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ORIGINAL SCIENTIFIC PAPER

Analysis of the Possibilities for Improving Traffic Flow Conditions by Introducing a DLT Intersection in the City of Novi Sad

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Abstract: Displaced left-turn (DLT) intersections have gained their popularity because their implementation reduces control delay and improves the level of traffic safety. Their alternative configuration of traffic lanes enables the execution of left turns within the central part of the intersection without conflict with vehicles from the opposite direction. On the other hand, in Serbia, a large number of roundabouts have been constructed in recent decades for which no prior analyses of capacity and level of service were carried out, nor forecasts of traffic demand for the planned operational period. For that reason, some roundabouts exhibit very unfavorable traffic flow conditions with high vehicle delays, especially in situations when the circulating zone is blocked. Within this research, the possibility of applying a DLT intersection is considered by reconstructing a roundabout in the city of Novi Sad where unfavorable traffic flow conditions occur during peak hours. The analysis was conducted through a comparison of delays, queue lengths, and level of service in relation to a conventional (four-leg) signalized intersection as another proposed solution. The evaluation of traffic flow conditions was carried out through simulation in the Vissim software (Student version). By applying both proposed solutions, efficient traffic flow would be ensured, where the obtained parameters indicate the advantage of the DLT intersection.
Key words: DLT intersection, four-leg signalized intersection, control delay, level of service.

INTRODUCTION

One of the fundamental problems in the field of traffic regulation and management is the traffic flow conditions at intersections. When the traffic intensity exceeds the objective capacity of the intersection, control delays begin to increase sharply, and for that reason, the method of traffic regulation at intersections changes. One typical drawback of roundabouts is the inability to respond to high traffic demands due to blockage of the circulating zone, and thus of all approaches [1]. In that case, it is often a realistic possibility to carry out a reconstruction into a multi-lane signalized intersection. Also, under conditions of significant traffic loads, as a transitional solution between conventional and grade-separated intersections, Unconventional Alternative Intersection Designs (UAIDs) are increasingly applied in developed countries. These are signalized intersections where left turns are redirected, thereby reducing the number of conflict points in the central part of the intersection, and thus avoiding the addition of phases for protected left turns. The application of UAIDs shortens travel time [2] and improves the level of traffic safety [3-6]. Due to their more complex geometry, UAIDs occupy more space than typical intersections, so their application is often on the outskirts of cities where transit and local traffic meet.

The aim of this research is to examine the possibility of applying one of the UAID types in the city of Novi Sad at the location of a roundabout whose construction cannot efficiently ensure the flow of the existing traffic intensity. It concerns the *Displaced Left-turn* (DLT), also known as *Continuous Flow Intersection* (CFI) and *Crossover Displaced Left-turn* (XDL). The analysis was conducted through a comparison of delays, queue lengths, and level of service in relation to a four-leg signalized intersection as another proposed solution. For the evaluation of parameters, the PTV Vissim software (Student version) was used [7].

At DLT intersections, left turns are redirected over lanes designated for opposing traffic before the central part of the intersection. The idea is that left turns are then served in the same phase together with through movements from the opposite direction, without conflict. As a consequence of this type of regulation, new, secondary intersections arise. A typical configuration of a full DLT consists of five intersections: one main and four newly created intersections at each approach (**FIGURE 1**). Traffic control at all five intersections is managed by traffic signals. It is common for right turns to be channelled and served behind the newly created intersections. In addition to full DLT, there are also partial DLT intersections (configuration with three intersections) where the displaced left turns are only located along the main corridor while the minor approaches have standard geometry. DLT and other UAID intersections have gained popularity through application in the United States of America. The state of Utah has more than ten DLT intersections, and they are also found in locations such as New York, Oakland, Louisiana, Los Angeles, Maryland, etc. [8], emphasising the success of this unconventional intersection design.

