UDC 656.13 DOI https://doi.org/10.33082/td.2023.1-16.11

THE PRACTICAL ASPECTS OF REDUCING THE LEVEL OF ACCIDENTS ON CITY ROADS BY FORMING A SAFETY PROFILE

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Summary

***Introduction**. Recent decades have been characterized by high rates of motorization. At the same time, Ukraine has one of the highest rates of deaths and injuries as a result of road accidents among European countries, and the level of road safety organization remains extremely low. An analysis of international practice has shown that the infrastructure of streets and highways in Ukrainian cities does not fully meet modern requirements. During their construction and reconstruction, ground and underground pedestrian crossings and special bicycle lanes are not always arranged, which could significantly reduce the level of road traffic injuries and deaths.*

Therefore, analyzing the main reasons for the insufficient level of road safety is one of the steps towards making effective decisions to reduce the risk of road accidents.

***Purpose.** The main purpose of this article is to study the experience of implementing low-risk road infrastructure in the cities of the European Union and compare it with the conditions of traffic management in Ukrainian cities.*

***Results.** The analysis of the factors influencing the level of mortality and injuries due to road accidents contributed to the formation of a road safety profile, which is a triad of interaction between three systems in the environment. The study made it possible to assess the level of safety in the organization of traffic on identical sections of urban infrastructure in Rzeszow (Poland) and Kyiv (Ukraine). The paper presents the comparison criteria and parametric indicators of the sections of the road transport network of the cities.*

***Conclusions.** Based on the calculations, the most critical points are identified and the conditions for safe traffic management are outlined. Taking into account the directions of strategic and territorial development of Kyiv, the main measures for the development of the city's street and road network are determined, taking into account the experience of the European analog.*

***Key words:** street and road network, traffic safety profile, traffic safety profile triad, accident rate, traffic flow, critical points, traffic organization.*

ПОРІВНЯЛЬНИЙ АНАЛІЗ ПРОФІЛЮ БЕЗПЕКИ ОРГАНІЗАЦІЇ РУХУ ВУЛИЧНО-ДОРОЖНЬОЇ МЕРЕЖІ МІСТ

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Анотація

Вступ. *Останні десятиліття характеризуються високими темпами автомобілізації. Водночас Україна має один з найвищих показників смертності та травматизму внаслідок дорожньо-транспортних пригод серед європейських країн, а рівень організації безпеки дорожнього руху залишається вкрай низьким. Аналіз міжнародної практики показав, що інфраструктура вулиць і магістралей в українських містах не повною мірою відповідає сучасним вимогам. Під час їх будівництва та реконструкції не завжди облаштовуються наземні та підземні пішохідні переходи, спеціальні велосипедні доріжки, які могли б суттєво знизити рівень дорожньо-транспортного травматизму та смертності.*

Тому аналіз основних причин недостатнього рівня безпеки дорожнього руху є одним із кроків до прийняття ефективних рішень щодо зниження ризику виникнення дорожньо-транспортних пригод.

Мета. *Основною метою цієї статті є дослідження досвіду впровадження дорожньої інфраструктури низького ризику в містах Європейського Союзу та порівняння його з умовами організації дорожнього руху в містах України.*

Результати. *Аналіз факторів, що впливають на рівень смертності та травматизму внаслідок ДТП, сприяв формуванню профілю безпеки дорожнього руху, який являє собою тріаду взаємодії трьох систем у навколишньому середовищі. Дослідження дозволило оцінити рівень безпеки при організації дорожнього руху на ідентичних ділянках міської інфраструктури в Жешуві (Польща) та Києві (Україна). Наведено критерії порівняння та параметричні показники ділянок дорожньо-транспортної мережі міст.*

Висновки. *На основі проведених розрахунків визначено найбільш критичні точки та окреслено умови для безпечної організації дорожнього руху. З урахуванням напрямів стратегічного та територіального розвитку Києва визначено основні заходи щодо розвитку вулично-дорожньої мережі міста з урахуванням досвіду європейського аналогу.*

Ключові слова: *вулично-дорожня мережа, транспортний потік, перехрестя, організація руху.*

Introduction. Problem statement. The increase in the number of vehicles in cities and the growth of traffic intensity have led to a decrease in traffic speed, delays at transport hubs, deterioration of traffic conditions, increased pollution and noise levels in cities, and an increase in accidents on the street and road network. This has necessitated the search for effective measures to eliminate these negative consequences on the example of the organization of the street and road network of European cities.

