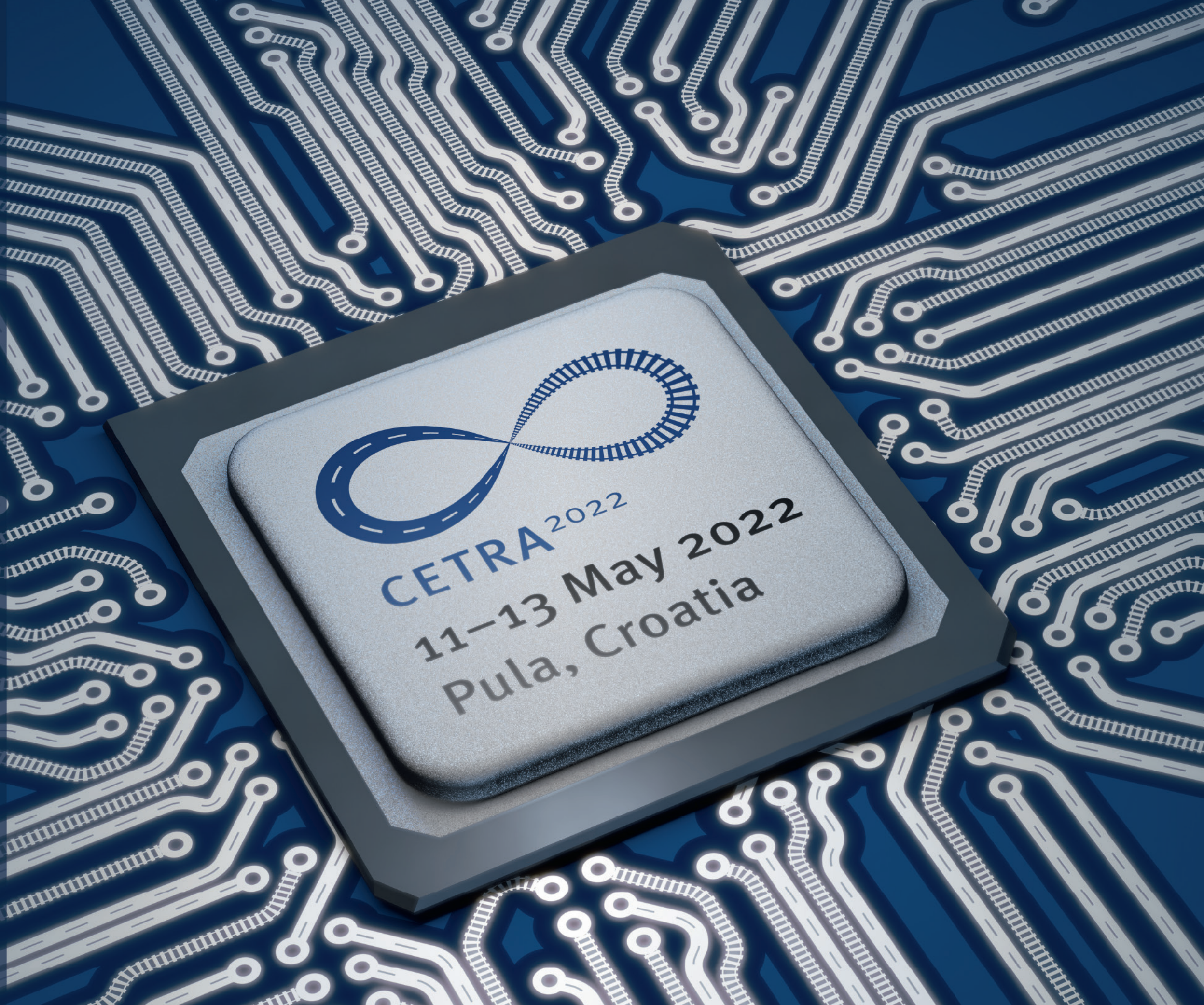

7th International Conference on Road and Rail Infrastructure
11–13 May 2022, Pula, Croatia

Road and Rail Infrastructure VII

Stjepan Lakušić – EDITOR

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CETRA2022

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Road and Rail Infrastructure VII

EDITOR
Stjepan Lakušić
University of Zagreb
Faculty of Civil Engineering
Department of Transportation
Zagreb, Croatia

CETRA2022

7th International Conference on Road and Rail Infrastructure
11–13 May 2022, Pula, Croatia