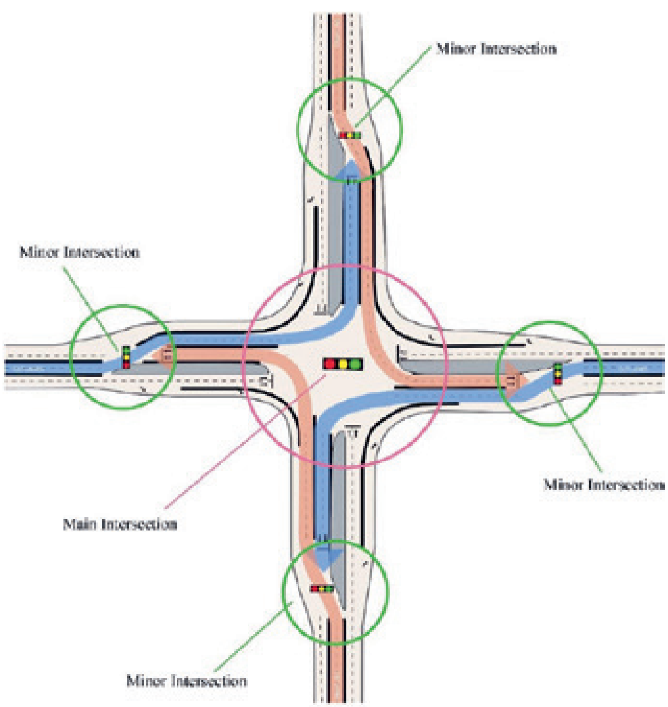

Figure 1. Typical concept of a full DLT intersection with left-turn paths. [9]

Performance of DLT Intersections

DLT intersections provide better operational performance than conventional signalized intersections in several aspects (delay, safety, environment), which is especially pronounced when the flow on the approaches exceeds 1000 veh/h [10]. In some cases, the capacity of a DLT intersection can be 80%, and even up to nearly 100% higher under saturated traffic flow conditions compared to conventional intersections [11-13]. Also, under unsaturated flow conditions, DLT intersections have better operational performance, where the number of stops is 15-30% lower compared to conventional intersections, and under saturated traffic conditions by 85-90% [14]. Furthermore, the performance of DLT intersections is also more favourable compared to roundabouts [15].

Also, DLT intersections are safer compared to standard signalized intersections [16]. The introduction of DLT can reduce the number of traffic accidents by 15-25% [3, 4]. However, a certain group of users requires time to adapt to driving through DLT intersections [17]. From an environmental and fuel consumption perspective, some studies [16, 18] give preference to DLT over conventional intersections, where, in cases of heavy traffic flows, emissions are reduced by approximately 10%

CURRENT STATE DESCRIPTION

The research area is the location of a roundabout in Novi Sad, formed by the intersection of Bulevar Evrope and Rumenački put (**FIGURE 2**). Bulevar Evrope represents one of the most significant roads in Novi Sad as it connects the urban areas of the city with the E-75 motorway, and at the same time is the longest boulevard in Novi Sad. The intersection is located in the wider central zone of the city. It consists of four legs with two traffic lanes each in the circulating area and entry arms. Due to high traffic flow demands, it is known that unfavourable traffic flow conditions occur at all approaches of the subject intersection, especially during peak hours, where traffic flows often become oversaturated – with delays exceeding 60, and sometimes even 100 seconds (level of service F).

Figure 2. Research area

The basis for the analysis was the real traffic load measured in the field during the peak hour. In the table (**TABLE 1**) the flows by direction are shown, after forming a conditionally homogeneous flow in passenger car units.

Table 1. Traffic Flow by Direction

Direction	1_2	1_3	1_4	2_3	2_4	2_1	3_4	3_1	3_2	4_1	4_2	4_3
veh/h	143	585	432	15	458	206	244	722	35	491	421	367
Approach total		1160			679			1001			1279	
Total						4119						

Due to the location of the intersection, pedestrian flows are negligible and were not taken into account. The research area is flat terrain, so a longitudinal slope grade of 0% was adopted.

METHODOLOGY

In the area of the Bulevar Evrope – Rumenački put, there is a possibility of reconstructing the roundabout into another form of multi-lane intersection. Two solutions with the same number of traffic lanes were proposed for evaluation:

1. Four-leg signalized intersection with four lanes on the approaches where right turns are channelled;
2. Full DLT intersection with four lanes on the approaches where left turns are displaced and right turns are channelled.

In recent years, two-lane roundabouts are often reconstructed into so-called turbo roundabouts, which are effective in situations where flows do not exceed about 3500 veh/hour [19]. This is one of the reasons why such types of intersections were not considered in the analysed case.