The increase in the number of cars in the largest cities of Western Europe, which began in the 50s of the last century, followed almost the same pattern for all countries: a linear increase in the number of cars to the level of 300–350 cars/1000 inhabitants, then a slowdown in the growth trend and stabilization at the level of 550 ± 50 cars/1000 inhabitants [1]. A limit of saturation with individual cars was adopted, after which the level of motorization stabilizes, and only the rotation of the fleet takes place [2].

In order to find ways to ensure the effective functioning of the city's SRN, it is necessary to analyze the basic principles of improving the transport and operational qualities of city streets and roads, ensuring road safety, and increasing their capacity. To improve the efficiency of vehicles in the urban environment, the speed of cargo delivery and passenger transportation.

Research statement. Road safety is one of the main criteria for evaluating transportation systems. As a result, one of the primary tasks of optimizing transport systems is to improve road safety. A road is a complex dynamic system that includes a set of human-vehicle-road elements that operate in a certain environment. These elements are interconnected with each other and form an integrated transportation system. From the point of view of road safety, both the risk factors themselves and their various combinations are of interest for systematic study.

Literature review. It is known that about 75% of road accidents occur in cities, and more than half of them are concentrated in the areas of intersections of transport highways [3]. Therefore, the problem of traffic organization and safety is the most important urban planning task, the correct solution of which determines the reliability and quality of the entire urban transport system and the possibility of implementing the necessary engineering and technical solutions, including those to reduce the level of road accidents [4]. In different countries, scientists use far from identical methods of organizing traffic flows, as there is no general, universal solution to this problem. To ensure the safe passage of vehicles at any time of the year, it is important to constantly monitor the condition of roads, timely identify structural elements and areas requiring urgent repair, and a detailed assessment of traffic conditions of different densities. To perform these works, comprehensive road condition survey plans are required, which are used to develop measures to improve traffic conditions.

Main part. Traffic flow is a complex system that includes vehicles, roadways and the environment, which includes all street and road arrangements and pedestrian traffic. The basic principle of the traffic flow system is the integrity of the traffic process, where the integrity of the flow is primary and the position and speed of vehicles in the flow is secondary [5].

The analysis of a priori information and technical and legal documentation allowed us to conduct a systematic analysis of the interaction of the components of the TFC and the factors influencing the safe organization of traffic (Fig. 1). This served as the basis for the formation of the conceptual principles of the safety profile to identify the causes of road accidents and reduce the occurrence of dangerous situations on the roads.

Research has shown that such scientists as Guk V.I. and Stepanchuk O.V. [6, 7] suggest that the main reasons that reduce traffic safety are a few characteristic features

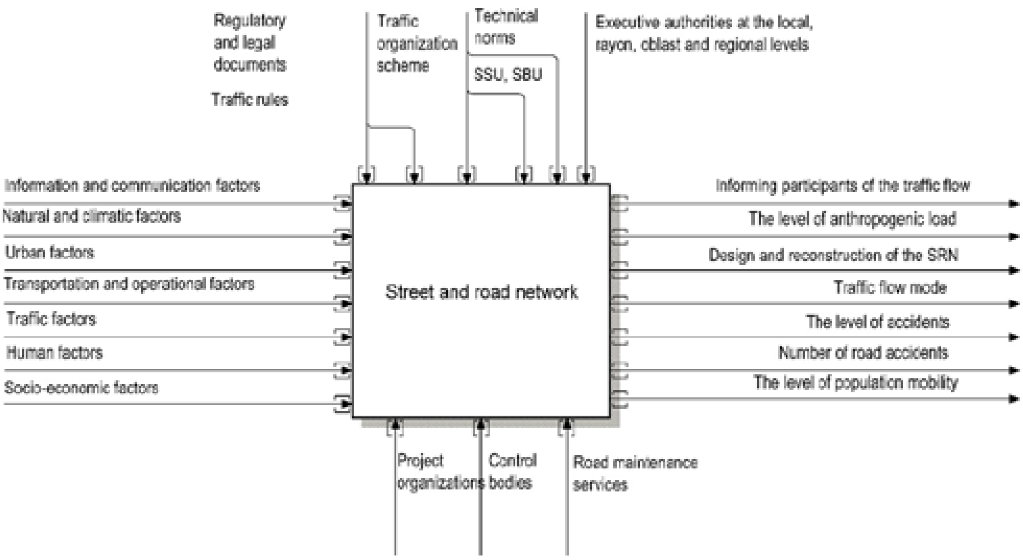


Fig. 1. Conceptual scheme of street and road network functioning

of the road and traffic flow, such as insufficient width of the roadway; insufficient visibility; sharp unexpected change of road direction; intersection with unregulated traffic flow; lack of acceleration and braking lanes; bus stops without smooth adjacencies to the roadway; steep ascents and descents, etc. Statistical information on road accidents provides a fundamental opportunity for a comparative assessment of the degree of traffic safety under different parameters of the road elements and traffic intensity on the road.