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FOREWORD

The 7th International Conference on Road and Rail Infrastructure – CETRA 2022 was organized by the University of Zagreb - Faculty of Civil Engineering, Department of Transportation Engineering. The Conference was held in Pula, 3000-year-old city located at the tip of the Istrian peninsula. The Greek myth tells Pula was founded by Jason and Medea during their escape from Colchis fleets. Because of that, literature and poetry consider Pula to be the city of refuge. And indeed, in many ways, it is a place of retreat to people tired of everyday worries, hungry for culture, joy and entertainment. Pula was governed by many cultures since mythological times, and each of them left a mark on its ground. This largest Istrian city is symbolised by its Roman remains – like the Arena, the 2,000-year-old amphitheatre with its nearly intact walled ring – but also Venetian, Napoleonic, and Habsburg fortresses. Pula is situated on the shores of its eponymous bay, built atop seven hills as a parallel to ancient Rome, and even though it is a city with shipyard docks and not beaches, the natural beauty of the surrounding countryside and turquoise water of the Adriatic have made it a popular vacation destination.

The 1st International Conference on Road and Rail Infrastructure – CETRA 2010 was held on 17-18 May 2010 in Opatija. The 2nd International Conference on Road and Rail Infrastructure – CETRA 2012 was held on 7-9 May 2012 in Dubrovnik. The 3rd International Conference on Road and Rail Infrastructure – CETRA 2014 was held on 28-30 April 2014 in Split. The 4th International Conference on Road and Rail Infrastructure – CETRA 2016 was held on 23-25 May 2016 in Šibenik. The 5th International Conference on Road and Rail Infrastructure – CETRA 2018 was held on 17-19 May 2018 in Zadar. The 6th International Conference on Road and Rail Infrastructure – CETRA 2020* was held on 20-21 May 2021 in Zagreb. The CETRA 2020 was to be held on 20-21 May 2020 in Pula. However, due to the COVID-19 pandemic and earthquakes in Croatia it had to be postponed and was held in May 2021 on the same dates on which it was to take place in 2020. We also partly kept the identity of the conference so that in 2021 the conference was organized under the name of CETRA 2020*. Nevertheless, due to the pandemic, the conference CETRA 2020* was organised via an on-line platform.

Great interest of participants in topics from the field of road and rail infrastructure, as expressed during the previous CETRA conferences, confirms the adequacy of the Department for Transportation Engineering's decision to organise this international event in 2022 as well (i.e., a year after the last conference), the wish being to come back to the former practice of organising CETRA conferences in even years. Positive comments given by participants in past Conferences motivated the Department for Transportation Engineering of the Faculty of Civil Engineering - University of Zagreb, to organise the new CETRA conference (CETRA 2022) on 11-13 May 2022 in Pula.

The CETRA conference has established itself as a venue where scientific and professional information from the field of road and rail infrastructure is exchanged. The idea on linking research organisations with economic sector has been the guiding concept for the realisation of this conference. Conferences of this kind are undoubtedly a proper place for establishing closer contacts between economy and academia, and for facilitating communication and inspiring greater confidence, which might result in cooperation on new projects, especially those that contribute to greater competitiveness. Lectures organized in the scope of the conference are based on interesting technical solutions and new knowledge from the field of transport infrastructure as gained on the projects already realised, projects currently at the planning stage, and those now under construction, in all parts of the world. In addition to presentations given by authors from the academic community, lectures were also presented by practical authors, the idea being to ensure the best possible synergy between the theory and practice. Because of great interest for the themes relating to the field of road and rail infrastructure, as shown during the past six conferences (CETRA 2010, CETRA 2012, CETRA 2014, CETRA 2016, CETRA 2018 and CETRA 2020*), the Department for Transportation Engineering of the Faculty of Civil Engineering – Zagreb has assumed the responsibility to organise the new CETRA Conference in 2022 as well.

This year, the 7th International Conference on Road and Rail Infrastructure – CETRA 2022 was organized with the intention of bringing together scientists and experts in the fields of road and railway engineering, so that they can present the results of their research, their findings and innovations, and analyse problems encountered in everyday engineering practice and, finally, offer solutions that will undoubtedly contribute to a more efficient planning, design, construction, and maintenance of transport infrastructure. The CETRA 2022 Conference serves as a platform for presenting a broad blend of scientific and technical papers in the fields of civil, transport, geotechnical, environmental, traffic, and electrical engineering, with practical application in the road and rail infrastructure.

This year's CETRA 2022 Conference attracted a large number of papers and presentations from 35 countries. More than 100 papers were presented at the Conference and are contained in these proceedings Road and Rail Infrastructure VII. We believe that these CETRA 2022 proceedings will prove to be, just like the preceding six proceedings from the CETRA cycle, highly interesting and useful to all experts exhibiting a scientific and professional interest in the road and rail infrastructure. The DOI (Digital Object Identifier) number is assigned to each published paper.

