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Professional paper

ANALYSIS OF THE LEVEL OF SERVICE AND CAPACITY OF THE THREE-LEGED INTERSECTION IN THE CITY OF TETOVO, PROPOSAL FOR IMPROVING SAFETY AND THE LEVEL OF SERVICE

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Abstract

With the increase in population and the improvement of living standards, the level of motorization also rises. Therefore, it is essential to implement road projects that play a key role in improving traffic efficiency—in other words, in eliminating traffic congestion, increasing the speed of vehicle flow within the road network, enhancing the economic indicators related to vehicle use, primarily by reducing fuel consumption and saving travel time, decreasing environmental pollution, and, most importantly, improving road safety.
With the increase in the rate of motorization, there is also a growing demand for expanding the capacity of existing roads and constructing new multi-lane roads in order to ensure efficient traffic flow and provide a higher level of service for all road users. However, for high-speed, multi-lane roads, increasing efforts are being made to reduce conflict points by designing and constructing intersections in various forms, both at-grade and grade-separated.

Key words: Level of service, Capacity, Traffic congestion, Intersection, Nonlinearity, SimTraffic, Safety, traffic analysis.

1. Introduction

For the most complete description of traffic flows and the study of the legality of the movement of motor vehicles in traffic flows on roadways, the most significant features of the traffic flow, as well as the characteristic values of the basic parameters of the traffic flow, should be defined. (1)
The characteristic values of the basic parameters of traffic flow are important for adequately describing the relationships between the basic parameters of traffic flow and for solving specific traffic problems.
Among the more important characteristics of traffic flow, significant for describing the regularity of vehicle movement in traffic flows on roadways and for more significantly describing the basic parameters of traffic flow, primarily vehicle flow, is the complexity of traffic flow, primarily vehicle flow, including the complexity of the traffic flow, general traffic flow conditions, traffic flow composition or structure, and temporal unevenness of the traffic flow.
The theory of traffic flows (traffic) is a science that studies the laws of movement of motor vehicles in traffic. The movement of vehicles depends on many factors, therefore the description of the regularity is a very complex process.
The most important factors that influence the way vehicles move in traffic are: the size of the traffic flow, the characteristics of the flow, the driving and dynamic characteristics of the vehicle, the psychophysical characteristics and motivation of the driver, the characteristics of the traffic control and management system and the environmental conditions (visibility, road conditions, climate etc.).

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The simultaneous action of several of the aforementioned factors affects the complexity of the description of the regularity of vehicle movement in the traffic flow, and is increased by the fact that the basic influencing factors are variable in space and time.

2. Traffic analysis at a three-leged intersection in the city of Tetovo

2.1. Description of the intersection

The traffic flow and level of service at an intersection located in Tetovo will be analyzed. The intersection has no slope and is in the shape of a "T". The street "M.A.Cento" according to traffic signs is a main road, connecting the main boulevards of the city of Tetovo, namely: bul. "B. Toska" bul. "V.S. Bato". Street "120" is a side street that connects "M.A.Cento" Street with "M.Tito" Blvd. (Iliria) and the green market. Street "120" has traffic during the day due to the green market, as well as connecting to "M.Tito" Blvd., which has the highest traffic in the city.

