MULTI-CRITERIA ANALYSIS OF DESIGN ALTERNATIVES FOR AN URBAN SIGNALIZED INTERSECTION: A CASE STUDY FROM SPLIT (CROATIA)

Biljana Maljković, Katarina Rogulj, Deana Breški, Marko Protrka
University of Split, Faculty of Civil Engineering, Architecture and Geodesy, Croatia

Abstract

Urban signalized intersections operating under high traffic demand are among the most complex elements of the urban road network. They frequently experience excessive delays, long queues, and reduced safety performance, all of which collectively diminish the overall efficiency of the transport system. Maintaining an adequate level of service therefore requires both proper geometric design and the implementation of effective traffic control strategies. Under conditions of poor performance, efficiency can often be enhanced through relatively simple measures such as optimizing signal timings or adding auxiliary lanes. However, in cases of severe congestion or compromised safety, large intersections may require more extensive and costly interventions, such as the construction of grade-separated interchanges. Given the growing traffic volumes and limited spatial capacity of urban areas, the selection of the most suitable improvement strategy becomes a complex engineering and decision-making task. This study analyses several design alternatives for a signalized intersection of a major and minor urban arterials in Split (Croatia), using the analytical model SIDRA INTERSECTION. Traffic data were collected during the afternoon peak period under favourable weather conditions using two cameras positioned at strategically selected locations, ensuring comprehensive coverage for model development and calibration. To enhance the intersection's operational performance, three design alternatives were evaluated: (1) signal timing optimization, (2) adding a right-turn lane to one approach and extending the existing exclusive left-turn lanes, and (3) constructing a single roundabout interchange. Each alternative has specific advantages and limitations, and their feasibility depends on multiple factors. Therefore, a multi-criteria decision-making approach was applied to support the evaluation process, considering safety, level of service, cost-effectiveness (fuel consumption), construction cost, spatial and aesthetic integration, and environmental impact.

Keywords: traffic analysis, urban signalized intersection, SIDRA INTERSECTION, multi-criteria decision-making (MCDM), evaluation based on distance from average solution (EDAS)

1 Introduction

Urban road network consists of links and nodes whose individual performance significantly influences the overall efficiency, safety, and sustainability of the transport system. Intersections, where traffic streams cross, merge, diverge, and frequently stop, represent the most complex and critical components of the network. High traffic volumes combined with limited spatial capacity often result in excessive control delay, long queues, and reduced safety. Therefore, adequate design of urban streets and intersections, as well as the application of appropriate regulation and control of traffic flows, is very important.

DOI: https://doi.org/10.5592/CO/CETRA.2026.1856

Operational measures, such as signal timing optimization, can significantly reduce delay at moderate levels of congestion [1], while geometric improvements such as the addition of exclusive turning lanes, can increase capacity and mitigate queue spillback [2]. However, in cases of persistent congestion, more comprehensive infrastructure interventions such as grade separation may be required. Consequently, selecting the most appropriate improvement strategy represents a complex problem, which can be addressed using multi-criteria decision-making (MCDM) methods. For traffic performance assessment, various analytical and simulation-based models are used [3].
By combining the analytical model SIDRA INTERSECTION [4] with a MCDM method EDAS (Evaluation based on Distance from Average Solution) [5], this study evaluates three alternative improvement strategies for a congested urban signalized intersection in the city of Split, Croatia. The objective is to identify the traffic control and infrastructure measures that represent the best compromise solution with respect to safety, traffic performance (LOS), economic feasibility, construction cost, spatial and aesthetic integration, and environmental impact.

2 Methodology

In this study, improvement alternatives for an urban signalized intersection were analysed using the SIDRA INTERSECTION and evaluated using MCDM approach. The methodology is described in the following sections.