The organizers of the Conference express their thanks to all Businesses and Institutions that provided support to this Conference. Special thanks are extended to the IRF - International Road Federation, and to FEHRL – the Forum of European National Highway Research Laboratories, for their assistance and support in organizing very important conference sessions relating to innovations in roads maintenance, and to innovative transport infrastructure development concepts. These operators have contributed, each in its own way, to the success of this conference. Great thanks are also extended to the following institutions that have supported the CETRA conference over the past twelve years: University of Zagreb, Ministry of Sea, Transport, and Infrastructure, Ministry of Science and Education, Croatian Academy of Engineering, and Croatian Engineering Association.

The Editor commends all authors for excellent papers contributed to these proceedings, and wishes to thank members of the Local Organizing Committee and International Academic Scientific Committee, and numerous experts who participated in the review process. The gratitude is also extended to all participants for taking part in the CETRA 2022 Conference. The quality of the papers presented at the CETRA Conference is best demonstrated by the fact that a considerable interest is being expressed for most of these papers by researchers and industry operators from all parts of the world. We have been receiving, almost on a daily basis, numerous queries regarding papers published at previous CETRA conferences. This is not only due to the high visibility of the conference thanks to its presence in relevant databases, but is also a logical consequence of the quality of papers published in the scope of this conference series. Lectures that are organised at the conference are based on interesting technical solutions and latest findings in the field of transport infrastructure from the projects already realised, those that are at the design stage, or projects that are currently being realised in all parts of the world. Problems encountered in everyday engineering practice are analysed through papers presented at the conference, where practical solutions are offered in order to enable a more efficient planning, design, construction, and maintenance of transport infrastructure.

Because of the COVID-19 pandemic that caused a two-year pause in the organisation of live conferences, the organization of the CETRA 2022 Conference has proven to be a greater challenge compared to the organisation of the previous CETRA 2020* Conference. The persistence of organisers and great perseverance of the authors who have accepted to present their valuable scientific achievements and interesting professional projects present on conference in front of a live audience are the proof that only by acting together we will be able to overcome challenges that inevitably occur in the society. High quality papers published in the Conference Proceedings are the result of great efforts of the authors and reviewers as they have worked in close synergy to achieve outstanding papers that are included in the proceedings and presented at the conference. All those who took part in the preparation of the proceedings (authors, reviewers, members of the Organizing Committee, technical editor, and the editor-in-chief) have worked hard to enable timely publication of the proceedings. We believe that the papers published in the proceedings will be interesting not only to our colleagues in the everyday engineering practice but also to students of technical faculties where disciplines from the field of road and rail infrastructure are studied.

Zagreb, May, 2022

THE EDITOR

Lakušić S.

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ANALYSIS OF THE CAPACITY AND LEVEL OF SERVICE FOR URBAN INTERSECTION

Ivona Nedevska, Riste Ristov, Zlatko Zafirovski, Slobodan Ognjenovik, Vasko Gacevski
University "Ss. Cyril and Methodius", Faculty of Civil Engineering – Skopje

Abstract

The augmentation of motorization level leads us to the need for mobility and demands better infrastructure, in urban and suburban areas. The complexity of this problem is especially notable in urban areas where the space delimitations, functional characteristics and different transportation must be considered. The intersection between Partizanska street and Boris Krajger street, in Shtip, has been analysed with the methodology for capacity and level of service, according to international software and manuals. Both streets are with one lane per direction, and lately it is very frequent intersections in Shtip. Number of vehicles is determined by measuring the traffic, and those inputs are used to analyse three solutions: the current solution (unsignalized intersection), four legged intersection and roundabout both with boulevard profile for the main corridor and two way street for the secondary corridor. Calculations are based on custom measurements within a week.

Keywords: intersection, analysis, roundabout, capacity, level of service, boulevard, street

1 Introduction

City development affects all the movements and needs for transportation. Besides the motor traffic, bicycles and pedestrians are an essential part of city traffic in urban areas [1]. The choice of the type of intersection and thus the applied design elements depends on the category of the road and its function in the network, as well as the ratio of the forecasted intensities and throughput [2]. Traffic conditions at the intersection must be regulated in such a way as to ensure maximum safety of all traffic participants and the required traffic flow. When choosing the type of intersection, one should strive for uniform solutions, which contributes to the driver creating a "picture of the expected situation" and recognisability of the road category, which positively affects the driver's behavior and thus the level of safety.
Intersection type is essential and depends on many factors. For instance, if both roads have similar traffic loads, a roundabout is recommended. In the case of different traffic loads, signalized or unsignalized intersection is a better solution. If the roads have more than four lanes, the classical intersection is the best solution or intersection with the required signalization [3].
The Highway capacity manual analyzes capacity and level of service for many various facilities [4]. The analyzed flows are classified as interrupted or uninterrupted flows. Uninterrupted flows are all the flows with no fixed elements (like traffic signals). Traffic flows depend on vehicles interactions and geometric and environmental characteristics. Interrupted flows, on the other hand, have controlled and uncontrolled access points that interrupt the flow. This includes signals, stop signs, and any control that interrupts or slows the traffic. City roads are classified as interrupted because of the signs, signalization, and bicycle and pedestrian presence.