Thus, the parameters that significantly affect the situation during traffic and ensure safety can be represented as a triad of individual street and road network systems and road users (Fig. 2). This analysis was the basis for the formation of the traffic safety profile.

An analysis of the number of accidents on Western European roads showed that their number is lower than in Ukraine. Therefore, we will compare similar sections of the urban road network and their operating conditions.

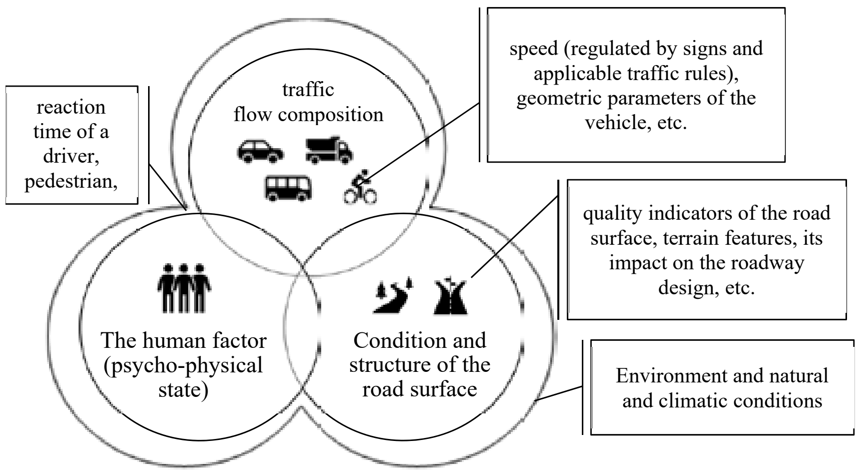


Fig. 2. Triad of the traffic safety profile

As the main criteria for the comparative analysis of traffic organization at the junctions of the urban road network in Kyiv (Ukraine) and Rzeszow (Poland), several parameters of the street and road network and the road transport system were considered, which are given in Table 1 [8, 9].

In accordance with the methods [9, 10], based on the data in Table 1, we calculated and analyzed the quantitative indicators of traffic flow in Kyiv (Ukraine) and Rzeszow (Poland). The initial data and their corresponding calculation coefficients, traffic conditions at each of the intersections and adjacent streets, and the ranges of calculations under different traffic conditions were considered. In addition to the geometric parameters of the street and road network, a number of other parameters were considered [11].

The quantitative indicators of the triad are presented in Table 2, which makes it possible to evaluate and compare their values.

The essential elements of influence on the situation on the road by road users are primarily the composition of the traffic flow. The analysis of traffic flow on the city streets of the studied cities of Ukraine and Poland showed that there are differences in the types of vehicles and their technical and operational characteristics, which differ significantly from each other. Therefore, its composition plays an important role in shaping traffic conditions. The share of mass passenger transport on main city streets is 3–25%; trucks 2–15%; cars 60–95% [12, 13]. Such a range of changes in indicators depends on a number of factors, namely: time of day, day of the week, city district and its main function. The real traffic flow has a stochastic nature of movement, which depends on random changes in the traffic situation and individual characteristics of vehicle drivers, so the capacity of the street and road network is subject to statistical patterns of traffic flow.

