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ASSESSMENT OF THE INFLUENCE OF THE TIME SPENT BY VEHICLES AT THE STOPPING POINT OF URBAN PASSENGER TRANSPORT ON THE LEVEL OF CONFLICT IN THE INTERACTION OF THE ROUTE FLOW

Об'єктом дослідження виступає вплив часу перебування транспортних засобів у зупинному пункті на показники рівня конфліктності взаємодії маршрутного потоку. В якості керованого параметру, що визначає рівень резерву пропускної спроможності зупинного пункту та відтворює характеристичний вплив на конфліктність взаємодії, виділено час додаткового сервісного простою транспортних засобів. В ході дослідження використовувалося імітаційне моделювання та статистична обробка отриманих результатів, що дозволило встановити типові види закономірностей для зупинних пунктів з різною інтенсивністю вхідного маршрутного потоку. Встановлено, що для зупинних пунктів з низькою та середньою інтенсивністю (до 40 авт/год) резерв пропускної спроможності має зворотню лінійну залежність від часу сервісного простою, а для пунктів з високою інтенсивністю (понад 40 авт/год) – експоненціальну. Зміна резерву пропускної спроможності за рахунок встановлення раціональної тривалості сервісного простою дозволяє впливати на кількість конфліктних ситуацій та тривалість знаходження у черзі. Це дає можливість визначити її допустимі значення для відповідного рівня інтенсивності маршрутного потоку. На основі проведених експериментальних досліджень встановлено, що додатковий сервісний простій для зупинного пункту з інтенсивністю до 40 авт/год є допустимим тривалістю до 40 с. При впровадженні понад 125 с – у 71,2 % вхідного потоку буде спостерігатися конфліктні ситуації. З позиції мінімізації конфліктності взаємодії для зупинних пунктів з вхідною інтенсивністю маршрутного потоку понад 40 авт/год впровадження додаткового сервісного простою є зовсім не можливим. Встановленні залежності є методологічною основою для формування елементів системи підтримки прийняття управлінських рішень на основі аналізу впливу часу простою транспортних засобів на конфліктність взаємодії маршрутного потоку. Вони вносять певну впорядкованість у процеси планування роботи об'єктів пасажирської інфраструктури, дозволяють систематизувати їхні сервісно-ресурсні параметри та сприяють підвищенню безпеки транспортного обслуговування пасажирів.

Ключові слова: *міський пасажирський транспорт, зупинний пункт, час простою, кількість конфліктних ситуацій.*

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1. Introduction

The task of improving the safety of urban passenger transport (UPT) requires the introduction of an integrated approach to eliminating the complication of the implementation of technological operations of interaction of all subjects of the transport process. In addition to solving the problems of improving traffic on the road network, an important role in ensuring the safety of the transport process at the UPT is played by the organization of the work of passenger transport infrastructure facilities, among which stopping points take the leading role [1]. An analysis of the technological process of rolling stock operation showed that the existing approaches to organizing the interaction of route flow entities at UPT stopping points have a number of disadvantages associated with the lack of clear planning and control over the downtime of vehicles at stopping points under boarding and unboarding passengers [2]. A long stay of vehicles at a stopping point leads to its overload, reduces throughput and is a source of partial or complete blocking of traffic on adjacent sections of the road network [3]. This position of the organization is unacceptable from the point of view of ensuring inter-level consistency of the UPT operation parameters [4] and should be considered as a prerequisite for the risk of a traffic accident. Identification of the conflict of interaction of the route flow is carried out on the basis of establishing the correspondence of the number of vehicles simultaneously at the stopping point and its capacity. The situation in which the number of route vehicles exceeds their permissible (normative) capacity is a conflict of interaction. Each conflict situation is characterized by unproductive delays of rolling stock, deterioration of traffic safety conditions and is a potential source of emergency events [5]. One of the main reasons for the emergence of conflict situations is the lack of a clear understanding of the effect of the length of time downtime of vehicles at stopping points on the level of conflict [6]. The additional downtime used by drivers to accumulate passengers significantly aggravates the organizational shortcomings of the operation of route networks and is one of the main reasons for the overload of stopping points. Among the ways to reduce the level of traffic conflict in the area of stopping points, methods of architectural and planning improvement have become widespread [7, 8]. As well as approaches to rationalizing the placement of routes between service points [9, 10]. However, the implementation of such approaches in practice is significantly limited by the existing territorial space, and does not make it possible to use them in the existing passenger infrastructure without significant reconstruction. Using methods of rational planning of downtime makes it possible to establish acceptable parameters of the technological parameters of the rolling stock, which reduce the level of conflict of movement in the area of stopping points. So, *the object of research* is the influence of the time spent by vehicles at the stopping point on indicators of the level of conflict in the interaction of the route flow. *The aim of research* is to establish the characteristic effect of the length of time downtime of vehicles at stopping points on technological indicators that determine the level of conflict in the interaction of route flow entities.

