

Article

The Impact of Road Realignment on the Traffic Load in the Surrounding Area

Peter Fabian , Kristián Čulík * , Alica Kalašová  and Ľubomír Černický 

Department of Road and Urban Transport, University of Žilina, Univerzitná 1, 01026 Žilina, Slovakia; peter.fabian@stud.uniza.sk (P.F.); alica.kalasova@uniza.sk (A.K.); lubomir.cernicky@uniza.sk (Ľ.Č.)

* Correspondence: kristian.culik@uniza.sk; Tel.: +421-41-513-3507

Abstract: This paper examines how the unidirectional alignment of a selected street affects traffic load at nearby signal-controlled intersections. Using the Aimsun 8 simulation model, the intersections in the city of Topoľčany were evaluated. A simulation model was created based on a traffic survey conducted by video detection at selected signal-controlled intersections. Both the negative and positive impacts of this modification were analyzed. This study shows a significant deterioration in the traffic situation. This paper further investigates the improvement achieved through corrective measures such as implementing an actuated control plan, modifying signal plans, and coordinating traffic flows. The results show the effectiveness of these measures in reducing congestion and improving traffic flow. They also serve as a foundation for optimizing traffic systems and implementing measures to improve urban mobility.

Keywords: road realignment; simulation model; traffic signal control; intersection evaluation; vehicles



Citation: Fabian, P.; Čulík, K.; Kalašová, A.; Černický, Ľ. The Impact of Road Realignment on the Traffic Load in the Surrounding Area. *Vehicles* **2024**, *6*, 1942–1962. <https://doi.org/10.3390/vehicles6040095>

Academic Editor: Elżbieta Macioszek

Received: 10 October 2024

Revised: 20 November 2024

Accepted: 21 November 2024

Published: 22 November 2024



Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The provision of human needs is increasingly intertwined with the necessary road modifications. These adaptations must be made in various contexts, such as developing ‘walkable cities’, securing sufficient parking spaces, or modernizing road infrastructure [1–3]. However, any intervention can affect the traffic situation in the surrounding area, and in some cases, even in areas of entire cities. Multiple studies prove the importance of parameters such as arrival flow rates and queue formation [4]. Therefore, it is crucial to consider the consequences and implement measures to ensure a smooth transition from the original to the new situation, minimizing negative effects.

This paper aims to identify and evaluate the negative impact on selected signalized intersections following the realignment of a street located in their vicinity. Significant traffic deterioration is encountered in practice when reducing the number of lanes [5]. In this case, however, the number of lanes in a given direction will not only be limited but the passage of vehicles in one direction will be fully restricted, which will cause a significant worsening in the surrounding area [6,7]. Road realignment also negatively affects public transport, as it causes asymmetry in the creation of public transport lines and the search for the shortest route [8].

The hypothesis of this study is that, given all these negative impacts, the overall traffic situation will significantly worsen after the selected street is made unidirectional. The negative impacts were evaluated by creating a simulation model in the Aimsun 8 software [9,10]. This software was chosen because it combines micro-, meso-, and macroscopic simulations that may be used in the future. Aimsun also provides advanced visualization tools that help to identify mistakes made while creating infrastructure.

However, in addition to negative impacts, realignment also brings positive impacts, such as creating on-street parking spaces, which can be combined with smart solutions like locating free parking places or creating safer transport infrastructure [11,12]. The results of

the different variants were evaluated and compared with each other to identify flaws and develop appropriate measures [13].

It is also hypothesized that corrective measures, such as creating a traffic-dependent signal plan at signalized intersections and creating traffic flow coordination, can significantly affect the worsened situation caused by the unidirectional alignment of the selected street.

This paper is organized into several key sections: Materials and Methods, Results, Discussion, and Conclusion. The Materials and Methods section details the traffic surveys, the development of a simulation model, and its calibration process. In the Results section, we assess the current quality level and examine various scenarios that may influence traffic loads. The Discussion summarizes the results, while the Conclusion addresses the limitations of the study, the potential future applications of the simulation, and additional solutions that could be explored.

2. Materials and Methods

Road transport currently dominates the transportation sector within the European Union [14]. However, this mode of transport has numerous negative environmental impacts, including high spatial demands, greenhouse gas emissions, noise pollution, and risks associated with traffic collisions [15–17]. Conventional vehicles continue to overwhelmingly dominate road transport over autonomous options [18], making infrastructure adjustments and reorganization of vehicle routing the most viable tools for improving traffic flow in urban areas nowadays.

Most projects focus on assessing road adjustments and creating simulations, often without including broader areas. This study focuses primarily on intersections and roads in adjacent areas to these changes. Although modifications can directly improve conditions on the modified road segment, they may also cause significant adverse effects in connected areas. This research aims to identify such negative impacts on areas indirectly affected by the adjustments. Additionally, it includes recommendations to minimize these negative effects.

To facilitate this assessment, a directional survey was conducted to determine the number of vehicles on the newly realigned one-way road. Additionally, an intersection survey was performed at three signalized intersections outside the one-way segment. Data from the intersection survey were collected using video detection, which automatically counted the data required for simulation modeling. Given the extensive data collected, these traffic figures were also used in the study entitled ‘Research on the Impact of Flexible Working Hours on Reducing Traffic Delays in the City’ [19].

The simulation model was built using actual values from the traffic survey, which collected data for individual vehicles and identified their entry and exit points [20]. The data collection was situated at three signal-controlled intersections in the city of Topolčany. The precise locations of these intersections are shown in Figure 1 (numbers 1–3).

The data were collected using video detection with automatic vehicle counting, as shown in Figure 2. The video detection was implemented through entry (green) and exit (red) gates, where the system automatically determined each vehicle’s origin, destination, and type. Similar cameras can also be used for video detection at traffic-dependent signal-controlled intersections to create a dynamic signal plan, where the presence of a vehicle triggers the extension or start of a green signal at a given entrance [22,23].

The survey data were used to create a simulation model of the study area, with exact vehicle counts given in Aimsun 8 software at 15 min intervals [24]. The simulation duration matches the traffic survey, running from 5:30 to 18:30 for 13 h. The road infrastructure was created on a map background to match the actual distances and to create a reliable model.

This map background, shown in Figure 3, was created with QGIS 3.34 software in two layers. The first layer serves as a base background map to verify the second layer’s accuracy. The base layer was created using the tool QuickMapServices, specifically the

OSM standard. The second layer, which can be seen in Figure 3, represents an orthophoto map created using a WMS connection to the national geoportal.

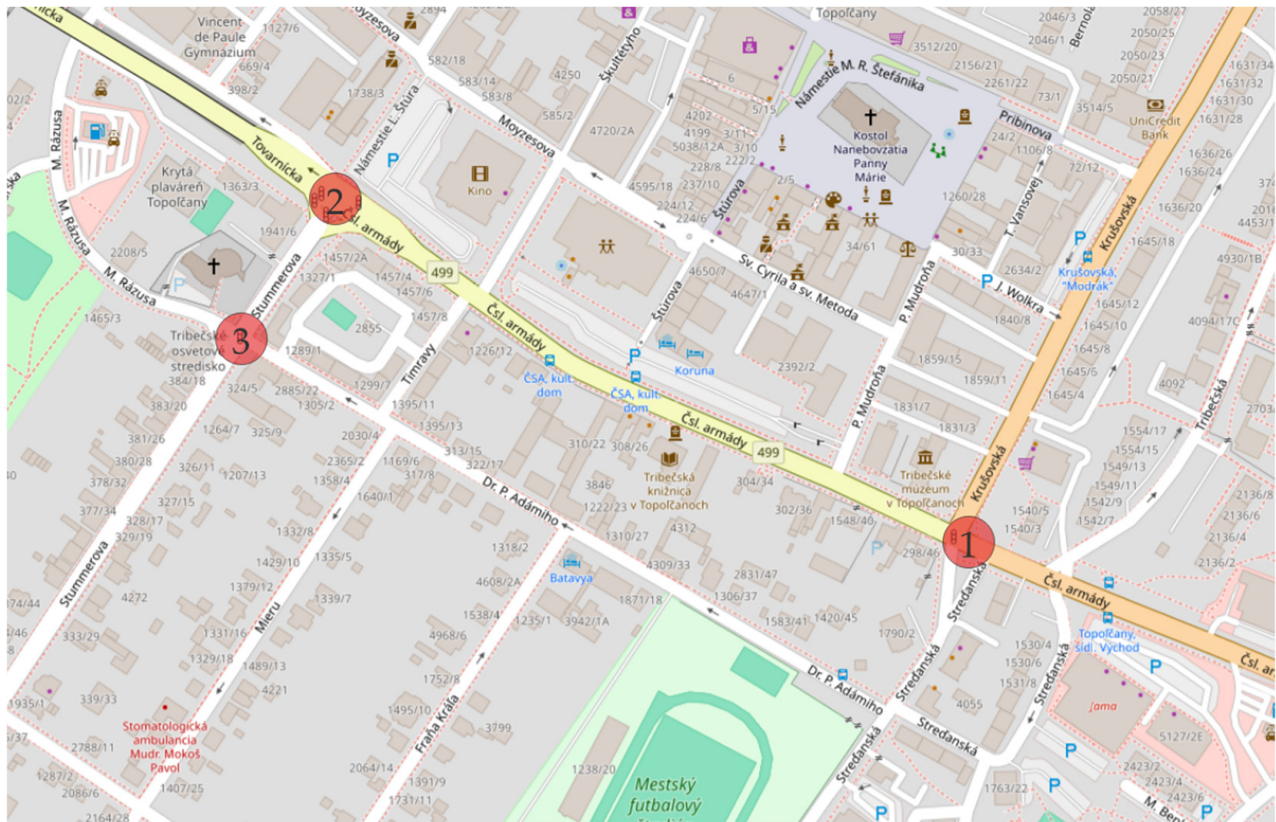


Figure 1. Location of chosen intersections. Source: processed by authors from [21].

