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An AHP Model to Evaluate Road Intersection Design

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Abstract

Road intersection design is an essential part of traffic infrastructure projects in which sections of the same road may need to be designed with different characteristics to meet local needs or accommodate local constraints. The present work describes applying the multi-criteria analytical hierarchy process (AHP) method to evaluate road intersection design in a suburban environment through differential weighting of various criteria and sub-criteria. The main purposes of this paper are to propose a specific AHP model for reconstruction of road intersection and apply and verify the proposed AHP model. The model is tested on a road intersection in the county road 5025 and Marinići street in Viškovo, a suburb outside the city of Rijeka, Croatia. For applying the AHP method the Expert Choice software package has been used. Simulation of the current state and optimal variant is made in PTV VISSIM.

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Keywords: Multi-Criteria Decision Making; AHP; Road Intersection Design; Roundabouts; Sensitivity Analysis.

1. Introduction

The main purpose of an intersection in the road network is the connection of two or more roads and the enabling of a safer and efficient traffic connection between two places. On this basis, the place of the intersection sees a mutual interaction between various participants in traffic, which can often result in conflicting and dangerous situations. If an analysis shows that certain elements (connected with the project itself and the design) of the intersection do not meet the set standards or if there is a notice of a higher frequency of traffic accidents, the next course of action must be the reconstruction of the very intersection.

Numerous multi-criteria models have been applied to socially important investment projects (Nowak 2005), especially traffic infrastructure projects (Barić et al. 2018; Stepić 2016; Barić et al. 2016). These methods differ primarily in their optimisation criteria, which always involve a combination of technological, technical, ecological and other criteria. One of the most frequently used multi-criteria models is the Analytical Hierarchy Process (AHP) model (Podvezko 2009). The AHP model has proven valuable not just in traffic sciences but also in most other spheres of human activities, including civil engineering (Aghdaie et al. 2012; Cerić et al. 2013; Karleuša et al. 2014),

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marketing (Gholami et al. 2012), entertainment (Vidal et al. 2011) and the selection of academic staff (Rouyendegh et al. 2012). In this paper Analytical Hierarchy process (AHP method) has been applied.

The main purpose of the study is to describe and analyse the current state of the on a road intersection in the county road 5025 and Marinići street in Viškovo, a suburb outside the city of Rijeka (Croatia), propose new variants for the intersection reconstruction, evaluate variants by multi-criteria method AHP and eventually, according to AHP method results, select the optimal design solution of LC for the reconstruction. This work defines three variants of reconstruction which have been simulated in the "PTV Vissim" software.

2. Methodology

The methodology understands the following steps, with the aim of determining the optimal variant of road intersection, based on the applied AHP method:

- Analysis of the current condition of a road intersection in the county road 5025 and Marinići street in Viškovo (characteristics of the current traffic network, collection of real data about the size and distribution of the current traffic load, traffic count, determining the drivers' habits and their traffic culture, etc.);
- Development of simulation of the existing condition in the software tool PTV VISSIM;
- Proposal of new variants for reconstruction;
- Evaluation of the variants using AHP method with the application of the software tools Expert Choice (defining of the hierarchical structure of AHP model, ranking of criteria and sub-criteria, evaluation of variants, selection of the optimal variant);
- Development of simulation of the proposed variants in software tools PTV VISSIM;
- Choose the best variant for reconstruction according to results of applied AHP method and simulation;
- Sensitivity analysis.

Thomas Saaty developed the AHP method to guide complex multi-criteria decision-making problems. It can perform better than other multi-criteria methods because it can be easily adapted to different numbers of attributes (criteria) and alternatives, which can be described both quantitatively and qualitatively (Saaty 1995).

3. Using the AHP method to Evaluate Road Section Design

3.1. Study Area and Problem

The subject intersection to be elaborated in this work is located in the north of the city of Rijeka, and the city center is only eight kilometers away. The intersection is the main road (County Road 5025) connecting the center of Rijeka and the secondary road (Marinići Street) connecting the business zone (Fig. 1). According to the number of approaches, the intersection belongs to a group of triangle intersections. The side of the sidewall is connected to the main road at an angle of 90 °. The north approach (3) is on the main road and is heavily loaded. It consists of a passageway and a left turn bar. It has been observed that the left turn bar is incorrectly designed, i.e. its length is less than five meters and the width is less than a minimum of three meters, which is the difficulty of driving the relevant vehicles which in this case makes the trailer truck and thereby increases the possibility of the occurrence of a traffic accident. There is no pedestrian crossing in the northern approach, and since this crossroads have a greater number of pedestrians, the lack of pedestrian crossings reduces the pedestrian safety level at the crossing of the pavement. Also, in the northern approach, an improperly positioned vertical traffic signaling was detected, i.e. two traffic signs of speed limitation (B31) were unnecessarily imposed. The southern approach (1) is also located on the main traffic road. It consists of a common passband and a right turn bar. There is also a pedestrian crossing that is quite far from the intersection area. An incorrectly positioned vertical signaling indicates pedestrian crossing over the road (C02). East approach (2) connects the business zone with county road 5025. It consists of a common left and right turn bar. In the eastern approach, a pedestrian crossing that is not correctly marked by horizontal traffic signaling is designed. At the eastern approach, the traffic island of the drift form is lacking vertical signage, and it is also extremely awkward at pedestrian crossing. It was observed that the vertical stop sign (B02) was placed considerably ahead of the stopping lines, i.e. vertical and horizontal traffic signaling may be noticed. There is a great problem in this approach of the inability to engage the vehicle in the main traffic direction. In the afternoon peak hour (15: 30-16: 30), an echo tailback is generated from the average 12 vehicles, which is a major problem of this intersection.

