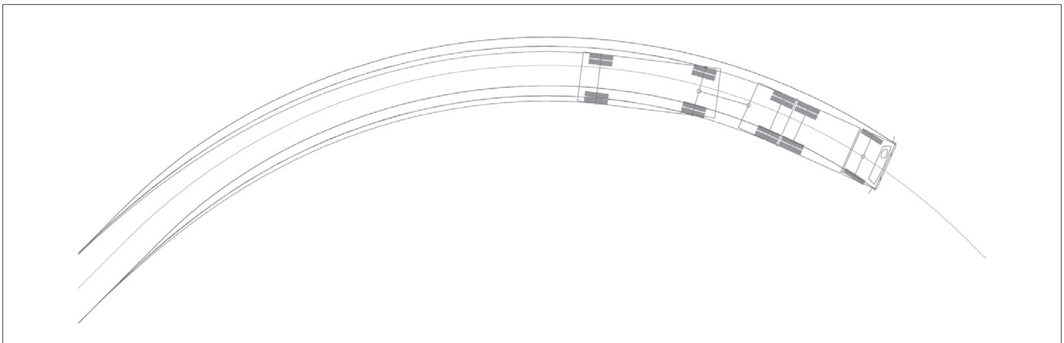

**Figure 3a.** Simulation of vehicle movement from the starting to the end point of a forest road

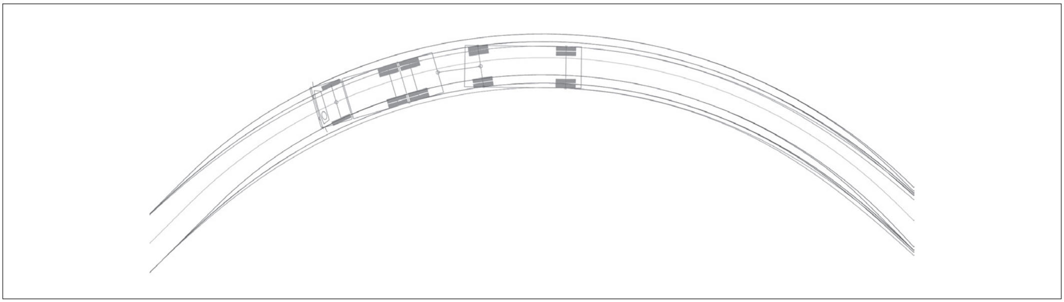

**Figure 3b.** Simulation of vehicle movement from the end to the starting point of a forest road

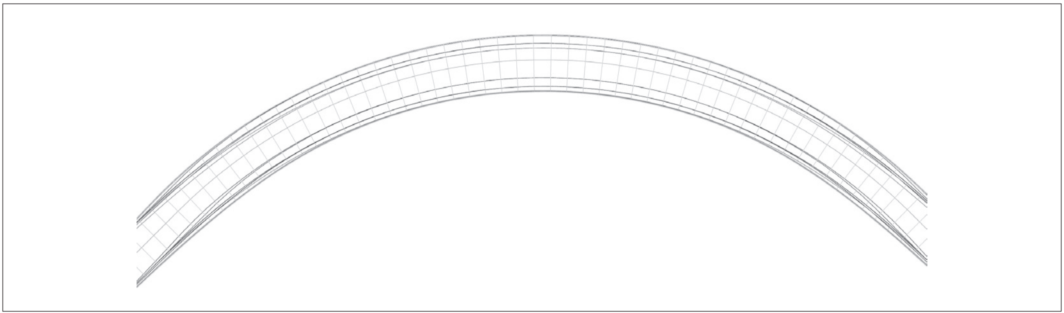

**Figure 3c.** Determination of the utmost left and utmost right edges of the forest road traveled way

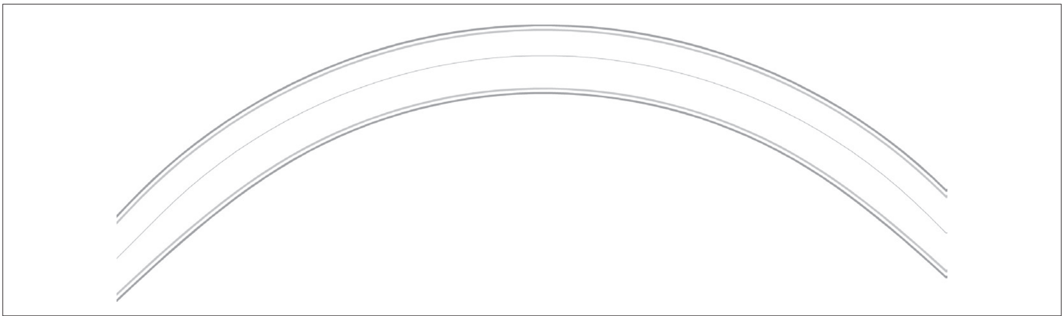

**Figure 3d.** Widening of a forest road traveled way edges for the width of a safety belt

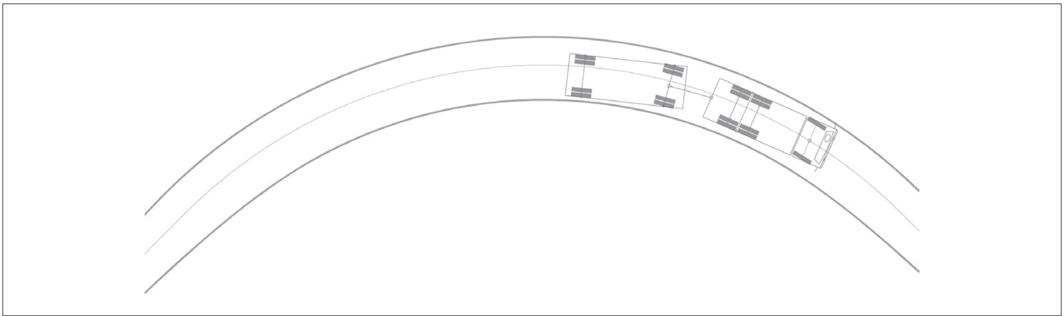

**Figure 3e.** Simulation of the movement of a truck with a trailer after widening

Unlike the traditional methods of calculating the size of the widening in curves with the same widening size along the entire length of the circular arc, the application of this method shows that the maximum required widening is in the middle of the circular arc, and that it is smaller at the beginning or end of the curve, where it is usually the same. In addition, the length of the transition lenght is not strictly defined, but depends on the curve radius and the deflecting angle.

Table 1 presents the works items affected by traveled way width and the volume of works for each item:

**Table 1.** Volume of works

| | **Measurement unit** | **Quantity (Traces curve method)** | **Quantity (Traditional method)** |
|---|---|---|---|
| Cut volume | $m^3$ | 20.858,10 | 21.728,74 |