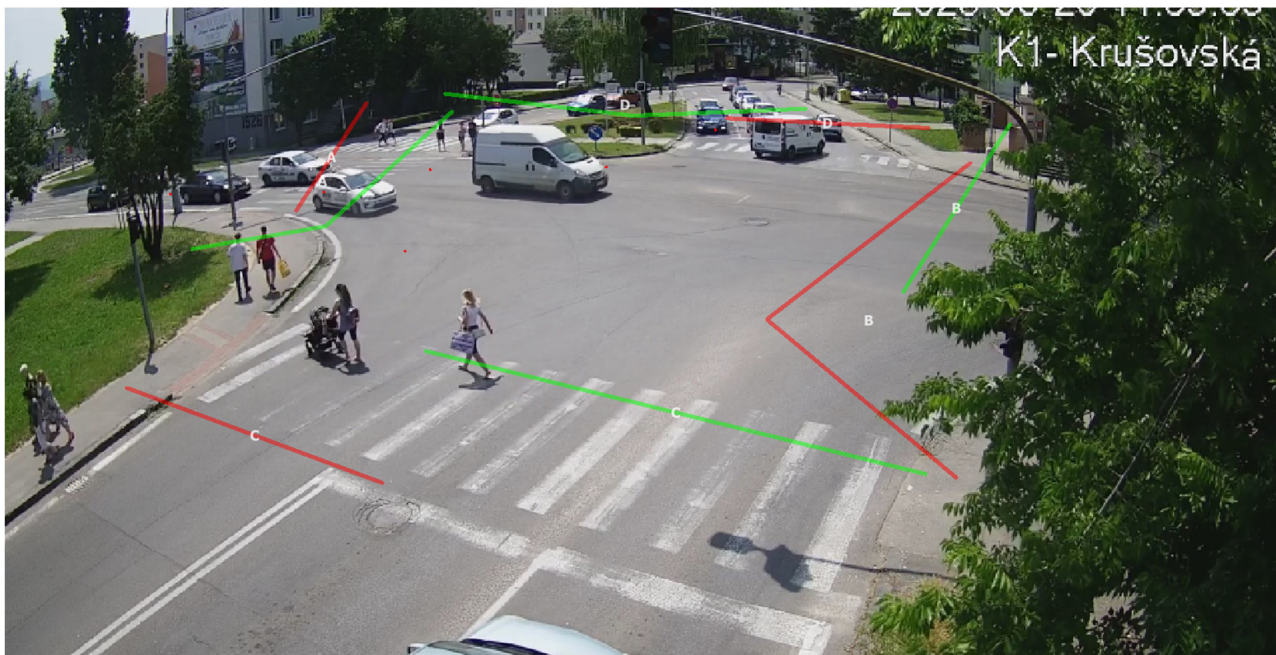


Figure 2. Gates in video detection. Source: processed by authors.

Figure 4 depicts the created road infrastructure, in which the entire traffic organization has been considered, including public transport stops, dedicated lanes for a given vehicle type, etc. The simulation model consists of three main intersections and one extra

intersection used to adjust the number of vehicles entering the main three signal-controlled intersections. This is a necessary step since many vehicles may have left the simulated area using an intersection where vehicles were not counted. In this case, the main road is located between Intersections 1 and 2 in a straight line. This information is critical for creating coordination. The vehicles in the model were calculated and divided into three types: cars, trucks, and public transport [25]. The exact numbers of these vehicle types were added to the simulation model using the traffic state function. This function allows the user to set the number of chosen vehicle types along specific paths through the intersection. Traffic states at all intersections were set at 15 min intervals, corresponding to the traffic survey.



Figure 3. Orthophoto background map. Source: [21].

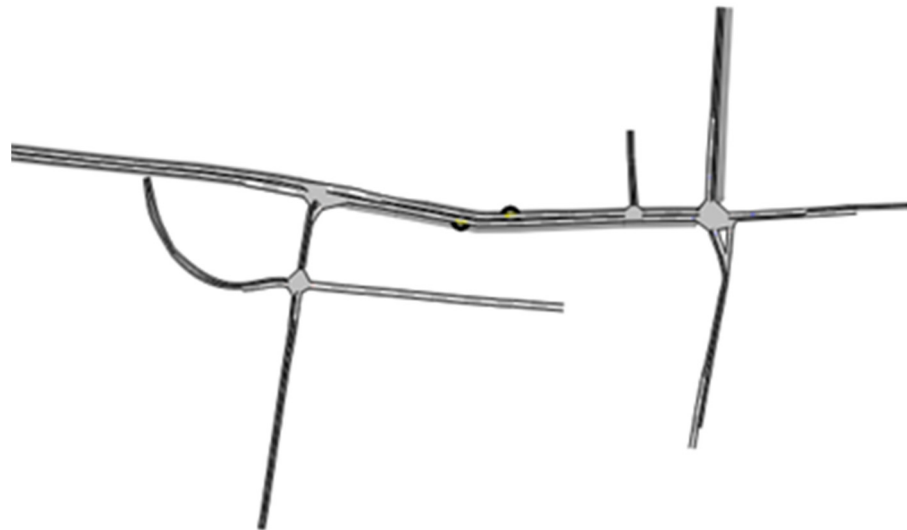


Figure 4. Infrastructure in Aimsun 8. Source: processed by authors.

In the simulation model, there are two signal-controlled intersections with a fixed cycle time, also known as off-line control, which means that the signal timing is predetermined and cannot adapt to changes in the intensity of traffic [26]. In addition, there is one traffic-dependent intersection in the model with a dynamic cycle, which means that this intersection can react to the number of vehicles at its entrances [27–29]. This is the

intersection number 1 in Figure 1. As this is a traffic-dependent control, it is also necessary to create detectors at each entrance in the simulation model. The detectors will ensure that the presence of a vehicle is identified, based on which it will extend the length of the green light for the corresponding cycle. In practice, loop detectors or video detectors are mainly used for this purpose, but video detectors are sensitive to environmental factors such as rain, snow, etc., while loop detectors are not [30,31]. There is no coordination between the modeled intersections.

The simulation model needs to be calibrated, as the pre-calibration results do not correspond to the actual state [32,33]. The model was calibrated using travel times on different predefined sections. The contribution of the calibration can be seen in Figure 5, where the blue curve represents the actual measured values. The gray curve shows the results provided by the simulation model before its calibration. The calibrated result is represented by the orange curve, which largely corresponds to the reference values.

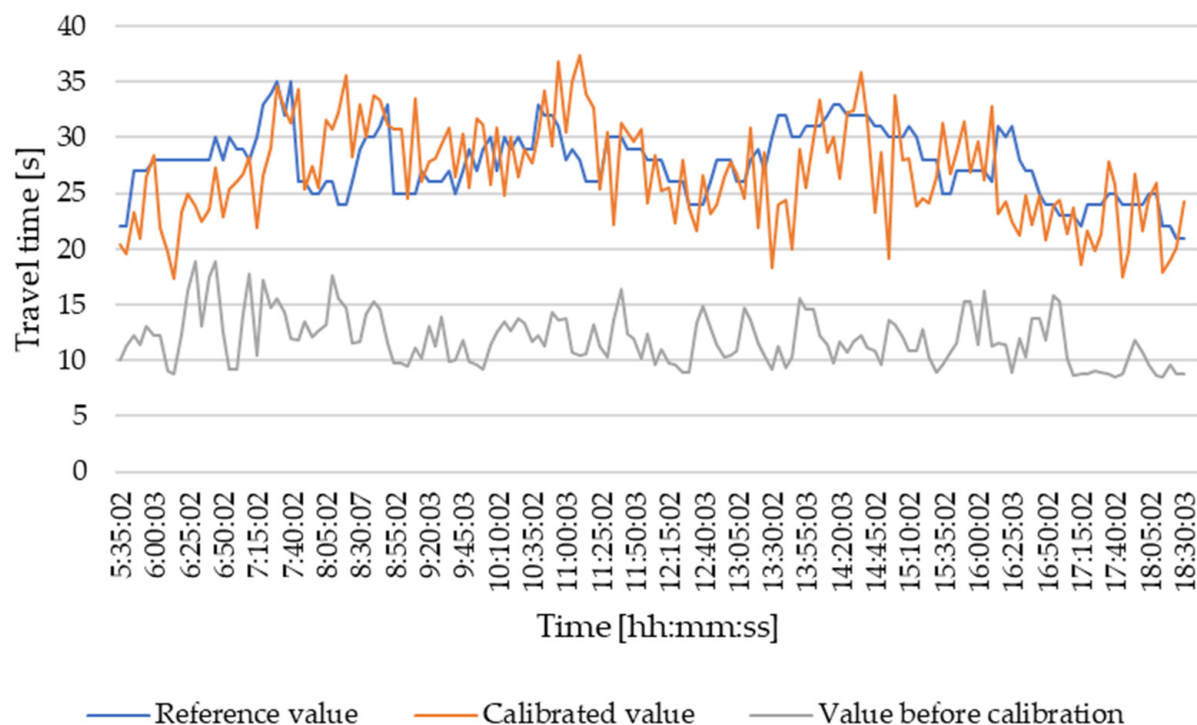


Figure 5. Comparison of uncalibrated model with calibrated model. Source: processed by authors.

The same calibration process was applied to each of the selected intersections. In cases where a change in speed alone was not sufficient to match the values in the graphical comparison with the actual values, adjustments to acceleration and deceleration were also made in the simulation model.

3. Results

Dedicated parameters were chosen for the comparison of traffic load change related to the realignment. The selected parameters were the number of vehicles and the average delay time at the entrance. The values achieved can be found in Figures 6 and 7.

According to Figure 6, the most significant number of vehicles, 7101, is at Intersection 1, at Entrance B. On the other hand, the smallest number of vehicles is at Intersection 3, where Entrance C is used by only 539 vehicles per day.

Figure 7 shows that Intersections 1 and 2 currently have comparable delay times, ranging from 17 to 32 s. Intersection 3 has worse results, with an average delay time of 47 s at Entrance A.

