ICCPT 2019: Current Problems of Transport: Proceedings of the 1st International Scientific Conference, May 28-29, 2019, Ternopil, Ukraine

Comparative study of level-of-service determination based on VISSIM software and Highway Capacity Manual as exemplified by T-shape and partial cloverleaf interchanges

Volodymyr Sistuk [1], **Yurii Monastyrskyi** [2]

[1] Kryvyi Rih National University, 11 Vitalyi Matusevich str., 50027, Kryvyi Rih, Ukraine; sistuk07@gmail.com
[2] Kryvyi Rih National University, 11 Vitalyi Matusevich str., 50027, Kryvyi Rih, Ukraine; monastirskiy08@ukr.net
* Corresponding author: sistuk07@gmail.com

Abstract: This paper presents a comparative analysis of the level-of-service (LOS) determination based on the VISSIM simulation software and technique described in Highway Capacity Manual (HCM). The methodology used in the analysis is that of the level of service determination for road transport network as exemplified by T-shape intersection and partial cloverleaf (parclo AB3) interchange in the city of Kryvyi Rih. The Department of Road Safety of the National Patrol Police of Ukraine set the task to determine the vehicles queuing length on the bridge if traffic lights at the T-shape intersection are installed. To conduct the project, the VISSIM simulation model of the intersection was developed according to site data collection on workdays and at weekends. LOS criteria were determined by using both traffic management assessment methods. The scenario of traffic lights installation at the intersection was elaborated. It was determined that with traffic signalization adjustment the average travel speed would be about 40% of the free flow speed for a street class. The two assessment methods vary significantly regarding traffic flow density criterion (35.1%). The conclusion is that flow density criterion is not reliable for the node LOS definition. By way of application value of the research findings the recommendations have been prepared for T-shape intersection traffic management that dismissing the project of traffic lights installation at the intersection needs to be considered.

Keywords: road network, VISSIM, HCM, level-of-service, microsimulation model, intersection.

1. Introduction

The network assessment is a basic and necessary element of civil engineering, specifically site plans, network routing patterns, traffic management layouts. Thus, the assessments methods and criteria are one of the most important parts of road network design and operation procedures. At the same time, there is no generally recognized method of road network assessment which is laid out as appropriate specifications and design guidelines in Ukraine. Not only the publication review shows that the specialists in city planning and road traffic management use principally different approaches to decision-making processes. Design of road traffic management is based on traffic flow theory and detailed modelling and characterized by various mathematical tools. In city planning, at the stage of site plans and network routing pattern development, sketchy solutions of road network are accepted. More elaborated design of the road network is performed at the stage of detailed project planning. However,

ICCPT 2019: Current Problems of Transport. https://iccpt.tntu.edu.ua
https://doi.org/10.5281/zenodo.3386809

Peer-review under responsibility of the Scientific Committee of the 1st International Scientific Conference ICCPT 2019: Current Problems of Transport

in this case, an accurate calculation of highway capacity is not carried out. Therefore, the road network assessment is formalistic. As such, parameters like network density and values of line capacity for streets of various categories are used for finding solutions in road network design. However, except for the presented partial criteria, there are other approaches to road network assessment when the integrated criterion is obtained as the main assessment value. It is a so-called level-of-service (LOS) criterion specified in Highway Capacity Manual (HCM) [1] applied at various stages from planning and design to operation of the road network. The recent edition of HCM has been changed significantly: LOS criterion for almost all road network elements have been included in it, the performance of pedestrian and bicycle traffic and quality of public transport services have been considered. For further analysis and the most efficient decision-making (in terms of safety, road capacity, etc.) it is possible to use traffic microsimulation. In general, improvement of road network assessment methods which would be based on the results of traffic microsimulation and determination of LOS criterion for case-study of traffic management in Ukrainian cities is viewed as a pressing task for transport modellers and civil engineers.

2. Materials and Methods

Traffic simulation models are used by numerical techniques on a digital computer to create a description of traffic behaviour over extended period of time for a given transportation facility or system [2-8]. As compared to empirical and analytical models, simulation models predict performance iteratively tracking events as the system status unfolds. Time can be continuous or discrete, and a status of a system is a technical term that is determined effectively by current conditions. Empirical models predict system performance on the basis of relationships developed through statistical analysis of site data, whereas analytical models express relationships among system components on the basis of theoretical considerations being tempered, validated, and calibrated by site data [8].

