Представлено математичну модель функціонування зупиночних пунктів транспортно-пересадочних вузлів. У середовищі PyCharm створена програма для проведення імітаційного моделювання при різних значеннях вхідних факторів: час відправлення транспортних засобів з початкового зупиночного пункту, кількість місць обслуговування. Розроблений інструмент дозволяє автоматизувати визначення оптимальної комбінації значень вхідних факторів за критерієм мінімального часу очікування у черзі

Ключові слова: зупиночний пункт, час очікування в черзі, час відправлення, місце обслуговування

Представлена математическая модель функционирования остановочных пунктов транспортно-пересадочных узлов. В среде PyCharm создана программа для проведения имитационного моделирования при различных значениях входящих факторов: время отправления транспортных средств с начального остановочного пункта, количество мест обслуживания. Разработанный инструмент позволяет автоматизировать определение оптимальной комбинации значений входных факторов по критерию минимального времени ожидания в очереди

Ключевые слова: остановочный пункт, время ожидания в очереди, время отправления, место обслуживания

UDC 656.025.2-111
DOI: 10.15587/1729-4061.2017.103333

METHOD OF TRAFFIC OPTIMIZATION OF URBAN PASSENGER TRANSPORT AT TRANSFER NODES

V. Vdovychenko
PhD, Associate Professor*
E-mail: Vval2301@gmail.com

O. Driuk
PhD
Department of software engineering
Kharkiv National University of Radio Electronics
Nauka ave., 14, Kharkiv, Ukraine, 61166
E-mail: sanya40@ukr.net

G. Samchuk
Postgraduate student*
E-mail: ganna.samchuk@gmail.com

*Department of transport technologies
Kharkiv National Automobile and Highway University
Yaroslava Mudroho str., 25, Kharkiv, Ukraine, 61002

1. Introduction

The importance of urban passenger transport (UPT) is increasing every year, which is predetermined by necessity of provision of sustainable city mobility. An integral part of UPT is the transportation hubs (TH), the efficiency of functioning of which depends on indicators of operation of constituent elements, in particular, stop points.

In the process of construction of stop points, their structural parameters are determined based on existing Road construction standards [1], and the number of places for simultaneous service is selected taking into account the traffic frequency. However, the throughput, obtained as a result, may be insufficient, because its calculated value is higher than the actual one. The difference arises because a variety of random factors influencing the duration of technological sub-processes are not considered; among them irregular arrivals of vehicles, service duration at TH. Due to this, there occur queues, traffic jams, which prolong their staying at TH, as a result, loading on the environment increases as emissions of greenhouse gases into the atmosphere rise. Thus, the intensity of the inflow may not be the main indicator for making decisions regarding parameters of stop points. Along with the throughput, estimated time of vehicles' waiting in a queue may be selected as an important marker for operation of stop points. The specified time consumption is an indicator of imperfection of the UPT traffic organization in the area of TH and of inappropriate structural parameters of stop points. The basic technical mechanism of a decrease in the specified indicator is an increase in number of places for simultaneous service at a stop point. It is an extensive and not always effective way.

Thus, the relevant problem is not only to substantiate parameters of stop points taking into account stochastic sub-processes, but also to develop technological mechanisms for the coordination of traffic schedules on UPT routes. Harmonization of vehicle flow at TH and determining the sequence of their service is a promising field of research.

2. Literature review and problem statement

It is important to examine functioning of stop points of TH both to assess existing facilities and to design the new ones. Considering stop points, the authors pay primary attention to determining their throughput, which is proved by a large number of existing studies, the results of which were published in specialized journals. Recommendations [2, 3] provide analytical models for determining this indicator, with the help of which it is possible to obtain only approximate and rough assessment, compared with the results of simulation. In addition, characteristics of arrivals of vehicles at a stop point are not taken into account.