Table 1

Criteria comparing the elements of the SRN

	Rzeszow (Poland)		**Kyiv (Ukraine)**	
	A. Asnyk str.	**J. Pilsudski Ave.**	**Aviakonstruktora Antonova str.**	**Chokolovsky Boulevard**
Lane width, m	3,5	3,75	3,75	3,5
Width of the roadside, m	3	3,75	3,37	3
Presence of side obstacles	Yes	Yes	Yes	Yes
Visibility distance, m	250–350	250–350	>350	250–350
Curve radius in plan, m	<100	100–250	100–250	<100
Speed limit, km/h	50	60	60	50
Share of cars turning left, %	20	20	20	20
Condition of the pedestrian sidewalk	Solid coating	Solid coating	Solid coating	Solid coating
Coating type	Cement concrete	Cement concrete	Asphalt concrete	Asphalt concrete
Marking type	Axial and edge	Axial and edge	Axial and edge	Axial and edge
Bandwidth	700	2000	2000	700

Table 2

Quantitative indicators of traffic flow

	Rzeszow (Poland)		Kyiv (Ukraine)	
	A. Asnyk str.	**J. Pilsudski Ave.**	**Aviakonstruktora Antonova str.**	**Chokolovsky Boulevard**
T_p – driver reaction time, s;	1	1	1	1
T_{cp} – brake actuator response time, s	0,3	0,35	0,4	0,27
K_e – braking efficiency coefficient;	1	1,5	1,35	1,2
φ – the coefficient of tire adhesion to the road surface;	0,7	0,65	0,7	0,62
I – road slope;	0	0,2	0,2	0
L_a – overall length of the vehicle, m;	4	4	4	4
$S_з$ – the value of the reserve, m;	4	5	5	4
V_0 – minimum speed, km/h.;	50	60	60	50
α – speed reduction factor, which depends on the composition of the TF.	0,008	0,005	0,0045	0,0085

To analyze and calculate, we selected statistical data on changes in the dynamics of the traffic situation over time on identical sections of the SRN in Kyiv and Rzeszow (Fig. 3). Monitoring of quantitative indicators of traffic flow made it possible to obtain average statistical data and, using mathematical dependencies, to model their change within 24 hours for both options.

When determining the quantitative indicators of traffic flow, the presence or absence of traffic control devices, pedestrian crossings, safety islands, adjacent buildings, parking spaces and the degree of infrastructure development, location in relation to the city center, and population density in the area were taken into account.

The structural elements and parameters of the street and road network of the study sites and the condition of the roadway made it possible to evaluate and verify the results of the calculations and their adequacy in practice.

It is impossible to completely prevent accidents, as the causes of accidents are not only unfavorable road conditions, but also the influence of many factors that relate to

a) Intersection of Y. Pilsudskoho Avenue and A. Aznuka Street *b) Intersection of Chokolovsky Boulevard and Aviakonstruktora Antonova Street*

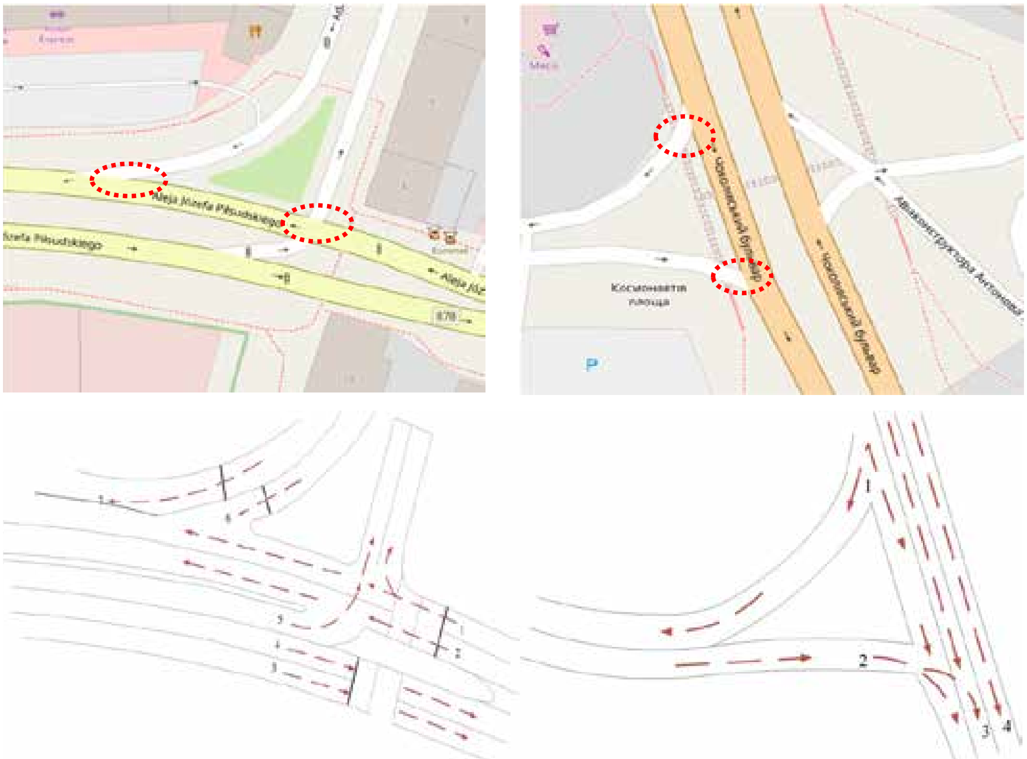
Fig. 3. Schematic representation of urban road network nodes