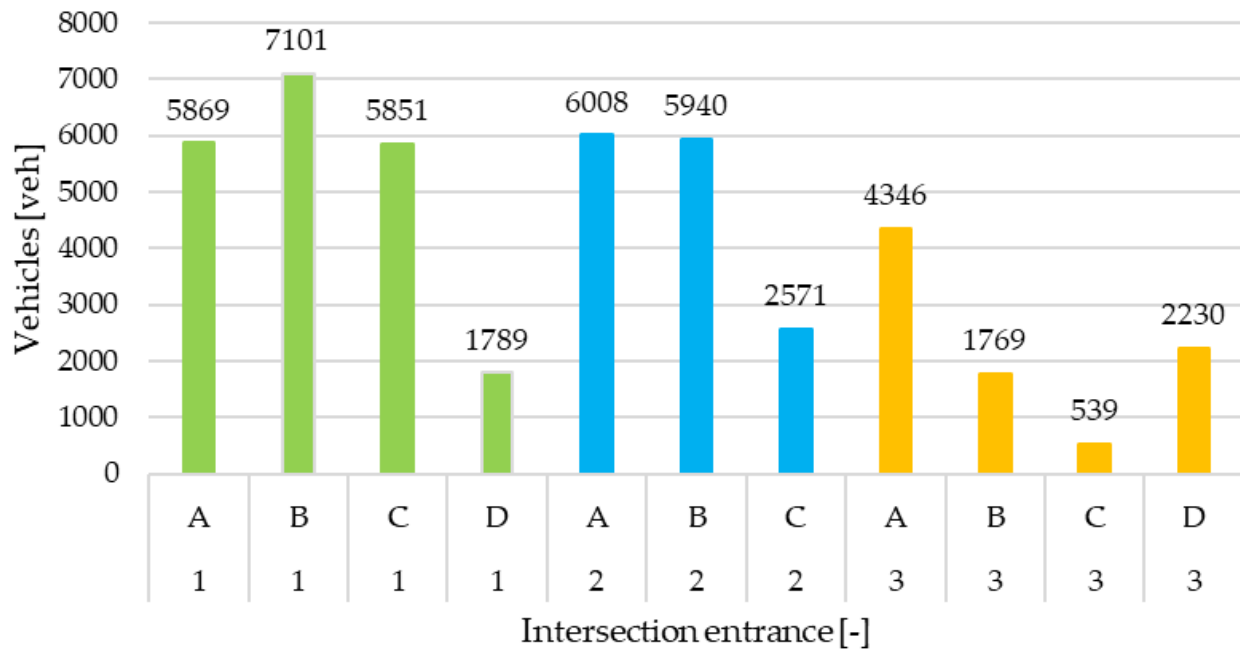


Figure 6. Number of vehicles during the day. Source: processed by authors.

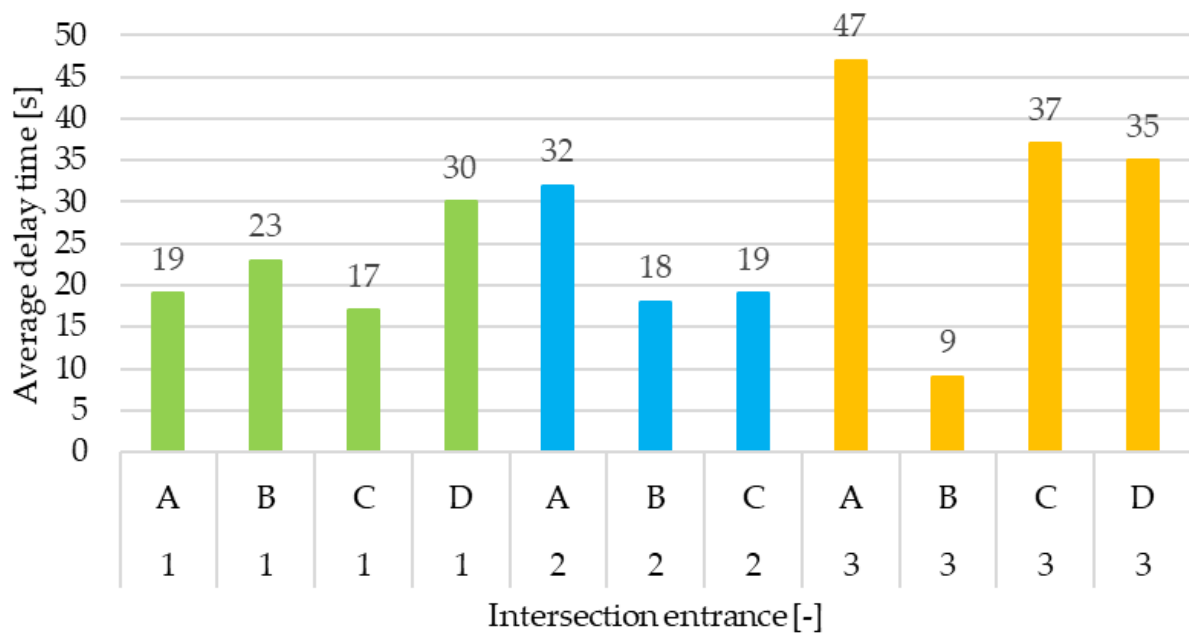


Figure 7. Average delay time during the day. Source: processed by authors.

The capacity assessment of an intersection was used to evaluate the real state of the intersection [34]. The quality level of the intersections was assessed in compliance with Technical Conditions 102 (TP 102), which represents the national standard for the Slovak Republic. The evaluation was based on the waiting time at the entrances for uncoordinated entrances and the percentage of vehicles passing without stopping at coordinated entrances and sections. The evaluation criteria are depicted in Table 1. The evaluation of intersections is an essential part of smart cities, as the choice of the proper means of transport and route is highly influenced by the degree of quality of each intersection [35,36].

Table 1. Evaluation based on TP 102.

Uncoordinated Entrances			Coordinated Entrances		
QSV		Delay time [s]	QSV		Percentage of vehicles without stopping
A	$\leq$	20	A	$>$	95
B	$\leq$	35	B	$>$	85
C	$\leq$	50	C	$>$	75
D	$\leq$	70	D	$>$	65
E	$\leq$	100	E	$>$	50
F	$>$	100	F	$\leq$	50

The initial simulation yielded data about the maximum delay time at the entrances, which we used to assign a quality level based on Technical Conditions 102. These ratings and delay times are shown in Table 2.

Table 2. Current state, evaluation of rush hours.

Intersection	Rush Hour	Maximum Delay Time [s]	QSV
1	7:15–8:15	31	B
	15:00–16:00	34	B
2	7:15–8:15	50	C
	14:15–15:15	47	C
3	7:15–8:15	77	E
	14:30–15:30	65	D

The data indicate that Intersection 1 had the best ratings, while Intersection 3 had the worst, with an E rating during the morning rush hour. Given that these results were obtained before the realignment of the adjacent street, it can be expected that the condition of the intersections will be unsatisfactory after the realignment.

Once a credible simulation model was developed, the unidirectional alignment of the selected street, located near the signal-controlled intersections, was implemented. Vehicles using this road were rerouted to alternative routes, which may have included the simulated signal-controlled intersections.

During the same time as the traffic survey at signal-controlled intersections, a directional traffic survey was also carried out with the recording of vehicle registration numbers at several locations within the area. These counting posts can be seen in Figure 8. The map backgrounds in Figures 8–10 are from [37].

Using the directional survey results, vehicles on this road were assigned to an alternative route through the simulated area. The change initiated an additional load on the signal-controlled intersections, worsening the traffic situation. Both possible road alignments were considered in the development of alternative routes, with the realignment in the simulation model directly affecting all three intersections. The first variant of the unidirectional alignment is shown in Figure 9, where there is a unidirectional alignment between Counting Posts 2A/2B and 1A/1B. The second highlighted alignment, near Counting Post 3A/3B, represents a restriction that is already in place at the current time. Based on the detection time, two artificial counting posts were also created, which are X1 and X2. Creating such posts ensured that vehicles with a destination in the area would be simulated correctly, and their route would be adjusted to match the actual route.

Variant 1 was a unidirectional alignment in the same direction as the existing restriction near Counting Post 3A/3B, making it theoretically a less suitable variant as there would be a more significant load on the signal-controlled intersections. The results achieved are shown in Table 3 below.



Figure 8. Location of the traffic survey posts Source: processed by authors from [21].

From the simulation results for Variant 1, we conclude that there is an increase in delay time at all intersections and entrances, except Entrances B and C at Intersection 2. However, the decrease observed at these two entrances is negligible as it is a change of up to 2 s. The most significant difference is at Intersection 1 at Entrance A, where there is an increase from 19 s to 51 s, an increase of 168.42%.

According to TP 102, the intersections after the alignment in this variant were assigned the ratings shown in Table 4, where the maximum delay time at the entrance is also provided. The most significant worsening occurred at Intersection 1, with its satisfactory stage rating decreasing from Grade B to Grade D.

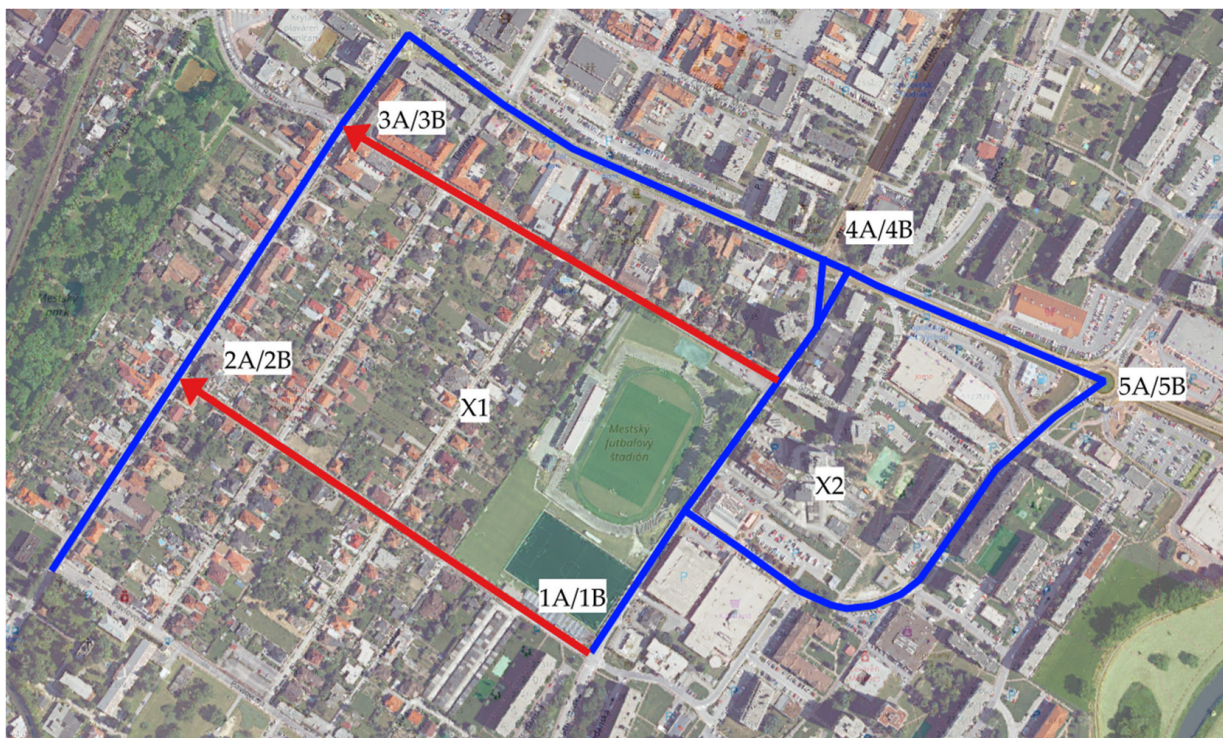


Figure 9. Variant 1. Source: processed by authors from [21].