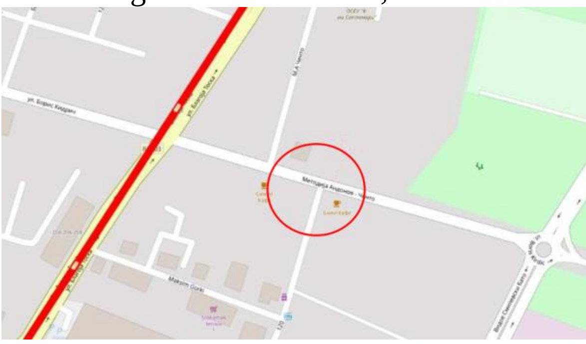

Figure 1. View of the intersection of M.A.Cento Street and 120 Street

2.2. Existing condition: The current condition of this intersection cannot be described as satisfactory, with vehicles moving slowly during rush hour. This most often happens on weekdays in the morning from 08:00, where a large number of passengers use this road as an alternative to connect to the city center as well as to the green market, when citizens go to work, as well as when the green market and surrounding shops are supplied with goods, the same situation occurs around 16:00-17:00, when citizens leave work and when the market and shops are empty. And during the day from 12:00 to 13:00 there is increased traffic flow.
Vertical and horizontal signage has been installed at the intersection, according to which the "M.A.Cento" road has priority, while "120" is a secondary road.
The road has two lanes and the gradient at the entrance to the intersection is 0%. This road or intersection is not used by city and intercity buses, nor heavy vehicles - trucks, but only trucks and delivery vans.

3. Geometry and existing signage of the intersection

3.1. Traffic signals: Horizontal and vertical signage is installed at the intersection, where from the road direction "120" the signs (201) (Crossing with a road with right of way) and (302.1) Pedestrian crossing are installed. Street "120" is a secondary road, on "M.A.Cento" street there are signs in both directions (302.1) marked pedestrian crossing, where it gives way. Where as a road with priority of passage is given by "M.A.Cento" street. Also included in the horizontal signage are: pedestrian crossings, solid and dashed lines, stop lines, guide lines, and direction arrows.

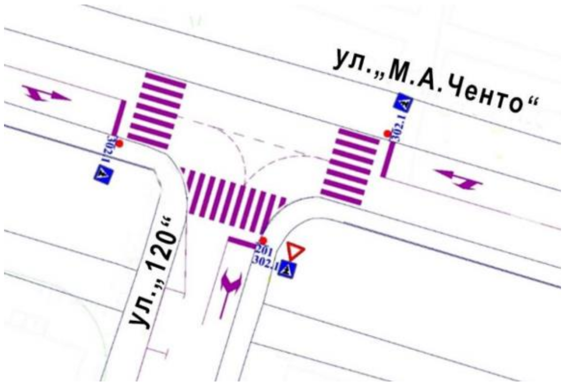

Figure 2. Traffic signals

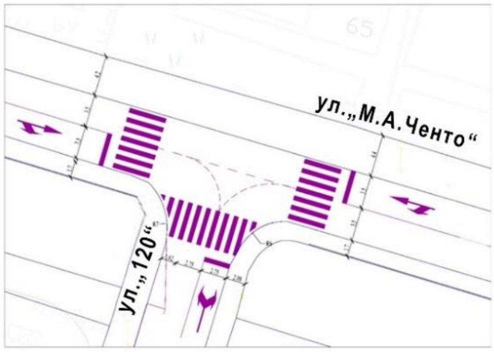

Figure 3. Geometric elements of the intersection.

3.2. Geometric elements of the intersection: The intersection is in the shape of the letter "T", where both roads have one lane in each direction, as well as sidewalks on both sides. "M.A.Cento" Street has two lanes in both directions with a width of 3.5 meters, i.e. 2x3.5=7 meters of road width, where there is no space for street parking. And "120" street has two 2.75-meter-wide lanes, and 2 meters for parking vehicles on the street (1.6 meters on the street and 0.4 meters on the sidewalk) (Fig.3).

4. Traffic measurement and distribution of traffic in time intervals

Through traffic recording or counting, an overview of the current state of traffic flow is provided, from which the ongoing needs for reconstruction, construction of new traffic routes, or other measures to improve the existing traffic flow may arise. Traffic recording or vehicle counting can be performed in two ways:

- Using measuring devices (automatic counter)
- In manual mode (manually)

Recording with measuring devices is carried out over a longer period of time and is very accurate, as the measurements are performed 24 hours a day without interruption throughout the entire year. Later, depending on our interest in analyzing each specific case, the corresponding data are reviewed. However, in our case, the counting was done manually, where certain data are necessary, such as:

- Date
- Day
- Atmospheric conditions
- Start and end times of peak hour measurements.