In the literature, there are different simulation models for assessment of throughput and studying of functioning stop points, among which the simulators IRENE [4] and PASSION [5] are the most common. In article [6], the author compares them, revealing "convenience of IRENE and flexibility of PASSION", and presents a new version of PASSION. Using these tools, it is possible to evaluate the operation of stop points, but not to determine the optimal settings. In paper [7], a microscopic simulation model in AIMSUN 6.1 for a bus station with three service places was developed. The authors proposed the model for estimation of the potential throughput using the average for all routes passengers' get-on-off time, which cannot reflect the actual process. In research [8], the simulation model was developed using the Arena. In this paper, the average time of dwell time, the headway, configuration of loading areas, availability of devices of traffic control are considered for evaluation of throughput of a bus station. Although for each case of the values of input data the rejection level is calculated, the time consumption, associated with this, is not determined. The rejection level is also used in article [9]. The throughput was found to increase disproportionately when adding a service place to a stop point. It is noted that results, presented in the article, differ from the information, provided by professional reference books. One of the goals of the study [10] is to model a queue length for different combinations of parameters of the vehicles flow, and its coefficient of variation. The duration of a vehicle staying in the queue not was estimated. Article [11] carried out a comparative analysis of determining throughput of stop points using the principles of queuing system and regression analysis. The movement of vehicles of UPT is considered as one flow, characterized by an interval that is a random magnitude. But unlike the requests that come to the system randomly, the arrival of vehicles of each UPT route at a stop point of TH is possible not only to predict, but, if necessary, to control this moment. At the accepted law of distribution of random magnitude of the moment of vehicles' arrival, it is possible to determine the time interval, within which a vehicle arrives at a stop point with the assigned probability.

In addition, it is not possible to be limited only to the value of throughput when forming effectively functioning objects of the passenger transport system, such as TH. It is necessary to evaluate additionally the possible situations of destabilization of their operation, i.e. refusal of service at the simultaneous arrival of a number of vehicles that cannot be serviced, and time consumption, associated with it.

We propose a method, the implementation of stages of which will allow identifying the optimum variant of coordination of UPT traffic at TH by the criterion of minimization of waiting time for vehicles in line at each value of the number of service places at a stop point. The method implies the development of a simulation model of functioning of a stop point and software implementation.

3. The aim and objectives of the study

The aim of the study is to develop the methods for optimization of traffic flow of UPT and for selecting the required number of service places at a stop point, which will provide for a decrease in waiting time for vehicles.

To achieve the set aim, the following tasks had to be solved:

– to develop a simulation model of a stop point operation in order to determine the waiting time and the number of vehicles in line;

– to establish parameters of input data, to determine the laws of distribution of random magnitudes of the time of motion of vehicles from the starting stop point to TH, service duration and their numerical characteristics;

– to determine the required mechanisms, the introduction of which will provide for a minimum value of unproductive downtime of vehicles for each number of service places at a stop point.

4. Materials and methods of examining the impact of traffic parameters and the number of service places at a stop point in TH on waiting time and the number of vehicles in a line

4. 1. Model of operation of a stop point

The object of the present research is functioning of stop points of TH, the subject is the influence of traffic parameters and the number of service places on the duration of unproductive downtime. The hypothesis of the study is that implementation of technical and technological mechanisms will decrease the vehicles' waiting time in a queue and improve operation efficiency of TH stop points. Improvement of operation of stop points is accomplished by setting the order of servicing of vehicles arriving at TH depending on their traffic parameters and duration of the service. This is achieved by shifting the time of vehicles' departure from the starting stop point. It is proposed to assess every possible combination based on the total waiting time in a queue in order to make adjustments in the schedule at the established traffic intervals. Refusal of service occurs if a stop point is engaged with other vehicles.

Calculations are carried out at each number of service places in the recommended limits, which allows exploring the influence of parameters of stop points on the selected indicator.

Conditional designations, which are used:

R is the set of routes, arriving at TH;

NR is the number of routes, which pass through a stop point;

i is the index of a route;

V_i is the set of vehicles of the i-th route, arriving at TH;

B_i is the number of vehicles of the i-th route, arriving at TH;

b is the index of vehicles;

k is the index of loading areas at a stop point;

L is the number of loading areas for simultaneous service of vehicles at a stop point;

N_L is the maximum number of loading areas for simultaneous service of vehicles at a stop point under consideration;

$\tau_S;\tau_E$ is the start and the end of estimated time respectively;

$td_i^{(b)}$ is the departure time of the b-th vehicle of the i-th route from the starting stop point;

I_i is the headway on the i-th route;

$\tilde{t}_i^{(b)}$ is the travel time of the b-th vehicle of the i-th route from the starting stop point to TH;

μ is mathematical expectation of time of motion from the starting stop point to TH;

σ is the root mean square deviation of time of motion from the starting stop point to TH;

$\tilde{M}a_i^{(b)}$ is the moment of arrival of the b-th vehicle of the i-th route at TH;

$\tilde{t}s_i^{(b)}$ is the service time of the b-th vehicle;

k is the parameter of gamma-distribution for service time at a stop point;

E is the mathematical expectation of service time at a stop point;

$\tilde{t}st_i^{(b)}$ is staying of vehicles of the i-th route in TH;

$\tilde{M}d_i^{(b)}$ is the moment of departure of the b-th vehicle of the i-th route from TH;

z_i is the magnitude of shifting of departure time from the starting stop point;

$\tilde{t}q_i^{(b)}$ is the time of the b-th vehicle waiting in a line in front of a stop point;

td_i' is the changed time of departure of the first vehicle of the i-th route from the starting stop point;

t is the total waiting time of vehicle in line in front of a stop point;

nw is the number of vehicles, waiting in a queue.

