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ANALYSIS OF THE RESOURCES PROVISION OF STOPPING POINTS OF TRANSPORT-TRANSFER STATIONS OF URBAN PASSENGER TRANSPORT

Запропоновано розглядати ефективність функціонування транспортно-пересадочних вузлів з позицій впливу ресурсного забезпечення зупиночних пунктів на тривалість знаходження пасажирів в них. На основі принципів стабілізації роботи міського громадського пасажирського транспорту та умов сталого розвитку міського середовища виділено структуру контурного зв'язку технологічних рішень. Функціональною задачею є забезпечення рівня організації, спрямованого на максимізацію сервісно-ресурсного потенціалу маршрутів та нейтралізацію негативних наслідків роботи транспортно-пересадочних вузів. Представлений зв'язок ґрунтується на обліку багаторівневого представлення наслідків роботи елементів транспортно-пересадочних вузлів на сервісно-ресурсний потенціал маршрутів міського громадського пасажирського транспорту та соціальні сфери міського середовища. Запропонований зв'язок дозволив обґрунтувати загальну форму та структуру критерію оцінки ефективності транспортно-пересадочних вузлів. Представлений критерій ефективності враховує обмеження впливу організації функціонування зупиночних пунктів на час руху пасажирів через транспортно-пересадочні вузли, якість дорожнього руху на прилеглих ділянках вулично-дорожньої мережі та міське середовище.

На основі експериментальних досліджень встановлена характеристична залежність впливу ресурсного забезпечення зупиночних пунктів на ефективність їх функціонування. Отриманий вигляд функції впливу ресурсного забезпечення зупиночних пунктів на тривалість простою транспортних засобів у черзі, рівень блокування проїжджої частини вулично-дорожньої мережі та навколишнє середовище має експоненціальну залежність. Для виділеного зупиночного пункту встановлено, що допустимим значенням з точки зору забезпечення сервісної якості є рівень резерву пропускної спроможності в межах 0,1–0,4. При збільшенні резерву пропускної спроможності з 0,1 до 0,4:

– середній час загального простою транспортних засобів знижується в 1,6 рази (з 3,9 хв до 2,4 хв);
– середній час простою у черзі знижується в 5,7 рази (з 0,4 хв до 0,07 хв);
– питома вага блокування проїжджої частини знижується в 3,6 рази (з 0,65 до 0,18).

Отримані залежності дозволяють встановити допустимі значення параметрів резервного забезпечення зупиночних пунктів транспортно-пересадочних вузлів. На основі представленої методології оцінки ефективності транспортно-пересадочних вузлів можливо оцінити доцільність впровадження оптимізаційних управлінських заходів, спрямованих на упорядкування прибуття транспортних засобів у зупиночні пункти.

Ключові слова: *транспортно-пересадочний вузол, міський громадський пасажирський транспорт, зупиночний пункт, пропускна здатність.*

1. Introduction

In modern conditions of development of urban areas, acute problems acquire the issues of ensuring high-quality and safe mobility of the population. Effective way to ensure the mobility of the urban population in conditions of compliance with the requirements to reduce the negative consequences and ensure resource-saving is the spread of the use of urban public passenger transport (UPPT). The main condition for the formation of the population's priorities in the selection of the combination options based on the UPPT is its compliance with the social and marketing requirements they impose, which consist in the full and timely satisfaction of the requirements of passengers. An important element of the UPPT is transport transfer stations (TTS), which along with the highways of high-speed transport is the basic framework of the network. The state of the organization of technological processes in the TTS largely determines the conditions for using the UPPT potential and next to the task of stabilizing the movement of route transport along the street-road network is very relevant today. Dwell time of the vehicles in UPPT, which is necessary to provide landing and transshipment operations refers to the servicing functions and by its target character is unproductive. To a large extent, the situation is exacerbated by the absence of integrated regulation of the UPPT interaction in TTS, which leads to the emergence of conflict situations. Such situations are a source of reduced transport capacity, an increase in the travel time of passengers, the occurrence of road accidents and additional air pollution. Increasing the efficiency of the UPPT operation requires the use of sound technical and technological regularities in assessing the parameters of stabilizing the TTS operation and should take into account the principles of sustainable urban development.