Measurements are made for a typical day of the week such as: a workday Friday.

Table 1.Traffic Counting

Vehicle Counting		
Day: Friday	**Date:** 15/11/2024	**Weather Conditions:** Good
Start Time	**End Time**	
07:00	08:00	
12:00	13:00	
16:00	17:00	

The recording of vehicles is done from three directions:
1. The first direction straight and left
2. The second direction straight and right
3. The third direction left and right

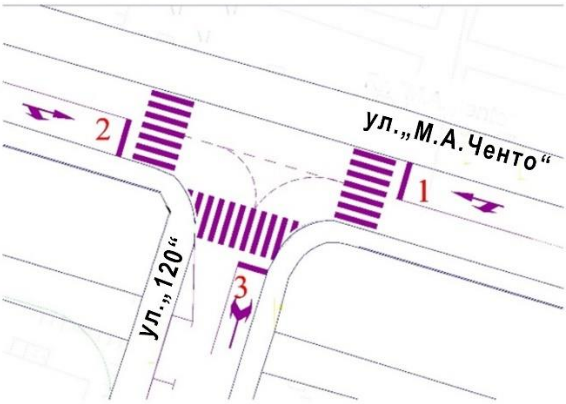

Figure 4. Counting directions.

4.1. Traffic counting from 07:00 to 08:00

Direction 1		Left		Straight		Right		Total number
Hour		PC	BUS+CV	PC	BUS+CV	PC	BUS+CV	
7:00	7:15	9	1	16	3	0	0	29
7:15	7:30	3	1	26	10	0	0	40
7:30	7:45	12	3	19	5	0	0	39
7:45	8:00	8	2	30	9	0	0	49
Total		32	7	91	27	0	0	**157**
Direction 2		Left		Straight		Right		Total number
Hour		PC	BUS+CV	PC	BUS+CV	PC	BUS+CV	
7:00	7:15	0	0	19	8	20	3	50
7:15	7:30	0	0	31	2	10	1	44
7:30	7:45	0	0	26	6	30	5	67
7:45	8:00	0	0	29	9	25	4	67
Total		0	0	105	25	85	13	**228**
Direction 3		Left		Straight		Right		Total number
Hour		PC	BUS+CV	PC	BUS+CV	PC	BUS+CV	
7:00	7:15	10	1	0	0	4	3	18
7:15	7:30	6	1	0	0	12	1	20
7:30	7:45	8	2	0	0	20	2	32
7:45	8:00	5	3	0	0	16	4	28
Total		29	7	0	0	52	10	**98**
Total		Left		Straight		Right		Total number
Hour	7.00-8.00	PC	BUS+CV	PC	BUS+CV	PC	BUS+CV	
Direction 1		32	7	91	27	0	0	157
Direction 2		0	0	105	25	85	13	228
Direction 3		29	7	0	0	52	10	98
Total		61	14	196	52	137	23	**483**

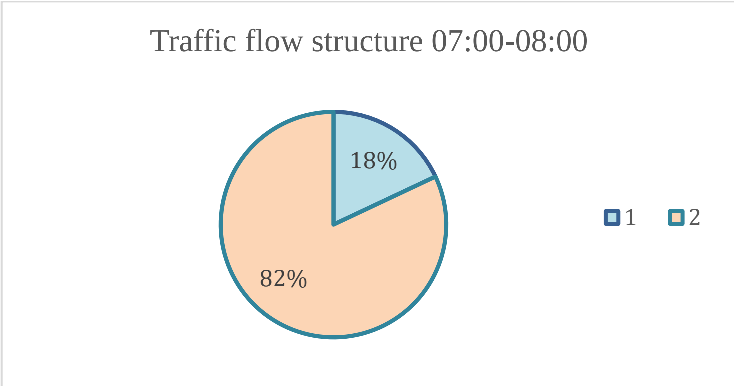

Chart 1 Traffic flow structure (1-BUS+CV, 2-PC)