The geometries of the intersections for the proposed solutions were implemented in the PTV Vissim software (Student version) (**FIGURE 3**, **6**), where the evaluation of traffic signal operation parameters was also carried out. One of the limitations of the student version of this software relates to the simulation duration, which is limited to 600 seconds, and this was applied in the analysed case, with the evaluation starting from the 150th second (vehicle accumulation period – so-called "warm-up" of the simulation). The authors consider that in the analysed case this limitation on simulation length presents justified values of the measured indicators, because the evaluation for both proposed solutions resulted in delays reflecting conditions of unsaturated traffic flows, and vehicles rarely remain in the intersection area after the current cycle ends. Furthermore, to account for stochasticity, multiple simulations of 10 iterations each were conducted at the subject intersections (*Random Seed:* 12, 22, ..., 102), with the results analysed based on average parameter values.

To compare the efficiency of traffic operation under traffic signal control, it is necessary to optimise their functioning. In the case of fixed-time signal operation, this is achieved by calculating the elements of the signal plan, that is, determining the optimal cycle length and green times. To determine the optimal cycle length, data on the saturation flow rate are required, which for both proposed solutions was obtained using the HCM method [20].

Scenario 1 – Four-Leg Signalized Intersection

The proposed solution represents a signalized intersection (**FIGURE 3**) with four traffic lanes on the approaches (two through, one for left turn, and one channelized for right turn), of which the short lanes are those extending along the edges of the carriageway. The short lanes on the approaches were assigned lengths of 60 meters. The exits consist of three traffic lanes, with the short merge lane extending along the right edge of the carriageway. The width of all traffic lanes is 3.5 meters.

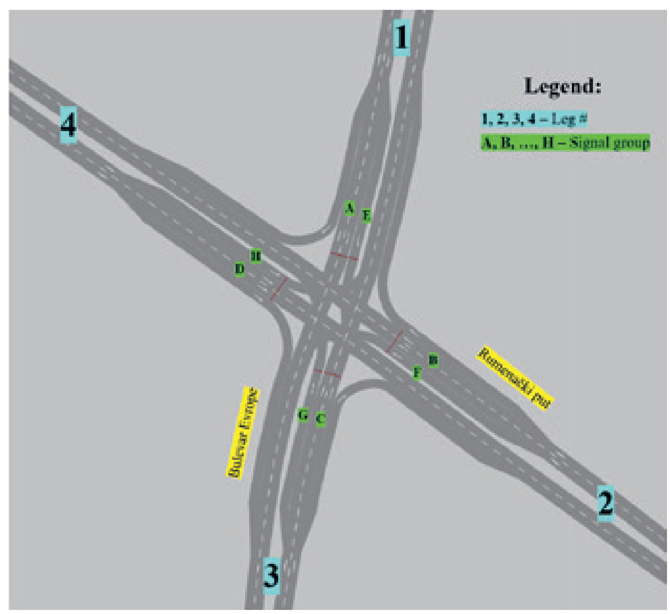

Figure 3. Layout for Scenario 1

Efficiency testing of the intersection was carried out using several different scenarios of signal plans and phase sequences. It was determined that the following phase sequence (**FIGURE 4**) provides a stable movement regime by directions and approaches, with the lowest values of control delay.

The calculation of the signal plan elements was carried out using the *Critical flow method* [21], where the optimal cycle length (C_o) is obtained as follows:

$$C_o = \frac{(1{,}4 + k) \cdot L + 6}{1 - Y} \quad (1)$$

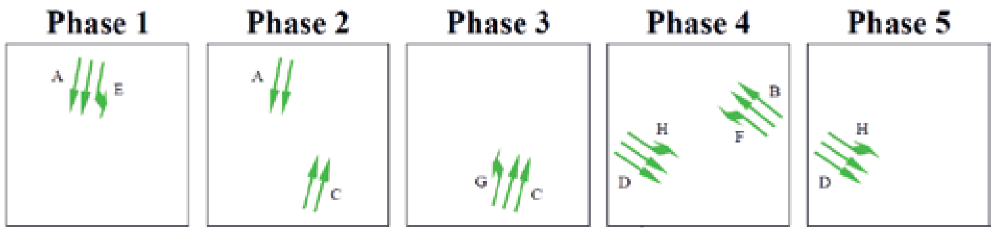

Figure 4. Proposed phasing diagram for Scenario 1

where:

- L – lost time during the cycle;
- Y – sum of the flow ratios of the signal groups forming the critical flow;
- k – additional optimisation parameter (for minimum control delay, the value k = 0 is adopted).

For the practical saturation degree values of all flows, the value X_p = 0.85 was selected. The lost time at start-up and the utilisation of the yellow interval were both adopted as equal, 2 seconds for all flows.