2. The object of research and its technological audit

The TTS state is determined by the level of operation of the stopping points (SP), which are its main structural element. For a period of time (t), an input route arrives at each SP, which is determined by the arrival rate of vehicles and is characterized by the number of passengers in their cabin and the number of passengers leaving them at the SP. For each route, based on field observations, the average interval and the range of fluctuations in the arrival of the TS are determined. The presence of each vehicle in the SP is characterized by the moments of the beginning (τ_{ar}^{rs}) and the end of their dwell (τ_{dp}^{rs}), connected with the loading and unloading of passengers. During the corresponding period, a flow of transit passengers is formed in the SP, which makes transition between routes and the flow of passengers, come from adjacent territories. The inter-trip arrival interval is determined based on the time difference between the arrival time of the next vehicle ($\tau_{ar_r}^{rs_{i+1}}$) and the arrival of the previous ($\tau_{dp_r}^{rs_i}$). For the period ($\tau_{dp}^{rs_{i-1}} - \tau_{ar}^{rs_i}$) between the trip departure rs_{i-1} and the arrival rs_i, a volume of passengers $q_r(\tau_{dp}^{rs_{i-1}} - \tau_{ar}^{rs_i})$ is formed. During the dwell time of the vehicle in the SP in the period ($\tau_{ar}^{rs_i} - \tau_{dp}^{rs_i}$) up to the SP, passengers in the volume $q_r(\tau_{ar}^{rs_i} - \tau_{dp}^{rs_i})$ are came, who can use the vehicle for loading. This volume can be divided into two parts: the first part – passengers, who came during the technological dwell time, and the second – the passengers, who came during additional service dwell time. The total dwell time of the vehicle, which consists of the time of maneuvering, the time of technological dwell time for loading and unloading of the passengers and the additional service time of dwell time determines the planned level of SP loading and the level of reserve of its throughput.

The object of research is the process of TTS SP operation. The main control action is the time of additional service dwell time of the vehicle. By changing its value, an appropriate level of SP loading and the time for the passengers in TTS are achieved. The increase in the dwell time of the vehicles leads to an increase in the level of SP conflict. Conflict is understood as the simultaneous presence in the SP of the vehicle in an amount exceeding the number of service posts. Determination of a rational level of SP loading based on an assessment of the effect of the duration of an additional service dwell time is the main technological tasks of the organization of the SP operation. The posed technological task requires the creation of an appropriate analytical apparatus for evaluating the SP operation efficiency and conducting experimental studies of determining the characteristic influence of the level of resource provision on its significance.

3. The aim and objectives of research

The aim of research is determination of the impact of SP resource conditions on the efficiency of its operation.

To achieve this aim, it is necessary to solve the following tasks:

1. To formulate a criterion for evaluating the efficiency of the SP operation of the joint venture on the basis of the analysis of the influence of technological solutions on the interaction of the UPPT subjects.

2. To experimentally establish the characteristic dependences of the influence of the SP resource level on the efficiency of its operation.

4. Research of existing solutions of the problem

Evaluation of the UPPT efficiency is a priority task in the formation of strategic decisions to improve its work. The necessity to solve the problem of objective representation of the results of the work of the UPPT is confirmed in a number of scientific and practical works [1–4].

In [2–6], the question of assessing the efficiency of individual elements of the UPPT in formal form is not considered. However, some authors attempted to describe the UPPT efficiency on the basis of assessing the performance indicators of its operation. In work [2], the efficiency of urban passenger transport is represented by a set of indicators totaling more than 50. Indicators are divided into the following groups: the quality of transport services, socio-demographic, organizational, economic and environmental. The presented form of the evaluation of efficiency allows carrying out only a stating assessment and is aimed at the realization of the chronological analysis of the changes. The absence of formalized links between operations and the efficiency of transport does not allow this approach to be used to investigate the impact of individual technological sub-processes. The influence of organizational factors on the efficiency of urban passenger transport is presented in [3]. The authors propose to consider efficiency as a technical characteristic, which in their opinion depends on the forms of ownership. Attention in this work deserves an attempt to represent efficiency in the form of a linear empirical function, which includes parameters that determine the level of organization of processes. The dependence is constructed based on the statistical processing of the results. The disadvantage of this approach is that it is a generalized character that does not allow to describe the influence of specific factors on the efficiency of urban passenger transport.

In [4], the author proposes to evaluate the efficiency of the routes due to a combination of two indicators – efficiency and productivity. Efficiency in this case provides an assessment of the level of provision of transportation of the population of cities, and productivity – the level of use of the route's transport resources. As the main factors of influence, it is suggested to use the following indicators: the cost of travel, the time of travel, the type, the capacity of the rolling stock, etc. However, the approach presented in the work as a generalizing concept was not subsequently realized in the form of specific functions. In work [5] the efficiency of passenger transport is considered through the calculation of a set of technical and operational indicators that reflect the economic performance of rolling stock fleet. This form of representation of efficiency represents processes in a generalized manner and only from the standpoint of assessing the interests of transport enterprises.