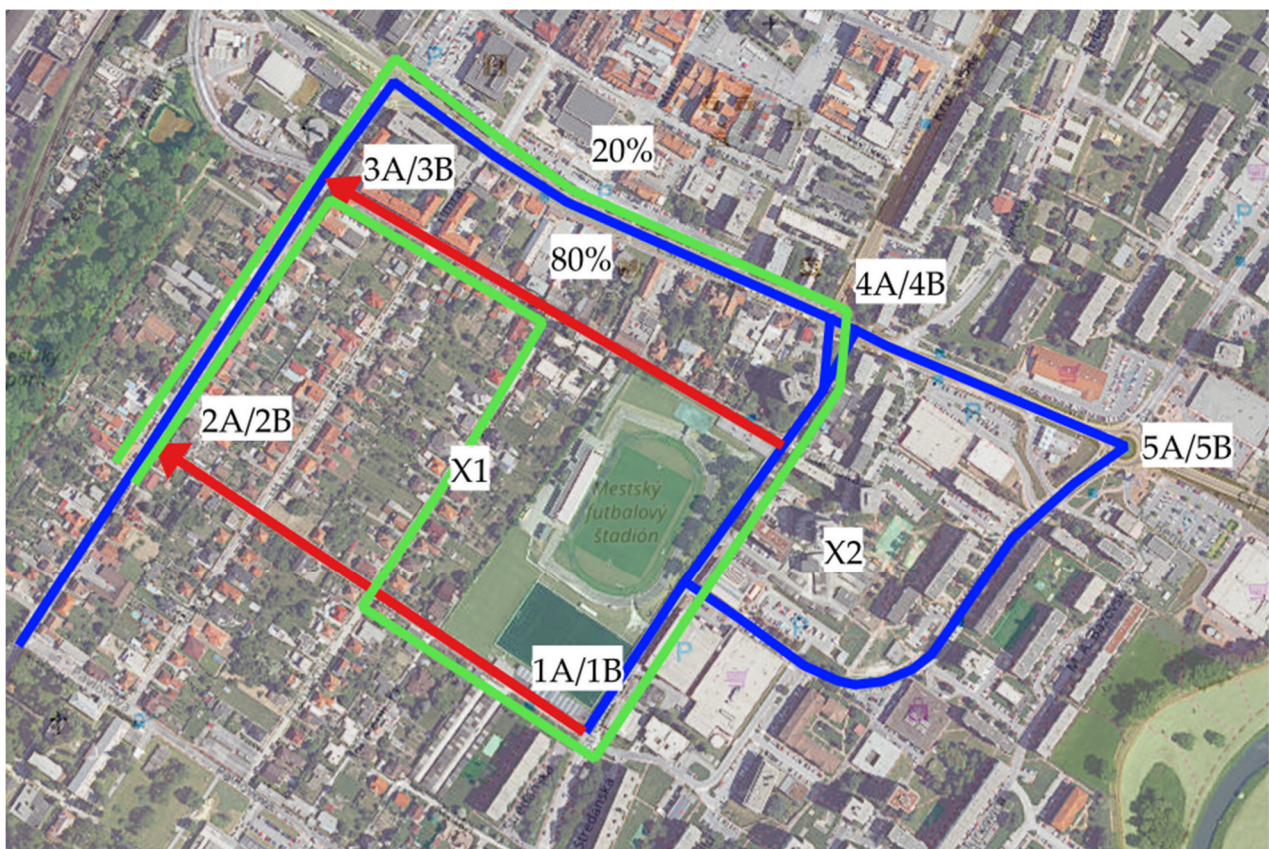


Figure 10. Variant 2. Source: processed by authors from [21].

The resulting values show that each of the affected intersections experienced a decline, with the most significant deterioration observed at Intersection 1, where a percentage increase in the delay time of 96.77% was recorded during the morning rush hour.

In Variant 2, the load changed in the same manner, but the alignment was in the opposite direction. This concept can be seen in Figure 10. Since multiple alternative routes were available in this case, drivers were assigned to these routes by expert estimation using percentages. Routes were prioritized based on the shortest and fastest route. The figure also provides a graphical representation of the route from Site X1 to Site 2A/2B, considering that 80% of the vehicles used the fastest route, and 20% of the drivers chose the longer alternative.

The probabilities of alternative routes are listed in Table 5, which also describes the route in question, along with the source and destination. Based on these probabilities, the vehicles were rerouted on a newly created path.

The simulation model was cleared from previous variant data and then adjusted with vehicle values, as shown in Table 5. The results are presented in Table 6.

Again, the results for this variant show that the most significant worsening occurred at Entrance A at Intersection 1. Although this entrance was not directly affected by the change in load, the increase is due to the fact that it is a traffic-dependent control. Thus, the intersection automatically adjusts the cycle based on the number of vehicles.

Table 7 shows the change in rush hours, maximum delay time at entry, and quality level.

As with Variant 1, there was a significant decline. During the morning rush hour, traffic collapsed at Intersections 2 and 3, with an increase of 114% at Intersection 2 and 85.71% at Intersection 3.

Both variants were significantly affected by the increase in load, with the best situation being in the current state without any change in the load. Variant 2 achieved lower delay times despite worse ratings during rush hour. This was due to the better condition of the main traffic flows, while the minor traffic flows experienced a collapse. The specific delay time at these intersections for all variants is shown in Figure 11.

Table 3. Variant 1, percentual change in vehicles and delay time.

Intersection	Entrance	Number of Vehicles [veh]	Percentual Change	Delay Time [s]	Percentual Change
1	A	7635	30.09%	51	168.42%
	B	8232	15.93%	26	13.04%
	C	5825	−0.44%	30	76.47%
	D	1784	−0.28%	58	93.33%
2	A	7414	23.40%	39	21.88%
	B	4486	−24.48%	16	−11.11%
	C	2573	0.08%	17	−10.53%
3	A	9337	114.84%	73	55.32%
	B	1774	0.28%	10	11.11%
	C	549	1.86%	47	27.03%
	D	2232	0.09%	52	48.57%

Table 4. Variant 1, evaluation of rush hours.

Intersection	Rush Hour	Maximum Delay Time [s]	Percentual Change	QSV
1	7:15–8:15	61	96.77%	D
	14:45–15:45	57	62.86%	D
2	7:15–8:15	55	10.00%	D
	14:00–15:00	60	27.66%	D
3	7:15–8:15	94	22.08%	E
	13:45–14:45	69	6.15%	D

Table 5. Probability of alternative routes.

From	To	Probability	Chosen Route
X1	2	80%	Through Intersection 3
		20%	Through Intersections 1 and 2
	3	80%	Through Intersection 3
		20%	Through Intersections 1 and 2
X2	2	70%	Through Intersection 3
		30%	Through Intersections 1 and 2
	3	80%	Through Intersection 3
		20%	Through Intersections 1 and 2
4	2	50%	Through Intersection 3
		50%	Through Intersections 1 and 2
	3	50%	Through Intersection 3
		50%	Through Intersections 1 and 2
5	2	20%	Through Intersection 3
		80%	Through Intersections 1 and 2
	3	30%	Through Intersection 3
		70%	Through Intersections 1 and 2

Table 6. Variant 2, percentual change in vehicles and delay time.

Intersection	Entrance	Number of Vehicles [veh]	Percentual Change	Delay Time [s]	Percentual Change
1	A	5865	−0.07%	52	173.68%
	B	7072	−0.41%	27	17.90%
	C	5862	0.19%	31	82.35%
	D	2401	34.21%	57	90.00%
2	A	7996	33.09%	51	59.38%
	B	4560	0.82%	16	−11.11%
	C	2583	0.47%	18	−5.26%
3	A	4351	0.12%	55	17.02%
	B	2346	32.62%	13	44.44%
	C	531	−1.48%	42	13.51%
	D	2258	1.26%	35	0.00%

Table 7. Variant 2, evaluation of rush hours.

Intersection	Rush Hour	Maximum Delay Time [s]	Percentual Change	QSV
1	7:15–8:15	64	106.45%	D
	15:00–16:00	57	62.86%	D
2	7:15–8:15	107	114.00%	F
	15:00–16:00	62	31.91%	D
3	8:45–9:45	143	85.71%	F
	14:15–15:15	75	15.38%	E

For Variant 1, we observed an increase in total delay time of 71.51% during the day. In Variant 2, this increase was slightly lower, at 55.55%, although the growth remained significant. A comparison of the two variants revealed that Variant 2 performed better than Variant 1 by 9.22%.

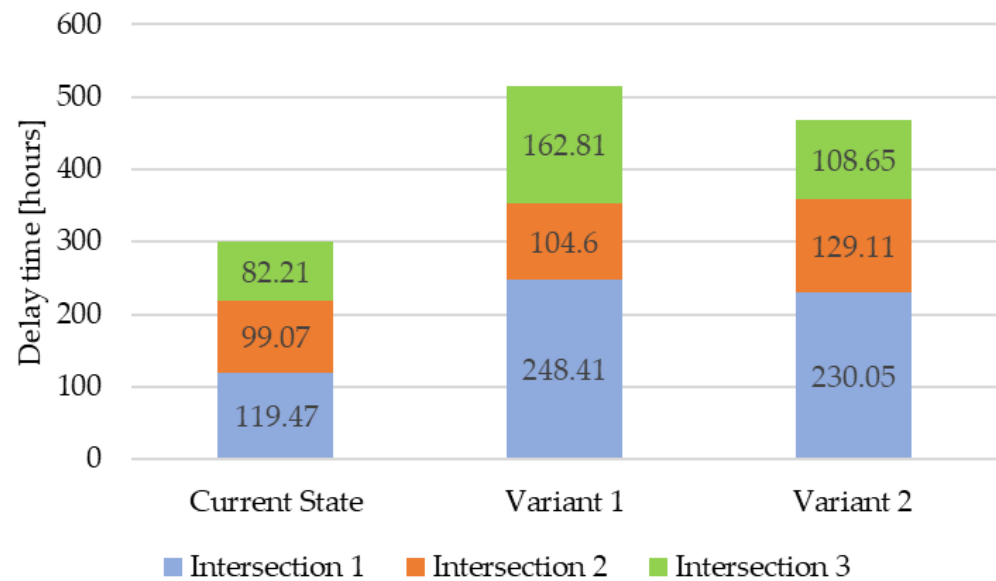


Figure 11. Comparison before corrective measures. Source: processed by authors.