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The question is how to choose an appropriate traffic solution in intersections and the correct solution for intersections?
Such a complex question can be answered only with appropriate traffic analysis to check the capacity and level of service for the considered intersection. One way to make such a big decision is by applying the HCM methodology. Depending on how much traffic loads are involved and what spatial constraints occur. There are appropriate methods according to HCM that provide the level of service and capacity for signalized intersection, unsignalized classical or roundabout intersection, and interchange.
With these methods, an analysis was made of the intersection of Partizanska street and Boris Krajger street in the city of Shtip, and the obtained results are demonstrated in the reports. Furthermore, calculations have been made for different solutions at the indicated intersection to determine which solution is most favorable.
First, a review of previous research on the topic was made. Then, the variant solutions for the intersection in question were given with all the technical and traffic parameters. Then, in item 4, an analysis of each of the considered solutions' capacity and level of service is made. Finally, there is a discussion about the obtained results, and recommendations and conclusions are given.

2 Review of the previous related studies

In planning and designing road intersections, the common question is whether to apply roundabouts or a traditional type of intersection. As a result, numerous studies have been conducted that consider the type of intersection, mainly between classical signalized and unsignalized intersection and roundabout [5].
Parameters commonly considered in the analysis are adequate intersection capacity, main road capacity, minor road capacity, significant road average delay, minor road average delay, major road, 95 % queue length, minor road 95 % queue length [6].
So far, several researches have been done in the field, some of them are contained in the papers in the literature, where the influence of non-motorized road users on the traffic performance for motor vehicles is taken [7] and another research for non-signaled intersections where a comparison of HCM 2000 and Conflict method using field data [8].
From the results of the intersection capacity analysis studies based on HCM 2000, it is evident that the application of a roundabout scenario shows higher performance at the intersections than the intersection having a secondary signal [9]. In general, it was found that the two-way stop-controlled intersection performed best for relatively low major road one-way volumes, the pre-timed signal performed best for relatively high major road one-way volumes, and the roundabout performed best for a mid-range volume between the two.
For the specific case, there are no similar studies.

3 Description of the variant solutions

The street "Partizanska" in the city of Stip in Republic of North Macedonia is the principal city road with a total length of 1800 m. According to the detailed urban plan for the city of Stip, this road is classified as magistral road and is part of the regional road 2334. Furthermore, with the detailed urban plan, this road is planned to be a boulevard with an entire length. In the analysis, three solutions are taken into consideration:
- the existing current solution (unsignalized intersection),
- four-legged intersection with boulevard profile for the main corridor and two – way street for the secondary corridor and
- roundabout with boulevard profile for the main corridor and two-way street for the secondary corridor.

3.1 Existing solution

The existing section of the road has no pedestrian or bicycle paths on the main street Partizanska and is a “bottleneck” of the traffic in this part of town of Stip.
The existing solution of the intersection is an improvised roundabout created on a four-legged unsignalized intersection. Partizanska Street does not have existing pedestrian and bicycle paths, so the movement of these participants in the traffic is very unsafe, and they are present in the traffic flows. Unfortunately, traffic jams and unsafe traffic for drivers and other road users often appear due to this improvised solution.

Figure 1 Existing solution of the intersection – view from both sides of street Partizanska [source: Author]

Figure 2 Existing solution – view from both sides of Boris Krajger street [source: Author]

The existing cross-sections of the streets within the considered intersection are the following:

<u>Partizanska street – South</u>

Lanes 2 x 2.25 = 5.50m

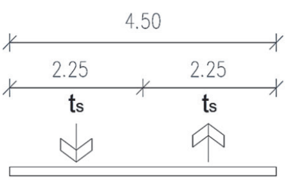

Figure 3 Geometrical cross-section of Partizanska street South [source: Author]

The longitudinal slope of the street in the intersection region is i = 1.5 %.

<u>Partizanska street – North</u>

Lanes 2 x 3.5 = 7.00m
Pedestrian path <u>2.00 m</u>
Total: 9.00 m

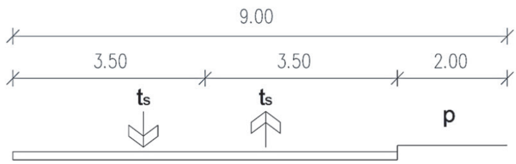

Figure 4 Geometrical cross-section of Partizanska street North [source: Author]

The longitudinal slope of the street in the intersection region is i = 1.5 %.