One of the attempts of scientists to present a formal form of the UPPT operation function is the work [6]. It proposes the use of a continuous function as the efficiency of transport services. The structure includes: the level of transport services, the state of the environment, the level of resources of the transport process, the volume of daily

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traffic flows and the like. The presented work is also a generalized form and does not contain specific models for formalizing the efficiency criterion. To assess the UPPT efficiency in [7], the author proposes to use the empirical dependence of the change in its energy consumption. Dependencies depict trends in energy consumption over time. This approach refers to the type of models describing the chronology and can't be used to evaluate the performance of the elemental objects of the UPPT. On the basis of the analysis of works [5–7], it can be concluded that among these studies the methods of assessing the UPPT efficiency are almost not represented explicitly. The formalization of models has a generalized form. The evaluation of the efficiency of the UPPT operation in most cases rests with experts and is implemented, as a rule, through a subjective assessment of the state of the quality indicators of transport services. A variant of the approach presentation to using the time of movement as a criterion of the UPPT effectiveness is the work [8]. The author proposes to take as a criterion the value of the functional, which is formed as a weighted sum of the individual expenses of the time for passengers to travel. However, the time for travel reflects the interests of only passengers and does not reflect the whole specifics of the transport process.

Among the works devoted to the efficiency evaluation of the operation of individual elements of the passenger transport infrastructure, in which the main generalizing approaches are presented, are the works [9–13]. To estimate the efficiency of the operation of the stopping points, it is proposed in [9] to use time indicators. The indicators can be presented both as a separate parameter and as an integral part of the general criterion of temporal consistency of interaction. The main drawback of this approach is its limited internal environment, the lack of consideration for the influence of the elementary level of the working conditions of the routes and the transport system of the city as a whole.

The increase of the interaction efficiency of the UPPT subjects within the TTS framework is presented in [10]. It addresses the issues of synchronizing the movement of vehicles from the perspective of ensuring minimum time spent on passengers. The drawback of this approach to assessing the interaction efficiency in TTS is that the presented models do not take into account the effect of capacity on vehicle delays. In [11], the authors consider the question of estimating the influence of the loading level of the stopping point on the average time of standing of the vehicle in the queue. The main disadvantage of this study is that the process of arrival of vehicles is presented in a stable form with constant characteristics. This form of presentation does not correspond to the existing practical state and can't be used to assess the influence of throughput on simple vehicles in the existing real operation conditions of the UPPT.

Summarizing the analysis of existing publications, it should be noted that the UPPT efficiency evaluation is an important stage in the formation of its management strategy and largely influences the definition of the forms and mechanisms of the increase. The efficiency of the objects of the passenger transport infrastructure should reflect its efficiency in relation to the selected entities and it is advisable to represent it as a form of reflecting the level of achievement of the targeted interests of the UPPT. Existing approaches to assessing the UPPT efficiency are aimed at determining its efficiency against internal actors and are presented as internal economic, technological, social, and environmental indicators. This form of presentation of the UPPT efficiency indicators does not allow for the assessment of the impact on the external components of the urban environment, nor does it reflect its role in ensuring the quality of life of the population. The solution of the problem of searching for objective methods for evaluating the efficiency of individual elements of the passenger transport infrastructure, which includes TTS, lies in the development of theoretical and methodological foundations for distinguishing the levels of its consideration. Such conditions require the development of new forms of presentation of resource-efficient parameters of its operation, taking into account the description of multi-level interference and taking into account the conditions for the formation of sustainable development of cities.

5. Methods of research

The paradigm of increasing the efficiency of UPPT technological interaction in the TTS is based on taking into account the features of demand and the level of resource support for the serving subsystem. The structure of the implementation of the production program largely depends on the volume of demand, the level of resource provision and determines the composition of technological measures to improve interaction. The state of operations and algorithms that ensure the corresponding results are evaluated by quality indicators, which include performance, resource intensity and the level of reverse influence. In the aggregate, the efficiency indicators, resource intensity and influence generate a complex system property – the efficiency of the process. This property manifests itself in the realization of the functional processes of the object and depends on the internal and external conditions of implementation. Efficiency estimation of the UPPT operation is realized from four main levels [14]: elemental, aggregate, system and metasystem. TTS refers to the first elemental level. To assess the UPPT efficiency at this level, time indicators reflecting the quality of operations are used. This form provides for a qualitative assessment of the time spent by passengers on the implementation of landing and transfer operations. However, the presence of a characteristic inter-level influence in the structure of the interaction representation of the UPPT subjects requires the expansion of the area for the representation of TTS efficiency. Such conditions are based on the principles of system analysis and are implemented through the assessment of the integration impact of technical and technological interaction of TTS on the elements of the UPPT system efficiency. Taking into account such requirements, the overall framework for assessing the TTS efficiency operation in the relevant period (t) can be represented through a set of conditions:

- element level $S_e(t)$ (objects of passenger transport infrastructure);
- aggregate level $S_u(t)$ (UPPT routes);
- system level $S_t(t)$ (street-road network);
- metasystem level $S_c(t)$ (urban environment):

$$W(s)=\{S_e(t),S_u(t),S_t(t),S_c(t)\}. \qquad (1)$$

The problem statement of improving interaction in TTS provides, within the limits of its resource capabilities (R) and the available input route flow (V), the implementation of such control action (Z) aimed at ensuring the effective state of all levels:

$$Z \times R \times V \to W(s) \to \max. \tag{2}$$

Due to the presence of a complex in size and nature of the systemic connection, the solution of the task of searching for an effective general-level UPPT state is a very laborious procedure. Its solution requires the use of the principles of unity of analysis and synthesis of the study of individual processes. To do this, it is necessary to conduct a logical distribution of the overall task into separate component parts relative to the implementation areas and to highlight their characteristic influence on the globally general-level UPPT efficiency.

Decomposition of hierarchical levels of the efficiency criterion within the selected research object can be represented through their ordering by the main optimization criterion method. The main criterion is the service-resource sustainability of TTS operation. In the structure of the system of restrictions, it is necessary to take into account the service components of the operation of the «route», «urban transport system» and «urban environment» entities. The level of service and resource sustainability of TTS is estimated by an indicator that reflects the difference between the actual value of its potential and the value of the potential that meets the maximum allowable service-resource limit:

$$W_e(t) = \frac{A_{th}^Z(t) \cdot K_{th}^Z(t)}{A_{th}^B \cdot K_{th}^B} - 1 \to \max, \tag{3}$$

where $A_{th}^Z(t)$ – the level of quality of passenger service in TTS in the implementation of the control impact Z; $K_{th}^Z(t)$ – the level of reserves for the TTS throughput in the implementation of the control impact Z; A_{th}^B – the level of quality of passenger service in TTS, which reflects the boundary of the area of its service stability; K_{th}^B – the level of required reserves of TTS throughput, which reflects the boundary of its resource sustainability area.

The system of criterion limitations takes into account the change in the service state of the upper levels:

$$\begin{cases} \Delta W_u(t) = A_{rt}^Z(t) - A_{rt}^B > 0, \\ \Delta W_t(t) = A_{cr}^Z(t) - A_{cr}^B > 0, \\ \Delta W_c(t) = A_c^Z(t) - A_c^B \le 0, \end{cases} \tag{4}$$

where $A_{rt}^Z(t)$ – the level of passenger service quality on the routes passing through the TTS in the implementation of the control impact; A_{rt}^B – the level of quality of passenger service on routes passing through TTS that reflects the boundary of the area of their service stability; $A_{cr}^Z(t)$ – the traffic quality level on the sections of the street-road network (SRN) in the TTS zone when implementing the control action; A_{cr}^B – the level of traffic quality in the SRN sections of the TTS, which reflects the boundary of the area of their service stability; $A_c^Z(t)$ – an indicator reflecting the level of negative impact on the urban environment (UE) in the implementation of the control impact; A_c^B – an indicator reflecting the level of negative impact on the UE in the actual state of the organization of TTS operation.

The level of quality of passenger service in TTS is estimated by the degree of compliance with the actual time for moving through TTS to the marketing requirements of passengers:

$$A_{th}^Z(t) = \frac{\sum_{i=1}^{r_n} q_{sp_i}^{st}(t) \cdot \overline{t_{r_i}^{sn(P)}}(t) + \sum_{j=1}^{SP_n} q_{sp_j}^{en}(t) \cdot \overline{t_{th_j}^{tr(P)}}(t)}{\sum_{i=1}^{r_n} q_{sp_i}^{st}(t) \cdot \overline{t_{r_i}^{sn(Z)}}(t) + \sum_{j=1}^{SP_n} q_{sp_j}^{en}(t) \cdot \overline{t_{th_j}^{tr(Z)}}(t)}, \tag{5}$$