both traffic conditions on the road and the impact of the traffic flow itself, an individual car, the human factor (drivers and pedestrians), weather conditions, etc. [14].

Based on the results of the calculations, a comparative analysis of the experimental sections of the SRN was carried out and the hazardous areas were identified. The risk assessment of road accidents considers the analysis of critical points on the road sections and decision-making to increase their level of danger. The identified critical points take into account the peculiarities of vehicle movement. The study of the SRN section in Rzeszow (Fig. 4a) showed that the most dangerous places are the intersections of traffic flows 1, 2, 5 and 1, 6, 7. These locations are shown in Figure 4a.

As for the Kyiv SRN section, which corresponds to the indicators of the Rzeszow SRN section (Fig. 4b), the critical points are the intersection of the 2nd, 3rd, 4th and the distribution point of the 1st traffic flow. The calculated indicators were confirmed by practical observations [15].

At each of the SRN nodes, the safety profile triad was evaluated and the dynamics of changes in the level of traffic safety at speeds from 10 to 80 km/h was calculated. This range was chosen based on speed limits, terrain and design features of the SRN in these areas. The calculations did not take into account static indicators, such as the design parameters of the SRN, but only dynamic and psychophysiological (for the driver).



a) Intersection of Y. Pilsudskoho Avenue and A. Aznuka Street

b) Intersection of Chokolovsky Boulevard and Aviakonstruktora Antonova Street

Fig. 4. Schematic representation of critical points and hazard environments at the nodes of the urban road network

Based on the data in Tables 1 and 2, we mathematically processed the criteria presented in Table 3, which are the components of both vehicle trajectory safety and traffic flow.

The analysis of the research results and calculations showed that the numerical values correspond to the permitted speed limits on the studied sections. For example, calculations are presented at a speed of 50–60 km/h in accordance with the regulated speed limits on the sections during the day. The results of the calculations for the main and secondary roads in both cases and their difference are within the normal range, and the calculated value of the braking distance (S_t) corresponds to the designed values.

The values of the actual throughput ($N_ф$) and the calculated throughput taking into account unfavorable situations and emergency braking (N_{max}, N_{max}) do not exceed

Table 3

Results of calculating road capacity and density of vehicles

50–60 km/h.	Rzeszów (Poland)		Kyiv (Ukraine)	
	A. Asnyk str.	J. Pilsudski Ave.	Aviakonstruktora Antonova str.	Chokolovsky Boulevard
$S_р$ – is the vehicle path during the driver's reaction time, m	13,89	16,67	13,89	16,67
$S_{ср}$ – is the vehicle distance during the brake actuation, m	4,17	5,83	3,75	6,67
S_t – is the size of the braking distance, m	14,06	32,71	19,05	27,33
$S_о$ – braking distance, m	32,12	55,21	36,69	50,67
$L_Д$ – safety distance, m	40,12	64,21	44,69	59,67
$L_{ДУ}$ – is decreased value of the vehicle's dynamic dimension, m	24,06	36,60	26,34	34,33
$t_{пр}$ – is the time after which cars will pass one after the other through the road intersection, observing the safety distance, s	2,89	3,85	3,22	3,58
$t_{пр'}$ / taking into account the reduced value of the vehicle's dynamic dimension, s	1,73	2,20	1,90	2,06
N_{max} – is the capacity of the road section, car/hour,	1246,40	934,50	1000,88	1005,60
N_{max} – is the capacity of a road section, taking into account the reduced value of the dynamic size of the vehicle, car/hour,	2078,34	1639,22	1897,98	1747,60
$V_{ср}$ – average flow speed, km/h.	40,03	55,33	40,49	55,47
$V_{ср'}$ – average flow speed, taking into account the reduced value of the vehicle's dynamic dimension km/h.	33,37	51,80	33,87	52,14
q – traffic flow density, cars/km,	24,93	15,58	22,38	16,76
q' – traffic flow density, taking into account the reduced value of the vehicle's dynamic dimension, cars/km,	41,57	27,32	37,96	29,13
$N_ф$ – actual throughput of the sections, car/hour	601,30	1844,92	530,60	1661,23

the permissible values, and therefore no structural changes are required at the existing SRN nodes, only organizational measures are needed to regulate traffic flows at the junctions (for regulated intersections) and within a block distance from the intersection (for unregulated intersections) and the use of GPS beacons to respond quickly in case of emergencies or to inform road users about the situation on this section of the road, which is quite relevant during peak hours.