2. Methods of research

The methodological basis for determining the influence of the length of time a vehicle is at a stopping point on the level of interaction conflict is simulation of a technological process. The simulation model allows, within the framework of experimental studies, to establish a set of interrelated values of the indicators of the interaction of the route flow, characterizing the level of its conflict. The general structure of the simulation model of the process of staying route vehicles at a stopping point includes modules for generating moments of their arrival, generating passenger commissions, blocks of analytical calculations of time parameters and indicators for assessing the level of conflict of interaction. Fig. 1 shows the sequence of implementation of the stages of simulation when establishing the influence of the residence time on the level of conflict.

The introduction of control elements for the UPT interaction processes and their adaptation to real conditions requires the use of objective information about the parameters of the route flow formation within the stopping points. The complexity of this process is determined by the stochasticity of their change and the need to take into account the features for different types of stopping points with different intensities of the input route flow. In conditions of limited classification of stopping points and the absence of their typical distribution according to the size of the input route stream, it is possible to apply the gradation given in DBN B.2.3-5:2018 [11] as a criterion for their distribution. According to this standard, stopping points can be divided into two basic types, depending on the intensity of the input route flow:

1) with low and medium intensity (up to 40 vehicles/h);
2) with high intensity (more than 40 vehicles/h).

In order to analyze the distribution of stopping points according to the selected types, an analysis is made of the parameters of the formation of route flows in a number of transport and transfer hubs in Ukrainian cities: Kharkiv, Kryvyi Rih, Kherson, Slaviansk. For experimental research, two stopping points are chosen as basic prototypes: «Heroes of Labor» in Kharkiv (50.024616, 36.334937) and «Railway street» in Kherson (46.650216, 32.597849). The collection of primary information about the parameters of the input route flow, downtime elements and passenger exchange of stopping points is carried out using video recording with subsequent processing of the results. The examination period is the morning peak period (from 7:00 to 8:00), during which there is the greatest load of stopping points. The total number of primary field observations at these stopping points is 603 arrivals of vehicles. Subsequently, on their basis, average values of parameters and certain laws of distribution of random variables are established. The characteristics of stopping points and parameters of the incoming route flow are given in Table 1.

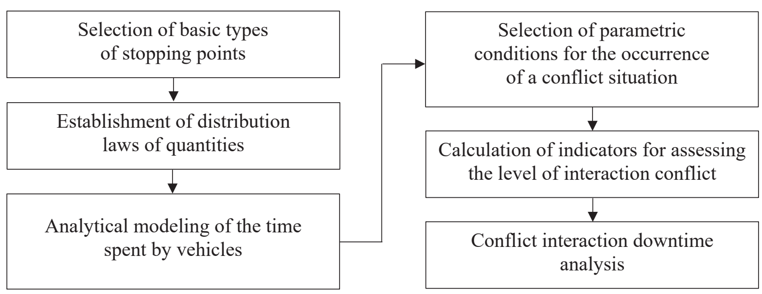

Fig. 1. The sequence of implementation of the simulation stages

Table 1

Description of base stopping points

Indicator	«Heroes of Labor»	«Railway street»
Number of service locations	2	2
Number of interaction routes	9	18
Intensity of the input flow stream, vehicle/h	26	72
The amplitude of the change in the interval of arrival of vehicles, min	3.8–7.5	1.2–4.3
The distribution law of the interval of arrival of vehicles on routes	normal	normal
Average maneuvering time on arrival, s	14.8	18.2
Average maneuvering time on departure, s	11.7	12.5
Amplitude of change to passenger exchange, pass.	5–26	2–18
Average passenger unboarding time, s	5.6	7.9
Average passenger boarding time, s	10.4	14.2

The general structure of operations that occur with the vehicle and determine the duration of its stay at the stopping point include:

– waiting in line;
– maneuvering when feeding and leaving;
– opening/closing doors;
– simple during exit, no entry of passengers;
– additional service downtime for passengers.