It is necessary to solve a set of problems of combinatorial optimization $\{\Phi_к\}: k \in 1...N_L$, the number of which corresponds to the number of service places at a stop point. Objective function will be presented in the following way:

$$\Phi_k : t(\vec{x}) \to \min_{\vec{x} \in \Omega_k}, \tag{1}$$

$$\Omega_k : \begin{cases} td_i^{(1)} \le td_i' < td_i^{(1)} + I_i; \\ td_i^{(1)}, td_i^{(B_i)} \in [\tau_S; \tau_E]; \\ L = k, \end{cases}$$

where

$$\vec{x} = \{td_1', td_2' ... td_{N_R}'\}.$$

Departure time of first vehicles on the routes that pass through a stop point of TH from the starting stop point was selected as control variables. It is necessary to determine a vector of their values to achieve effective functioning of stop points at a certain number of places of service.

The vector of control variables, accordingly, when solving Φ_k of problem $\vec{x}_k = \{td_1', td_2' ... td_{N_R}'\}$.

The first component in the system of limits indicates that the time of departure from the starting stop point varies within the range of the headway on the i-th route. The second expression indicates that modeling is carried out for a specific period of time. In the limits, the number of places of service, for which we search for extreme values of objective function, is indicated.

The arrival time for vehicles of each route at traffic intervals I_i is a function of the time of departure from the starting stop point. The arrival moment for vehicles for achieving synchronization is controlled by addition of magnitude z_i to existing value of the time of departure of the first vehicle on each route:

$$td_i' = td_i^{(1)} + z_i,\ z_i \in Z_{\ge 0}. \tag{2}$$

The magnitude of shifting the time of departure of a vehicle on the i-th route z_i belongs to the set of nonnegative integers $Z_{\ge 0}$.

The problem is solved at assumptions:

– the time of departure from the starting stop point is a determinate and assigned magnitude;

– vehicles depart according to the traffic schedule;

– on arrival at an engaged stop point, a vehicle waits for when the place of service is vacant;

– a vehicle takes one service place at a stop point.

Since most processes in the passenger transport systems are stochastic, in order to obtain the value of the time of waiting to be serviced, the simulation is necessary, which will make it possible to represent the operation process of stop points.

Considering TH (TR) as a technical-technological object, it is proposed to represent its basic parameters as a tuple from a set of stop points (S) and a set of distances between them (D), as well as a set of routes, arriving at TH $TR = \langle S, D, R \rangle$.

Each stop point $s_q \in S,\ q = 1...N_S$ is characterized by the number of places for simultaneous service of vehicles L_q and a set of routes, arriving at a stop point

$$R_q \subseteq R,\ R = \{r_i \mid i = \overline{1, N_R}\}.$$

Within the framework of the study, one stop point is examined, so the indices of stop points may be neglected.

The traffic schedule and a set of vehicles $V_i = \{V_i^{(b)}\}$ are characteristics of route r_i as an element of TH. The traffic schedule for the calculated period will be described by the departure time of vehicles from the starting stop point and the traffic interval on the route. The number of vehicles corresponds to the number of departures from the starting stop point within the calculated period, as in the framework of the study, the reverse rides are not modeled.

Each vehicle $V_i^{(b)} \in V_i$ of route r_i, arriving at a stop point in TH, may be described using the moment of arrival and time of service at TH, which are random magnitudes.