The advantages of simulation models are presented in HCM [1]. In such case other analytical approaches are not appropriate, there are as follows:

– they can experiment off-line without using on-line trial-and-error approach;
– they can experiment with new situations which do not exist today;
– they can yield insight into what kinds of variables are important and how they are interrelated;
– they can provide time and space sequence information as well as means and variances;
– they can study system in real time, compressed time, or expanded time;
– they can conduct potentially unsafe experiments without any risk to system users;
– they can replicate base conditions for equitable comparison of improvement alternatives;
– they can study the effects of changes on the operation of a system;
– they can handle interacting queuing processes;
– they can transfer unserved queued traffic from one time period to the another;
– they can modify demand over time and space,
– they can model unusual arrival and service patterns which do not follow more traditional mathematical models.

At the same time, it should be noted that the simulation model has several shortcomings, namely: it may be easier ways to solve the problem; simulation models require considerable input characteristics and data, which may be difficult or impossible to obtain; simulation models may require verification, calibration, and validation; development of simulation models requires knowledge in a variety of disciplines, including traffic flow theory, computer programming and operation, probability theory, decision making, and statistical analysis; simulation model may be difficult for analysts to use due to a lack of documentation or need for unique computer facilities; results may vary slightly each time a model is run [1, 2].

In this table it is presented the classification of road traffic situations for which microsimulation would be more acceptable in comparison with HCM technique 1 [6].

Table 1. The list of road traffic situations.

Road network element	HCM technique
Interrupted traffic flow (signalized and unsignalized intersections)	Saturation flow analysis (except signalized intersections), bus operation, street parking, special using of lane, queuing, pedestrians/ cycling interactions
Urban streets	Coupled control efficiency, traffic lights modes, impact from branch roads, impact from bottlenecks which appear on sections of roads, the design of traffic lights control
Signalized intersections	Geometric shift intersections, vehicles arrivals values, the shift of phase control, pedestrians' routes, the design of traffic lights control
Unsignalized intersections	Left turns from a two-laned road, delay before sign "Yield road"
Pedestrians	Pedestrian traffic impact
Bicyclists	Interrupted traffic delay
Transit flow	Interrupted traffic delay
Conditions of traffic interruption	Bottlenecks, saturation flow analysis, temporary transport demand, non-balanced using of lanes, special constraints to lanes using/use, transport service of work areas
Two-lined freeways	Interconnection of traffic and landscape conditions
Multiline freeways	Interrupted traffic delay
High-speed lanes	Lanes for cargo transport
Reference road section	Interrupted traffic delay
Ramps and its connections	Ramps measurement

Currently, one of the most commonly used solutions for traffic microsimulation is a VISSIM software package from PTV VISION Group [8]. The results of the comparative study of the road network evaluation criteria which can be obtained from HCM technique and from VISSIM simulation study are shown in Table 2. So, the value of traffic flow density, delay, volume to capacity ratio are computational parameters that cannot be defined directly through a simulation model analysis.

Table 2. The fusion of road network evaluation criteria which can be obtained from HCM technique and VISSIM simulation model.

Evaluation criteria for LOS defining	HCM technique	VISSIM simulation model
Speed	+	+
Travel time	+	+
Queuing length	+	+
Travel time	+	+
Flow density	+	-
Vehicle delay	+	+
Pedestrian delay	+	+
Volume of capacity	+	-
Public transport schedule	+	-
Vehicles emissions analysis	-	+

The volume to capacity (v/c) ratio [1, 6] isn't calculated through microsimulation in VISSIM due to a stochastic nature of this value. It is necessary to argue in favour of the fact that the capacity of road sections is a result of deterministic approach. Although the capacity could be determined in any moment of simulation time, this value could not be the same in other moments in the simulation process while complying to the components that define the capacity variance. The simulation study responds to the following questions:

- What will happen in real conditions if road congestion exceeds the node capacity?
- What values of traffic speed, flow density, vehicle inputs, traffic delay will be obtained?
- How these values can impact the road network status? [1].