Fig. 1. Image of the road intersection under investigation

3.2. Analysis of traffic flows

Traffic counts were carried out in the morning and afternoon peak hours, ie from 6.30 to 7.30 and from 15.30 to 16.30. There are countless light trucks, heavy trucks, personal cars, buses, motorcycles and pedestrians. All these vehicles are expressed in EJA units (Fig. 2).

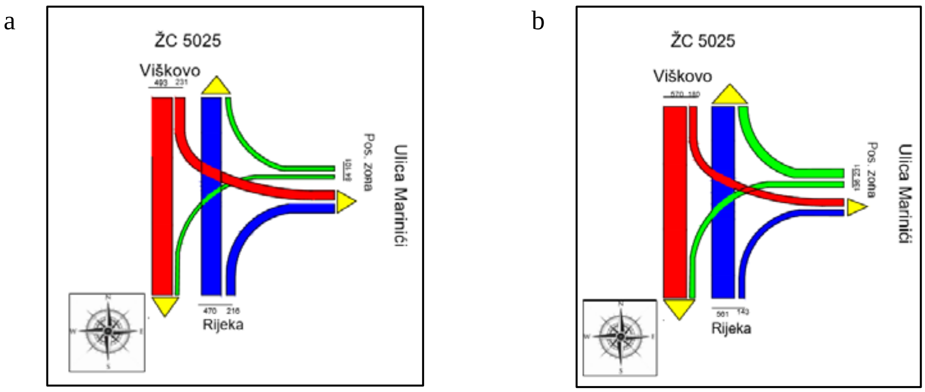

Fig. 2. Movement and intensity of traffic flows (a) in the morning peak hour (6.30-7.30); in the afternoon peak hour (15.30-16.30)

Figure 3 shows the intensity and movement of traffic flows in the forecasted five-year period for the four-cross intersection variant.

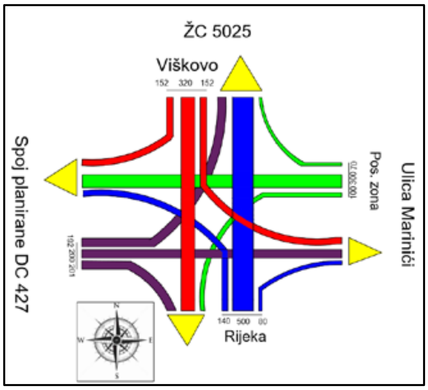

Fig. 3. Traffic intersection forecast following the construction of the fourth deprivation

3.3. Proposal of new variants and simulation of proposed variants

In order to improve the level of traffic safety and capacity, three possible variant designs for reconstruction are proposed. For the generation of simulation models of each variant, the traffic intersection forecasts for next five years were taken. The program interface of PTV Vissim has introduced the intensity and structure of the assumed traffic flows. Also, there are assumed pedestrian flows.

3.3.1. Variant 1

Variant 1 proposes reconstruction of the subject intersection is a classic four-way intersection (Fig. 4). This type of intersection is most often projected on roads outside and within the settlement. The main road extends in the direction of north-south, i.e. the main road is the existing county road 5025 and the side road is the east-west direction, the Marinići street and the new planned ditching of the state road D427. On main approaches, draft lanes are designed based on the estimated speed, which in this case is 40 km/h. The left-hander turns, as the most complicated in the intersection area, was performed by designing special lanes in the main and secondary traffic directions. All approaches have pedestrian crossings designed to facilitate pedestrian movement, especially in the direction of the business zone.