Modeling the moment of arrival of vehicles is possible by adding to the moment of departure of the b-th vehicle of the i-th route from the starting stop point of realization of random magnitude of duration of motion to TH:

$$\tilde{M}a_i^{(b)} = td_i^{(b)} + \tilde{t}_i^{(b)},\quad b = \overline{1, B_i}. \tag{3}$$

Vehicles depart from the starting stop point at a period of time equal to the traffic interval on the i-th route, i. e. departure for the b-th vehicle of the i-th route during the calculated period is determined as follows:

$$td_i^{(b)} = td_i^{(1)} + (b-1) \cdot I_i. \tag{4}$$

Time that vehicles of the i-th route spend at TH ($\tilde{t}st_i^{(b)}$) consists of the downtime in the line waiting for the stop point to be vacated (if available) and service time at a stop point, the duration of which are random magnitudes:

$$\tilde{t}st_i^{(b)} = \tilde{t}q_i^{(b)} + \tilde{t}s_i^{(b)}. \tag{5}$$

The service time includes duration of the following operations: maneuvering, opening/closing of doors, passengers' getting on/off, and additional downtime. The moment of departure of the b-th vehicle of the i-th route from a stop point is calculated according to the following dependence:

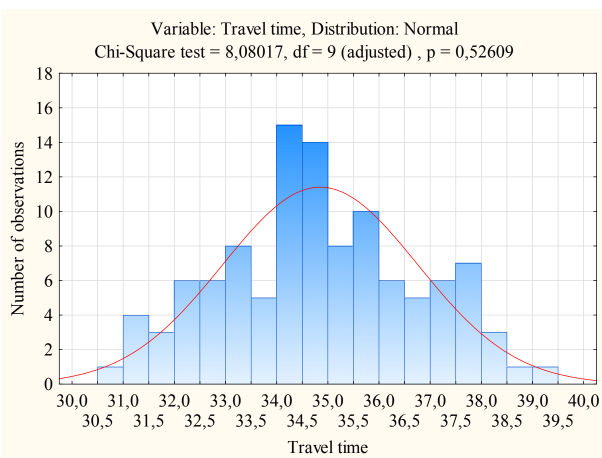
$$\tilde{M}d_i^{(b)} = \tilde{M}a_i^{(b)} + \tilde{t}st_i^{(b)}. \tag{6}$$

When modeling technological sub-processes for vehicles of UPT at the time of arrival of each of them, the availability of a vacant service place at a stop point is checked, if it is not available, then a vehicle waits in a queue for a certain period of time. To establish the value of the latter, it is necessary to determine the difference between the moment of departure of a vehicle that is serviced at a stop point and the moment of arrival of a vehicle, waiting to be serviced.

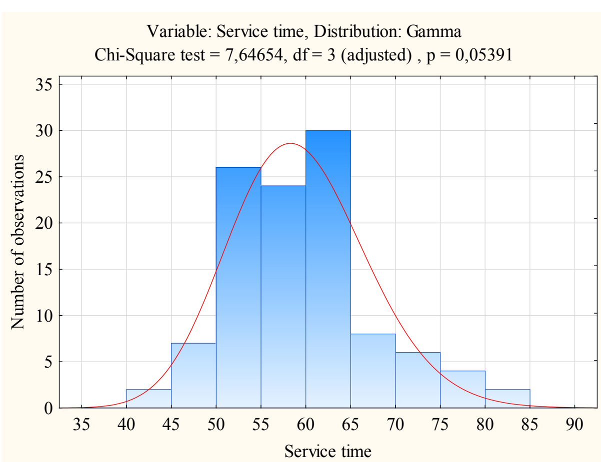
4. 2. Determining of parameters of operation of TH stop points

To obtain the required numerical values of input data, we carried out field studies on the route network of UPT and in particular at TH "Levada" (Ukraine) at the stop point "Gagarin Avenue" throughout October 2016 in a rush hour (from 7.00 to 9.00). Vehicles of 14 routes of UPT, 3 of which are trolleybus routes, arrive at this stop point; for routes No. 5, No. 79, No. 115, separate stop points are prepared. Record-keepers at a stop point registered a type of transport, a route number and its state registered number, time of arrival at the stop point and time of departure from it. In addition, there were record-keepers at the starting stop points of the routes, passing through TH "Levada", who registered the time of departure from them.

Processing of an array of statistical data enables us to determine the law of distribution and parameters of random magnitudes of travel time of vehicles from the starting stop point to TH, as well as the law of distribution of service time for each route. Collected numerical values were used to construct histograms of distribution of random magnitudes, based on the form of which, the hypotheses about the laws of distribution were put forward. Fig. 1 shows the histograms of distribution of random magnitudes for route No. 119.



a



b

Fig. 1. Histograms of distribution of random magnitudes: *a* — travel time; *b* — service time

The normal and Gamma distribution laws for the duration of motion to TH and for service time, respectively, were considered. Hypotheses about the laws of distribution of random magnitudes of the travel time to TH and service time were verified using the software StatSoft Statistica using a Distribution Fitting tool. The Pearson chi-square criterion was used to verify statistical significance of the hypotheses. Analysis in Statistica provides data on the calculated value of the criterion, as well as for determining the number of degrees of freedom that were used to determine its table value by using MS Excel. Results of verification of the hypotheses are given in Table 1.