where $q_{sp_i}^{st}(t)$ – the number of passengers who travel by routes without the implementation of loading and unloading in TTS, pass.; $q_{sp_j}^{en}(t)$ – the number of passengers departing from the SP, pass.; $\overline{t_{r_i}^{sn(P)}}(t)$ – average marketing time of the passenger's stay in the TTS that moves to the routes without the loading and unloading, s; $\overline{t_{r_i}^{sn(Z)}}(t)$ – the average actual time of the passenger's stay in the TTS that moves to the routes without the implementation of loading and unloading, s; $\overline{t_{th}^{tr(P)}}(t)$ – the average value of the marketing time of the passenger's stay in TTS, departing from the SP, s; $\overline{t_{th}^{tr(Z)}}(t)$ – the average value of the actual time of the passenger's stay in the TTS departing from the SP, s.

The actual time of moving passengers through TTS is determined on the basis of calculating the length of stay of passengers in the vehicle, which have an additional dwell time in the SP:

$$\overline{t_r^{sn(Z)}}(t) = \frac{\sum_{c=1}^{SP_n} \sum_{i=1}^{k_{r_c}^{sp}(t)} (\tau_{dp}^{rs_{rci}} - \tau_{ar}^{rs_{rci}}) \cdot (q_{en}^{r_{ci}} \cdot \gamma_{en}^{rs_{rci}} - p_{ex}^{rs_{rci}})}{\sum_{c=1}^{SP_n} \sum_{i=1}^{k_{r_c}^{sp}(t)} (q_{en}^{r_{ci}} \cdot \gamma_{en}^{rs_{rci}} - p_{ex}^{rs_{rci}})}, \tag{6}$$

where $\tau_{dp}^{rs_{rci}}$ – the moment when the vehicle of the trip $rs_{r_{ci}}$ departing from the SP c, s.

Marketing time means time that is set by passengers as a requirement to the level of quality of transport services. The average marketing time of a passenger's stay in TTS is determined based on the minimum duration of the vehicle's dwell time:

$$\overline{t_r^{sn(P)}}(t) = \frac{\sum_{c=1}^{SP_n} \sum_{i=1}^{k_{r_c}^{sp}(t)} (\tau_{ad}^{rs_{rci}} - \tau_{ar}^{rs_{rci}}) \cdot (q_{en}^{r_{ci}} \cdot \gamma_{en}^{rs_{rci}} - p_{ex}^{rs_{rci}})}{\sum_{c=1}^{SP_n} \sum_{i=1}^{k_{r_c}^{sp}(t)} (q_{en}^{r_{ci}} \cdot \gamma_{en}^{rs_{rci}} - p_{ex}^{rs_{rci}})}, \tag{7}$$

where $\tau_{ad}^{rs_{rci}}$ – the moment of the end of the loading and unloading of the passengers of the trip $rs_{r_{ci}}$ to the SP c, s; $\tau_{ar}^{rs_{rci}}$ – the moment of arrival of the vehicle of the trip $rs_{r_{ci}}$ to the SP c, s; $k_{r_c}^{sp}(t)$ – the number of route trips r arriving in the period t in the SP c; $q_{en}^{r_{ci}}$ – capacity of the vehicle on the route, pass.; $\gamma_{en}^{rs_{rci}}$ – the level of filling the vehicle at the arrival of the trip $rs_{r_{ci}}$; $p_{ex}^{rs_{rci}}$ – the number of passengers leaving the vehicle at the arrival of the trip $rs_{r_{ci}}$, pass.

Within the framework of the selected research subject, the quality of passenger service on routes passing through TTS $A_{rt}^Z(t)$ is estimated by the average length of stay of a transit passenger in the TTS:

$$A_{rt}^{Z}(t)=\frac{\sum_{c=1}^{SP_n}\sum_{d=1}^{SP_n}\sum_{i=1}^{k_{rc}^{sp}(t)}(\tau_{dp}^{rs_{rdi}}-\tau_{ar}^{rs_{rci}})\cdot q_{sp_c}^{tr}(\tau_{ar}^{rs_{rci}})}{\sum_{c=1}^{SP_n}\sum_{b=1}^{t}q_{sp_c}^{tr}(\tau_{ar}^{rs_{rci}})}, \quad (8)$$

where $\tau_{dp}^{rs_{rdi}}$ – the moment of departure of the trip $rs_{r_{di}}$ to which the transfer is made to the SP d, s.