Public transport schedule is the input data in VISSIM. Optionally VISSIM can determine the value of vehicles delay but this value is not HCM compliant [6]. VISSIM directly measures the total delay, which consists of control delay, stopped delay, and other delay incurred in the vicinity of the traffic control device, such as vehicles slowing down for turn movements [8]. Properly calibrated microscopic simulation models will produce delays that more accurately reflect field operations related to the given network geometry, multimodal volumes, and control strategies than deterministic equation based on methods like those included in HCM. VISSIM explicitly models vehicle-vehicle (vehicle-pedestrian, auto-transit, etc.) interactions, queue interactions, freeway and signalized arterial interactions, arterial actuated signal control operations, events (e.g., railroad preemption), ramp metering, etc., unlike the deterministic approaches [3].

In HCM, delay is considered as control delay and vehicles stop. It is determined as follows [1]:

$$d = d_1(PF) + d_2 + d_3, \tag{1}$$

here d_1 –control delay, veh/s; PF– adjustment factor for the traffic light; d_2 – additional delay for casual arrivals and queuing saturation which are adjusted according for an analysis period and a type of traffic light; d_3 – start delay of queuing which causes subsequent delay of all analyzed vehicles.

The first and second values are defined as follows:

$$d_1 = \frac{0,5 \cdot C \cdot (1 - g/C)^2}{1 - \left[g/C \cdot \min(1, X) \right]}, \tag{2}$$

$$d_2 = 900 \cdot T \cdot \left[(X-1) + \sqrt{(X-1)^2 + \frac{8 \cdot k \cdot I \cdot X}{c \cdot T}} \right], \tag{3}$$

here T – duration of the analysis period, h; C – cycle length, s; k – delay factor that depends on traffic light settings; I – filtration adjustment factor; c – capacity of a signal group (veh/h); X – saturation rate.

Saturation rate is:

$$X_c = \frac{Y_c \cdot C}{C - L}. \tag{4}$$

The capacity is defined with retaliation to adjustment saturation flow for the appropriate lane:

$$c = s_i \cdot \frac{g}{C}, \tag{5}$$

here g – green time signal, s; C – control time, s; s_i – saturation flow, veh/h.

In HCM [1] the set of adjustment factors is presented for an accounting additional impacts on the basic value of saturation flow:

$$s = s_0 \cdot N \cdot f_w \cdot f_{HW} \cdot f_g \cdot f_p \cdot f_{bb} \cdot f_a \cdot f_{LU} \cdot f_{LT} \cdot f_{RT} \cdot f_{Lpb} \cdot f_{Rpb}, \tag{6}$$

here s_0 – base saturation flow, (vh/h/ln); N – number of lanes, N; f_w – lane width adjustment factor; f_{HW} – heavy-vehicle adjustment factor; f_g – grade adjustment factor; f_p – parking adjustment factor; f_{bb} – bus blockage adjustment factor; f_a – area type adjustment factor; f_{LU}– lane utilization adjustment factor; f_{LT} – left-turn adjustment factor; f_{RT} – right-turn adjustment factor; f_{Lpb} – left-turn ped/bike adjustment factor; f_{Rpb} – right-turn ped/bike adjustment factor.

Thus, capacity ratio and saturation flow are the main factors for additional delay definition. LOS is defined just from the additional delay. Ultimately travel time just has the main influence on the average traffic speed ST:

$$ST = T_r + d. \tag{7}$$

Despite that T_r is defined, depending on free flow speed and street category it is retrieved from the data specified in the table. This seriously decreases the accuracy of HCM method.

For traffic management analysis in real conditions, it is viable to provide 8-step procedure which consists of the determination of project scope, goals and obtained results, site data collection, simulation model development, input data calibration, assessment of simulation results, LOS criteria definition, and alternative scenarios analysis.

The research aims to develop the methodology of road network LOS determination is based on VISSIM microsimulation evidence from the case-study of traffic lights expediency at the T-shape intersection which transits to a bridge.

3. Results

3.1. Project description

This research was conducted for the road conditions of the city of Kryvyi Rih, a large industrial centre of Ukraine. Its transportation system is strategic for numerous mining and manufacturing enterprises. Initially, urban agglomeration and specificity of urban development aimed to meet the needs of the industry. That's why the urban transportation system is characterized by great haulage distances due to remote locations of isolated industrial facilities (more than 50 km).