Several corrective measures are available, including modifying the signal plans at affected intersections [38,39]. Changing the signal plan has a direct impact on the traffic capacity of the intersection in question [40]. The Aimsun 8 software facilitates the creation of an automatic signal plan. Still, this plan must be modified since it misrepresents the collision point locations that are part of the calculation under TP 102. Specifically, the collision points were used to calculate the time required for vehicles to clear the intersection area before the next traffic flow receives a green signal. However, signal-controlled intersections differ from uncontrolled intersections in terms of the number of conflict points [41]. Once the intersection projects were created, the distances of the collision points were extracted directly from the drawings. A sample of these drawings can be seen in Figure 12.

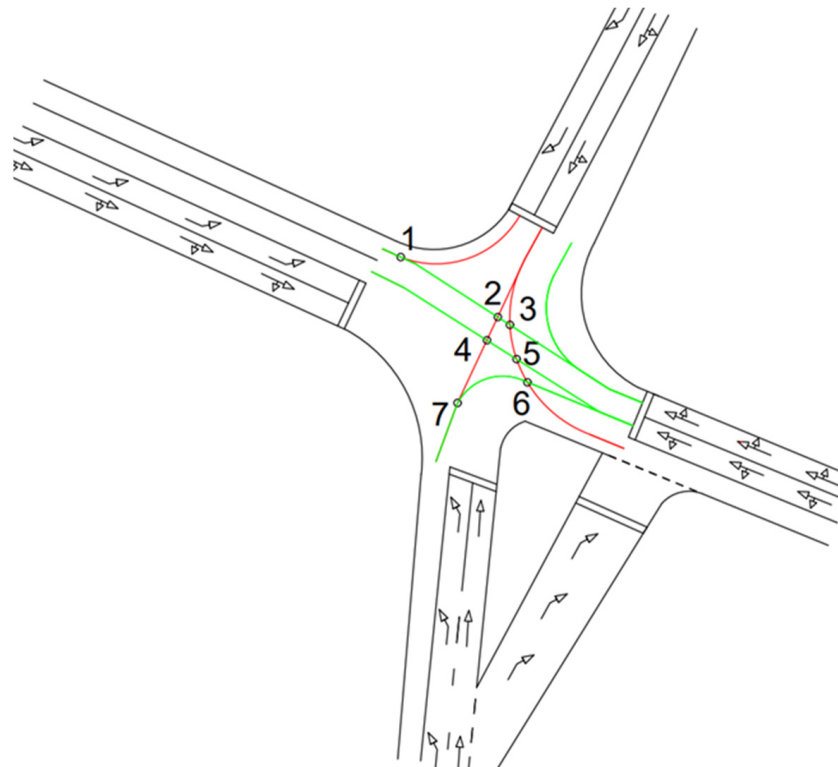


Figure 12. Intersection 1, collision points. Source: processed by authors.

Figure 12 illustrates the collision points located at the intersection of the entering traffic flow, shown in green, and the exiting traffic flow, shown in red. Once the collision points were identified, the in-between times were calculated. Following this, a signal plan was generated in Aimsun and adjusted to ensure that vehicles were provided with sufficient time to clear the intersection.

The measures for reducing congestion included introducing traffic-dependent control at Intersections 2 and 3. Traffic-dependent control is one of the most commonly used measures in smart cities to solve problems at signal-controlled intersections, as it helps to increase intersection capacity and reduce congestion [42–46]. With reduced congestion, traffic flow is improved, which also has an impact on accident rates and traffic safety [47]. Delay times at intersection entrances are significantly reduced when traffic becomes continuous [48]. Traffic-dependent control requires installing detectors at each intersection entrance to identify vehicle presence and parameters like speed, vehicle type, and intensity [49–52]. Detectors were located 20 m before the stop line at all intersections. In addition to reducing congestion, creating an appropriate signal plan also helps improve driver behavior [53].

Another measure for reducing traffic load was coordinating the main traffic flow between Intersections 1 and 2. Creating coordination between signalized intersections has several positive impacts. In addition to creating continuous traffic flow and reducing delay time, there is also a reduction in emissions, as well as noise emissions [54,55]. Coordination is also beneficial for emergency services, which, in this case, reduces the time needed to cross the necessary area [56]. The coordination was set using the travel time between these intersections, which ensured that vehicles coming from one intersection to another would always have a green signal.

The quality level of coordinated traffic flows was evaluated by the percentage of vehicles that passed without stopping. The current situation, without the introduction of coordination for the main traffic flow, is shown in Table 8. These data are significant for identifying whether coordination is effective.

Table 8. Evaluation before coordination.

From Intersection 1 to Intersection 2		
Delay time [s]	Stop time [s]	Percentage of stopping vehicles
21.69	17.48	64%
From Intersection 2 to Intersection 1		
Delay time [s]	Stop time [s]	Percentage of stopping vehicles
30.23	25.87	69%

To evaluate coordination at all, the ratio of stopping vehicles must be less than 50%. In this case, we observed higher values for both intersections, which corresponds to the fact that there is no coordination between these intersections. The results after the implementation of coordination are shown in Table 9.

Table 9. Evaluation after coordination.

From Intersection 1 to Intersection 2		
Delay time [s]	Stop time [s]	Percentage of stopping vehicles
3.48	2.11	11%
From Intersection 2 to Intersection 1		
Delay time [s]	Stop time [s]	Percentage of stopping vehicles
21.05	17.68	46%

With the implementation of coordination, we observed a significant improvement in the percentage of stopping vehicles, which decreased from 64% of stopping vehicles in the

direction from Intersection 1 to Intersection 2 to 11% of stopping vehicles. Worse results were obtained in the opposite direction, as coordination was only partial. However, in this case, there was also an improvement from 69% of stopping vehicles to 46%.

Once the new signal plans were implemented and coordination was in place, both unidirectional options were evaluated in the same way. The results for Variant 1 are shown in Table 10 below.

Table 10. Variant 1, percentual change in vehicles and delay time after corrective measures.

Intersection	Entrance	Number of Vehicles [veh]	Percentual Change	Delay Time [s]	Percentual Change
1	A	6864	−10.10%	51	0.00%
	B	8638	4.93%	21	−19.23%
	C	5841	0.27%	31	3.33%
	D	1782	0.11%	54	−6.90%
2	A	7457	0.58%	47	20.51%
	B	4486	0.00%	4	−75.00%
	C	2569	−0.16%	34	100.00%
3	A	5858	−37.26%	32	−56.16%
	B	1766	−0.45%	27	170.00%
	C	550	0.18%	55	17.02%
	D	2253	0.94%	35	−32.69%

The results show that worse outcomes were achieved than before the implementation of the corrective measures themselves. However, the real point of comparison was the total delay time during the day, as it indicated whether there was a time saving, considering that the increase in the total delay is dependent on the number of vehicles. The principle is that the main traffic flow with the highest number of vehicles is improved. In contrast, minor traffic flows with fewer vehicles are worsened at the expense of the main traffic flow being improved.

Based on Figure 13, it can be concluded that the corrective measures contributed to an improvement in delay time, reducing it from 515.82 h to 385.3 h, representing a time saving of 25.30%.

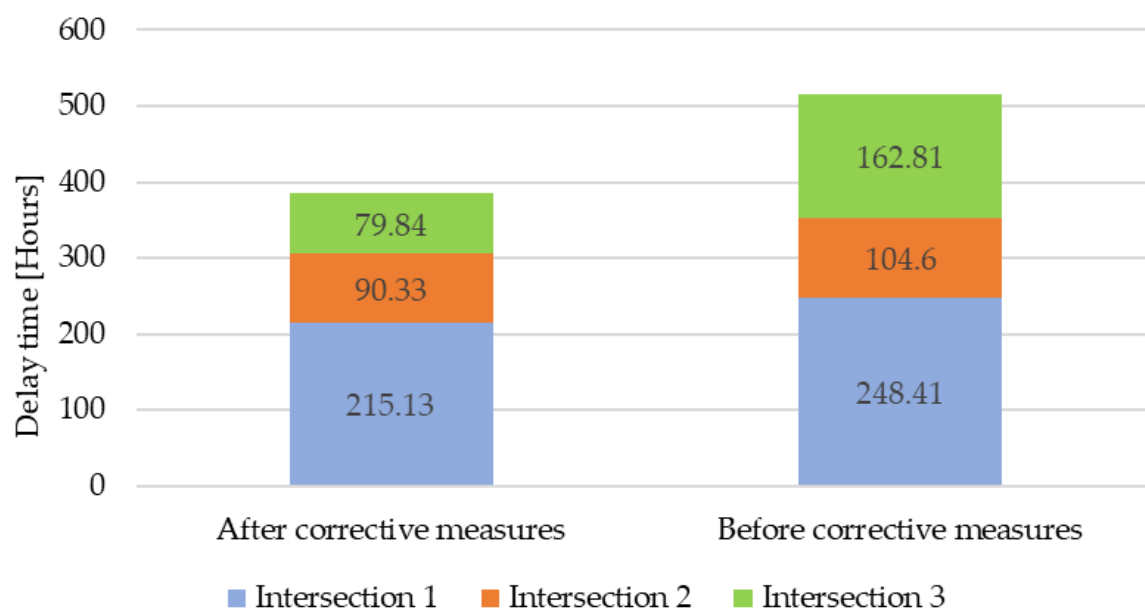


Figure 13. Comparison of states before and after corrective measures, Variant 1. Source: processed by authors.

For specific inputs during rush hours, the changes are outlined in Table 11.

Table 11. Variant 1, evaluation of rush hours after corrective measures.