| Filling volume | $m^3$ | 3.502,85 | 3.749,65 |
| Subgrade preparation | $m^2$ | 17.766,48 | 18.262,53 |
| Pavement construction | $m^3$ | 6.931,54 | 7.135,80 |

Tables 2 and 3 present the costs of performance of the listed work items. The price of the implementation of these works is obtained as the product of the quantity and unit cost taken from the price list of works on the construction and modernization of roads (SE "Roads of Serbia", 2012).

**Table 2.** Volume of works in Project development by the traces curve method

| **Work item** | **Measur. Unit** | **Quantity** | **Unit cost [RSD]*** | **Implementation price [RSD]*** |
|---|---|---|---|---|
| Mechanical excavation of category III and IV earth with pushing up to 60 m | $m^3$ | 20.858,10 | 165,81 | 3.458.481,56 |
| Machine filling with category III and IV earth | $m^3$ | 3.502,85 | 189,33 | 663.194,59 |
| Subgrade preparation (the price involves: rough and fine grader planning, compaction with a vibratory roller with possible wetting or drying) | $m^2$ | 17.766,48 | 59,77 | 1.061.902,51 |
| Construction of the pavement from crushed stone aggregate 0-60 mm (price includes purchase of materials and transport for up to 30 km, mechanical spreading, planning, compaction with the necessary wetting or drying. Friability coefficient of 1.30) | $m^3$ | 6.931,54 | 1.746,34 | 12.104.825,56 |
| | | | **IN TOTAL** | **17.288.404,22** |
| | | | **IN TOTAL PER 1 km** | **3.271.221,23** |