The adopted cycle length with the distribution of green times is presented using the standard display in Vissim (**FIGURE 5**)

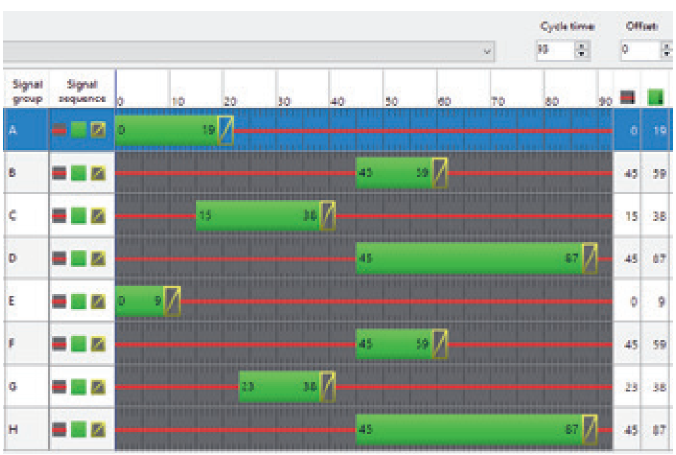

Figure 5. Signal settings for Scenario 1

Scenario 2 – DLT intersection

The proposed solution represents a full DLT intersection with displaced left turns on all approaches (**FIGURE 6**). All approaches to the central intersection zone (I1) consist of four traffic lanes (two through, one displaced for left turns, and one channelized for right turn), where the short lane is the one extending along the right edge of the carriageway with a length of 60 metres. Additionally, the displaced left-turn lane in DLT intersections is generally shorter than the lanes serving through movements, as it consists of two parts: a short lane before the displacement to the opposite side of the road (signal groups E', F', G', H') and a somewhat longer lane after the displacement (signal groups E, F, G, H). In the analysed case, the length of the northern approach is limited due to a bridge located approximately 130 metres from the centre of the intersection (**FIGURE 2**). For this reason, the length of the displaced left-turn lane is about 70 metres, which is slightly shorter than the standard length [8]. However, no issues were observed during the simulation, as the volume of vehicles turning left from that approach is not significant. Additionally, **FIGURE 6** shows that, due to limited space at certain roadside areas, the analysed DLT intersection has fewer lanes on the approaches compared to some standard solutions, which typically have two lanes for displaced left turns (**FIGURE 1**), and often even three lanes for through movements. All traffic lanes on the approaches and exits are 3.5 metres wide, except for the short left-turn lanes (signal groups E', F'…), which are 3 metres wide.

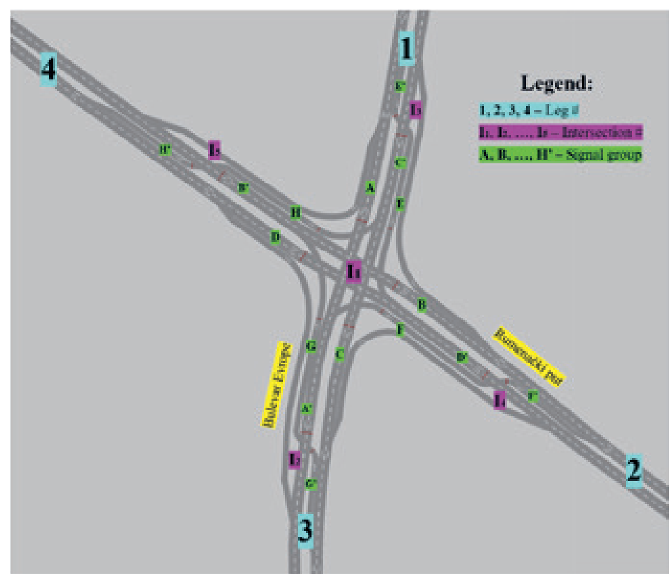

Figure 6. Layot for Scenario 2

The standard phase diagram for full DLT intersections consists of two main phases that cover all five intersections simultaneously (**FIGURE 7**). Traffic signal control can be implemented using a single controller that manages both the main intersection (I1) and the secondary intersections (I2, I3, I4, I5), or by using five separate controllers, one for each intersection, whose signal plans are coordinated through offset green times. In this case, the simulation of traffic flows in Vissim was conducted using a single signal controller.