Table 1

Verification of statistical hypotheses about the law of distribution of traffic parameters and service time for route 119

Magnitude	Distribution law	Number of parameters that characterize distribution law	Number of degrees of freedom	Criterial statistics	Tabular value of Pearson criterion
Travel time from starting stop point to TH	Normal	2	17	8.1	27.6
Service time of vehicles at TH	Gamma-distribution	2	8	7.6	15.5

Calculated values of the Pearson criterion do not exceed tabular values, which is why the hypotheses are not rejected. Selected distribution laws and their parameters: normal for the travel time from the starting stop point and Gamma-distribution for service time can be used in a simulation model.

Numerical values of the input data and parameters of the random magnitudes of indicators that characterize technological sub-processes for vehicles at TH "Levada" are given in Table 2.

In addition, collected data provided information on traffic schedule on the examined routes. It was recorded that the frequency of arrival of vehicles exceeds permissible value for this type of a stop point, which is 30 units. In accordance with recommendations [1], it is necessary to equip separate stop points for trolley buses and buses. That is why, trolleybus routes were not considered in the subsequent studies.

We shall note that the number of combinations increases exponentially with an increase in the number of routes and traffic intervals, and the problem is NP-complex. In order to reduce the number of combinations for evaluation, routes No. 68 and No. 305 were excluded from the study. Since the traffic interval on the mentioned routes is longer than 20 minutes, and service time is less than a minute, they do not exert a significant effect on the results of modeling.

Table 2

Numerical values of characteristics of UPT traffic

Route	Time of departure from starting stop point of i-th route	Interval on i-th route, min	Parameters of random magnitude of time of departure from starting stop point to TH of the i-th route		Parameters of random magnitude of service time of vehicles at stop point of i-th route	
			Mathematic expectation, min	Root mean square deviation, min	Parameter k	Mathematic expectation, s
89	7:00	25	30	2	81	60
119	7:00	15	35	1,75	75	60
147	7:00	10	5	0,5	187	150
218	7:00	15	5	0,75	77	60
246	7:00	20	7	0,75	150	120
304	7:00	20	10	1,25	225	180

5. Results of research into unproductive downtime and the number of vehicles in line and traffic optimization

We conduct study with the aim to assess unproductive downtime at different variants of time of departure of UPT vehicles from the starting stop point and number of service places at a stop point of TH. Software implementation of the simulation model was created in the programming environment PyCharm, which models the main processes: departure from the starting stop point, arrival at TH, service time at a stop point, and waiting time in a queue.

Preparatory stage of the work with a simulation model is the creation of file with input data, to which numerical values must be entered. Normal law of distribution of random magnitude of time of motion is assigned using mathematical expectation and root mean square deviation $\tilde{t}_i^{(b)} \sim N(\mu, \sigma)$; Gamma-distribution of service time is assigned by parameter of the k form and mathematical expectation $\tilde{ts}_i^{(b)} \sim G(k, E)$, based on which a parameter of scale is determined.

Input data: model time, number of routes, arriving at a stop point. For each route we assign: time of departure from the starting stop point, mathematic expectation of time of motion form the starting stop point to TH, root mean square deviation of the time of motion, traffic interval on the route, parameter k of Gamma-distribution for service time at a stop point, mathematical expectation of service time at a stop point. The output parameters include waiting time and the number of vehicles in a queue.

The algorithm of operation of the program also includes a procedure of creation of all possible combinations of ordering (agreement) of motion of vehicles. Then, the optimal values of the time of departure from the starting stop point for each UPT route are determined by the criterion of minimum time of waiting of vehicles in a line in the TH zone for each number of service places at a stop point.

Thus, to optimize the traffic at TH, the following steps are performed:

1. Read out information about the values of input data.

2. For each number of service places, in the range from 1 to 4, the determined sub-processes are modeled and calculations of waiting time and of the number of vehicles in the queue are performed.

2. 1. Based on the assigned traffic intervals, combinations of shifting of time of departure from the starting stop point are formed.

2. 1. 1. In accordance with the obtained combinations of shifting for each of them and for each route, the time of departure of the first vehicle from the starting stop point is created.

2. 1. 2. For the assigned number of routes N_R, the time of departure of all vehicles from the starting stop point within the model time is formed.