The length of the transit passenger's stay in the TTS, reflecting the boundary of the area of their service stability, is determined, based on the availability of a trip time reserve for each route. This time is determined by actual observations of the actual time of the trip.

The quality of traffic in the SRN sections is determined by the level of service. The basic quality characteristic of the service level is the load factor. In the case of a conflict situation in the TTS zone, the lane is blocked, which leads to a decrease in the SRN capacity. The specific weight of the blocking time of the carriageway is the basic characteristic that reflects the impact of the TTS operation on the quality of road traffic:

$$A_{cr}^{(Z)}(t)=\frac{t_{bc}^{(Z)}(t)}{t}, \quad (9)$$

where $t_{bc}^{(Z)}(t)$ – the time of blocking the roadway on the SRN sections, s.

A qualitative assessment of the negative impact of control actions on the urban environment is the number of conflict situations that characterizes the main factor of the possibility of the occurrence of an accident in the TTS and the duration of the unproductive dwell time of the vehicle in the queue before the SP $T_{rsp}^{st}(t)$. This directly affects the amount of additional environmental pollution of the environment. The indicator reflecting the level of negative impact on the urban environment is represented by a verbal form of description (negative or neutral impact) and can be represented by a binary function:

$$A_{c}^{Z,B}(t)=\left\{1: k_{bt_i}^{(Z,B)}(t)>k_{bpt_i}; 0: k_{bt_i}^{(Z,B)}(t)\le k_{bpt_i}\right\}, i=\overline{1,n_{sp}}, \quad (10)$$

where $k_{bt_i}^{(Z)}(t)$ – the number of vehicles in the i-th ZP; k_{bpt_i} – the allowable number of vehicles for the simultaneous location of the i-th SP; n_{sp} – the amount of SP in TTS.

The main technical and technological parameter of the interaction option in TTS is the resource provision of the stopping points, which is indicated by the reserve capacity level of the stopping points (K_R). Using as a parameter the management of the level of reserves of the TTS SP capacity is based on the fundamental principles for the stabilization of technological processes and is an effective tool for ensuring the UPPT stability. To determine the range of rational values of the reserves of the TTS throughput capacity, it is necessary to establish a dependence of the form $We(t)=f(K_R)$. The task can be solved by carrying out experimental studies.

6. Research results

Along with the formalization of the structural components of the criterion, the main task of research is determination of the parametric connection between the planned reserve of the SP capacity and the efficiency of their operation. The complexity of the description of the inter-layer communication procedure is caused by the considerable dimensions and stochastic conditions of interaction. Experimental studies are carried out on the basis of the developed simulation model of the TTS SP operation. Based on the analysis of the contour linkage of technological solutions to improve the efficiency of interaction in TTS, it is advisable to use the parameter of the planned reserve of the SP capacity as an efficiency indicator. This form allows to ensure the consistency of the existing strategy for implementing input management actions. External factors of influence are: passenger exchange of the vehicle, interval on the route, loading (unloading) time, maneuvering time, level of filling, time of transition between SPs during transition. In order to determine the nature of the change in external factors, field observations were carried out at the TTS in Kharkov (Ukraine), G. Shironintsiv Street – Valentynivska Street (50.013268, 36.341187) .The results of field observations establish patterns of changes in the parameters of the incoming route flow (Table 1).

Table 1

Parameters for changing the parameters of the incoming route flow

Parameter	Distribution law	Mathematical expectation	Range of change	
			Min	Max
Passenger traffic of the vehicle, pass.	Lognormal	20.3	0	39
Arrival time of vehicle, min	Lognormal	1.8	0.6	3.4
Fluctuation of vehicle arrival, min	Lognormal	0.9	0.2	1.9
The time of loading(unloading) of the passenger, s	Gamma distribution	2.4	1.1	8.6
Level of vehicle's filling, pass.	Gamma distribution	0.894	0.742	1.236
Maneuvering, s	Lognormal	16.2	11	23
Transit time between passengers, min	Lognormal	2.7	1.6	3.8

Operation in discrete-event simulation is represented as a chronological sequence of events. The event occurs at a certain point in time and marks a change in state. For modeling, the time range corresponding to the morning peak period (from 7 to 8 o'clock) is adopted. The number of experiments in the series is justified by the Chebyshev unevenness. To ensure significance, 100 experiments were conducted in each series. On the basis of simulation calculations, it is possible to analyze the change in service-resource parameters of the operation, depending on the change in the SP resource supply. Such analysis is conducted in analytical form on the basis of established distribution schedules of the obtained results and is intended to determine the main trends on the allocation of internal cause-effect relationships. These links in the future will make it possible to become the basic criterion for the practical adaptation of the proposed mechanisms of technological solutions to the formation of a production program for the TTS operation. Analysis of the received data is carried out on following basic directions of the analysis of communications:

- SP reserve capacity – time spent by passengers in the TTS (Fig. 1);
- SP reserve capacity – time spent by vehicles in the TTS (Fig. 2);
- SP reserve capacity – the specific weight of the blocking time for the carriageway (Fig. 3).