The functional state of the stopping point is characterized by the type of operations that occur with the subjects of the route flow in time and is described by the chronological sequence of their changes. When establishing a conflict of interaction, two types of operations are distinguished: normal and unproductive. The actual time spent at the stopping point is allocated to the technological, non-productive and service components. The unproductive component includes a simple queue in front of a stopping point, arising from conflict situations. The service component includes an additional downtime, aimed at the expectations and accumulation of passengers in the cabin. Its value is established as planned or may have a spontaneous character. The lack of rationing of this time along with the irrational planning of stopping points is the main cause of conflict situations. The technological component includes all other types of operations. Its duration depends on the traffic conditions in the area of the stopping point, the average time of unboarding and boarding of the passenger and the passenger commander. To establish the length of time spent in vehicles at stopping points, analytical models are used [12].

A feature of this study is its target orientation to establish patterns of change in the values of indicators, reflecting the level of conflict in the interaction of the route flow by taking into account the reserve capacity of the stopping point, the random nature of the formation of the passenger and the arrival times of vehicles. Using the reserve capacity level as an input quantity to establish a change in the level of conflict allows taking into account the duration of technological operations for various routes. Its value is calculated by the formula:

$$k_h^r(t) = 1 - \frac{\lambda_{sp}^t(t)}{n_{sp} \cdot t}, \tag{1}$$

where $\lambda_{sp}^t(t)$ – the total duration of technological downtime of all vehicles arriving in the calculated period t, s; n_{sp} – number of service locations; t – duration of the calculated period, s.

The characteristic component of the calculation period t is the time instants τ, which is its smallest indivisible part and is taken equal to 1 s. To describe the dynamics of changes in the state of the subjects of interaction in time, a matrix description form is used, in which the corresponding elements are represented as an array of moment values of the types of operations (normal or conflict state). The procedure of setting the type of operation provides for fixing at each moment of time τ the corresponding type of action (maneuvering, unboarding, boarding, service downtime, waiting in line). Depending on the presence of a conflict situation at the time of arrival of vehicles τ, an array of states of the subjects of the incoming route flow is determined. The parameter characterizing the conflict state is the total time spent by vehicles in the queue:

$$T_{rsp}^{st}(t) = \sum_{i=1}^{r_{sp}} \sum_{j=1}^{t} \tau_{st_{ij}}^r, \tag{2}$$

where $\tau_{st_{ij}}^r$ – belonging of the j-th moment of time of the i-th route to the conflict state; r_{sp} – the number of routes passing through the stopping point.

The specific gravity of the queue time of vehicles at a stopping point is established by the formula:

$$\rho_{sp}^q(t) = \frac{1}{t} \sum_{i=1}^{t} (1 : n_{sp_q}^{\tau_i} > 0;\ 0 : n_{sp_q}^{\tau_i} \le 0). \tag{3}$$

The duration of the conflict in the area of the stopping point:

$$t_{sp}^l(t) = \sum_{i=1}^{t} \max(0, n_{sp_a}^{\tau_i} - (n_{sp} - n_{sp_s}^{\tau_i})), \tag{4}$$

where $n_{sp_a}^{\tau_i}$ – number of vehicles arriving at a stop at a point in time τ_i; $n_{sp_a}^{\tau_i}$ – the number of vehicles in a state of technological downtime at a time τ_i.

The simulation procedure was implemented using the ModellingSP program developed at the Department of Transport Technologies of Kharkiv National Automobile and Highway University (Ukraine). During the simulation for the selected stopping points, 84 series of experiments were carried out in which the situation of arrival of 2684 vehicles was simulated.