Intersection	Rush Hour	Maximum Delay Time [s]	Percentage of Vehicles Passing Without Stopping	Percentual Change	QSV
1	7:15–8:15	61	69.66%	0.00%	D
	14:45–15:45	51	65.42%	−10.53%	D
2	7:15–8:15	48	91.50%	−12.73%	C
	14:00–15:00	48	88.17%	−20.00%	C
3	7:15–8:15	54	-	−42.55%	D
	13:45–14:45	60	-	−13.04%	D

The introduction of traffic-dependent control and coordination of selected traffic flows between intersections resulted in improvements at all intersections. Intersection 1 was the least affected, as it was already traffic-dependent in its current state. Based on this, we determined that the coordination resulted in an improvement of approximately 10% during the afternoon rush hour. In other cases, we observed improvements ranging from 12 to 40%.

For Variant 2, the same procedure as in the previous case was chosen. The first step was, therefore, to identify the time savings during the day, which can be found in Figure 14.

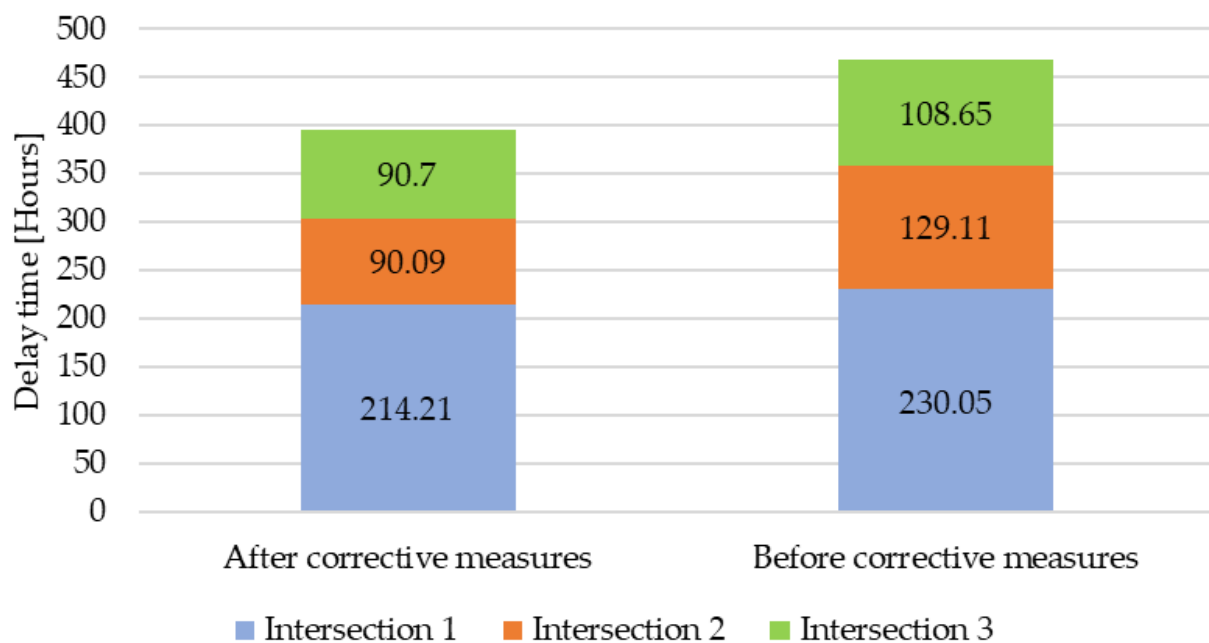


Figure 14. Comparison of states before and after corrective measures, Variant 2. Source: processed by authors.

Variant 2 revealed an improvement of 15.56% relative to the current situation. Compared to Variant 1, which achieved an improvement of 25.30%, it was a worse solution. Nevertheless, the overall delay time after corrective measures was comparable to the delay time for Variant 1. The difference between the two variants was 2.5%.

The results from the length of the simulations are presented in Table 12.

Table 12. Variant 2, percentual change in vehicles and delay time after corrective measures.

Intersection	Entrance	Number of Vehicles [veh]	Percentual Change	Delay Time [s]	Percentual Change
1	A	5864	−0.02%	51	−1.92%
	B	8638	22.14%	21	−22.22%
	C	5841	−0.36%	30	−3.23%
	D	1782	−25.78%	54	−5.26%
2	A	6226	−22.14%	39	−23.53%
	B	6018	31.97%	11	−31.25%
	C	2569	−0.54%	34	88.89%
3	A	5858	34.64%	32	−41.82%
	B	1766	−24.72%	27	107.69%
	C	550	3.58%	55	30.95%
	D	2247	−0.49%	52	48.57%

The results show that, together, the intersections were able to serve a larger number of vehicles. Before the implementation of the corrective measures, the total number of vehicles was 45,825. After the implementation, the total number of vehicles increased to 48,064 for Variant 1 and 47,359 vehicles for Variant 2. On average, there was a 4.1% increase in the number of vehicles. For delay times, we observed significant improvements in the main traffic flows where the number of vehicles was the highest. On the other hand, minor traffic flows experienced an increase in average delay times by up to a factor of two. However, if we consider the number of vehicles at a given entry, it is evident that there is an overall saving as a result. This effect is due to the fact that traffic-dependent control is more advantageous for the main traffic flow, as there is a greater chance of a vehicle appearing to extend the green signal time.

The results of the rush hours are shown in Table 13, where they are compared with the state before the change.

Table 13. Variant 2, evaluation of rush hours after corrective measures.

Intersection	Rush Hour	Maximum Delay Time [s]	Percentage of Vehicles Passing Without Stopping	Percentual Change	QSV
1	7:15–8:15	61	70.34%	−4.69%	D
	14:45–15:45	53	65.14%	−7.02%	D
2	7:15–8:15	49	90.06%	−54.21%	C
	14:00–15:00	49	87.67%	−20.97%	C
3	7:15–8:15	50	-	−65.03%	C
	13:45–14:45	50	-	−33.33%	C

As with Variant 1, the smallest improvement was achieved at Intersection 1. This is due to the fact that the intersection is already traffic-dependent. From the results, it can be inferred that the coordination of the traffic-dependent intersection alone helped to improve the condition by approximately 5%. For the other intersections, there were significant improvements in the range of 20% to 65%, showing that the introduction of traffic-dependent control and coordination can significantly improve the situation at a signal-controlled intersection.

4. Discussion

This paper used a simulation model to demonstrate the changes in the load on the roads due to the introduction of traffic restrictions in their vicinity. Two different variants for the load change were created to identify the changes, and significant worsening was achieved in both cases. Following the increase in traffic load, corrective measures were implemented in the simulation model to reduce the negative impact of the changes. These measures included adjusting the signal plans at selected signalized intersections,

constructing detectors, implementing traffic-dependent signal control, and establishing coordination of the main traffic flow. The simulation results after the implementation of these measures show a positive impact. The intersections were able to handle a higher number of vehicles during the day compared to the situation before the changes were introduced, and overall delay times decreased. During rush hours, we observed an improvement compared to the conditions before the changes were implemented. For Variant 1, improvements of up to 42.55% were recorded during rush hours, and improvements of up to 65.03% were observed for Variant 2. Despite these positive results, even after the implementation of the changes, the results did not reach the values that these intersections were achieving before the increase in load. At best, the condition at these intersections worsened by 28.11%. If no changes had been made to the intersections, the most favorable results would have been 55.55% worse than the current state. From these data, it can be concluded that in the case of an increasing load on the roads in question, appropriate measures should be taken to reduce the negative impact.

Table 14 summarizes the relevant data and compares the current state and the alternatives. Variant 2, after the implementation of corrective measures, would be the most appropriate option. Although the total delay time was 9.7 h higher, it was the preferred variant as the quality grades achieved more favorable results. Therefore, the condition of the intersections was more balanced.

Table 14. Summary of achieved results.

Intersection	Current State		New State Before Corrective Measures				New State After Corrective Measures			
	QSV	Delay Time During the Day [Hours]	Variant 1		Variant 2		Variant 1		Variant 2	
			QSV	Delay Time During the Day [Hours]	QSV	Delay Time During the Day [Hours]	QSV	Delay Time During the Day [Hours]	QSV	Delay Time During the Day [Hours]
1	B	119.47	D	248.41	D	230.05	D	215.13	D	214.21
2	D	99.07	D	104.60	F	129.11	C	90.33	C	90.09
3	E	82.21	E	162.81	F	108.65	E	79.84	C	90.70
Σ	-	300.75	-	515.82	-	467.81	-	385.30	-	395.00

However, these results show that even implementing corrective measures did not lead to significant improvements at Intersection 1. Since this intersection has two entrances and exits at nearly every entrance, introducing a turbo-roundabout could be considered a potential solution [57,58].

Another corrective measure that could help, without altering the intersection's design, is to create a new public transportation service plan and make it more attractive to city residents [59,60]. Enhancing the appeal of public transport can also contribute to reduced emissions in the city, which in turn would improve the quality of life [61].

5. Conclusions

The first hypothesis, which was established at the beginning of the study and predicted a significant worsening in the entire area, was confirmed. When comparing the total delay time during the day, we observed an increase at each of the intersections, with the most significant increase occurring at Intersection 1.

The second hypothesis assumed an improvement in the traffic situation after the implementation of corrective measures. This hypothesis was also confirmed since we observed improvement in both variants. However, the improvement was insufficient to achieve values corresponding to the current state.

This study demonstrated how one-way road alignments impact traffic load at adjacent signalized intersections, with simulations revealing significant worsening and subsequent improvement after the implementation of adaptive measures such as dynamic signal plans and main traffic flow coordination. The proposed practices, including intersection

coordination and adaptive control, proved to be effective strategies that can bring cities a 20% to 65% reduction in traffic delays.

The results show that the traffic situation significantly worsened with the realignment of the selected road. This deterioration can lead to driver frustration, which may negatively influence road safety. Additionally, traffic collapse occurred without implementing corrective measures, as summarized in Table 14. Since this means that traffic completely stops, and vehicles are not moving or stopping frequently, we conclude that environmental impact is also significant.

The corrective measures did not yield satisfactory results, particularly due to the worsening at Intersection 1. Therefore, it is not recommended that the realignment of the selected street be implemented.

The limitations of this paper primarily stem from the fact that the traffic survey was conducted only at signal-controlled intersections. To obtain the most accurate data, it could be beneficial to conduct traffic surveys at every intersection that vehicles pass through. One of the limitations is also the fact that the traffic survey was only 13 h long. This duration was chosen to represent traffic during the day. However, a 24 h long traffic survey could potentially uncover more issues that need to be addressed.