2.1 Analytical traffic model

The Highway Capacity Manual (HCM) [6] is the most widely accepted methodology worldwide for the analysis of capacity and operational performance of signalized intersections, as well as other elements of the road transport system. The HCM framework was applied in this study through the use of the SIDRA INTERSECTION software package [4]. After defining the required input parameters and performing the analysis, the model provides a range of measures of effectiveness (MOEs). The quality of traffic operations at intersections is commonly expressed through the level of service (LOS), based on average control delay and volume-to-capacity (v/c) ratio [6]. Among the numerous available output indicators, the following MOEs were considered in this study: control delay, v/c, LOS, fuel consumption (FC), and carbon dioxide (CO_2) emissions.

2.2 Multi-criteria decision-making (MCDM)

To select the optimal project alternative, the EDAS method [5] was applied, which belongs to the group of MCDM methods. This method is based on the alternative's evaluation according to their positive and negative distance from the average solution for each criterion, unlike some other MCDM methods that use ideal and anti-ideal solutions. In this way, it allows a balanced evaluation of alternatives that have different advantages and disadvantages in relation to the observed criteria. The EDAS method is applied in this study because the analysed alternatives show different performances with respect to multiple criteria. Since no single alternative is optimal according to all criteria, it is necessary to apply a multi-criteria approach that allows ranking of the alternatives and selecting a compromise solution, taking into account various technical, environmental, and economic aspects of the observed traffic system. The method consists of several basic steps. First, a decision matrix is formed that contains all the analysed alternatives and the corresponding criterion values. Then, an average value is determined according to all criteria. In the next step, positive (PDA) and negative distance (NDA) from the average solution is calculated, depending on the type of criteria (benefit and cost).

After that, the obtained values are weighted (SP, SN) according to the importance of individual criteria and their normalization (NSP, NSN) is carried out. Finally, the appraisal score (AS) of each alternative is calculated, and the ranking of alternatives is carried according to the decreasing values of AS. At the end, the optimal solution is determined.

3 Case study

The analysis was conducted at a four-leg signalized intersection of Poljička Street and Velebitska Street in Split, Croatia (figure 1). According to the hierarchical classification of urban roads, Poljička Street is a major arterial road and part of the state road network due to its regional traffic function, while Velebitska Street is a minor arterial road. Poljička Street has six lanes, whereas Velebitska Street has four lanes, with additional exclusive left-turn lanes on all approaches. The lane width is 3 m, and the longitudinal grades (g) are indicated in figure 1. Traffic data were collected on a weekday during the afternoon peak period under favourable weather conditions using two cameras installed on the terrace of a residential building. Camera positions are indicated by red dots in figure 1.

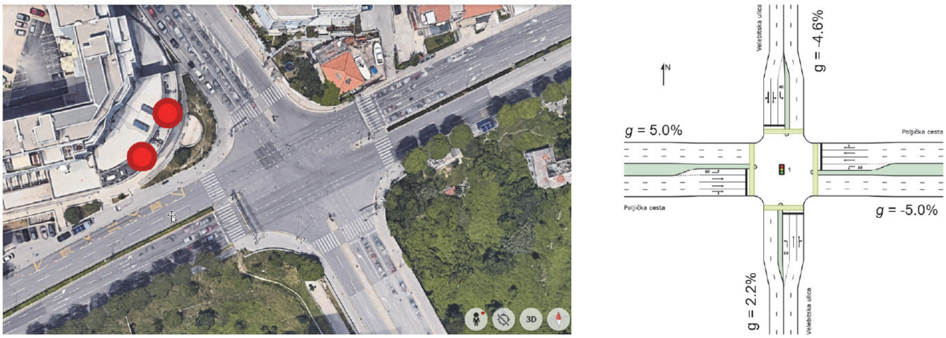

Figure 1 Analysed signalized intersection in Split

4 Analysed alternatives and results

Based on the conducted traffic counts, the collected geometric and traffic signal control data, a base model representing the existing conditions was developed. Model calibration was performed using the basic saturation flow rate as one of the key calibration parameters, as recommended in [4]. The lane saturation flow was measured in the field for the through lane of the east approach using the ARR 123 method [4]. Based on the measured value of 1,683 veh/h, the model was calibrated by adjusting the basic saturation flow rate, and a value of 1,851 veh/h was adopted for further analyses. After calibrating the base model for existing conditions, additional models were developed by introducing selected geometric and traffic engineering improvements that were expected to improve the operational performance of the intersection. Considering the available space and potential capacity improvements, the following three alternative solutions were analysed:

- **Alternative 1:** signal timing optimization
- **Alternative 2:** the addition of a right-turn lane on the east approach and the extention of the existing exclusive left-turn lane
- **Alternative 3:** the construction of a single roundabout interchange.