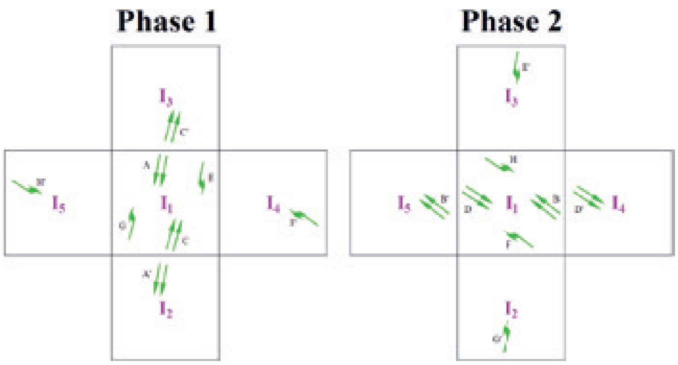

Figure 7. Basic phase diagram for a full DLT intersection

However, for even more efficient traffic flow, DLT intersections often implement a green time offset for the through movement signal groups (e.g. A→A'), which also creates an offset for the left-turn movements (e.g. E'→E). Achieving an ideal green time offset simultaneously for both through and left-turn movements would be quite complex, so a compromise should be made depending on the distribution of traffic loads. In the analysed case, an 8-second green time offset was applied, focused on through movements (**FIGURE 9**). As a result, the phase diagram becomes somewhat more complex, with the addition of two phases (interphases) (**FIGURE 8**).

In the case of applying either a single comprehensive or multiple separate signal controllers, it can be observed that control at all five intersections must operate with the same cycle length, and therefore [9]:

$$P_1 I_1 + P_2 I_1 = C \tag{2}$$

$$P_1 I_{2,3} + P_2 I_{2,3} = C \tag{3}$$

$$P_1 I_{4,5} + P_2 I_{4,5} = C \tag{4}$$

where:

- $P_1 I_1; P_2 I_1$ – first and second phase duration for intersection I_1;
- $P_1 I_{2,3}; P_2 I_{2,3}$ – first and second phase duration for intersections I_2 i I_3;
- $P_1 I_{4,5}; P_2 I_{4,5}$ – first and second phase duration for intersections I_4 i I_5.

$$C_o = \frac{1{,}5 \cdot L + 5}{1 - Y} \tag{5}$$

The calculation of the optimal cycle length and green times was carried out using the *Webster* method [22], based on the basic phase plan (**FIGURE 7**) relying on the signal groups within the main intersection (A-H). According to this method, the optimal cycle length is obtained as follows:

Based on the obtained cycle length and green times according to the basic phase plan, green time offsets are applied to the signal groups at the secondary intersections (**FIGURE 8**). Methodologies for calculating signal plans and traffic signal operation parameters for DLT and other types of alternative intersections can also be found in the HCM [23].

The adopted cycle length with the distribution of green times is presented in the signal settings (**FIGURE 9**).

Figure 9. Signal settings for Scenario 2

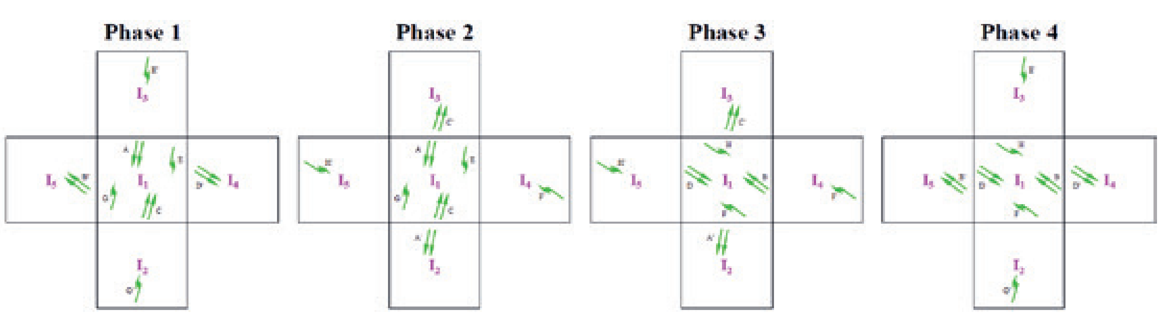

Figure 8. Phase diagram for Scenario 2 with green time offset

RESULTS AND DISCUSSION

Based on the evaluation in Vissim, a comparison of the proposed solutions was carried out (**TABLE 2**) according to the average vehicle control delay (**Delay** – s/veh), queue length (**QLen** – m), and level of service (**LOS**), for each direction and the entire intersection.