Boris Krajger – West
Lanes 2 x 3.5 = 7.00 m
Pedestrian path 1.50 m
Total: 8.50 m

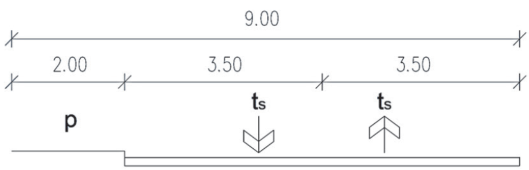

Figure 5 Geometrical cross-section of Boris Kragjer – West [source: Author]

The longitudinal slope of the street in the intersection region is i = 2.2 %.

Boris Kragjer – East
Lanes 2 x 6.00 = 12.00 m
Pedestrian path 1.30 m
Pedestrian path 2.50 m
Total: 15.80m

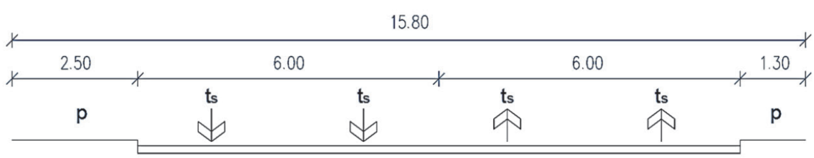

Figure 6 Geometrical cross-section of Boris Kragjer – East [source: Author]

The longitudinal slope of the street in the intersection region is i = 2.5 %.

3.2 New design – four-legged intersection

According to the detailed urban plan, street Partizanska is planned to be a boulevard with an entire length, with pedestrian and bicycle paths on both sides of the street. Considering the project documentation and the requests from the Investor, two solutions were designed for the considered intersection, a classic signalized four-legged intersection, and a roundabout.

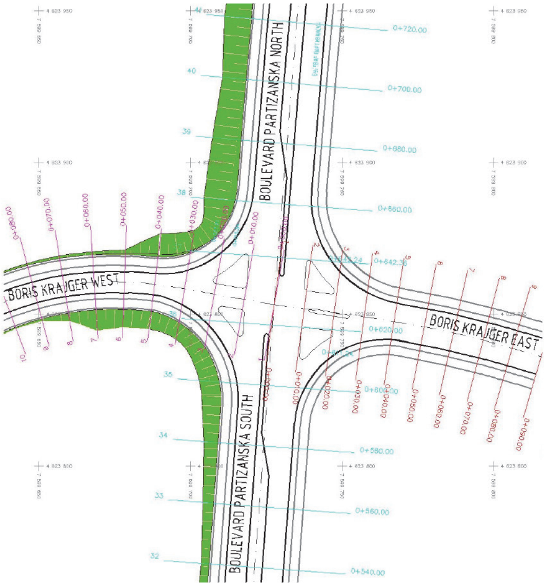

Figure 7 Layout – horizontal solution about four-legged intersection [source: Main Design for boulevard Partizanska]

The newly designed solution with a four-legged intersection envisages construction works to expand the profile of the existing streets. In particular, we are talking about widening the lanes and providing pedestrian and bicycle paths with appropriate width for safe traffic.
The cross-sections of the streets within the considered intersection, according to this solution, are as follows:

<u>Partizanska street – South and North</u>

Lanes	2 x 7.00 = 14.00 m
Bicycle path	2 x 2.00 = 4.00 m
Pedestrian path	2 x 3.00 = 6.00 m
Central reservation	5.00 m
	Total: 29.00 m

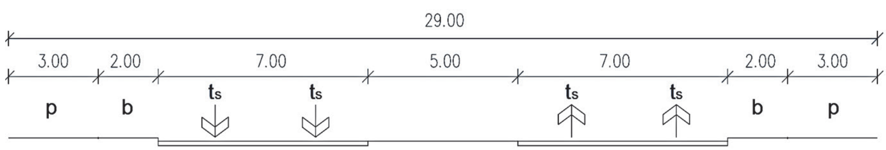

Figure 8 Geometrical cross-section of Boulevard Partizanska [source: Author]

The longitudinal slope of the street in the intersection region is i = 1.5 %.

<u>Boris Kragjer – West</u>

Lane	2 x 3.50 = 7.00 m
Bicycle path	2 x 2.00 = 4.00 m
Pedestrian path	2 x 3.00 = 6.00 m
	Total: 17.00 m

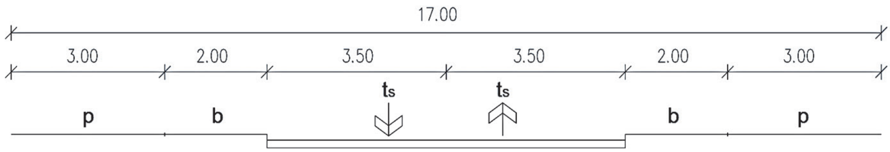

Figure 9 Geometrical cross-section of Boris Krajger – West [source: Author]

The longitudinal slope of the street in the intersection region is i = 2.5 %.