2. 1. 3. 100 iterations are conducted, because the magnitudes are random.

2. 1. 3. 1. Moments of arrival of all vehicles at the TH and the service time are modeled in accordance with the distribution laws.

2. 1. 3. 2. Arrival moments are ordered by means of sorting.

2. 1. 3. 3. A condition of the route point being occupied is checked. If it is confirmed:

2. 1. 3. 3. 1. Waiting time is calculated as the difference between the first time of departure from the stop point of TH and time of arrival of the examined vehicle. According to the proposed model, the time of a bus approaching any service place of a stop point may be neglected.

2. 1. 3. 3. 2. The time of starting service is equaled to the moment of the first time of departure.

2. 1. 3. 4. Otherwise, computation of points 2. 1. 3. 3. 1–2. 1. 3. 3. 2 is not performed. Departure time is recorded.

2. 2. For any number of places for simultaneous service at stop points, among all obtained values, we search for and derive the minimum and maximum values of indicators, given in point 2, specifying the combination of shifting a departure time.

3. The end.

Fig. 2 shows a scheme of the snippet of algorithm, according to which the operation of a stop point of TH is simulated. As a result, we calculate value of waiting time and the number of vehicles in a line for every combination of shifting of time of departure of vehicles from the starting stop point.

The following designations were introduced:

t_{model} is the simulation time ;

comb is the combination of shifting the time of departure of vehicles from the starting stop point.

iter is the iteration during modeling;

times is the set of moments of arrival of vehicles TH;

Ma_true is the moment of arrival of a vehicle at a stop point of the examined TH.

We shall note that the shift of departure time does not occur for the first route.

Implementation of the algorithm allows conducting experimental research by automating lookup and assessment of all possible combinations of coordination.

The boundaries of variation of input factors are given in Table 3. The number of service places at a stop point of TH varies from 1 to 4. A change in the time of departure from the starting stop point of the i-th route takes place based on the accepted limitations (2).