4.1 Existing conditions

Based on field observations, the main operational problem under the existing conditions at the analysed signalized intersection is the significant right-turn traffic demand on the east approach. Due to the absence of an exclusive right-turn lane, right-turning vehicles share a through-right lane with through traffic. The analysis of existing conditions for the afternoon peak period confirmed unsatisfactory level of service on the affected approach (table 1). The resulting LOS F on the east approach indicates oversaturated conditions (v/c = 1.21) and substantial average delays for both right-turn movements (244 s/veh) and through movements (139 s/veh). The high volume of right-turning vehicles significantly reduces the operational efficiency of the shared lane group and causes additional delay not only for right-turning vehicles but also for through traffic.

Table 1 Measures of effectiveness for existing conditions

Intersection approach	North			South			East			West		
Movement	L	T	R	L	T	R	L	T	R	L	T	R
Control delay [sec/veh] and v/c ratio	48	35	17	38	38	25	65	139	244	56	39	40
	39 / 0.68			33 / 0.56			161 / 1.21			41 / 0.78		
LOS	D			C			F			D		
Fuel consumption [l/h]	60.2			67.5			308.4			183.3		
CO_2 [kg/h]	141.8			159.4			727.8			433.3		

4.2 Alternative 1

Signal timing optimization was considered as the least invasive and most cost-effective measure. In this analysis, the "Optimum Cycle Time" option available in the SIDRA INTERSECTION software was applied. This procedure allows the program to optimize the signal cycle time based on a selected performance measure, which in this case was control delay. The optimal cycle length of 100 s was determined while maintaining the existing phase sequence. With the optimized signal timing, significantly improved operational results were obtained on the critical east approach compared with the existing conditions. However, due to the high v/c ratios, this measure cannot be considered a long-term solution, as the capacity limit is reached even with a small increase in traffic volumes. It should be noted that the intersection was analysed as an isolated intersection. Nevertheless, optimization within a coordinated signal network could lead to different optimal parameters.

Table 2 Measures of effectiveness for Alternative 1

Intersection approach	North			South			East			West		
Movement	L	T	R	L	T	R	L	T	R	L	T	R
Control delay [sec/veh] and v/c ratio	52	35	19	44	30	20	72	49	33	74	31	23
	41			28			47			37		
LOS	D / 0.87			C / 0.97			D / 0.90			D / 0.72		
Fuel consumption [l/h]	58.1			65.9			290.1			211.4		
CO_2 [kg/h]	136.7			155.6			684.7			499.5		

4.3 Alternative 2

This variant includes relatively simple geometric improvements. A 90 m long right-turn lane was added to the east approach. Accordingly, the existing left-turn lane on the same approach was extended from 40 to 90 m. In addition, signal timing was optimized by using the “Optimal Cycle Time” option at SIDRA INTERSECTION, while maintaining the existing phase order. These measures significantly reduced control delay and improved the level of service on the critical east approach (table 3), resulting in a satisfactory LOS D. This alternative also provides a significantly higher capacity reserve compared with Alternative 1.