Boris Kragjer – East

Lane	2 x 6.00 = 12.00 m
Bicycle path	2 x 2.00 = 4.00 m
Pedestrian path	2 x 3.00 = 6.00 m
	Total: 22.00 m

The longitudinal slope of the street in the intersection region is i = 2.5 %.

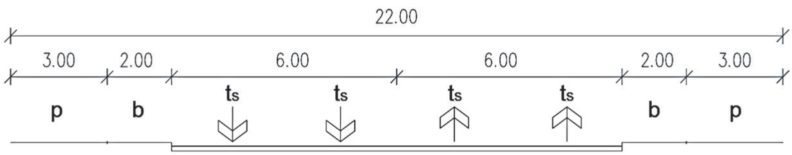

Figure 10 Geometrical cross-section of Boris Krajger – East [source: Author]

3.3 New design – roundabout

The intersection of Partizanska Boulevard with the existing Boris Kreiger Street has been solved with a newly designed roundabout. The circle has an outer radius R = 24 m. The roundabout is designed with two lanes without separate lanes for left turns. As previous design about the four-legged intersection, this design also envisages construction works to expand the profile of the existing streets, i.e., widening the lanes and providing pedestrian and bicycle paths with the appropriate width.

The cross-sections of the streets, according to this solution, are with the same width of the profiles as for the four-legged intersection. The longitudinal slopes of the streets in the intersection region are:

- i = 2.5 % for Partizanska North and South,
- i = 2.5 % for Boris Krajger West and
- i = 2.5 % for Boris Krajger East.

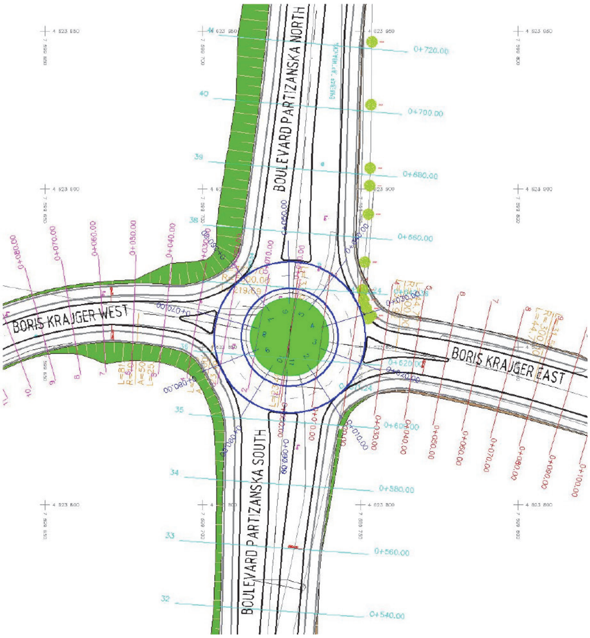

Figure 11 Layout – horizontal solution about roundabout [source: Main Design for boulevard Partizanska]

4 Capacity analysis

The purpose of the research is to analyze the capacity and the level of service for the crossroads. In urban areas, there are intermittent flows, either due to signalization crossing of pedestrians or cyclists. Such interruptions limit the movement time of the participants in the part of the intersection. On the other hand, the roundabout's capacity depends on one side of the surface and on the other side of the time constraints. This paper covers the methodologies for analyzing traffic light and non-traffic light intersection (roundabout), which lists the necessary input data the procedure for analysis and comparison of the obtained solutions. The capacity calculation is done according to the standard method, which is part of HCM 2010.
To start, it is necessary to know the geometric characteristics of the analyzed intersection (number and width of lanes, longitudinal slopes, etc.) and to provide traffic data. The input data for traffic at the intersection are obtained from the database of the Municipality of Stip. The data on the realized road traffic is collected, processed, and stored to direct the future development of the road network. The data is used to prepare various studies on the justification of the construction of new roads, dimensioning of road structures, construction, and reconstruction of the road network. These measurements are made to determine the exact number of traffic and find an appropriate solution for the daily congestion in this part of the city. The measurements are made manually with adequately prepared forms in which the classification of vehicles is defined, in 2018, in one week.
By knowing this data, we can categorize the bands according to the movements they distribute. Then, further calculations and analyzes are performed for each group of lanes, respectively, and the results are summarized at the intersection level.