a b

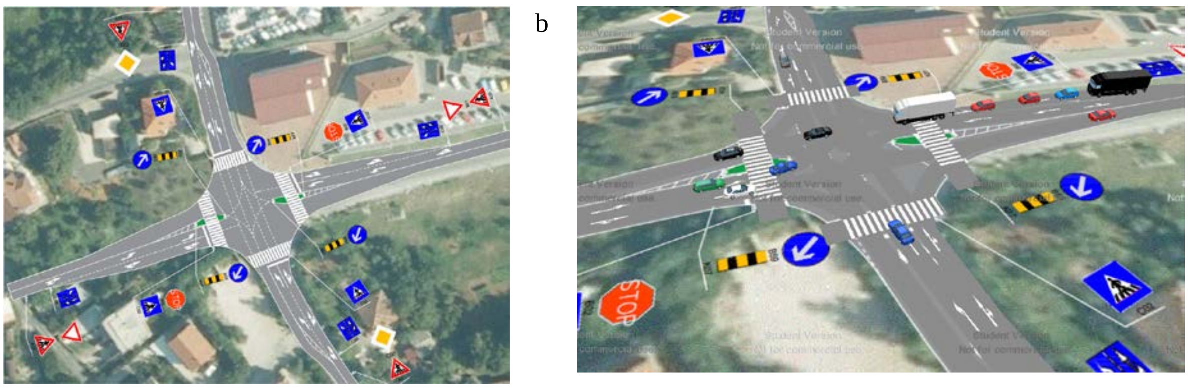

Fig. 4. (a) Proposal of Variant 1; (b) Simulation model of Variant 1

By creating a simulation model of Variant 1, output results were obtained on the basis of which the efficiency of a particular investment can be estimated. Some of the significant output outcomes are shown in Table 1.

Table 1. Outcome Results of Simulation of Variant 1

Average Vehicle Delay Time (s/veh)	Average speed of vehicle movement (km/h)	The maximum length of the waiting time on the entrances (m)	Average traveling time of vehicles (s)	Maximum emission of harmful gases (g/Kwh)	Maximum fuel consumption (l)
19,24	*15,67*	*45*	*11324,19*	*411,85*	*5,89*

3.3.2. Variant 2

The proposal of the design solution Variant 2 is intersection operated by traffic lights (Fig. 5). Since the traffic forecast predicts that intersection will cross two intensive traffic flows that cross, i.e. one intensive traffic flow will move along the main road, and the other intensive traffic flow will move by a secondary roadway, the intersection of controlled traffic lights are recommended for Variant 2.

a b

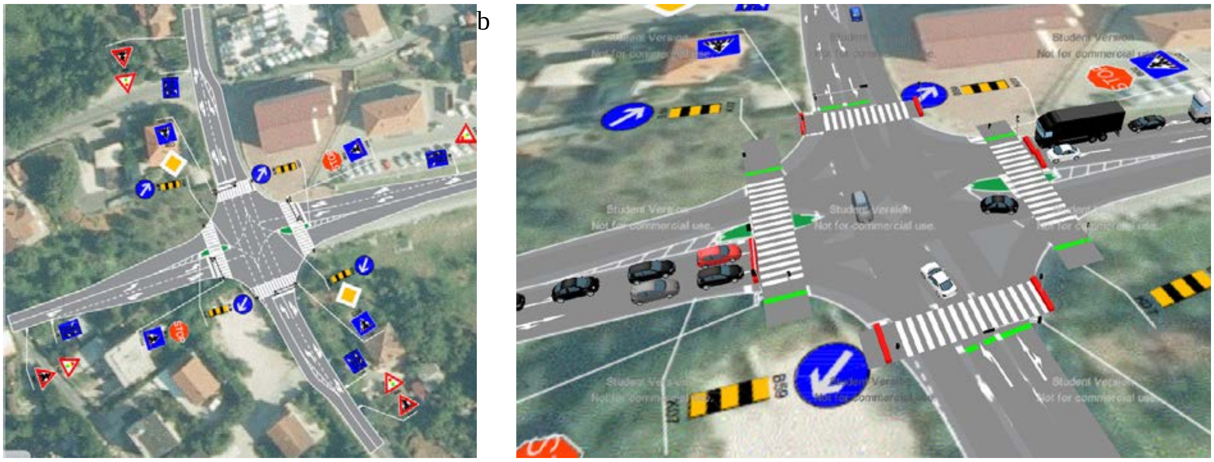

Fig. 5. (a) Proposal of Variant 2; (b) Simulation model of Variant 2

Since Variant 2 proposes designing intersections with traffic lights, one of the very important elements in simulation modelling is the development of a proper signalling plan. The signal plan is a blueprint for light signal modification. In the signal plan the duration of a single signal light can be seen (red, yellow or green on the traffic light) as well as the number of signal groups or number of phases. In Fig. 6 it can be seen that there are four signal groups in the signal program, the first for the main flow and the second for the secondary stream.