The VISSIM-based simulation study of the transportation system of the city of Kryvyi Rih has been worked out by the efforts of the members of Automobile Transport Department (Kryvyi Rih National University) since 2016 for developing appropriate practical recommendations and further decision-making. During this time the critical for social safety areas of road network were detected. The visual observing for quantity and quality of traffic flows and pedestrian flow rates were provided for these urban areas. Based on the results of the site data collection, for the first time the set of microsimulation models of black spots were created in VISSIM. There are 3 urban areas in Central district of the city which include cloverleaf interchange, 9 intersections in Metallurgical district, 11 interchanges in Saksahanskyi and Pokrovskyi districts. The results of computer experiments were used to analyze the impacts of various traffic management options on the transportation system capacity and vehicle/pedestrian safety [10].

The case-study is devoted to expediency of traffic lights at the T-shape intersection of Bykova and Ivana Avramenka streets which transits to the bridge.

The Department of Road Safety of the National Patrol Police of Ukraine has set the task to investigate the possibility of queuing on the bridge in Bykova street if the traffic lights at the intersection of Bykova and Ivana Avramenka streets are installed. Moreover, the intersection is characterized by the parameters which should not be taken into account when calculating via pure HCM technique. They are: a bus stop; traffic concentration; intersection's inclination impact; some road capacity limiting (the confined bridge); overload of urban intersection with traffic flows.

The Bypass (Obyizna street) adjoining to the intersection of Bykova and Ivana Avramenka streets is a parclo AB3 interchange (a partial cloverleaf interchange) [11]. One-lane road at Bykova street from the side of Vechirnyi Boulevard overpasses Obyizna street and pass into Symonova street. Obyizna street has two lanes for each way and an additional lane for Bykova street. The interchange scheme and directions of the traffic flows are presented in Figure 1.

The public transport routes # 15, 201, 210, 293, 295, 306 are transit on the interchange. The closest bus stops are situated in Ivana Avramenka and Symonova street. The interchange is a node for transport service of Vechirnyi Boulevard district and Schidnyi-1 residential area. A primary school, METRO Cash & Carry wholesaler and Epicenter hypermarket are situated near the intersection.

The proposed program of lights control (project CB-04/1-18-EH) and their designed locations are shown in Figure 2.

3.2. Site data collection

In case of traffic lights control adjustment on the T-shape section of the intersection, it is important to determinate the traffic flows values and directions accurately. According to this, the traffic flow 1 in Bykova street splits on two left-turn flows before the bridge and to Ivana Avramenka street, and also on the straight traffic in Symonova street. The flows from the latter street were fixed from the two points: before (flow 8) and after (flow 5) the bridge that allows collecting vehicle inputs data more accurately. The ramp from Symonova street is performed in two routes to Vechirniy Boulevard (flow 2) and across the bridge to Schidnyi-1 residential area (flow 4).

The lengths of the routes are shown in Figure 1, they define microscopic simulation model boundaries. The measurements of vehicles inputs are provided in various periods of time at the weekend and on workdays with 15-minute interval for each route. The traffic flow mix value was assumed with 13% average ratio of heavy vehicles. A clear trend to traffic load increasing at certain periods at weekend as well as on workdays can be traced from the collected data. So, there are the clear peak hours in interchanging. The collected site data of the traffic and pedestrian inputs are used for microsimulation model development in VISSIM software with static vehicles routes assignment.