The speed limits are justified for this range of vehicle movement (50–60 km/h). However, calculations and observations have shown that increasing the speed to 70–80 km/h leads to accidents on both sections, which in 65% of cases are caused by the human factor and psycho-physiological characteristics of drivers.

According to Table 3, other calculations were carried out in the range of 10–80 km/h. The mathematical dependencies of changes in traffic flow indicators – throughput and average speed – allowed us to graphically assess their dynamism (1):

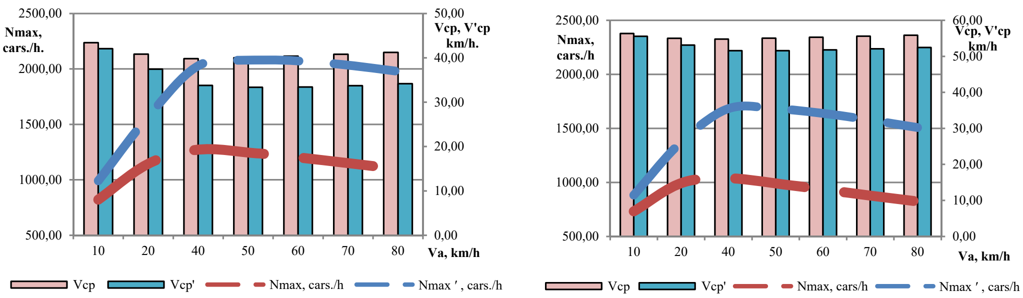
$$\begin{aligned} N_{\max} &= f(V_a) \\ N'_{\max} &= f(V_a) \\ V_{cp} &= f(V_a) \\ V'_{cp} &= f(V_a) \end{aligned} \qquad (1)$$

The graphical interpretation of the calculation results showed that on the studied sections of the SRN (Fig. 5, Fig. 6) there is a clear decrease in traffic capacity when leaving the junctions and intersections. The maximum throughput values are achieved at traffic speeds of 35–45 km/h.

The analysis of the graphs showed that there is a direct proportional relationship between the average speed and traffic capacity at road junctions and intersections. In this case, the presence of traffic lights and other means of traffic management can be ignored.

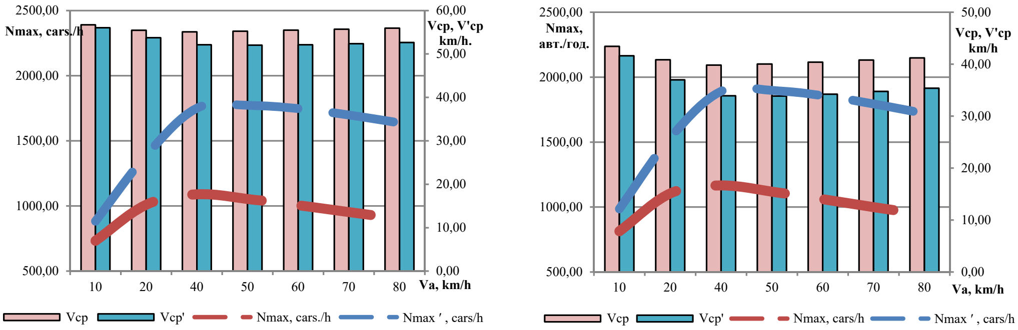
In the calculations, 80 km/h was proposed as the maximum value of the speed range, because, despite the design and parametric features of the studied sections, the time intervals when the car can move with a higher value on the speedometer are minimal in relation to the total time used for the calculations.

Conclusion. The result of mathematical processing allowed us to confirm compliance with the designed requirements for the qualitative and quantitative indicators of these transport nodes of the city's street and road network.