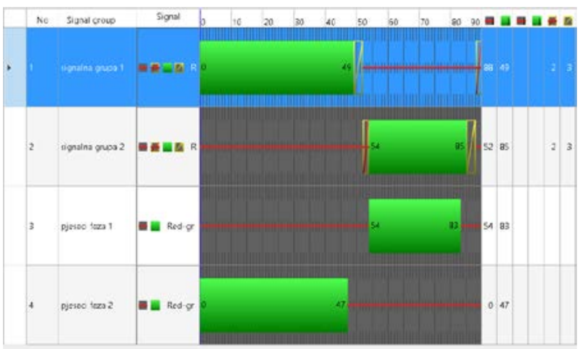

Fig. 6. Signal plan for Variant 2

The third and fourth signalling groups refer to pedestrian flows. Two phases have been designed for the vehicle, i.e. the first phase carries on the main traffic flow, and the second phase is driven by vehicles with a secondary flow. Since the intersection does not move a larger number of left-handers, the left-hand stage will not be projected. Two phases of pedestrian crossings have been designed which, in relation to the phases of the vehicle, have a certain protective interval. The recommended cycle time is 90 seconds.

By creating a simulation model of Variant 2, output results were obtained on the basis of which the efficiency of a particular investment can be estimated. Some of the significant output outcomes are shown in Table 2.

Table 2. Outcome Results of Simulation of Variant 2

Average Vehicle Delay Time (s/veh)	Average speed of vehicle movement (km/h)	The maximum length of the waiting time on the entrances (m)	Average traveling time of vehicles (s)	Maximum emission of harmful gases (g/Kwh)	Maximum fuel consumption (l)
33	*10,52*	*59*	*12919,08*	*351,30*	*5,026*

3.3.3. Variant 3

Variant 3 represents roundabout with an outside radius of 17 meters (Fig. 7). The circulatory roadway width is 6 meters. The entry radius is 24.6 meters, and the exit radius is 34.8 meters. On each approach entry are pedestrian crossings and traffic islands of 15 meters long. Within the roundabout, a 1.5 m long crossover ring was designed to facilitate the movement of larger vehicles at the intersection.

a b

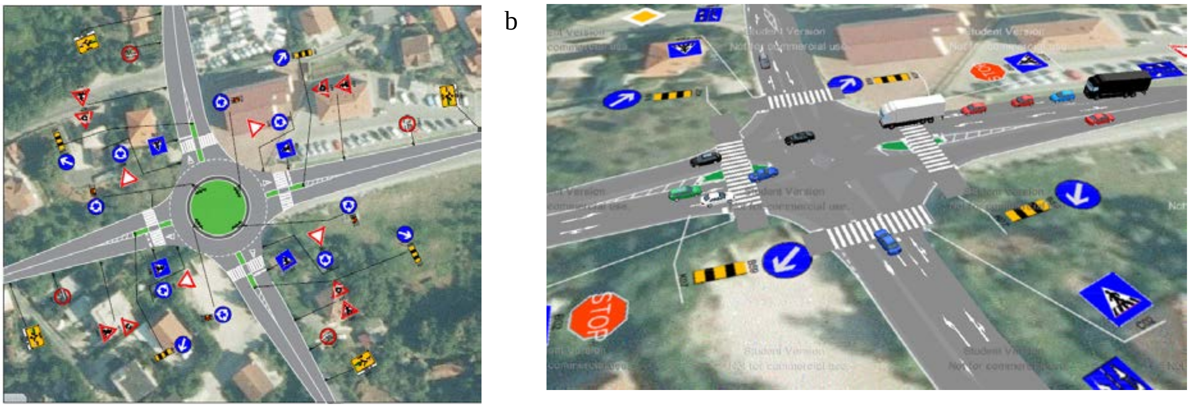

Fig. 7. (a) Proposal of Variant 3; (b) Simulation model of Variant 3

By creating a simulation model of Variant 3, output results were obtained on the basis of which the efficiency of a particular investment can be estimated. Some of the significant output outcomes are shown in Table 3.

Table 3. Outcome Results of Simulation of Variant 3

Average Vehicle Delay Time (s/veh)	Average speed of vehicle movement (km/h)	The maximum length of the waiting time on the entrances (m)	Average traveling time of vehicles (s)	Maximum emission of harmful gases (g/Kwh)	Maximum fuel consumption (l)
25	*14,41*	*38,19*	*11368,33*	*438,066*	*6,267*

3.4. The AHP model

The hierarchical structure of every AHP model consists of: objective, criteria, sub-criteria and variants. The evaluation of the proposed design solutions using the AHP method with the application of the software tool Expert

Choice is performed on the basis of the defined criteria and their sub-criteria. The proposed criteria with the respective sub-criteria in order to evaluate the variants are presented in the hierarchical structure of the AHP model (Fig. 8)