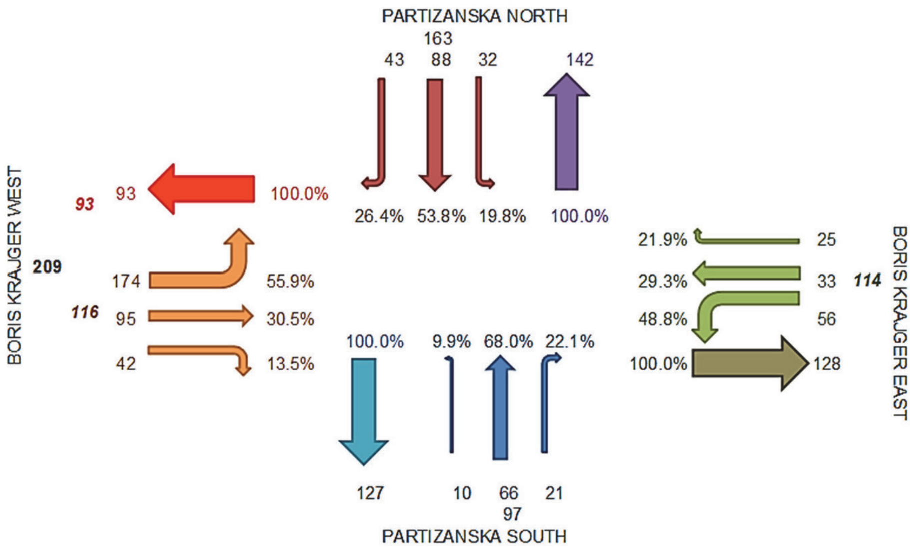

Figure 12 Traffic data about the considered intersection presented by cars/15 minutes [source: Author]

Considering the input data for traffic and geometry, the flow saturation is calculated, through which the capacity of the groups of lanes and the retention is obtained. The level of service is related to the size of delays (the greater delays, the lower level of service). The Origin - Destination matrix is presented for 15 minutes' traffic for the analyzed intersection (Table 1).

Table 1 Origin – destination matrix

Cars/15 minutes	Partizanska South	Partizanska North	Boris Krajger West	Boris Krajger East	Total
Partizanska South	0	63	18	33	**114**
Partizanska North	72	0	40	51	**163**
Boris Krajger West	14	59	0	43	**116**
Boris Krajger East	42	20	35	0	**97**
Total	**128**	**142**	**93**	**127**	**490**

Considering the influence of traffic, geometric and signalization conditions, appropriate correctional factors are used in order to calculate the saturation flow rate.

First step in the calculation is grouping the lanes, so that the capacity and level of service can be calculated for each group [10].

For this research lanes are grouped in 3 groups: Left turns and Through, Through and Right turns. The left turns and through movements are actuated because they depend on the signalization, but the right turns as independent are classified as pretimed. After grouping the lanes, volume adjustment is made by considering the percentage of heavy vehicles and peak hour factor. Next step is calculation of saturation flow rate, by knowing the number of lanes and appropriate adjustment factor (for lane width, HV, grade, area type, lane utilization...). Now that both, adjusted flow rate in lane group and adjusted saturation flow are familiar, the capacity analysis can be done. For each group of lanes on each leg, critical lane group or phase is determined by the biggest flow ratio (v/s).

Table 2 Output data from the analysis with HCM2000

Type of intersection	Existing solution			
Leg	East	West	North	South
v/c (for critical group of lanes)	1.31	1.11	1.60	0.98
Control delay	12.7	10.4	145	116
Level of service	B	B	F	F
Type of intersection	**Four-legged intersection**			
Leg	East	West	North	South
v/c	0.15	0.17	0.25	0.62
Control delay	0.10	0.09	0.20	1.20
Level of service	A	A	A	A
Type of intersection	**Roundabout**			
Leg	East	West	North	South
v/c	0.38	0.41	0.29	0.24
Control delay	9.27	9.92	7.55	6.91
Level of service	B	B	B	B

The calculation refers to the measured traffic of the intersection. This data was used for all three types of intersection.