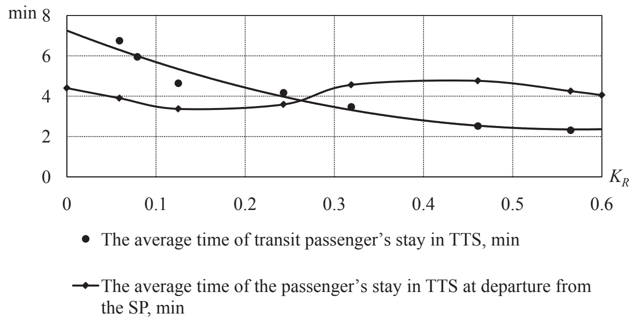

Fig. 1. Change of time of stay of passengers

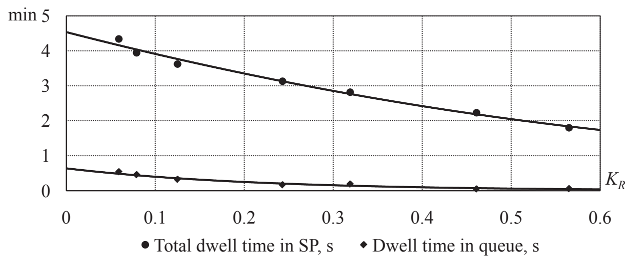

Fig. 2. Change in average time of vehicles

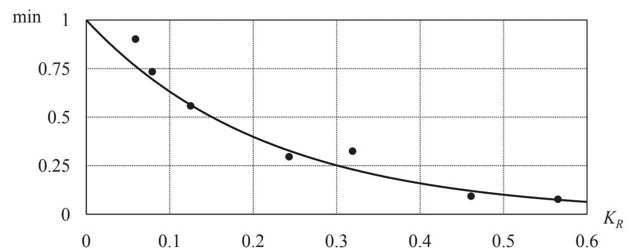

Fig. 3. Change in the specific weight of roadway blocking time

Analyzing the obtained dependences of the change in the efficiency indicators, it is possible to establish the level of influence of the SP resource supply on the components of the operation efficiency. A characteristic parameter of the quality of passenger service in TTS is the time spent by passengers. With the increase in the time of the additional service dwell time of the vehicle, the load level is increased, and the reserve level of the SP capacity is reduced. This situation leads to a reduction in the time of passenger transitions between the routes of different SPs. However, this also leads to an increase in the time of passengers' stay in the TTS, which realize transit movements without leaving the vehicle. Based on the analysis of the change in the average time of passengers' stay departing from the SP, it can be established that when the level of SP reserve capacity is within the range of 0.1–0.4, its decrease is observed. With an increase of more than 0.4 – time increases. This is explained by the influence of the rational duration of the additional dwell time of the vehicle for the possibility of implementing a transition without waiting. With its further increase, the dwell time of the vehicle and passengers increases, including those who loading at the SP. Increasing the level of SP reserve capacity leads to a decrease in the total dwell time of the vehicle, the level of conflict, the duration of the queues and reduces the specific weight of blocking the roadway. So it is established that for the considered SP with an increase in the reserve capacity from 0.1 to 0.4:

– the average time of total dwell time of the vehicle is reduced 1.6 times (from 3.9 minutes to 2.4 minutes);
– the average dwell time of the vehicle in the queue is reduced by 5.7 times (from 0.4 minutes to 0.07 minutes);
– the specific weight of blocking the roadway is reduced by 3.6 times (from 0.65 to 0.18).

7. SWOT analysis of research results

Strengths. As strength of the research, it should be noted that the proposed approach to assessing the efficiency of operation is based on the principles of the system approach and takes into account the inter-level influence of the resource provision of SP on the state of UPPT external elements. The assessment of efficiency provides compromise possibilities for determining service-resource indicators of SP operation in combination with an accessible form of accounting for changes in the quality parameters of the operation of the UPPT routes, SRN elements, and the impact on the urban environment. The proposed analytical models of the efficiency criterion are combined on the principles of a social marketing approach to assessing the quality of transport services and allow their adaptation to the conditions for the implementation of discrete-event modeling. The peculiarity of the proposed approach to determining the impact of resource provision on SPs on their efficiency is that it provides for the formation of its rational value through technological solutions without changing the TTS layout structure. This fully meets the modern requirements for the implementation of programs to improve the UPPT operation from the standpoint of resource-saving principles of urban development.