а) A. Asnyk str. *б) J. Pilsudski ave.*

Fig. 5. Graphical dependencies of capacity and average speed at a controlled intersection



a) Aviakonstruktora Antonova str. *b) Chokolovsky Boulevard*

Fig. 6. Graphical dependencies of capacity and average speed at an unregulated intersection

As an indicator of the effective organization of traffic flows is the minimum value of peak conditions and accidents. Therefore, the traffic safety profile took into account the experience of Western European countries to improve the level of vehicle safety. The analysis of statistical information [2, 7] on the causes of traffic accidents showed the awareness of all categories of users of the SRN due to technical means of traffic organization and modernization of existing elements of the traffic management system. This helps to reduce accidents, but cannot completely eliminate the peculiarities of the psychophysical state of the population, both on the part of drivers and pedestrians in real time.

Conclusions. As the practice shows, the modernization and reconstruction of road traffic facilities is not always feasible and economically justified. Therefore, the formation and analysis of a traffic safety profile will help identify the most effective solutions to reduce road accidents and hazards in urban areas. One of the most effective means is to develop not the entire city network, but only its information component and communication between its elements.

Thus, the rational use of the existing transport network to improve the safety of the SRN includes such measures as the distribution of transport by lanes and adjacent streets and highways to optimize road congestion, prevent and avoid congestion, and prompt notification of emergencies and emergencies on the transport and road network.

REFERENCES

1. Fornalchyk Ye.Iu., (Ed). (2018). Mohyla I.A., Trushevskyi V.E., Hilevych V. V. *Traffic management at controlled intersections in cities* [*Upravlinnia dorozhnim rukhom na rehulovanykh perekhrestiakh u mistakh*] Lviv:Vydavnytstvo Lvivskoi politekhniky. (in Ukrainian)
2. Lutsyk O., Stepanchuk O., Bieliatynskyi A., Pylypenko O. (Eds.). (2013). *Peculiarities of Passenger Transportation Traffic in Kyiv City. Transbaltica: 8th International Scientific Conference*. Vilnius:Technika. (in Ukrainian)
3. Global Plan for the Decade of Action for Road Safety 2011–2020. (2022, December). Retrieved from: https://www.who.int/roadsafety/decade_of_action. (in English)

4. Statistics of accidents in Ukraine by the Road Safety Administration. [Statystyka avariinosti v Ukraini Upravlinnia bezpeky dorozhnoho rukhu]. (2020). (2022, December). Retrieved from: http://patrol.police.gov.ua/statystyka (in Ukrainian)
5. Huk V.Y. (Ed). *Elements of traffic flow theory and design of streets and roads* [*Elementu teoriy transportnukh potokiv y proektyvani vulyts i dori*] (1991) Kyiv: UMK VO. (in Ukrainian)
6. Huk V.I., Shkodovskyi Yu.M. (Eds.). (2009). *Traffic flows: theories of their use in urban planning (Transportni potoky: teoriia yikh zastosuvannia v urbanistytsi)*. Kharkiv: Zoloti storinky. (in Ukrainian)
7. Stepanchuk O.V. (Ed.) (2018). Methodology for improving the efficiency of the fog lane [*Metodolohiia pidvyshchennia efektyvnosti funktsionuvannia vulychno-dorozhnoi merezhi mist*]. (Doctor of technical science). National Aviation University, Kyiv. (in Ukrainian)
8. Mapa Rzeszow, plan miasta Rzeszow. (2022, December). Retrieved from: https://mapa.nocowanie.pl/rzeszow/ulice/ulica_adama_asnyka (in English)
9. OpenStreetMap is the free wiki world map. (2022, December). Retrieved from: https://www.openstreetmap.org/#map=14/50.4317/30.4548 (in English)
10. *DSTU 8824:2019 Automobile rods. Characteristics of the intensity of the hand of the transport stream flow*. [*Avtomobilni dorohy. Vyznachennia intensyvnosti rukhu ta skladu transportnoho potoku.*] (2019) Tekhnichnyi komitet standartyzatsii TK 307 Avtomobilni dorohy i transportni sporudy. (in Ukrainian)
11. Polishchuk V.P., Dziuba O.P. (Eds.). (2007). *Theory of transport: metody and model of organization of road transport* [*Teoriia transportnoho potoku: metody i modeli orhanizatsii dorozhnoho rukhu*]. Kyiv: NTU. (in Ukrainian)
12. Stepanchuk O.V., Timkina Yu. (2015). *Analysis of design features of public passenger transport stops on main streets* [*Analiz osoblyvostei proektuvannia* zupynok hromadskoho pasazhyrskoho transportu na mahistralnykh vulytsiakh]. *Naukoiemni tekhnolohii.* 3 (27). 266–270. (in Ukrainian)
13. Binder R., Lancaster Z., (2019). Transport modeling with a purpose: how urban systems design can bridge the gaps between modeling, planning, and design. Wit *Transactions on the Built Environment.* 186. 85–96. 10.2495/UT190081.
14. *Stan sprav avariinosti na transporti v Ukraini za 2020 rik*. (2020) Dyrektorat z bezpeky na transporti. m. Kyiv. Ministerstvo infrastruktury ukrainy. (in Ukrainian).
15. Weigang G., Komar K. (Eds.). (2021). Ensuring compliance with international requirements for efficient traffic management in inner city areas Problems with traffic flows and directions of their solution: abstracts of the IV All-Ukrainian scientific and theoretical conference. 27–29. (in English).