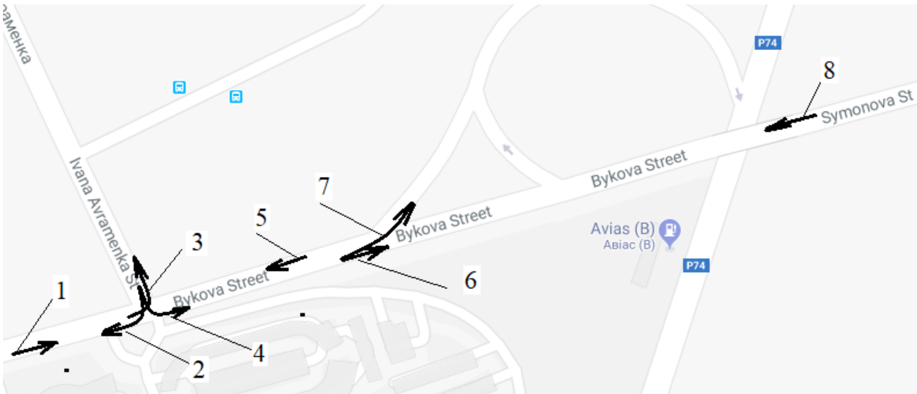


Figure 1. The input traffic flows and lengths of their routes: *1* – traffic from Epicenter hypermarket straight to Bykova street (366 m); *2* – right-turn traffic from Ivana Avramenka street to Bykova street (283 m); *3* – traffic from Bykova street to Ivana Avramenka street (290 m); *4* – left-turn traffic from Ivana Avramenka street to Bykova street (232 m); *5* – straight traffic from the bridge to Epicenter hypermarket (112 m); *6* – traffic on road section from the T-shape intersection to the bridge toward Schidnyi-1 residential area (115 m); *7* – left-turn traffic from Bykova street (113 m); *8* – ramp from Symonova street to Bykova street (270 m).

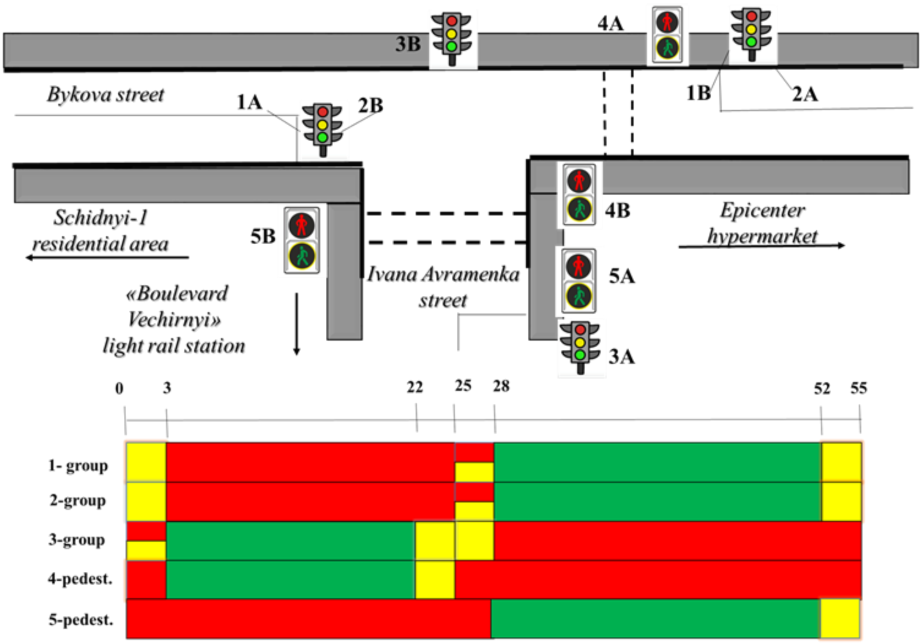


Figure 2. The proposed timing program and traffic lights locations (Project CB-04/1-18-EH).

3.3. Simulation results analysis

VISSIM defines the priority rule of conflict points via conflict areas assignment [2, 8]. The conflict areas were determined following traffic management: at ramp from Symonova street and before roundabout of parclo the yield sign has been installed. VISSIM traffic control block requires setting signal groups of lights control. For this purpose, the proposed program of traffic signalization was implemented in VISSIM model.

The VISSIM-simulation results show that queuing is absent for the unsignalized intersection option. It is also proved by the data obtained during investigation of traffic flows on the interchanging. These data were also used as input values of simulation model calibration.

The average value of vehicle travel time for various vehicles routes (Figure 3) are determined based on the microsimulation results for traffic management provided that traffic lights are installed according to the scheme (Figure 2).