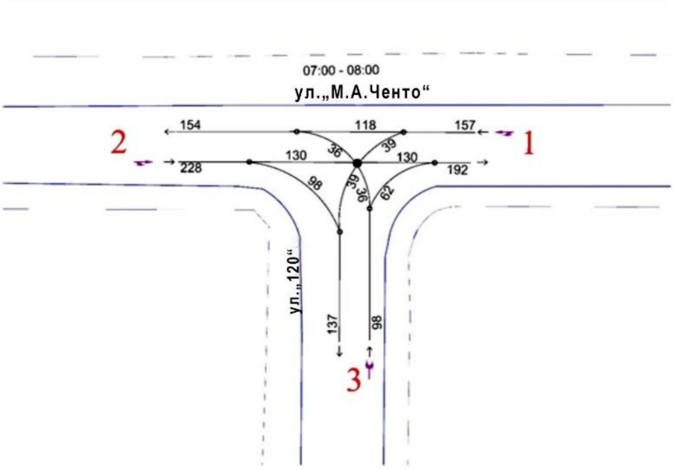

Figure 5. Traffic distribution from 7 a.m. to 8 a.m.

4.2. Total Traffic counting from 12:00 to 13:00

Total		Left		Straight		Right		Total number
Hour	12:00-13:00	PC	BUS+CV	PC	BUS+CV	PC	BUS+CV	
Direction 1		70	10	196	12	0	0	288
Direction 2		0	0	114	6	123	10	253
Direction 3		82	15	0	0	54	7	158
Total		152	25	310	18	177	17	**699**

PC-passenger cars
BUS-buses
CV-commercial vehicles
Traffic flow structure from 12:00 to 13:00

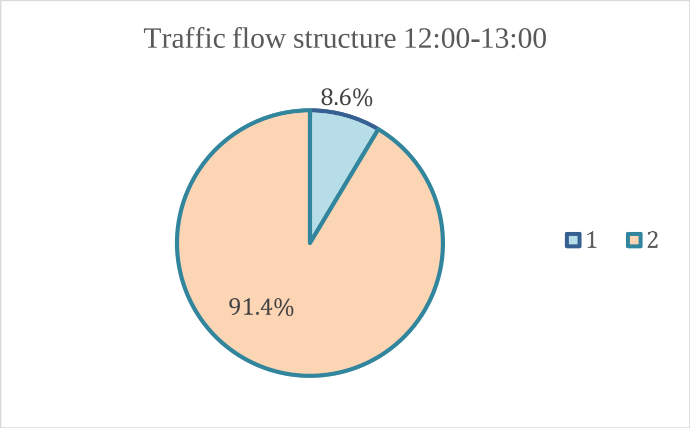

Chart 2 Traffic flow structure
Traffic distribution from 12:00 to 13:00 (1-BUS+CV, 2-PC)

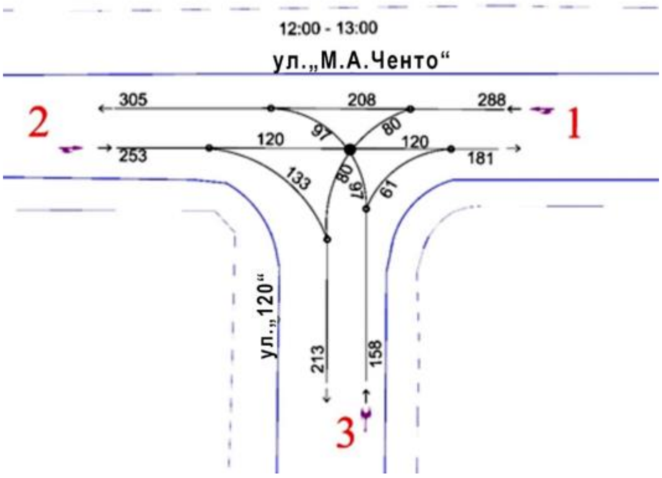

Figure 6. Traffic distribution from 12:00 to 1:00 PM

4.3. Total Traffic counting from 16:00 to 17:00

Total		Left		Straight		Right		Total number
Hour	16:00-17:00	PC	BUS+CV	PC	BUS+CV	PC	BUS+CV	
Direction 1		82	8	166	7	0	0	263
Direction 2		0	0	80	11	170	7	268
Direction 3		61	17	0	0	65	7	150
Total		143	25	246	18	235	14	**681**