Creating a simulation model like this can be useful for the cities deciding to realign selected roads and are interested in the impact this decision would bring. Furthermore, simulation models can also be used by project managers planning to build in urban areas. In that case, simulation models could provide necessary information that might result in financial savings. The results demonstrate the potential of measures such as adaptive control plans and coordination of major traffic flows for specific traffic situations in urban areas.

The results of this study provide a useful resource for urban traffic planners and policymakers to forecast and address the effects of road realignment. In addition, the simulation model created can be used as a basis for future research focused on optimizing traffic systems in different urban contexts, ultimately promoting sustainable and efficient urban mobility solutions.

For future applications of this simulation model, we suggest expanding the simulation model to cover a larger area or even the whole city. The only part that would need to be changed is the number of vehicles, which means organizing new traffic surveys at these intersections and also new ones that are located in extended areas.

Author Contributions: Conceptualization, L.Č. and P.F.; methodology, L.Č.; software, P.F.; validation, K.Č., A.K. and L.Č.; formal analysis, A.K.; investigation, K.Č.; resources, A.K.; data curation, P.F.; writing—original draft preparation, K.Č.; writing—review and editing, P.F.; visualization, K.Č.; supervision, A.K.; project administration, L.Č.; funding acquisition, A.K. All authors have read and agreed to the published version of the manuscript.

Funding: This paper has been developed under support of the project MŠVVŠ SR VEGA No. 1/0178/22 KALAŠOVÁ, A.: Basic research of the sharing economy as a tool for reducing negative externalities.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors upon request.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Shamsuddin, S.; Abu Hassan, N.R.; Bilyamin, S.F.I. Walkable Environment in Increasing the Liveability of a City. In *Procedia-Social and Behavioral Sciences, Proceedings of the ACE-BS 2012 BANGKOK, Bangkok, Thailand, 16–18 July 2012*; Abbas, M.Y., Bajunid, A.F.I., Azhari, N.F.N., Eds.; Elsevier: Amsterdam, The Netherlands, 2012; Volume 50, pp. 167–178.
2. Rosi, M.; Strmsek, L.; Dragan, D.; Rosi, B. Walkable Neighbourhoods in Smart Cities. In *Proceedings of the Business Logistics in Modern Management, Osijek, Croatia, 7–8 October 2021*; Dujak, D., Ed.; Faculty of Economics and Business: Osijek, Croatia, 2021; pp. 547–563.

3. Paril, V.; Viturka, M.; Oveckova, E. Socio-Economic Aspects of Reconstruction and Modernization of Regional Roads. In Proceedings of the 20th International Colloquium on Regional Sciences, Brno, Czech Republic, 14–16 June 2017; Klimova, V., Zitek, V., Eds.; Masarykova University: Brno, Czech Republic, 2017; Volume 2, pp. 366–373.
4. Macioszek, E.; Iwanowicz, D. A Back-of-Queue Model of a Signal-Controlled Intersection Approach Developed Based on Analysis of Vehicle Driver Behavior. *Energies* **2021**, *14*, 1204. [\[CrossRef\]](#)
5. Bindzar, P.; Saderova, J.; Sofranko, M.; Kacmary, P.; Brodny, J.; Tutak, M. A Case Study: Simulation Traffic Model as a Tool to Assess One-Way vs. Two-Way Traffic on Urban Roads around the City Center. *Appl. Sci.* **2021**, *11*, 5018. [\[CrossRef\]](#)
6. Gheorghe, C. Comparative Analysis of the Performance of One-Way and Two-Way Urban Road Networks. In Proceedings of the International Congress of Automotive and Transport Engineering—Mobility Engineering and Environment (CAR2017), Pitesti, Romania, 8–10 November 2017; IoP Publishing Ltd.: Bristol, UK, 2017; Volume 252, p. 012056.
7. Baskan, O.; Ozan, C. Determining Optimum Configuration of One-Way and Two-Way Streets Using Shortest Path Travel Costs Based on Results of Traffic Assignment. *Pamukkale Univ. J. Eng. Sci.* **2018**, *24*, 1087–1092. [\[CrossRef\]](#)
8. Melo, H.P.M.; Mota, D.P.; Andrade, J.S.; Araujo, N.A.M. Impact of One-Way Streets on the Asymmetry of the Shortest Commuting Routes. *Phys. Rev. Res.* **2022**, *4*, 023053. [\[CrossRef\]](#)
9. Horvat, R.; Kos, G.; Sevrovic, M. Traffic Flow Modelling on the Road Network in the Cities. *Teh. Vjesn.* **2015**, *22*, 475–486. [\[CrossRef\]](#)
10. Jeihani, M.; James, P.; Saka, A.A.; Ardeshiri, A. Traffic Recovery Time Estimation under Different Flow Regimes in Traffic Simulation. *J. Traffic Transp. Eng.-Engl. Ed.* **2015**, *2*, 291–300. [\[CrossRef\]](#)
11. Gragera, A.; Hybel, J.; Madsen, E.; Mulalic, I. A Model for Estimation of the Demand for On-Street Parking. *Econ. Transp.* **2021**, *28*, 100231. [\[CrossRef\]](#)
12. Poliak, M.; Poliakova, A.; Zhuravleva, N.A.; Nica, E. Identifying the Impact of Parking Policy on Road Transport Economics. *Mobile Netw. Appl.* **2023**, *28*, 203–210. [\[CrossRef\]](#)
13. Ilgakojyte-Bazariene, J.; Jablonskyte, J. Queueing Traffic Flow. In Proceedings of the Transport Means 2015: 19th International Scientific Conference, Kaunas, Lithuania, 22–23 October 2015; Kaunas Univ Technology Press: Kaunas, Lithuania, 2015; pp. 127–130.
14. Mesjasz-Lech, A.; Wlodarczyk, A. The Role of Logistics Infrastructure in Development of Sustainable Road Transport in Poland. *Res. Transp. Bus. Manag.* **2022**, *44*, 100841. [\[CrossRef\]](#)
15. Xu, S.; Sun, C.; Wei, H.; Hou, X. Road Construction and Air Pollution: Analysis of Road Area Ratio in China. *Appl. Energy* **2023**, *351*, 121794. [\[CrossRef\]](#)
16. Lan, Z.; Li, F.; Cai, M. Road Traffic Noise Exposure Assessment Based on Spatiotemporal Data Fusion. *Transp. Res. Part D Transp. Environ.* **2024**, *127*, 104044. [\[CrossRef\]](#)
17. Lindman, M.; Isaksson-Hellman, I.; Jeppsson, H.; Kovaceva, J.; Fernandez, P.D. Description of Same-Direction Car-to-Bicycle Crash Scenarios Using Real-World Data from Sweden, Germany, and a Global Crash Database. *Accid. Anal. Prev.* **2022**, *168*, 106587. [\[CrossRef\]](#)
18. Channamallu, S.S.; Kermanshachi, S.; Pamidimukkala, A. Impact of Autonomous Vehicles on Traffic Crashes in Comparison with Conventional Vehicles. In Proceedings of the International Conference on Transportation and Development 2023: Transportation Safety and Emerging Technologies, Austin, TX, USA, 14–17 June 2023; Wei, H., Ed.; Amer Soc Civil Engineers: New York, NY, USA, 2023; pp. 39–50.
19. Kalasova, A.; Pal'o, J.; Cernicky, L.; Culik, K. Research on the Impact of Flexible Working Hours on Reducing Traffic Delays in the City. *Appl. Sci.* **2024**, *14*, 7941. [\[CrossRef\]](#)
20. Ruzicka, J.; Silar, J.; Belinova, Z.; Langr, M. Methods of Traffic Surveys in Cities for Comparison of Traffic Control Systems—A Case Study. In Proceedings of the 2018 Smart City Symposium Prague (SCSP), Prague, Czech Republic, 24–25 May 2018; Ruzicka, J., Ed.; IEEE: New York, NY, USA, 2018.
21. OpenStreetMap: Map of Topoľčany. Available online: <https://www.openstreetmap.org> (accessed on 20 September 2024).
22. Tchuitcheu, W.C.; Bobda, C.; Pantho, M.J.H. Internet of Smart-Cameras for Traffic Lights Optimization in Smart Cities. *Internet Things* **2020**, *11*, 100207. [\[CrossRef\]](#)
23. Bruno, L.; Parla, G.; Celauro, C. Improved Traffic Signal Detection and Classification via Image Processing Algorithms. In Proceedings of the SIV-5th International Congress—Sustainability of Road Infrastructures, Rome, Italy, 29–31 October 2012; Dandrea, A., Moretti, L., Eds.; Elsevier: Amsterdam, The Netherlands, 2012; Volume 53, pp. 811–821.
24. Bindzar, P.; Macuga, D.; Brodny, J.; Tutak, M.; Malindzakova, M. Use of Universal Simulation Software Tools for Optimization of Signal Plans at Urban Intersections. *Sustainability* **2022**, *14*, 2079. [\[CrossRef\]](#)
25. Czapla, Z. Video-Based Vehicle Detection on a Two-Way Road. *Sci. J. Sil. Univ. Technol.-Ser. Transp.* **2016**, *92*, 23–29. [\[CrossRef\]](#)
26. Liu, S.; Fan, W.; Jiao, S.; Li, A. The Performance of Connected and Autonomous Vehicles with Trajectory Planning in a Fixed Signal Controlled Intersection. *Promet* **2024**, *36*, 164–176. [\[CrossRef\]](#)
27. Wang, Y.; Zhang, D.; Liu, Y.; Dai, B.; Lee, L.H. Enhancing Transportation Systems via Deep Learning: A Survey. *Transp. Res. Pt. C Emerg. Technol.* **2019**, *99*, 144–163. [\[CrossRef\]](#)
28. Genser, A.; Makridis, M.A.; Yang, K.; Ambuhl, L.; Menendez, M.; Kouvelas, A. Time-to-Green Predictions for Fully-Actuated Signal Control Systems With Supervised Learning. *IEEE Trans. Intell. Transp. Syst.* **2024**, *25*, 7417–7430. [\[CrossRef\]](#)