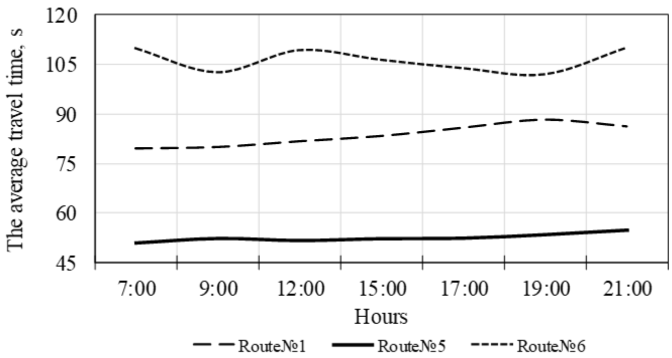
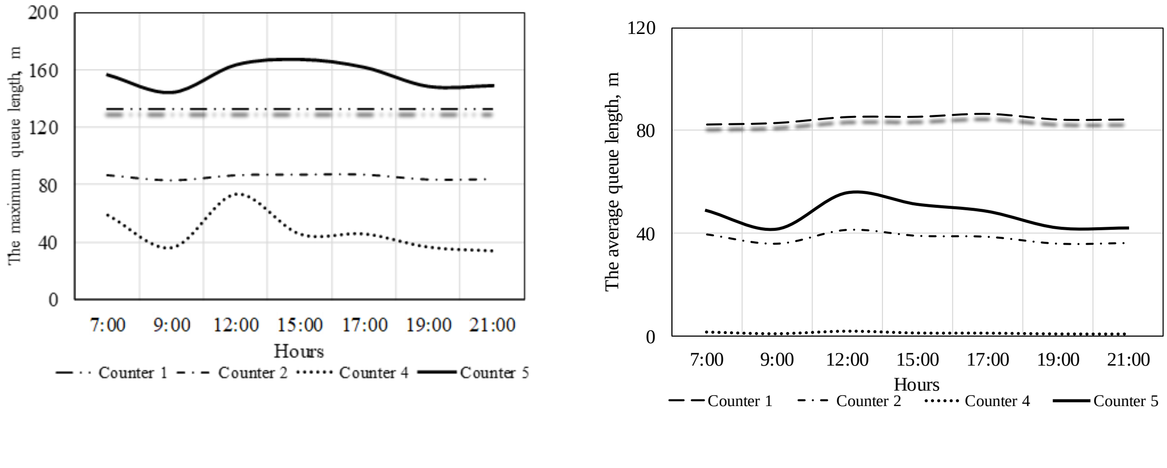


Figure 3. The average travel time for the most loaded routes: №1 – from Epicenter hypermarket towards Bykova street; №5 – left-turn ramp from Bykova street; №6 – ramp from Symonova street to Bykova street.

It was found that maximum travel time is spent for straight traffic. The value of travel time from T-shape intersection to the bridge towards Schidnyi-1 residential area is 106.3 s, from the bridge in Bykova street towards Epicenter hypermarket is 83.6 s, on the side of Epicenter hypermarket in Bykova street is 52.4 s.

The distribution of queue lengths obtained from the appropriate counters (Figure 4) is shown in Figure 5. Standard deviations of average queue length value during a day are 1.4 m, 2.4 m, 0.4 m, and 5.3 m for the routes pass through 1, 2, 4 and 5 counters respectively. But for the counter 3, the queue is absent. The major queue values are on the counters 1, 2, 5 through which individual transport routes with numbers 1, 4, 5, 6 are transited. Thus, the values of vehicle travel time are verified by created queues.

Figure 4. The location of queue counters: 1 – ramp from Bykova street to intersection; 2 – ramp from the bridge to Bykova street; 3 – straight traffic towards Symonova street; 4 – left turn ramp from the bridge; 5 – ramp from the Bypass to the bridge.



(a) (b)

Figure 5. The vehicle queue lengths: (**a**) The maximum value; (**b**) The average value.

If traffic signalization is installed, the average queue length of 84.4 m before the intersection will be on the ramp from Bykova street, 38.1 m before T-shape intersection at the same street at ramp from the bridge, 47.3 m from the ramp on the side of Symonova street. It should be noted, that there are peak traffic loads (peak-hour-factor – PHF [1, 6]) in the period from 11 to 13 p.m. Inequality of peak loads distribution is proved by variation of peak hour factor for different traffic routes where the maximum values of this parameter are associated with 1 and 8 routes presenting straight traffic on the bridge (Table 3).

Table 3. PHF determination for the vehicle routes.

	Routes							
	1	***2***	***3***	***4***	***5***	***6***	***7***	***8***
PHF	0.92	0.68	0.79	0.75	0.77	0.79	0.59	0.87

It can be noticed that the road section length from the T-shape intersection in Bykova street to the bridge aside Schidnyi-1 residential area is 115 m. This fact implies that about a half of the bridge length traffic queue is possible.

3.4. Node LOS determination

The next stage of analysis is the node LOS determination. For this purpose, the parameters from VISSIM were used, namely the value of delay and average control delay, and average traffic speed. For the node LOS calculation, the user defined attributes (UDAs) were used in VISSIM [12]. There were four UDAs: attribute LOS to calculate the average node LOS, attribute WorstLOS to determine the worst LOS of all time intervals and simulation runs, attribute WorstMovLOS to calculate the worst traffic LOS, attribute NodeLabel to show the results in one label for current, previous interval and worst throughout all simulation runs and time intervals.