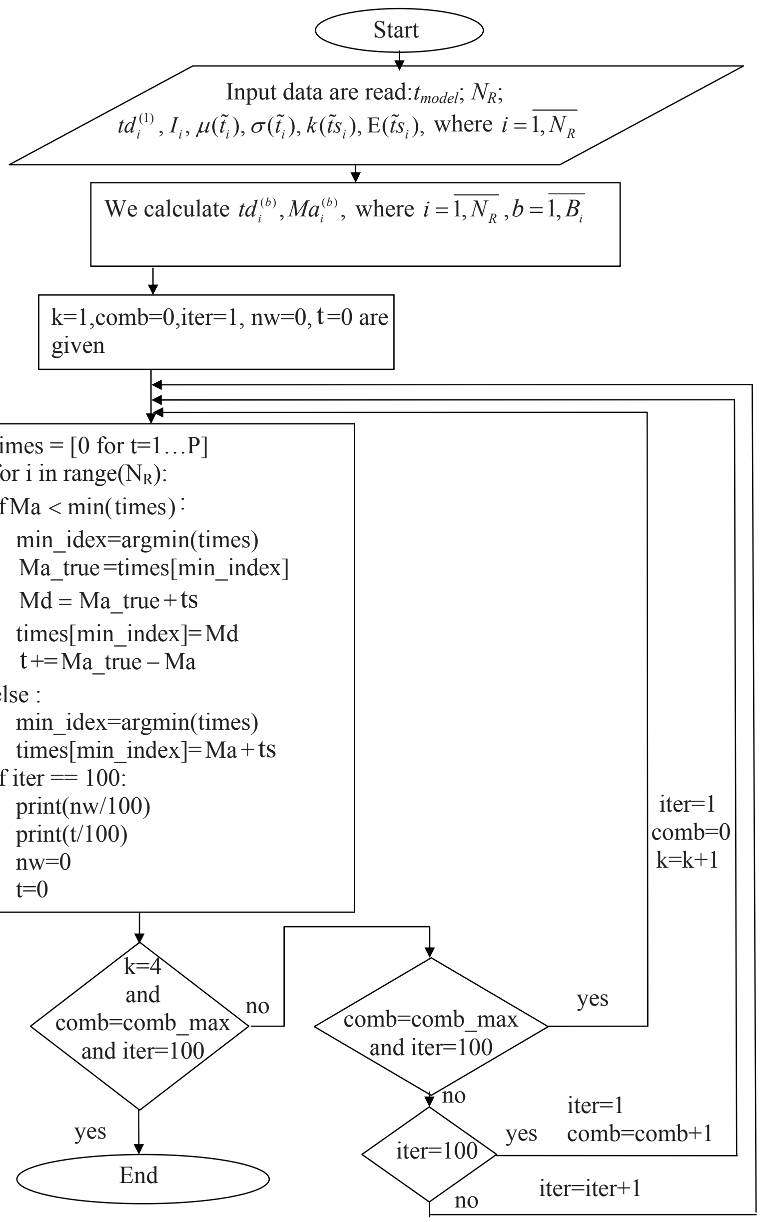


Fig. 2. Scheme of the algorithm of simulation of TH stop point

Table 3

Variation of input factors

Factor	Lower boundary	Upper boundary	Step
Number of service places at a stop point	1	4	1
Time of departure from starting stop point of the i-th route	td_i	td_i+I_i	1

The designed plan of experiment contains, respectively, (15×10×15×20×20) 900000 series for each number of service places, which satisfies all possible combinations of shift in a waiting time. Each series consists of 100 experiments (iter=100), by the results of which we calculate the mean value of waiting time and the number of vehicles in a queue for each possible combination of shifting.

Tables 4, 5 and Fig. 3 show results of modeling for the period of 7200 s with indication of the calculated waiting time and the number of vehicles in a queue. We present the values at basic variant, that is, without shifting; as well as at the combination that yields both the best and the worst result for each number of service places at a stop point.

Table 4

Results of modeling of waiting time in a queue

Number of service places	1	2	3	4
Total waiting time in queue				
Without shifting	34.29	1.73	0.04	0
Minimum value	15.47	0.31	0	0
Maximum value	62.2	8.44	0.81	0.02

Table 5

Results of modeling of the number of vehicles in a queue

Number of service places	1	2	3	4
Number of vehicles in queue				
Without shifting	25	4	1	0
Minimum value	15	1	0	0
Maximum value	26	8	2	1

In this case, a possible effect of the introduction of mechanisms of decreasing the waiting time for vehicles in a queue will amount to, respectively:

– 18.82 for 1 service place, that exceeds 50 %, in the case of adjustments in traffic schedule;

– 32.56, 34.25; 34.29 min. when adding an additional service place for the basic variant.

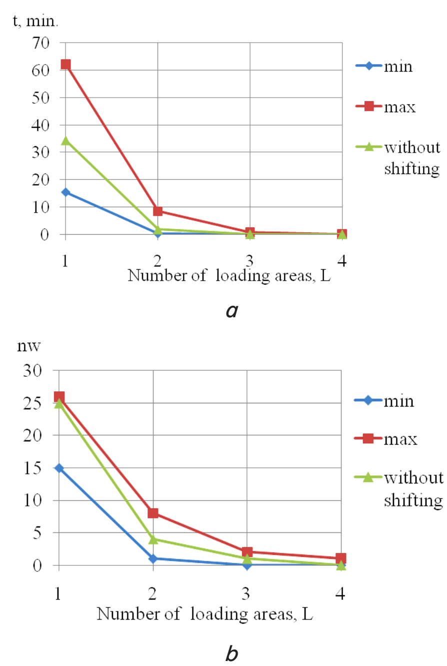


Fig. 3. Influence of the number of service places L on: *a* – waiting time of vehicles in a queue, t; *b* – number of vehicles in a queue, nw

6. Discussion of results of simulation of the operation of a TH stop point and optimization of UPT traffic

Results of simulation indicate that the organization of UPT traffic in TH exerts a significant influence on the downtime of vehicles in a queue. It is possible to decrease non-productive downtime by 50 % even for one service place with a change in the traffic schedule for the purpose of synchronization. In addition, when adding a service place, we observe a nonlinear decrease in the waiting time of vehicles in a queue.

Automation of stages of traffic optimization of UPT in the zone or stop points of TH was performed by means of the developed software. Non-productive downtime of vehicles is minimized by determining the corresponding vector of time of departure from a starting stop point. According to the results of implementation of steps of the algorithm of the developed program, it is possible to determine the required number of service places at stop points depending on the traffic parameters of UPT based on the obtained numerical values of waiting time and the number of vehicles in a queue.

Table 6 gives recommended time of departure from the starting stop point of the i-th route.