3. Research result and discussion

The obtained results of the set of simulation experiments allow to establish the nature of the influence of the duration of additional service downtime on the level of conflict of interaction, as the main variable component of the time spent by vehicles at a stop. To implement the procedure for analyzing the results of experimental studies, it is advisable to use a graphical representation. As a base value, it sets the level of reserve capacity of the stopping point, the average duration of service downtime of vehicles is used. Fig. 2 shows graphs of changes in the reserve capacity of stopping points «Heroes of Labor» and «Railway street».

The indicators for assessing the conflict of interaction of the route flow are the total downtime of vehicles in the queue and the number of conflict situations. To analyze the effect of the reservation level of the stopping point throughput on the conflict resolution parameters, basic graphs are constructed (Fig. 3, 4).

The effect of service downtime on bandwidth reserve is manifested through an increase in the load level of a stop point. For a stopping point with an incoming route flow intensity of up to 40 vehicles/h, this effect is described by a linear dependence, and with an intensity of more than 40 vehicles/h, an exponential dependence. Such trends are explained by the fact that in conditions of high load there is a rapid accumulation of vehicles in the area of the stopping point, which is caused by conflict situations and queues. For «Heroes of Labor» the maximum possible value of service downtime (t_s) is 2.1 min. For «Heroes of Labor» reduction in bandwidth reserve from 0.6 to 0.4 (with an increase t_s to 40 s) leads to an increase in conflict situations by 2 units (from 4 units to 6 units). And the total idle time in the queue for 5.7 minutes (from 1.8 minutes to 7.5 minutes).

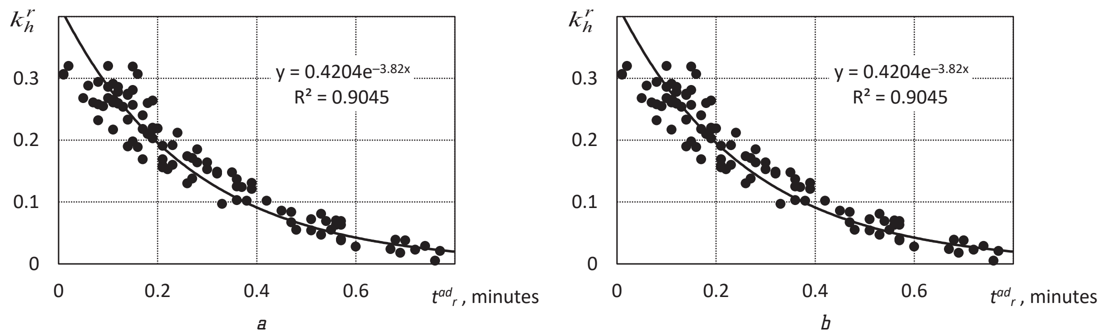

Fig. 2. The impact of service downtime on the reserve capacity of stopping points: *a* – «Railway street»; *b* – «Heroes of Labor»

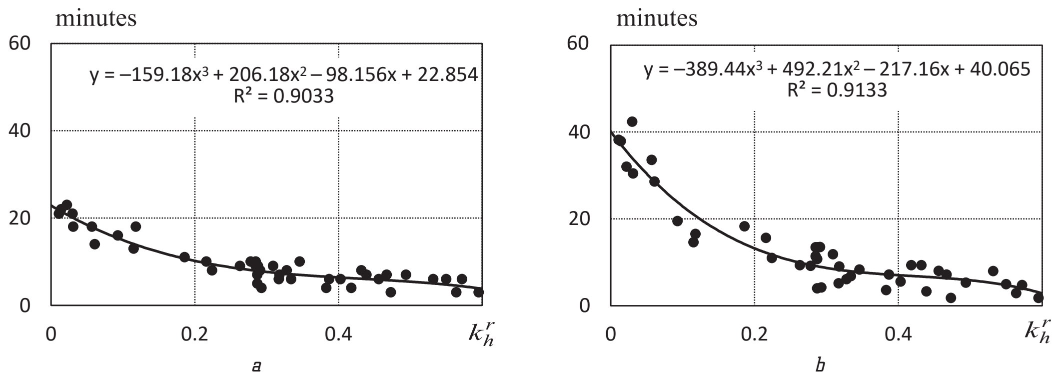

Fig. 3. The effect of the reserve capacity of the stopping point «Heroes of Labor» on the indicators of conflict of interaction: *a* – the total duration of idle time in the queue; *b* – the number of conflict situations