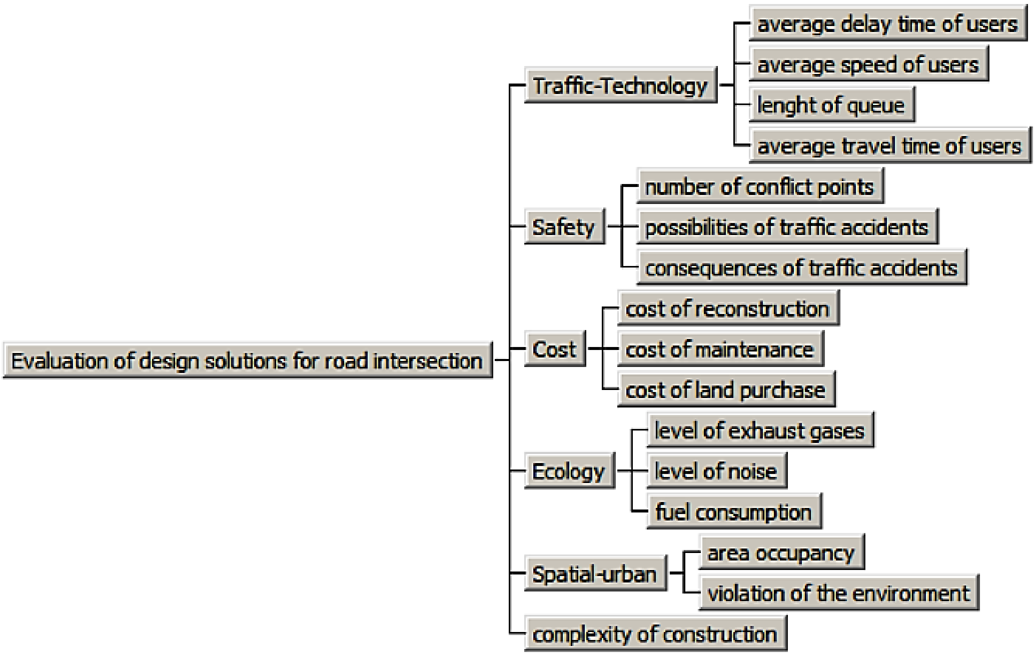

Fig. 8. Hierarchy structure of an AHP model for road intersection design

3.5. Results

After the problem has been structured, there comes the process of ranking the criteria and sub-criteria, followed by the evaluation of the variants according to each criterion and sub-criterion. The criterion “Safety” has been allocated the highest importance. The second important is the criterion “Traffic-Technology” due to all the advantages brought by the improvement of the traffic system. The “Cost” indicators are the third criterion regarding importance to invest financial means rationally in relation to the obtained benefits. Next importance belongs to the “Ecology” indicators due to the importance of adapting to the standards of environmental protection. The fifth important criterion is the “Spatial-urban” because of the possibility of the implementation of the advanced solutions that occupy relatively little space, and blend nicely into the environment and the last in importance is the complexity of construction criterion (Fig. 9). After having ranked the criteria, the sub-criteria were ranked as part of each criterion (Fig. 10 – 14).

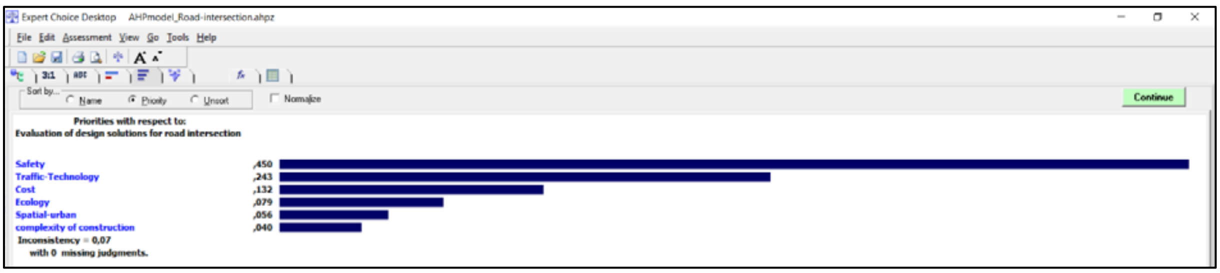

Fig. 9. Ranking of criteria

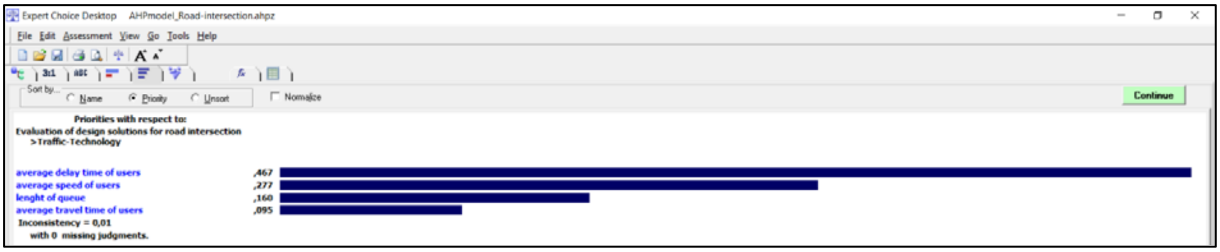

Fig. 10. Ranked sub-criteria of the criterion “Traffic technology”