Table 6

Recommended time of departure from starting stop point of the i-th route

Route	Recommended time of departure from starting stop point of the i-th route
89	7:00
119	7:00
147	7:05
218	7:08
246	7:08
304	7:14

The examined problem belongs to the class of problems of combinatorial optimization and is NP-complex. To solve such problems, it is advisable to develop and apply evolutionary algorithms, which provide an intelligent search for the vector of input factors for problems of large dimensionality. Because of the limited time resources, it is often impossible to use accurate methods of optimization. Thus, the efficiency of the algorithm for the lookup and evaluation of all possible combinations of input factors, implied by the presented method of optimization, may be guaranteed at compliance with the following limitations: the number of routes is up to 5, traffic interval is up to 30 min.

A promising direction of research is the development of a metric of traffic regularity, based on which it would be possible to estimate time consumption of vehicles at stop points of TH.

7. Conclusions

1. According to the developed simulation model of operation of a stop point of TH, we formed and implemented in the PyCharm environment the algorithm that optimizes the values of input factors. The efficiency of the algorithm may be guaranteed at compliance with the following limitations: the number of routes is up to 5, traffic interval is up to 30 min.

2. Based on a series of observations, we established parameters of input data and determined the laws of distribution of random magnitudes of the travel time of vehicles from the starting stop points to TH and the service time. Verification by the Pearson chi-square criterion showed that the hypotheses do not deviate from the normal and Gamma distributions.

3. We defined mechanisms, which provide minimization of unproductive downtime of vehicles, among which it is possible to highlight: determining of the number of service places at stop points and traffic coordination of UPT vehicles. Results of modeling revealed the possibilities of decreasing time consumption of vehicles in a line by more than 50 % for every number of service places. The introduction of technical and technological measures will improve major economic and environmental indicators at rational use of land resources in the city.

References

1. DBN V.2.3-5-2001. Vulytsi ta dorohy naselenykh punktiv [Text]. – Kyiv: Derzhbud Ukrayiny, 2001. – 50 p.
2. Highway Capacity Manual. TRB [Text]. – Transportation Research Board of the National Academies, Washington, D.C., 2000. – 1207 p.
3. Reilly, J. Public Transport Capacity Analysis Procedures for Developing Cities [Text] / J. Reilly, H. Levinson. – The International Bank for Reconstruction and Development/The World Bank, Washington, D.C., 2011. – 127 p. – Available at: http://siteresources.worldbank.org/INTTRANSPORT/Resources/336291-1239112757744/5997693-1294344242332/Public-Transport-Capacity-Analysis-Procedures.pdf
4. Gibson, J. Bus stops, congestion and congested bus stops [Text] / J. Gibson, I. Baeza, L. G. Willumsen // Traffic Engineering and Control. – 1989. – Vol. 30, Issue 6. – P. 291–302.
5. Fernandez, R. A new approach to bus stop modelling [Text] / R. Fernandez // Traffic Engineering & Control. – 2001. – Vol. 42, Issue 7. – P. 240–246.
6. Fernandez, R. PASSION 5.0 – a model for microscopic simulation of multipleberth bus stops [Text] / R. Fernandez // Traffic Engineering and Control. – 2007. – Vol. 48, Issue 7. – P. 324–328.
7. Widanapathiranage, R. A Microscopic Simulation Model to Estimate Bus Rapid Transit Station Bus Capacity [Text] / R. Widanapathiranage, J. M. Bunker, A. Bhaskar // Australasian Transport Research Forum 2013 Proceedings. – Brisbane, 2013. – 12 p.
8. Reilly, J. M. Estimating capacity of high volume bus rapid transit stations [Text] / J. M. Reilly, F. Aros-Vera // TRB Annual Meeting. – Washington, DC., 2013. – 11 p.
9. Gu, W. On the capacity of isolated, curbside bus stops [Text] / W. Gu, Y. Li, M. J. Cassidy, J. B. Griswold // Transportation Research Part B: Methodological. – 2011. – Vol. 45, Issue 4. – P. 714–723. doi: 10.1016/j.trb.2011.01.001
10. Widanapathiranage, R. Modelling the BRT station capacity and queuing for all stopping busway operation [Text] / R. Widanapathiranage, J. M. Bunker, A. Bhaskar // Public Transport. – 2014. – Vol. 7, Issue 1. – P. 21–38. doi: 10.1007/s12469-014-0095-y
11. Zhao, S. S. Study on the Number of Berths of Road-Side Bus Stop [Text] / S. S. Zhao, X. N. Zhu // Advanced Materials Research. – 2013. – Vol. 734-737. – P. 1598–1603. doi: 10.4028/www.scientific.net/amr.734-737.1598