* 120 RSD = 1 €

**Table 3.** Volume of works in Project development by the traditional method

| Work item | Measure. unit | Quantity | Unit cost [RSD]* | Implementation price [RSD]* |
|---|---|---|---|---|
| Mechanical excavation of category III and IV earth with pushing up to 60 m | $m^3$ | 21.728,74 | 165,81 | 3.602.842,38 |
| Machine filling with category III and IV earth | $m^3$ | 3.749,65 | 189,33 | 709.921,23 |
| Subgrade preparation (the price involves: rough and fine grader planning, compaction with a vibratory roller with possible wetting or drying) | $m^2$ | 18.262,53 | 59,77 | 1.091.551,42 |
| Construction of the pavement from crushed stone aggregate 0-60 mm (price includes purchase of materials and transport for up to 30 km, mechanical spreading, planning, compaction with the necessary wetting or drying. Friability coefficient of 1.30) | $m^3$ | 7.135,80 | 1.746,34 | 12.461.532,97 |
| | | | **IN TOTAL** | **17.865.848,00** |
| | | | **IN TOTAL PER 1 km** | **3.380.482,12** |

* 120 RSD = 1 €

## DISCUSSION

Determination of traveled way widening in small radius curves by the traces curve method has been well-known for a long time. However, due to the complexity of its application, it has not been widely used in forest road design and the necessary traveled way widening in curves was determined on the basis of formulas and nomograms. When designing forest roads, the traces curve method can be very useful in determining traveled way widenings in curves on roads planned for the operation of vehicles for the transport of long goods (trunks), which is often greater in length than the length of the body of trucks and trailers, or for the transport of special machines used in forestry and civil engineering (Stojnić, 2012). On the basis of studied literature, it was observed that there are many different formulas for calculating the required traveled way widening in curves, although all the authors take a truck with a trailer as the reference vehicle. The most commonly used formula for determining the traveled way widening of forest roads in Serbia is 40/2R. Aćimovski (1997) argues that the value of the traveled way widening in curves of small radiuses calculated on the basis of this formula is sufficient for an unobstructed passage of solo trucks, while for the calculation of the value of traveled way widening for passage of a truck with a trailer, he recommends the formula 64/2R. Formula 40/2R for forest road traveled way widening in curves was recommended by Pičman (2007), provided that the widening is rounded to 10 cm. Kuonen (1983) recommends that the size of forest road traveled way widening in curves should be determined by the formula 14/R for solo trucks or by the formula 26/R for trucks with trailers. Deitz et al. (1986) state that traveled way widening in curves should be calculated according to the formula 32/R, regardless of the type of vehicle. In North America, traveled way widening of a forest road in curves is generally calculated according to the formula 18.6/R (FAO, 1998), and in Greece according to the formula 17/R (Nikou, et al. 2004).

The application of the Software system SURVEY – Trasa – Modul za projektovanje saobraćajnica makes it easy to use the traces curve method for determining the required traveled way widening in curves. In the simulation of vehicle movement along the given alignment, the vehicle leaves traces of its outermost points (Figures 3a and 3b), and those traces are the basis for the determination of the edge lines of the traveled way. Schiess and

Whitaker (1986) reported that traveled way width obtained by the traces curve method should further be widened by 0.5 to 0.7 m due to the driver error and safety of driving. On the other hand, Kuonen (1983) points out that traveled way width depends on the width of the vehicle and that a safety belt of at least 0.35 m should be made on both sides. Minimum traveled way width can also be calculated by multiplying the maximum width of a vehicle by a coefficient of 1.3 to 1.5.

In addition to making it possible to determine the necessary traveled way widening for the movement of any vehicle, significant cost savings in the construction of forest roads can be achieved with the application of this method and software. Table 2 presents a comparative analysis of the quantity of works obtained in the production of the main projects of reconstruction for the forest road “Rasadnik - Pustinac”. One of the projects determined the traveled way widening in small radius curves by the traces curve method obtained by simulating the movement of reference vehicles, while the other one used the traditional method, i.e. the one based on the formula 40/2R. In the project which determined the traveled way widening by the traces curve method, the total area of the surfacing is by 2.79% smaller than the area of surfacing in the project that determined the traveled way widening through a formula. Traveled way width directly affected the scale of earthworks, and in the first case the volume of cuts was by 4.17% lower than in the second one. The volume filling was by 7.05% lower and the amount of material needed for making the pavement is lower by 2.94%.