29. Thunig, T.; Scheffler, R.; Strehler, M.; Nagel, K. Optimization and Simulation of Fixed-Time Traffic Signal Control in Real-World Applications. In Proceedings of the 10th International Conference on Ambient Systems, Networks and Technologies (ANT 2019)/The 2nd International Conference on Emerging Data and Industry 4.0 (EDI40 2019)/Affiliated Workshops, Leuven, Belgium, 29 April–2 May 2019; Shakhshuki, E., Ed.; Elsevier: Amsterdam, The Netherlands, 2019; Volume 151, pp. 826–833.
30. Rossi, R.; Gastaldi, M.; Gecchele, G.; Barbaro, V. Fuzzy Logic-Based Incident Detection System Using Loop Detectors Data. In Proceedings of the 18th Euro Working Group on Transportation, EWGT 2015, Delft, The Netherlands, 14–16 July 2015; Santos, B.F., Correia, G.H.A., Kroesen, M., Eds.; Elsevier: Amsterdam, The Netherlands, 2015; Volume 10, pp. 266–275.
31. Vujovic, I.; Jurcevic, M.; Kuzmanic, I. Traffic Video Surveillance in Different Weather Conditions. *Trans. Marit. Sci.-ToMS* **2014**, *3*, 32–41. [\[CrossRef\]](#)
32. Liu, H.; Deng, H.; Li, J.; Yang, S.; Dong, K.; Zhao, Y. Calibration Method for Microscopic Traffic Simulation Considering Lane Difference. *Simul.-Trans. Soc. Model. Simul. Int.* **2024**, 1–20. [\[CrossRef\]](#)
33. Ehlert, A.; Schneck, A.; Chanchareon, N. Junction Parameter Calibration for Mesoscopic Simulation in Vissim. In *Transportation Research Procedia, Proceedings of the International Symposium of Transport Simulation (ISTS) and the International Workshop on Traffic Data Collection and Its Standardization (IWTDCS): Advanced Transport Simulation Modelling Based on Big Data, Jeju City, Republic of Korea, 7–8 July 2016*; Lee, S., Kim, J., Eds.; Elsevier: Amsterdam, The Netherlands, 2017; Volume 21, pp. 216–226.
34. Afanasyev, A.; Panfilov, D. Estimation of Intersections Traffic Capacity Taking into Account Changed Traffic Intensity. In Proceedings of the 12th International Conference—Organization and Traffic Safety Management in Large Cities SPbOTSIC-2016, St. Petersburg, Russia, 28–30 September 2016; Brannolte, U., Pribyl, P., Silyanov, V., Eds.; Elsevier: Amsterdam, The Netherlands, 2017; Volume 20, pp. 2–7.
35. Wang, H.; Cao, J.; Xin, F.; Xu, L.; Li, X. Smart City: Road Traffic Evaluation Based on Traffic Flow Model. In Proceedings of the International Conference on Intelligent Traffic Systems and Smart City (ITSSC 2021), Zhengzhou, China, 19–21 November 2021; SPIE: Bellingham, WA, USA, 2022; Volume 12165, pp. 231–237.
36. Bachechi, C.; Po, L. Traffic Analysis in a Smart City. In Proceedings of the 2019 IEEE/WIC/ACM International Conference on Web Intelligence Workshops (WI 2019 Companion), Thessaloniki, Greece, 14–17 October 2019; Barnaghi, P., Gottlob, G., Katsaros, D., Manolopoulos, Y., Pandey, R., Tzouramanis, T., Vakali, A., Eds.; Assoc Computing Machinery: New York, NY, USA, 2019; pp. 275–282.
37. MAPKA: Real Estate Cadastre. Topol'čany. Available online: <https://zbgis.skgeodesy.sk/mapka/> (accessed on 20 September 2024).
38. Karmanov, D.; Zakharov, D.; Fadyushin, A. Evaluation of Changes in Traffic Parameters for Various Types of Traffic Signal Regulation. In *System and Digital Technologies for Ensuring Traffic Safety*; Zhankaziev, S., Ed.; Elsevier: Amsterdam, The Netherlands, 2018; Volume 36, pp. 274–280.
39. Bie, Y.; Cheng, S.; Liu, Z. Optimization of Signal-Timing Parameters for the Intersection with Hook Turns. *Transport* **2017**, *32*, 233–241. [\[CrossRef\]](#)
40. Wang, Q.; Shao, C. Evaluation of Signalized Intersection Service Level in the Traffic Impact Assessment. In Proceedings of the Sustainable Development of Industry and Economy, Shanghai, China, 12–13 November 2013; Xu, Q., Li, H., Li, Q., Eds.; Trans Tech Publications Ltd.: Stafa-Zurich, Switzerland, 2014; Volume 869–870, pp. 327–333.
41. Hasain, N.M.; Ahmed, M.A. Identification of Critical Conflicts and Its Implementation in Microsimulation for Effective Safety Assessment in Unsignalised Intersections. *Transp. B Transp. Dyn.* **2024**, *12*, 2350520. [\[CrossRef\]](#)
42. Cernicky, L.; Kupculjakova, J.; Pal'ó, J.; Kalasova, A. Reducing Delay Time at Signal Controlled Junction with the Help of Actuated Control. *Adv. Sci. Technol. Res. J.* **2020**, *14*, 149–157. [\[CrossRef\]](#)
43. Feng, Y.; Head, K.L.; Khoshmashgham, S.; Zamanipour, M. A Real-Time Adaptive Signal Control in a Connected Vehicle Environment. *Transp. Res. Part C Emerg. Technol.* **2015**, *55*, 460–473. [\[CrossRef\]](#)
44. Ahmed, A.H.; Fragonara, L.Z. Adaptive Intelligent Traffic Control Systems for Improving Traffic Quality and Congestion in Smart Cities. *Int. J. Qual. Res.* **2021**, *15*, 139–154. [\[CrossRef\]](#)
45. Dimon, C.; Teme, M.; Popescu, D. Optimization of Road Traffic Using Intelligent Traffic Light Systems. *Int. J. Comput. Commun. Control.* **2022**, *17*, 4866. [\[CrossRef\]](#)
46. Li, S.-C.; Kong, L.-J.; Liu, M.-R.; Zheng, R.-S. The effects of intelligent traffic light on the crossing traffic flow. *Acta Phys. Sin.* **2009**, *58*, 2266–2270. [\[CrossRef\]](#)
47. Retallack, A.E.; Ostendorf, B. Current Understanding of the Effects of Congestion on Traffic Accidents. *Int. J. Environ. Res. Public Health* **2019**, *16*, 3400. [\[CrossRef\]](#)
48. Paszkowski, J.; Herrmann, M.; Richter, M.; Szarata, A. Modelling the Effects of Traffic-Calming Introduction to Volume-Delay Functions and Traffic Assignment. *Energies* **2021**, *14*, 3726. [\[CrossRef\]](#)
49. Hybrid Strategy for Traffic Light Detection by Combining Classical and Self-Learning Detectors-Web of Science Core Collection. Available online: <https://www.webofscience.com/wos/woscc/full-record/WOS:000545971300012> (accessed on 14 September 2024).
50. Chan, K.Y.; Dillon, T.S. On-Road Sensor Configuration Design for Traffic Flow Prediction Using Fuzzy Neural Networks and Taguchi Method. *IEEE Trans. Instrum. Meas.* **2013**, *62*, 50–59. [\[CrossRef\]](#)
51. Grumert, E.F.; Tapani, A. Traffic State Estimation Using Connected Vehicles and Stationary Detectors. *J. Adv. Transp.* **2018**, *2018*, UNSP 4106086. [\[CrossRef\]](#)

52. Arinaldi, A.; Pradana, J.A.; Gurusinga, A.A. Detection and Classification of Vehicles for Traffic Video Analytics. In Proceedings of the INNS Conference on Big Data and Deep Learning, Denpasar, Indonesia, 17–19 April 2018; Ozawa, S., Tan, A.H., Angelov, P.P., Roy, A., Pratama, M., Eds.; Elsevier: Amsterdam, The Netherlands, 2018; Volume 144, pp. 259–268.
53. Palat, B.; Delhomme, P. A Simulator Study of Factors Influencing Drivers' Behavior at Traffic Lights. *Transp. Res. Pt. F Traffic Psychol. Behav.* **2016**, *37*, 107–118. [[CrossRef](#)]
54. Islam, T.; Vu, H.L.; Panda, M.; Ngoduy, D. A Study of Realistic Dynamic Traffic Assignment with Signal Control, Time-Scale, and Emission. *J. Intell. Transport. Syst.* **2018**, *22*, 446–461. [[CrossRef](#)]
55. Kirrian Fiedler, P.E.; Trombetta Zannin, P.H. Evaluation of Noise Pollution in Urban Traffic Hubs-Noise Maps and Measurements. *Environ. Impact Assess. Rev.* **2015**, *51*, 1–9. [[CrossRef](#)]
56. Muzzini, F.; Montangero, M. Exploiting Traffic Light Coordination and Auctions for Intersection and Emergency Vehicle Management in a Smart City Mixed Scenario. *Sensors* **2024**, *24*, 2036. [[CrossRef](#)]
57. Tollazzi, T.; Zgrablic, T.; Bergoc, J.; Rencelj, M. Comparative Analysis of “Turbo”, “Reduced-Turbo”, “Flower” and “Semi-Turbo” Roundabout. *Teh. Vjesn.* **2020**, *27*, 1410–1417. [[CrossRef](#)]
58. Giuffrè, O.; Grana, A.; Marino, S. Turbo-Roundabouts vs Roundabouts Performance Level. In Proceedings of the SIIV-5th International Congress—Sustainability of Road Infrastructures, Rome, Italy, 29–31 October 2012; DAndrea, A., Moretti, L., Eds.; Elsevier: Amsterdam, The Netherlands, 2012; Volume 53, pp. 590–600.
59. Uspalyte-Vitkuniene, R.; Kolodinskaja, J. Public Transport Route Network Optimization Criteria's for Cities. In Proceedings of the 11th International Conference Environmental Engineering (11th ICEE), Vilnius, Lithuania, 21–22 May 2020; Cygas, D., Vaiskunaite, R., Eds.; Vilnius Gediminas Technical Univ Press, Technika: Vilnius, Lithuania, 2020; p. enviro.2020.635.
60. Liu, Z.; Correia, G.H.d.A.; Ma, Z.; Li, S.; Ma, X. Integrated Optimization of Timetable, Bus Formation, and Vehicle Scheduling in Autonomous Modular Public Transport Systems. *Transp. Res. Pt. C Emerg. Technol.* **2023**, *155*, 104306. [[CrossRef](#)]
61. Konecny, V.; Petro, F. Calculation of Selected Emissions from Transport Services in Road Public Transport. In Proceedings of the 18th International Scientific Conference-LOGI 2017, České Budějovice, Czech Republic, 19 October 2017; Stopka, O., Ed.; EDP Sciences: Les Ulis, France, 2017; Volume 134, p. 00026.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.