The values for UDAs were accepted according to HCM table for signalized intersections [1]. The programming code for the first UDA is as follows:

```
IF([TOTRES\VEHDELAY(...ALL)]≤10; "A";
IF([TOTRES\VEHDELAY(...ALL)]≤20; "B";
IF([TOTRES\VEHDELAY(...ALL)]≤35; "C";
IF([TOTRES\VEHDELAY(...ALL)]≤55; "D";
IF([TOTRES\VEHDELAY(...ALL)]≤80; "E"; "F"))))).
```

To calculate the worst node LOS the following code was used:

```
IF(NUMTOSTR([TOTRES\VEHDELAY(MAX, MAX, ALL)])=";";
IF([TOTRES\VEHDELAY(MAX, MAX, ALL)]≤10; "A";
IF([TOTRES\VEHDELAY(MAX,MAX, ALL)]≤20; "B";
```

IF([TOTRES\VEHDELAY(MAX, MAX, ALL)]≤35; "C";
IF([TOTRES\VEHDELAY(MAX, MAX, ALL)]≤55; "D";
IF([TOTRES\VEHDELAY(MAX, MAX, ALL)]≤80; "E"; "F")))))).

For estimation of the worst movement LOS we made use of the code:

IF(NUMTOSTR([MAX:MOVEMENTS\VEHDELAY(MAX, MAX, ALL)])=";";
IF([MAX:MOVEMENTS \VEHDELAY(MAX, MAX, ALL)]≤10; "A";
IF([MAX:MOVEMENTS \VEHDELAY(MAX,MAX, ALL)]≤20; "B";
IF([MAX:MOVEMENTS \VEHDELAY(MAX, MAX, ALL)]≤35; "C";
IF([MAX:MOVEMENTS \VEHDELAY(MAX, MAX, ALL)]≤55; "D";
IF([MAX:MOVEMENTS \VEHDELAY(MAX, MAX, ALL)]≤80; "E"; "F")))))).

To show the node label we used the code:

"Current node LOS:"=[LOS, CURRENT, CURRENT];
"Last interval LOS:"=[LOS,CURRENT, LAST];
"Worst node LOS:"=[WORSTLOS];
"Worst movements LOS:"=[WORSTMOVLOS].

So, LOS definition is obtained considering the average delay at the intersection, delay upstream the traffic light, and the average traffic speed. The comparison of the obtained parameters with the same ones determined via HCM technique is shown in Table 4.

Table 4. The node results.

Parameter	HCM	VISSIM	Deviation, %	LOS criteria	
				HCM	VISSIM
Average travel speed, km/h	28.1	24.57	11.0%	C	C
Traffic flow density, auto/km	280.1	430.8	35.1%	F	F
Average delay, s	37.1	47.0	21.0%	D	D
Control delay (ACD), s	34.1	27.3	20.0%	C	C

4. Discussion

The maximum deviations between the traffic management performance indicators in the intersection are obtained for such criteria as the flow density ratio and average delay. They are 35.1% and 21.0% respectively. HCM technique and VISSIM-model made such data as the average travel speed and the average delay differ by 11.0% and 20.0% respectively. The worst node LOS is F. It was obtained upon indication of flow density for the two assessment methods. This implies that the average speed at the interchanging is 25–33% of the speed in freeway conditions (FFS) for this urban street type and extensive delays and queuing are observed at the intersection. The VISSIM model versus HCM technique showed more similar scenario if decision on signal lights installation is made. Based upon the average travel speed which is dependent on the running speed and the amount of control delay incurred at signalized intersections, the interchanging was assigned LOS C. This value describes stable operations; however, ability to maneuver and change lanes in midblock locations may be more restricted than at LOS B, and longer queues, adverse signal coordination, or both may contribute to lower average travel speed of about 50% of FFS for the street class [1].

In general, due to the results of HCM technique and VISSIM model application, it has been determined that according to the average delay and ACD the interchanging has got LOS D. This implies that small increases in traffic flow may cause substantial increases in delay and decreases in travel speed. Node LOS D occurs due to adverse signal progression, inappropriate signal timing, high traffic volumes, or a combination of these factors. The average travel speed is about 40% of FFS.