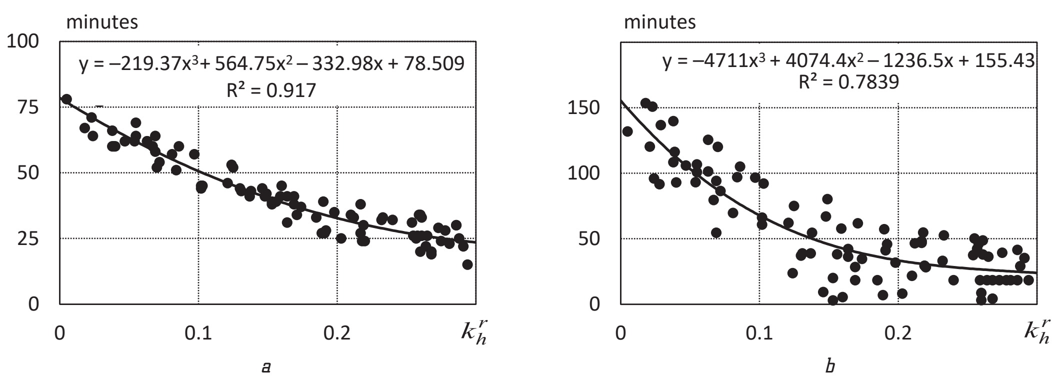

Fig. 4. The effect of the reserve capacity of the stopping point «Railway street» on the indicators of conflict of interaction: *a* – the total duration of idle time in the queue; *b* – the number of conflict situations

Reducing the reserve to 0.2 ($t_s = 80$ s) leads to an increase in conflict situations by 5 units (from 6 units to 11 units). And the total idle time in the queue for 7.2 minutes (from 7.5 minutes to 14.7 minutes). Complete liquidation of the reserve (at $t_s > 125$ s) will lead to an increase in conflict situations to 23 units (71.2 % of the input stream) and the total idle time in the queue up to 41 min. At the stopping point «Railway street» the effect of the reserve of bandwidth on the quality indicators of interaction is more pronounced. This is due to the high level of intensity of the incoming route flow. Reducing the reserve of bandwidth from 0.3 to 0.2 (with an increase t_s to 15 s) leads to an increase in conflict situations by 11 units (from 22 units to 33 units), and the total idle time in the queue is 13.5 minutes (from 24.1 minutes to 37.5 minutes). In the case of a decrease in the bandwidth reserve to 0.1 (at $t_s = 25$ s), there is an increase in conflict situations by 17 units (from 33 units to 50 units), and the total idle time in the queue is by 31.7 minutes (from 37.5 minutes to 69.2 minutes). With the liquidation of the reserve ($t_s > 50$), the number of conflict situations increases to 78 units (100 % of the input stream), and the total idle time in the queue to 153.5 minutes.

4. Conclusions

In the course of the study, it is shown that a decrease in the level of conflict between the subjects of the route flow within the infrastructure of the UPT is ensured by the invariance of the functioning of the stopping points by ensuring the necessary reserve level for their throughput. The main controlled element for influencing the reserve capacity level of a stopping point is the length of time that vehicles are located, which varies depending on the set time for additional service downtime. It has been established that for stopping points with low and medium intensity (up to 40 vehicles/h), the reserve of throughput has an inverse linear dependence on the service time, and for exponentials with high intensities (more than 40 vehicles/h) it is exponential. Changing the reserve of bandwidth, which is realized by establishing the appropriate duration of service downtime, makes it possible to influence the number of conflicts, the length of time in the queue, thereby reducing the risk of an emergency. An additional service downtime of up to 40 s is permissible for a stopping point with an intensity of up to 40 vehicles/h. With the introduction of more than 125 s – in 71.2 % of the incoming stream, conflict situations will be observed. With an input intensity of more than 40 vehicles/h, the introduction of an additional service simple is not at all advisable from the point of view of minimizing the conflict of interaction. Establishing dependency is the methodological basis for analyzing the impact of vehicle downtime on the conflicting interaction of the route flow. They introduce certain orderliness in the UPT planning and management processes, make it possible to systematize their service-resource parameters and contribute to improving the quality of transport services for passengers.

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