Weaknesses. The weak side of research is that the level of co-ordination of the vehicles' arrival has a significant influence on the level of resource support for the SP, apart from the duration of the additional service simplicity. The presence of such influence determines the fuzziness of the range of the obtained values of the reservation level and the possibility of overcoming its admissible limits. Proceeding from this, the task of streamlining the reservation level of the SP capacity should be considered in a complex manner together with the development of a single timetable for the movement from the position of slot-coordination of the interaction of the UPPT subjects in the TTS. To implement such program, adapted algorithms for selecting the permissible timetable variants can be used. The combination of the procedure for scheduling the traffic with an estimate of the permissible level of the SP capacity and the duration of the additional service simplicity makes it possible to achieve an effective general-level state of the UPPT.

Opportunities. The proposed approach opens the prospects for using the methods of technological management in the rational level of reservation of the SP capacity and allows the introduction of information mechanisms for coordination of interaction between the UPPT subjects. Using the established characteristic dependencies of the change in the parameters of the efficiency criterion, it is possible to form specific technological requirements for the duration of the vehicle dwell time in the SP. The introduction in the planning of the timetable for the routes on reasonable routes of the length of the dwell time of the vehicle in the SP ensures the reduction of their unpro-

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ductive dwell time and increases their productivity. This positively affects the economic and resource efficiency of the work of passenger transport enterprises.

Threats. The difficulty in determining the rational level of the resource supply of the SP is taking into account the parameters of the operation of the routes on all its elements and to estimate the level of loading by the movement of adjacent sections of the SRN. Obtaining such information requires conducting in-situ observations of the operating conditions of the UPPT routes and the traffic flow regime. Within a day, they can fluctuate significantly, which requires obtaining their operational values. The use of objective information on traffic parameters along the routes and the state of the transport flow will increase the model accuracy and ensure its adaptation to the actual conditions of TTS operation. To implement such information support, it is necessary to equip the vehicle with means to monitor the parameters of their traffic and integrate them into the general structure of the UPPT dispatch control.

8. Conclusions

1. A range of technological solutions for the organization of interaction in TTS, which describes its impact on the conditions for ensuring the full use of the service-resource potential of the UPPT, is singled out. This connection is based on taking into account the multilevel presentation of the results of the SP operation on the service-resource potential of the routes, SRN and the social conditions of the life of the urban environment. The presented contour connection allows to substantiate the general structure of the criterion for assessing the efficiency of the TTS SP operation. In contrast to existing approaches, it takes into account the inter-layered attainment of the sustainable state of the urban environment and reflects the characteristic influence of the resource supply of SPs on the level of the UPPT actual potential and the negative impact on SRN.

2. It has been experimentally established that the service parameters of the TTS SP operation efficiency depend on the level of their resource provision. As the level of reserves of the SP capacity increases, the transit time for transit passengers in the SRN is adversely affected, the dwell time of the vehicle in the queue, the level of blocking of the roadway of the TTS and the environment decrease exponentially. The duration of stay in the TTS of the passengers who realize the transplantation depends on the time of the additional service dwell time, which is the main mechanism of influence on the loading level. For the allocated SP it is established that the acceptable level from the point of view of maintenance of service quality is the reserve level of the SP capacity within the limits of 0.1–0.4. With an increase in the reserve capacity from 0.1 to 0.4:

– the average time of total dwell time of the vehicle is reduced by 1.6 times (from 3.9 minutes to 2.4 minutes);
– the average dwell time of the vehicle in the queue is reduced by 5.7 times (from 0.4 minutes to 0.07 minutes);
– the specific weight blocking the roadway is reduced by 3.6 times (from 0.65 to 0.18).

The revealed regularities of the change in the resource provision of the TTS SP to the efficiency of its operation reflect the existing real state of the organization of UPPT interaction. The obtained dependencies allow, in practice, when planning the operation of the UPPT routes, to establish the permissible dwell time of the vehicle on TTS SP, at which the required level of backup provision is achieved. Prospects for the development of the presented methodology are the possibility of conducting further studies on the boundaries of the implementation efficiency of optimization management actions.

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