Traffic flow structure 16:00 to 17:00

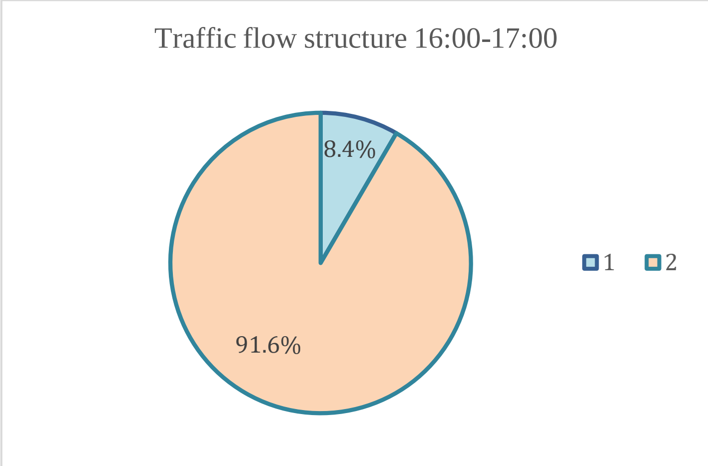

Chart 3 Traffic flow structure (1-BUS+CV, 2-PC)

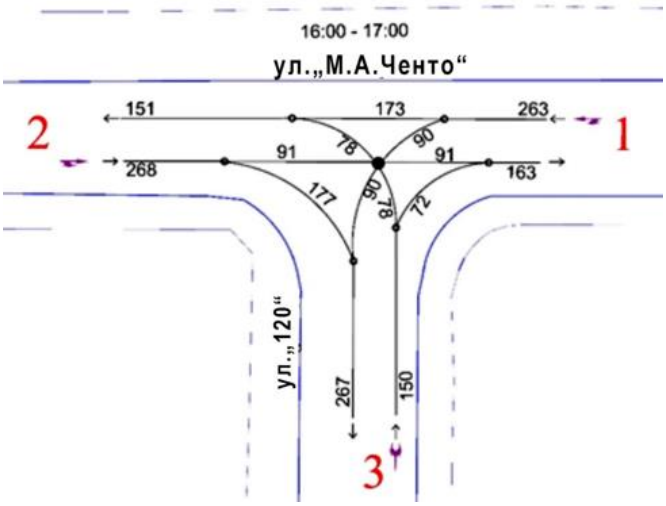

Figure 7. Traffic distribution from 4 to 5 p.m.

5. Capacity and level of service (LOS) analysis

Capacity is defined as the maximum amount of traffic that can pass through a given section of a roadway during a specified time period under the influence of road traffic conditions. Capacity is determined based on realistic forecasts. The absolute maximum amount of flow can vary from day to day from one section of the road to another.

Therefore, it is important to calculate the capacity for the observed road section. The concept of level of service is a qualitative measure that characterizes the traffic conditions on the road. The levels of service are indicated by certain letters from "A" to "F".

At service level "A" the traffic conditions are the most suitable, while at service level "F" the most unsuitable. It is important to determine the level of service. At the examined intersection we have three conflicting flows. Flows q1.1, q2.1 and q2.2 are flows with priority of passage therefore they have no time loss because they are flows of first rank because q1.1 and q2.1 are the movements directly from the main road, while q2.2 returns to the right of the main road. While conflicting flows are: q1.2 (Left turns from the main road), q3.1 (Left turns from the side road) and q3.2 (Right turns from the side road).