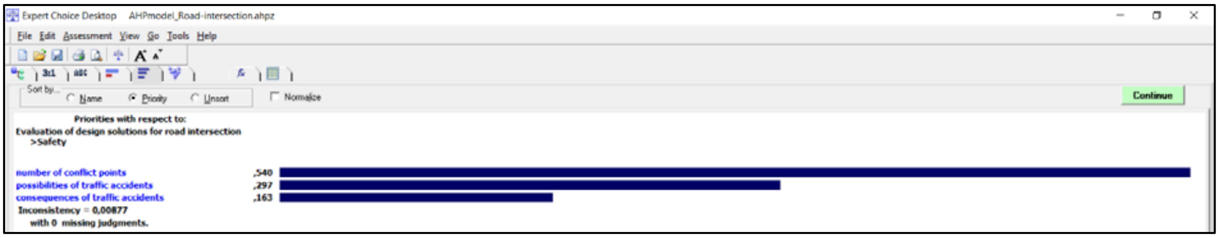

Fig. 11. Ranked sub-criteria of the criterion “Safety”

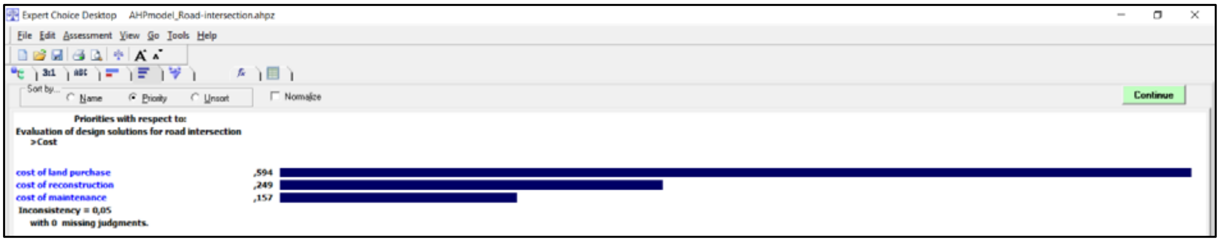

Fig. 12. Ranked sub-criteria of the criterion “Cost”

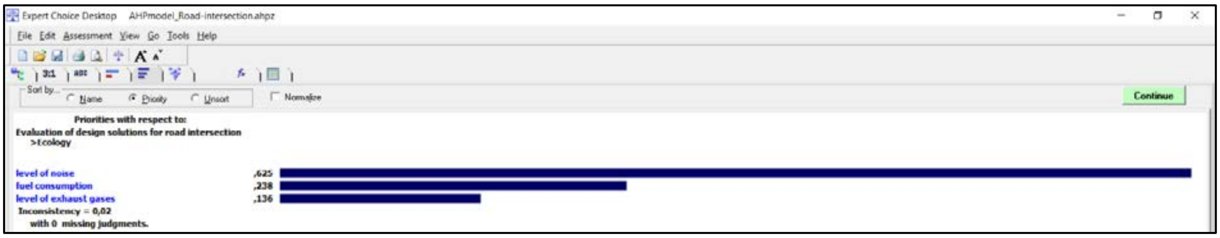

Fig. 13. Ranked sub-criteria of the criterion “Ecology”

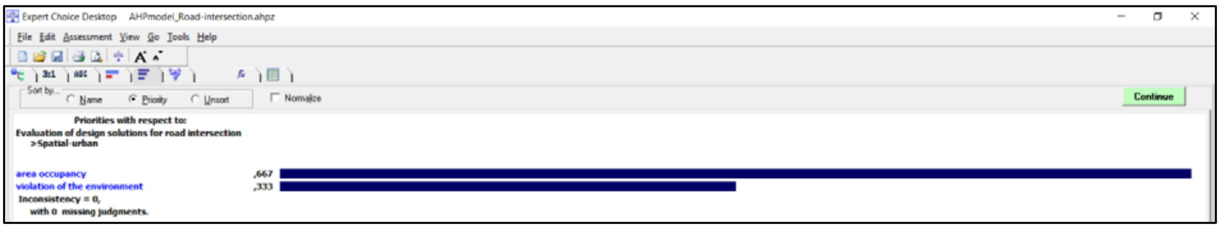

Fig. 14. Ranked sub-criteria of the criterion “Spatial-urban”

After performing the entire analysis and evaluation of the variants according to each criterion and sub-criterion using AHP method Variant 3 (38.6%) has been proposed as the best traffic solution (Fig. 15, Fig. 16). It is followed by Variant 1 (33.2%), and Variant 2 (28.2%).