Table 3 Measures of effectiveness for Alternative 2

Intersection approach	North			South			East			West		
Movement	L	T	R	L	T	R	L	T	R	L	T	R
Control delay [sec/veh] and v/c ratio	36	31	16	40	28	18	53	34	36	62	39	30
	32 / 0.66			26 / 0.41			36 / 0.83			42 / 0.83		
LOS	D			C			D			D		
Fuel consumption [l/h]	52.9			65.2			234.5			218.2		
CO_2 [kg/h]	124.4			154.0			553.5			515.7		

4.4 Alternative 3

Alternative 3 involves grade separation of the intersection and is the most complex and costly solution. The main traffic stream along Poljička Street is routed through an underpass, while a two-lane urban roundabout with an outer radius of 50 m is proposed above the underpass at the level of the existing intersection. The roundabout is connected to the main traffic stream by single-lane ramps in all directions. The proposed solution was adopted from the study [7] which suggested a single roundabout interchange at the intersection of Poljička Street and B. Bušić Street, and would also be suitable for the analysed intersection given the existing operational problems. It should be noted that, given the spatial constraints, a more detailed analysis would be necessary to verify the technical feasibility of implementing this solution. By separating the main traffic stream from minor, this solution significantly increases intersection capacity, reduces delay, and improves overall traffic safety. Consequently, this alternative provides the most favourable overall performance from both operational and safety perspectives.

Table 4 Measures of effectiveness for Alternative 3

	ROUNDABOUT				ARTERIAL	
Intersection approach / Direction	North	South	East	West	West	East
Control delay [sec/veh]	9	10	29	16	0.1	0.1
LOS	A	B	D	C	A	A
Fuel consumption [l/h]	75.8	45.8	93.3	39.6	76.4	68.5
CO_2 [kg/h]	178.5	108.0	220.3	93.6	182.0	162.4

4.5 Selection of the optimal solution using MCDM

Six criteria were used to evaluate the analysed alternatives: safety, traffic flow efficiency (LOS), spatial and aesthetic integration, cost-effectiveness (FC), environmental impact (CO_2), and construction cost. Table 5 summarizes the traffic performance results for the existing conditions and all analysed alternatives.

Table 5 Comparison of selected measures of effectiveness

	Control delay [sec/veh] / LOS				Total losses	
					FC [l/h]	CO_2 [kg/h]
Intersection approach	North	South	East	West		
Existing conditions	39 / D	33 / C	161 / F	41 / D	619.4	1, 462.3
Alternative 1	41 / D	28 / C	47 / D	37 / D	625.5	1, 476.5
Alternative 2	32 / D	26 / C	36 / D	42 / D	570.8	1, 347.6
Alternative 3	9 / A	10 / B	29 / D	16 / C	330.4	944.8

The decision matrix with criteria, rating scales, and units are presented in table 6. Also, the average values according to all criteria are given in table 6. Benefit criteria are Safety, LOS and Spatial and aesthetic integration, while cost criteria are FC, CO_2 and construction cost. Criterion weights were derived from the opinions of several stakeholders with different perspectives, including traffic engineering experts, a road designer, and a citizen representative. The first three criteria were evaluated on a scale from 1 to 5, while the remaining criteria were expressed numerically based on the analysis results or rough cost estimates. Safety was assessed based on the number of conflict points and the separation of conflicting traffic streams. Alternative 1 was assigned a score of 2 because the basic conflict structure of the intersection remains unchanged. Alternative2 received a score of 3 due to improved separation of turning movements. Alternative 3 was rated as the safest solution (score 5) because grade separation eliminates conflicts between the main and minor traffic streams. Construction costs were estimated as order-of-magnitude values representative of Croatian urban road projects, based on publicly available national reference costs and comparable recent road/intersection projects. The estimates are intended for relative comparison in the MCDM framework rather than for budgeting purposes. Table 7 presents the summary of EDAS method results.

Table 6 Input data for MCDM - decision matrix

CRITERION	EVALUATION		ALTERNATIVES			
	Score range / Units	Crit. weight	Alt. 1	Alt. 2	Alt. 3	Avg.
1. Safety	1 - 5	0.220	2	3	5	3.33
2. Traffic flow efficiency (LOS)	1 - 5	0.384	2	3	4	3.00
3. Spatial and aesth. integration	1 - 5	0.081	3	3	4	3.33
4. Cost-effectiveness (FC)	l/h	0.103	625.5	570.8	330.4	508.9
5. Environmental impact (CO_2)	kg/h	0.110	1, 476.5	1, 347.6	944.8	1256.3
6. Construction cost	Mil. €	0.103	0.01	0.1	10	3.37