Range of movement:

Rank I: q1.1, q2.1, q2.2 (Movements directly from the main road and left of the main road)

Rank II: q1.2, q3.2 (Movements Right of the side road as well as Left of the main road)

Rank III: q3.1 (Movements to the left of the side road)

Table 2. Vehicle traffic at the intersection entrance

Traffic Lanes	q1.1	q1.2	q2.1	q2.2	q3.1	q3.2
Number of vehicles (veh/hour)	80	208	120	133	97	61

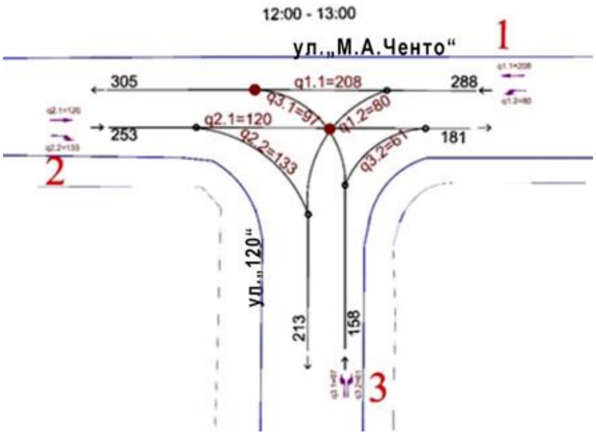

Figure 8. Vehicle flow by routes and directions

5.1. Calculation of potential capacity of a left-turn lane from the main road q1.2

Conflict flow qc1.2

$$q_{c1.2} = q_{2.1} + q_{2.2.} = 120 + 133 = 253\ [aut/h]$$

Time loss:

$$\boldsymbol{t_0 = t_g - \frac{t_f}{2} = 5.0 - \frac{2.1}{2} = 3.95}\ [\boldsymbol{s}]$$

$\boldsymbol{t_g = 5.0}$ [$\boldsymbol{s}$]-critical interval (follow up interval of vehicles)

$\boldsymbol{t_f = 2.1}$ [$\boldsymbol{s}$]- Initial time delay during vehicle entry

Potential capacity Cp1.2

$$\boldsymbol{C_{P,1.2} = \frac{3600}{t_f} \cdot e^{\frac{-[\sum q_{c,1.2}]\cdot t_0}{3600}} = \frac{3600}{2.1} \cdot 2.71^{\frac{-[253]\cdot 5}{3600}}} = 1300\ [\text{воз/Hour}]$$

T- Analyzed period (for a 15-minute time period), T=0.25

Average time losses:

$$D_{1.2} = \frac{3600}{C_{m,1.2}} + 900 \cdot T \left[\frac{q_{1.2}}{C_{m,1.2}} - 1 + \sqrt{\left(\frac{q_{1.2}}{C_{m,1.2}} - 1\right)^2 + \frac{\left(\frac{3600}{C_{m,1.2}}\right) \cdot \left(\frac{q_{1.2}}{C_{m,1.2}}\right)}{450 \cdot T}} \right] =$$

$$D_{1.2} = \frac{3600}{1300} + 900 \cdot 0.25 \left[\frac{253}{1300} - 1 + \sqrt{\left(\frac{253}{1300} - 1\right)^2 + \frac{\left(\frac{3600}{1300}\right) \cdot \left(\frac{253}{1300}\right)}{450 \cdot 0.25}} \right] =$$

$$D_{1.2} = 3.44\ [s] \ \le 5$$

SERVICE LEVEL A

The other calculations were done in the same manner; here, only the table with the obtained results will be presented.

Table 3. Service level with time losses

Time Losses When Entering the Intersection		Average time losses (sec/vehicle)	Level of service
Traffic lane flow:	Time losses D(sek)	Dx	A
q1.2	3.44	$\boldsymbol{D_X \leq 5}$	A
q3.2	3.88	$\boldsymbol{D_X \leq 5}$	A
q3.1	31.54	$\boldsymbol{30 < D_X \leq 45}$	E
q3.1	5.62	$\boldsymbol{5 < D_X \leq 10}$	B

5.2. Verification of Results through the Program "Sim Traffic": Through the Sim Traffic program, the results of capacity and level of service were confirmed for all on-ramps and off-ramps as well as for all lanes on the main and secondary roads. In addition to verifying the results, an appropriate 3D simulation of the intersection was created according to the new proposal.