A smaller volume of earthworks and material required for making the surfacing in the preparation of the Main project of reconstruction, in which the size of the widening was calculated by the traces curve method, made the estimated value of reconstruction of the 5.285 km forest road “Rasadnik - Pustinac” lower by 577,443.78 dinars or 109,260.89 dinars per kilometer. That value is by 3.34% lower than the value the total costs of reconstruction obtained in the preparation of the Main project of reconstruction for the same forest road when the widening size was calculated using the traditional method. This statement confirms the basic hypothesis used as a starting point in this research.

It should be noted that the application of the traces curve method widened all circular curves with radiuses of less than 100 m, and the application of the traditional method widened all circular curves with radiuses of less than 70 m. The required size of traveled way widening of between 0.29 and 0.20 m is obtained when the 40/2R formula for the radiuses of between 70 and 100 m is applied. According to the Regulations on the conditions that must be met by road structures and other elements of public roads from the safety aspect (Official Gazette of RS, 50/2011), a widening of over 0.20 m must necessarily be performed. That assumption challenges the justification of restrictions on the widening of traveled ways only to circular curves with radiuses of up to 70 m, as stated in the Guidelines for the design of truck roads (Butulija, Rađenović, 1993).

The total number of circular curves in the part of the route “Rasadnik - Pustinac” which was the subject of this study is 96, of which 83 curves have a radiuses of up to 100 m, and 15 curves radiuses ranging from 70 to 100 m. The percentage share of circular curves with radiuses of less than 100 m is 86.46%, which is approximately equal to the share of circular curves of the same radiuses obtained by Stefanović (1996), which amounted to 85.93%. Despite the larger number of circular curves that were widened in the preparation of the project by the traces curve method, the volume of works and therefore the costs of the forest road reconstruction were smaller.

By simulating the movement of vehicles along the given route, it can be seen that traveled way widening in curves of small radius is necessary on the inside and the outside of the curve, whereby the outer widening is substantially smaller than the inner one. On forest roads in Serbia, it is common practice to make widening only on the inner side of a traveled way, except in serpentines that require a widening of 2.0 m, of which a 1.0 m widening is performed on the inside and 1.0 m on the outside of the curve (Butulija, 2000). The need to expand the traveled way in curves both on the inside and the outside of the curves was written about by Kuonen (1983) and Schiess and Whitaker (1986). However, these authors stated that the widening on the inside and on the outside should be the same.

## CONCLUSION

In addition to its numerous advantages over the determination of forest road traveled way widening by the traditional method, application of the traces curve method obtained by simulating vehicle movement opens numerous questions that could be the subject of future research. The following conclusions can be drawn on the basis of this research:

1. In comparison with the traditional method of forest road traveled way widening in curves, a smaller size of the widening needed for an unobstructed passage of vehicles is obtained by applying the traces curve method;
2. The volume of earthworks and the amount of material needed for pavement construction depend on the size of the traveled way widening in curves. In the case of determining the size of the traveled way widening by the traces curve method, cut volume was lower by 4.17% than in the case of determining the widening by the traditional method, while the filling volume was by 7.05% lower, and the amount of material needed for pavement construction smaller by 2.94%;
3. The application of the traces curve method for determining the traveled way widening in curves in the reconstruction of the forest road "Rasadnik - Pustinac" with a length of 5.285 km will make savings of 577,443.78 dinars, i.e. the reconstruction costs will be lower by 3.34% compared to the costs of reconstruction when the widening size is computed by the traditional method, which confirmed the initial hypothesis; and
4. By applying the traces curve method, it was observed that the size of the traveled way widening in curves does not depend only on the radiuses of curves, but also on the deflection angle. In addition, the simulation of vehicle movement revealed that the traveled way widening should not be constructed only on the inside, but also on the outside of the circular curve.

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