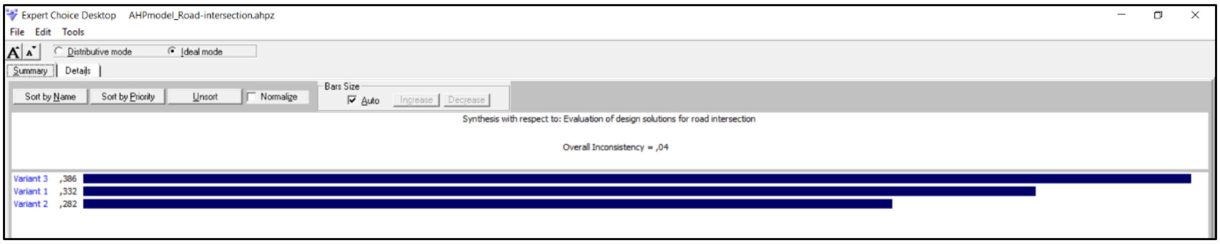

Fig. 15. Ranking of the variants

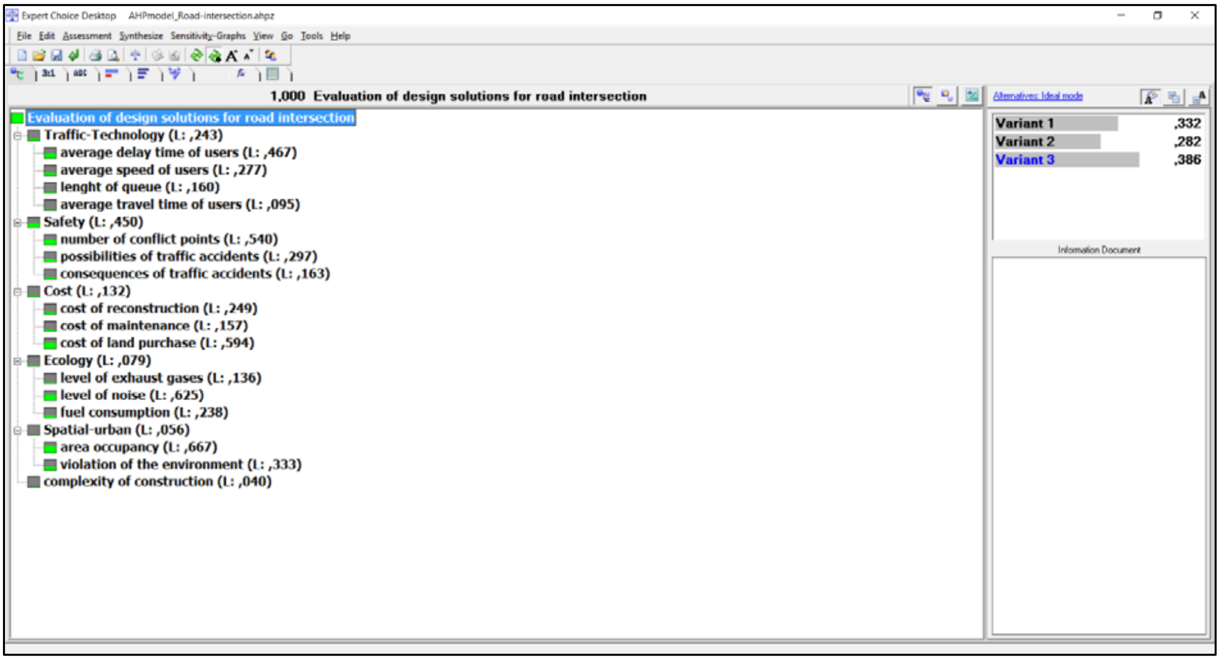

Fig. 16. Overall results - ranking of the criteria, sub-criteria and variants

3.6. Sensitivity analysis

Sensitivity analysis represents the final step of the AHP method. Based on the sensitivity analysis, the sensitivity of the project can be investigated if changes in critical decision variables change. Fig. 17 shows a dynamic graph of the current chosen optimal variant.