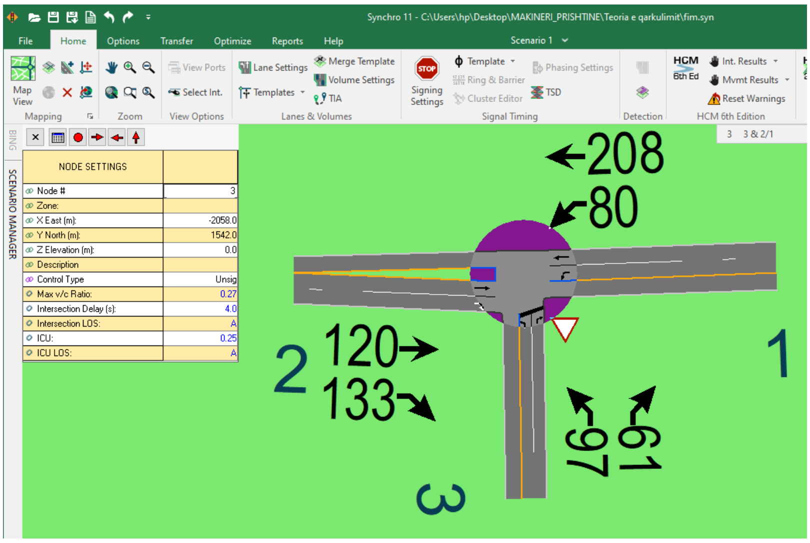

Figure 9. Geometric parameters of traffic flows from all directions

Table 4. Geometric parameters of traffic lanes in the conflict zone - Lanes - Volume – Time

HCM 2000 SIGNING SETTINGS	EBT	EBR	WBL	WBT	NBL	NBR
Lanes and Sharing (#RL)						
Traffic Volume (vph)	120	133	80	208	97	61
Future Volume (vph)	120	133	80	208	97	61
Sign Control	Free	—	—	Free	Yield	—
Median Width (m)	3.5	—	—	3.5	2.8	—
TWLTL Median	☐	—	—	☐	☐	—
Right Turn Channelized	—	None	—	Free	—	None
Critical Gap, tC (s)	—	—	4.1	—	6.4	6.2
Follow Up Time, tF (s)	—	—	2.2	—	3.5	3.3
Volume to Capacity Ratio	0.09	0.10	0.08	0.15	0.27	0.10
Control Delay (s)	0.0	0.0	8.2	0.0	16.7	9.5
Level of Service	A	A	A	A	C	A
Queue Length 95th (m)	0.0	0.0	2.0	0.0	8.2	2.4
Approach Delay (s)	0.0	—	—	2.3	13.6	—