5. Conclusions

The research presents the comparative study of the methodology of road network LOS determination which is based on VISSIM microsimulation results and HCM technique. To achieve this goal, it has been implemented that the project was aimed at determination of traffic lights installation viability at T-shape intersection of Bykova Street and Ivana Avramenka street in the city of Kryvyi Rih. In the course of the project the following results were achieved:

– the site data on vehicles and pedestrians' inputs were collected at the relevant week's time;

– the VISSIM-simulation model of the intersection was developed;

– based on the microsimulation results, it was determined that the traffic lights installation would rapidly increase queue origination;

– upon the average vehicles delay, ACD, flow density, average travel speed the appropriate node LOS criteria for the intersection were assigned via VISSIM and HCM technique;

– decision-making process was provided due to the determined LOS criteria; it is conceivable that if any signalized intersection with interrupted traffic stream is on the considered road area, the average travel speeds will be about 40% of FFS for the street class (node LOS D was obtained via HCM technique and VISSIM simulation);

– the developed recommendations for the intersection were considered by the Department of Road Safety of the National Patrol Police which was used as a reason to abandon the project of traffic management changing at the intersection.

It was found that the maximum deviations between the two methods of LOS determination were obtained for such performance criterion as traffic flow density (35.1%). This implies that the values received from this criterion are not adequate for the node LOS definition.

Further study will be focused on aggregation of modern measures of road network performance to quantitative and quality decisions making for social and economic safety of transportation system of the industrial city.

Funding: This research has received no external funding.

Acknowledgments: The authors express thanks to the head of Kryvyi Rih Department of Road Safety of the National Patrol Police of Ukraine for providing materials on the project of timing program and traffic lights locations at the intersection.

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

References

1. Report. Highway capacity manual, 2000. https://doi.org/10.1061/(ASCE)HY.1943-7900.0000746.
2. Barcelo, J.; Fellendorf, M.; Vortisch, P. *Fundamentals of Traffic Simulation. Simulation* 2010, *145*, https://doi.org/10.1007/978-1-4419-6142-6
3. Chen, X.; Guo, J.; Yu, L.; Yu, L.; Wan, T. Calibration of Vissim for Bus Rapid Transit Systems in Beijing Using GPS Data. *Journal of Public Transportation* 2015, *9(3)*; 239–257. https://doi.org/10.5038/2375-0901.9.3.13
4. Dowling, R.; Skabardonis, A.; Alexiadis, V. Traffic Analysis Toolbox Volume III : Guidelines for Applying Traffic Microsimulation Modeling Software. U.S. *Department of Transportation., III(July)*, 2004; 146.
5. Hussain, E.; Ali, M.S. Calibration and Validation of VISSIM for signalized intersection of Karachi Calibration and Validation of microsimulaiton software for intersection of Karachi, (December, 2017).
6. Milam, R.T.; Stanek, D. The Secrets to HCM Consistency Using Simulation Models. *Transportation Research*, 2015.
7. Vinayaka, B. *Saturation and Delay Model Microsimulation Using Vissim - A Case Study, 5(06),* 2016, 779–789.
8. Washington State Department of Transportation (WSDOT). Protocol for VISSIM Simulation. *Washington State Department of Transportation,* (September 2014), 162. https://doi.org/10.1088/1748-9326/8/2/024010
9. Carba, E.; Fuertes, J.O. Combination of travel time and delay measurements in an urban traffic controller. A case study of Zuidas, 2017.
10. Sistuk, V. Pedestrian Routes Organization Improvement using Microsimulation. *Visnyk National Transport University - Series «Technical Sciences»* 2018, *40*, 307 – 315.

11. Kaisar, E.; Raton, B.; Hourdos, J. Traffic Impact Assessment of Partial Cloverleaf Interchange. *International Symposium on Highway Geometric Design,* 2015.
12. Tettamanti, T.; Horváth, M.T. A practical manual for Vissim COM programming in Matlab - 3rd edition for Vissim version 9 and 10, (November, 2018). https://doi.org/10.13140/RG.2.1.1332.1683
13. Mukhtyarali, S.S.; Zala, L.B.; Amin, P.A. Capacities LOS Measures of Intersections. Kalpa Publications in Civil Engineering, 2017, 1; 209–218.