ЛІТЕРАТУРА

1. Форнальчик Є.Ю., Могила І.А., Трушевський В.Е., Гілевич В.В. Львів : Видавництво Львівської політехніки, 2018. 236 с.
2. Lutsyk O., Stepanchuk O., Bieliatynskyi A., Pylypenko O. Peculiarities of Passenger Transportation Traffic in Kyiv City. *Transbaltica: 8th International Scientific Conference*. Vilnius Gediminas Technical University, Vilnius: Technika, May 9-10, 2013. 2013. P. 117–121.
3. Global Plan for the Decade of Action for Road Safety 2011–2020. URL: https://www.who.int/roadsafety/decade_of_action. (дата звернення: 03.05.2020).
4. Статистика аварійності в Україні [Електронний ресурс] Управління безпеки дорожнього руху. URL: http://patrol.police.gov.ua/statystyka (дата звернення: 03.05.2020).
5. Гук В.И. Элементы теории транспортных потоков и проектирования улиц и дорог Київ.: УМК ВО, 1991. 255 с.
6. Гук В.І., Шкодовський Ю.М. Транспортні потоки: теорія їх застосування в урбаністиці. Харків: Золоті сторінки, 2009. 232 с.
7. Степанчук О.В. Методологія підвищення ефективності функціонування вулично-дорожньої мережі міст: дисертація на здобуття наукового ступеня доктора технічних наук за спеціальністю 05.23.20. 2018. 458 с.
8. Mapa Rzeszów, plan miasta Rzeszów. URL: https://mapa.nocowanie.pl/rzeszow/ulice/ulica_adama_asnyka (дата звернення: 12.10.2021).
9. OpenStreetMap is the free wiki world map. URL: https://www.openstreetmap.org/ #map=14/50.4317/30.4548 (дата звернення: 12.10.2021).
10. ДСТУ 8824:2019 Автомобільні дороги. Визначення інтенсивності руху та складу транспортного потоку. [Чинний від 2019-10-01]. Технічний комітет стандартизації ТК 307 «Автомобільні дороги і транспортні споруди», 2019. 57 с.
11. Поліщук В.П., Дзюба О.П. Теорія транспортного потоку: методи і моделі організації дорожнього руху. Навчальний посібник. Киїі: НТУ, 2007. 158 с.
12. Степанчук О.В., Тімкіна Ю. Аналіз особливостей проектування зупинок громадського пасажирського транспорту на магістральних вулицях *Наукоємні технології* 2015. Випуск №3 (27). С. 266–270.
13. Binder, Robert & Lancaster, Zachary & Tobey, Michelle & Jittrapirom, Peraphan & Yamagata, Yoshiki. TRANSPORT MODELING WITH A PURPOSE: HOW URBAN SYSTEMS DESIGN CAN BRIDGE THE GAPS BETWEEN MODELING, PLANNING, AND DESIGN. WIT Transactions on the Built Environment. 2019 Vol. 186. P. 85–96. 10.2495/UT190081.
14. Стан справ аварійності на транспорті в Україні за 2020 рік. Міністерство інфраструктури України. Директорат з безпеки на транспорті. Київ. 2019. 134 с.
15. Weigang G, Komar K. Ensuring compliance with international requirements for efficient traffic management in inner city areas. *Проблеми з транспортними потоками і напрями їх розв'язання* : тези доповідей IV Всеукраїнської науково-теоретичної конференції, 25–26 березня 2021 року, Львів. 2021. С. 27–29.