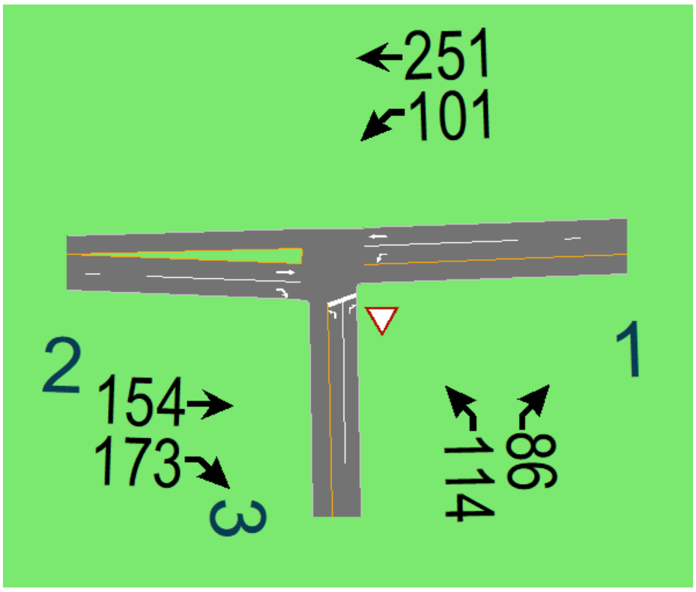

Figure 10. Predicted parameter

Table 5. Generating a simulation report from Sim Traffic

Baseline 12/15/2024

Summary of All Intervals

Run Number	2	3	4	5	6	7	Avg
Start Time	6:57	6:57	6:57	6:57	6:57	6:57	6:57
End Time	7:10	7:10	7:10	7:10	7:10	7:10	7:10
Total Time (min)	13	13	13	13	13	13	13
Time Recorded (min)	10	10	10	10	10	10	10
# of Intervals	2	2	2	2	2	2	2
# of Recorded Intervals	1	1	1	1	1	1	1
Vehs Entered	109	127	118	100	110	124	115
Vehs Exited	107	127	117	101	107	124	113
Starting Vehs	1	3	1	1	2	2	0
Ending Vehs	3	3	2	0	5	2	1
Travel Distance (km)	11	13	12	10	11	13	12
Travel Time (hr)	0.3	0.4	0.4	0.3	0.3	0.4	0.4
Total Delay (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Stops	9	14	11	9	9	7	9
Fuel Used (l)	1.5	1.7	1.6	1.4	1.5	1.6	1.5

Interval #0 Information Seeding

Start Time	6:57
End Time	7:00
Total Time (min)	3
Volumes adjusted by Growth Factors.	
No data recorded this interval.	

Interval #1 Information Recording

Start Time	7:00
End Time	7:10
Total Time (min)	10
Volumes adjusted by Growth Factors.	

Run Number	2	3	4	5	6	7	Avg
Vehs Entered	109	127	118	100	110	124	115
Vehs Exited	107	127	117	101	107	124	113
Starting Vehs	1	3	1	1	2	2	0
Ending Vehs	3	3	2	0	5	2	1
Travel Distance (km)	11	13	12	10	11	13	12
Travel Time (hr)	0.3	0.4	0.4	0.3	0.3	0.4	0.4
Total Delay (hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Stops	9	14	11	9	9	7	9
Fuel Used (l)	1.5	1.7	1.6	1.4	1.5	1.6	1.5

6. Conclusion

At this intersection, traffic nonlinearities were calculated for one day of the week during different time intervals. Based on these nonlinearities and other geometric parameters, the capacity and level of service, as well as the traffic safety level at the intersection, were analyzed and confirmed. A critical analysis was also conducted on the factors that influenced the increase in capacity and improvement of the level of service. The study's analysis of this intersection is based on the HCM (Highway Capacity Manual) methodology, considered the most appropriate method in this case to analyze all relevant factors affecting traffic conditions and to examine the impact of changing any parameter. The obtained results are presented through tables and figures.

Additionally, the results from the mathematical model were analyzed and compared using the SimTraffic software. Relying on the above calculations and illustrations, we can conclude that the current condition of the subject intersection is acceptable in terms of the arrangement of horizontal and vertical signage. From this study, we state that one aspect is not acceptable but can significantly improve vehicle flow by adding special lanes, especially for left turns.

Based on this study, we conclude that adding dedicated lanes not only brings advantages in increasing the safety of traffic participants and improving the level of service but also offers benefits from an economic standpoint as well as in terms of reducing environmental pollution.

We recognize the value of more extensive traffic data, but due to budget and resource constraints, our study relied on manual peak-hour counts. Automated or long-term data collection was not feasible, though the collected data still offers a representative view of typical congestion patterns. While our primary focus was vehicular traffic, we now include a discussion on pedestrian and cyclist impacts, emphasizing the need for safe infrastructure for all users. Additionally, we provide a brief qualitative overview of the potential environmental and economic benefits of the proposed interventions, such as reduced idling and travel delays.

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