Table 7 The EDAS calculation results

Alternatives	ΣwPDA (SP)	ΣwNDA (SN)	NSP	NSN	AS	Rank
Alternative 1	0.103	0.267	0.323	0	0.162	3
Alternative 2	0.100	0.051	0.315	0.810	0.563	2
Alternative3	0.318	0.203	1	0.241	0.620	1

5 Conclusion

In this study, three improvement measures for a congested urban signalized intersection in Split, Croatia, were analysed using SIDRA INTERSECTION and the EDAS MCDM method. The existing conditions showed poor LOS, particularly on the east approach, where the absence of an exclusive right-turn lane causes excessive delay for both right-turning and through vehicles. All three alternatives improve intersection performance, but with different levels of traffic efficiency, feasibility, and cost. Alternative 1, based on signal timing optimization, is the simplest and least expensive measure, but its low capacity reserve makes it unsuitable as a long-term solution. Alternative 2, which combines simple geometric improvements with signal timing optimization, provides better LOS on the critical approach and offers a greater capacity reserve than Alternative 1, making it the most realistic compromise solution. Alternative 3, which involves single roundabout interchange, provides the best traffic and safety performance, but also requires the highest construction cost. Nevertheless, the comparison of alternatives was carried out using the EDAS MCDM method. Applying the EDAS method to the three analysed alternatives, the following final ranking was obtained: Alternative 3 › Alternative 2 › Alternative 1. The best-ranked alternative is Alternative 3 with AS = 0.620, which achieves the highest overall score despite the high construction cost, primarily due to very favourable results in the criteria of safety, traffic flow efficiency and environmental impact. Alternative 2 represents the second-ranked, compromise solution, while Alternative 1 is rated as the least favourable among the considered alternatives. The study also confirms the usefulness of combining analytical traffic modelling with MCDM techniques in the evaluation of urban intersection improvements. Such an approach enables a more comprehensive assessment than relying on capacity and delay indicators alone.

Acknowledgments

This research was partially supported by project KK.01.1.1.02.0027, co-financed by the Croatian Government and the European Union through the European Regional Development Fund, and by the project Integrated Approach to the Sustainable Revitalisation of the URBan Environment Using NATural Materials (URB-NAT) project funded by the Ministry of Science, Education and Youth of the Republic of Croatia; grant recipient: FCEAG, Split, Croatia.

References

[1] Terraza, M., Zhang, J., Li, Z.: Intersection Signal Timing Optimisation for an Urban Street Network to Minimise Traffic Delays, Promet - Traffic&Transportation, 33 (2021) 4, pp. 579–592, DOI: 10.7307/ptt.v33i4.3694

[2] Breški, D., Maljković, B.: Simulation-Based Modeling of the Impact of Left-Turn Bay Overflow on Signalized Intersection Capacity, Sustainability, 17 (2025) 12, DOI: 10.3390/su17125397

[3] Cvitanić, D., Maretić, M., Zekan, J., Bošnjak, I.: Comparison of the Models for Analysing Signalized Intersections, 5th International Conference on Road and Rail Infrastructure - CETRA 2018, pp. 1541–1547, Zadar, Croatia, 17-19 May 2018., DOI: 10.5592/co/cetra.2018.666

[4] Akçelik, R.: SIDRA INTERSECTION User Guide 10.0, SIDRA Solutions Pty Ltd, Australia, 2026.

[5] Ghorabaee, M.K., Amiri, M., Zavadskas, E.K., Turskis, V.: Multi-criteria Inventory Classification Using a New Method of Evaluation Based on Distance from Average Solution (EDAS), Informatica, 28 (2017) 2, pp. 311–328, DOI: 10.15388/Informatica.2015.57

[6] Highway Capacity Manual, 7th edition, Transportation Research Board, Washington DC, 2022.

[7] IGH: Prostorno - prometna studija šireg područja grada Splita, Split, 2010.