Table 2. Comparison of Output Results for the Proposed Solutions

	Four-leg signalized			DLT		
Direction	**Delay**	**QLen**	**LOS**	**Delay**	**QLen**	**LOS**
1_2	46,82	9,88	D	30,84	1,50	C
1_3	35,29	17,63	D	17,02	7,13	B
1_4	3,10	0,00	A	1,80	0,00	A
2_3	46,98	1,23	D	33,78	0,24	C
2_4	37,71	17,07	D	12,36	3.85	B
2_1	0,86	0,00	A	0,67	0,00	A
3_4	44,73	17,56	D	37,73	3,59	D
3_1	34,68	22,51	C	21,39	9,90	C
3_2	2,35	0,00	A	1,11	0,05	A
4_1	40,33	27,87	D	45,30	14,94	D
4_2	17,42	6,75	B	11,36	3,26	B
4_3	1,90	0,29	A	1,14	0,18	A
Average	**26,01**	**10,07**	**C**	**17,88**	**3,72**	**B**

As can be seen from **TABLE 2**, both proposed solutions would achieve efficient traffic flow (levels of service C and B). Although having fewer lanes than usual, the application of the proposed DLT intersection would reduce control delays by 31% compared to the subject four-leg signalized intersection. Thanks to the shorter cycle length and elimination of conflicts, delay for a single through movement (3_1) barely exceeds 20 seconds. All other delays above level of service B belong to left-turn movements. The reason is that vehicles arriving in the second half of the phase often have to stop up to three times to pass through the intersection (e.g. for movement 1_3, vehicles follow the signal path E′→E→D′). This often applies to a small number of vehicles (usually fewer than five), while other vehicles make use of the green wave between at least two signals in sequence, which can also be observed in the short queue lengths. Only for movement 4_1 are delays somewhat higher at the DLT compared to the four-leg intersection, because for a flow of 491 veh/h (**TABLE 1**), it would be desirable for the DLT to have two displaced left-turn lanes. However, although delays for movement 4_1 are somewhat higher at the DLT, the queue length for the same movement is almost half compared to the four-leg intersection, confirming the previous statement. A similar pattern in the Delay:QLen ratio between the analysed intersections is also observed for movement 3_4, as well as for certain through flows, thanks to the green time offset.

On the other hand, although the introduction of the DLT intersection would achieve better performance compared to the four-leg intersection, due to uneven traffic flows between certain approaches, the potential of this type of intersection is not fully realised. An example of this is movement 2_3, where during the peak period a traffic flow of only 15 veh/h was measured, yet the delays for this movement exceed 30 seconds for the aforementioned reason related to the path of the displaced left turns, as well as due to the load from the opposing movement 4_1, which causes a longer phase duration. At the four-leg intersection, delays for left turns at 2_3 are also increased because they are served simultaneously with movement 4_1, so that the busier flows in other phases can be served more efficiently

For the reasons mentioned, the cost-effectiveness of constructing and installing a DLT intersection can often be questioned. However, the application of a DLT intersection with a sufficient number of traffic lanes and a more favourable distribution of vehicle flows on the approaches could efficiently control circulation with traffic volumes twice as high as in the analysed case.

Figure 10. Simulation of vehicle movement for the proposed DLT intersection at the analysed location

CONCLUSION

This study analysed the possibility of applying a DLT intersection by reconstructing an existing roundabout where traffic flows often become oversaturated. In addition, the application of a standard multi-lane signalized intersection was considered. As parameters for evaluating the efficiency of traffic operation between the proposed solutions, control delay was primarily tested, followed by queue length and level of service.

It was established that the application of either proposed solution would achieve quite favourable traffic conditions, with a level of service B (DLT) and C (four-leg signalized), so from this aspect both scenarios could be considered functional solutions. The analysed DLT intersection would achieve a significant reduction in delays of around 31% compared to the four-leg. Nevertheless, in the analysed case, the potential of the DLT intersection was not fully realised. Besides the common spatial limitations for implementing DLT intersections with multiple displaced lanes, a large unevenness in vehicle flows on the approaches served in the same phase (especially left turns) limits its operational efficiency.

For the above reasons, before making a decision to construct such and similar types of alternative intersections, it would be advisable to thoroughly assess the cost-effectiveness of such a solution through functional evaluation, cost-benefit analysis, and, if possible, to consider the traffic load forecast with growth factors for a multi-year operational period. The described procedures could be classified as directions for further research.

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