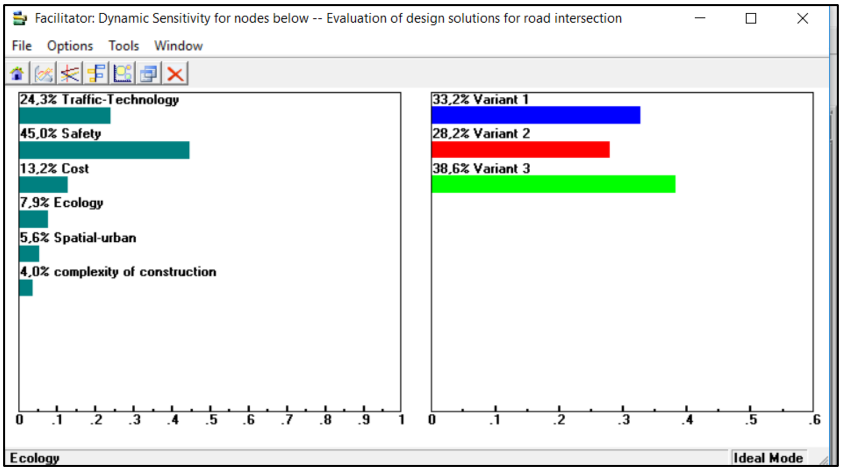

Fig. 17. Dynamic sensitivity – optimal variant

As shown in Fig. 17, the conclusions reached earlier can be ascertained. The most important criterion is safety, and the optimum variant of the multi-criteria analysis is Variant 3.

If there were any changes in some key indicators that in this case represented the traffic-technological criterion that was changed from 24.3% to 50.0% importance, Variant 3 wouldn't be the optimal solution. In this case, the most favourable solution becomes Variant 1. The traffic-technological criterion was chosen for the reason that no predicted traffic load would be achieved, or if there would be a significant increase in traffic at the intersection, the traffic techno- logy criterion would become much more important for the efficiency of a given investment.

In Fig. 18, a dynamic graph of the changed state can be seen after increasing the importance of the traffic-technological criterion by 25.7%. It can be seen that the optimal variant of the changed state becomes Variant 1 with a weight of 39.0%.

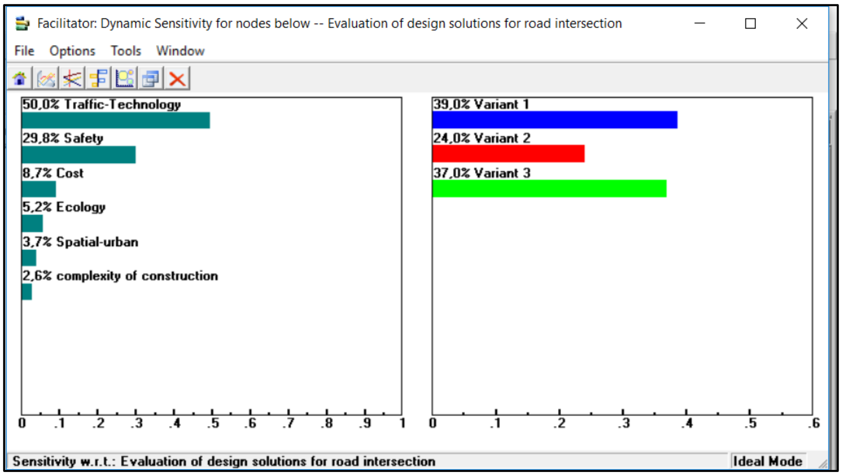

Fig. 18. Dynamic sensitivity – changed state

4. Conclusion

In this work the aim of the using the AHP method is the selection of the optimal design solution among the three proposed variants for the reconstruction of road intersection. Using the AHP method to assess a large number of alternatives on the basis of comprehensive parameters can significantly improve the quality of decision making about investments in transport infrastructure. Here we report one case study suggesting that the AHP method can work well for choosing the optimal design (reconstruction) of a road intersection in a suburban area.

The first variant proposes reconstruction of the subject intersection in a classic four-way intersection. The second variant proposes intersection operated by traffic lights. The third variant would include construction of roundabout.

The results of the performed AHP method show that the optimal selection is Variant 3 which is by 5.4% better than Variant 1, and by 10.4% better than Variant 2.

Of the six criteria selected for the AHP model, the most important was Safety, and the least important was Complexity of construction. Sensitivity analysis showed this result to be robust, affected only by a large increase in the weighting of the criterion Traffic-technology. Variant 1 was the optimal option only when we increase importance of the criterion Traffic-technology to double.

This study featured several limitations. One was that our data on the number and movements of traffic flow in the study area turned out to be inadequate for assessing functional efficiency or level of service, preventing us from simulating micro and macro aspects of traffic movements and flow using such tools as PTV Visum. Future studies should address these issues. Future work should also conduct a survey of road traffic engineering experts from and from outside Croatia and consider perspectives of other stakeholders, such as civil engineer, economist, ecologist, or urban planner. This input may significantly alter the choice and weighting of criteria and subcriteria, which may affect the recommended road section design. It is also possible to combine our AHP model with other MCDM models which may improve its performance, versatility or robustness.

The proposed AHP model with its criteria weighting structure may help policy makers select appropriate road intersection design projects for implementation. The model and the associated database may prove a useful and adaptable tool for dealing with a variety of problems.

Acknowledgements

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