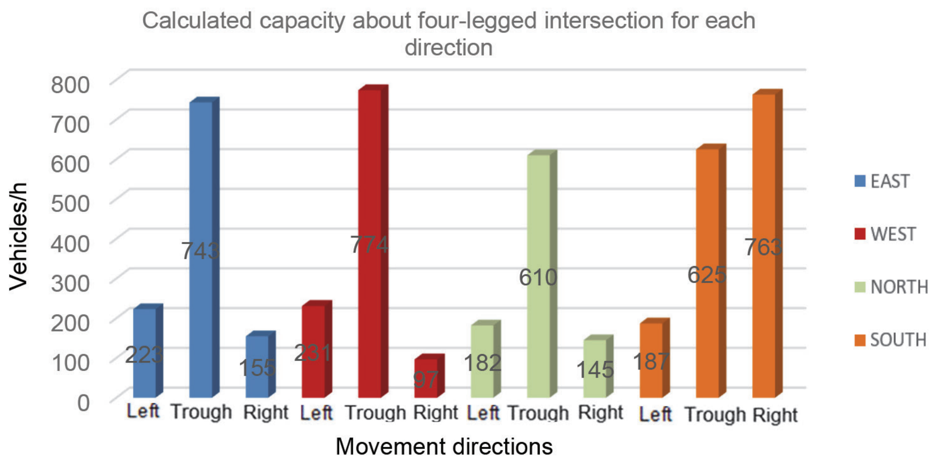

Figure 13 Calculated capacity (vehicles/h) about four-legged intersection [source: Author]

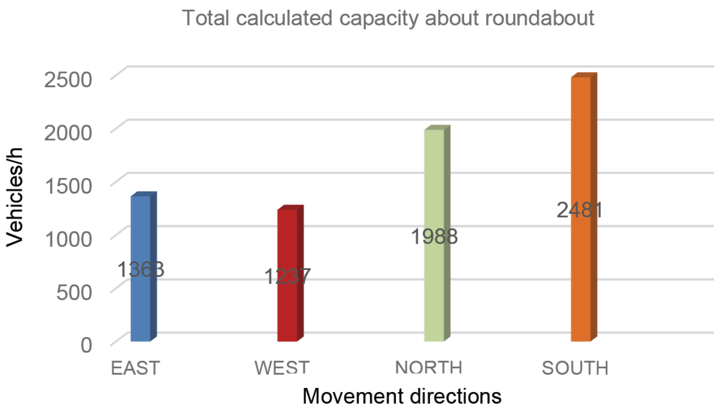

Figure 14 Calculated capacity (vehicles/h) about roundabout [source: Author]

5 Results and discussions

Achieving the required capacity and level of service on any road and intersection as a whole, urban or suburban, is correlated with traffic load and geometric features [11]. In the years to come, with the development of technology and industry, as well as with social changes, traffic planning will become even more complex. With the help of HCM methods that provide the level of service and capacity for signalized intersection, unsignalized classic or circular intersection, an analysis was made of the intersection in urban area in the city of Shtip. The aim is to achieve satisfactory level of service and capacity.
With the performed analyses, results can be obtained where the level of service for any of these solutions is not satisfied. In this case, it is necessary to make changes in the existing solution and direction of traffic.
One of the ways to improve the level of service at a given intersection is to redirect part of the traffic on the existing road network, which would relieve this intersection. The possibility to expand the existing road network is not the most favourable solution, because by increasing the number of lanes, the capacity of the leg can be increased, but in the part of the intersection, large delays can occur, which would make it non-functional.
In general, it was observed that the existing current solution has reached its maximum design service volume capacity and has crossed the Level of service (L.O.S-F) for Partizanska street.
Each of the proposed solutions has advantages and disadvantages.
It is evident that the existing solution at the intersection has unacceptable values for level of service and delays, and appropriate measures must be taken to increase the level of service.
On the other hand, the solution with signalized four-legged intersection has a relatively small delay for all approaches and excellent level of service.
The proposed roundabout, with two traffic lanes, gives satisfactory results both in terms of service level and delays.
Considering the capacity (throughput) in the part of the intersection from Figures 14 and 15, it can be noticed that the roundabout solution provides the largest capacity and throughput of vehicles.

6 Conclusions

At the moment when the existing intersection, due to overload or a large number of registered accidents, no longer functions as planned, the question arises whether there is a better solution, another type of intersection that works better. When introducing a new intersection into the traffic network, there is often a dilemma as to which type of intersection to apply. The path to a solution to these problems is not easy. The choice of the most favourable solution when choosing the type of intersection is influenced by aspects such as traffic safety and the quality of traffic flow determined by the capacity, waiting time and the degree of saturation. Other aspects that may influence the choice are the integration of the solution into the environment (surface and aesthetic) and of course the costs.

The measured traffic data, from the existing state, is the key element for making this type of analysis. The same data can be used for calculating the three types of intersections.

From the results obtained from the HCM model, due to the heavy traffic load, the most acceptable solution was a four-legged signalized intersection.

The previous results are important because they can determine level of service and capacity for different solutions and improve the traffic performance of them in the future.

Finally, future research should be conducted to extend all aspects of this research using comprehensive field data and traffic measuring. For each major and significant intersection in urban areas it is necessary to make an analysis of capacity and level of service, in order to solve the problem of traffic jams.

It is necessary to make measurements of traffic on a time interval to get a realistic picture of the growth of traffic, which would perform a satisfying capacity in the future.

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