

MODELLING OF PASSENGER FLOWS MOVEMENT AND OPTIMIZATION OF COMMUNICATION WAYS PARAMETERS

DOI: 10.36724/2072-8735-2024-18-2-58-64

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Manuscript received 12 January 2024;
Accepted 16 February 2024

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Keywords: passenger flows, optimization, model,
AnyLogic, hub

Transportation is an important issue for large cities and agglomerations, and as cities grow, it becomes more socially and macro-economically important. Transport interchange hubs (TIHs) are important structural elements of a city's transport network. They are complex, integrated facilities that perform a variety of social functions. Regional organization of the NTH should be based on standards and recommendations, considering the multifunctionality of transport facilities. Planning decisions, in particular, on transport-planning organization of the TIH, are currently made without a scientifically justified normative base for the design of such facilities. Integrated influence of various transport-planning, social and other factors is insufficiently considered. Traffic flow is one of the most important factors determining the technical and technological structure of the TIH. This is especially important when the TIU is formed in the suburban direction in the zone of suburban passenger traffic. Therefore, it is necessary to conduct research on the TIU functioning and passenger flow patterns. Considered the problem of passenger flow modelling at passenger transport infrastructure facilities, the regularities of passenger flow formation and promotion at TIH revealed, the dependencies between the main parameters of passenger flow movement to TIH obtained using a simulation model are given.

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Для цитирования:

Евреенова Н.Ю., Калинин К.А. Моделирование перемещения пассажиропотоков и оптимизация параметров коммуникационных путей // Т-Comm: Телекоммуникации и транспорт. 2024. Том 18. №2. С. 58-64.

For citation:

Evreenova, N.Yu., Kalinin K.A. (2024). Modelling of passenger flows movement and optimization of communication ways parameters. T-Comm, vol. 18, no.2, pp. 58-64.

Introduction

Among the problems of large cities and agglomerations, one of the most important is the transport problem, which, as cities grow, acquires an increasingly acute social and macroeconomic character. Recently, in foreign countries, there has been a clear tendency of transformation of transport hubs/ railway stations into modern complexes, a kind of transport, trade, cultural and public centres that define the face of the city. This is most clearly manifested in large cities, where objects of transport passenger infrastructure are traditional points of concentration of passenger traffic. Scientific basis of the issues of the functioning and development of passenger complexes, as well as the design of new ones, must be carried out dependably, considering the laws of the formation and movement of passenger flows in them.

General issues

When developing standards for the design and development of passenger complexes and their components – hubs, the issues of modelling passenger traffic were not sufficiently considered, as one of the main factors for determining the technological areas of stations, hubs, parameters of passenger platforms, concourses, pedestrian communications, etc. The development of passenger complexes in modern conditions should be carried out considering the technical and technological capabilities and verification of planning solutions, as well as the parameters of pedestrian communications on simulation models based on modelling passenger traffic. The currently practised intuitive assessment of the complexity of a transport infrastructure facility, including transport hubs, leads to errors that cause large financial losses.

At present, in numerous instances, the transfer of passengers at the hubs is accompanied by large losses of time. The organization of rational interaction of modes of transport in a hub is possible based on more complete use of digital technologies, intelligent transport systems, a unified management system for all modes of transport, coordination of timetables, etc.

The choice of modelling system

The choice of the modelling system is of great importance for achieving the accuracy of the study. There is numerous universal modelling systems in the world, many of which are used in Russia. Most of the systems have similar capabilities, the most frequently mentioned and typical ones are Arena, AnyLogic and multiagent systems.

The Arena modelling system is one of the most accessible and widespread universal modelling systems that allows you to build simulation models, run them and analyse the results of such playback. Arena is a universal tool for optimizing processes, and the models built with its help can be used for a wide variety of areas of activity – production and technological operations, warehouse accounting, banking, as well as modelling passenger traffic.

AnyLogic system includes a set of standard libraries, including those for modelling railway objects. This library implements visualization of some operations performed on the railway. The dynamics shows the movement of trains, but within the model, only flow units are serviced. Extending the functionality of the system requires the user to know the basics of programming.

Anylogic system needs to be adapted to be used in the simulation of railway transport. In addition to visualization tools, it requires additional modules that enable it to describe in models the features of performing various operations, display the dispatch control factor, process and analyse the results of calculations.

Multiagent, as the name implies, are systems formed by several interacting agents. They are characterized by the following signs:

- autonomy – agents act independently;
- limited representation – none of the agents has an understanding of the entire system;
- decentralization – there are no agents managing the entire system.

Their prototypes in nature are a swarm of bees and an anthill. Multiagent systems are used in online commerce, in the elimination of emergencies, for the organization of road traffic in the city and others, when it is necessary to find a solution in the conditions of independence of the participants, they do not have complete information about the entire system and a single control centre.

When choosing a modelling system, problems that will be solved thanks to this modelling system play an important role. These tasks can be classified by optimization parameters. For example:

– to determine the optimal parameters of the system (stations, transport hubs): the dimensions of the area of the premises, the layout, and width of the entrances / exits, which minimize the loss of passenger time in the system, provided that the train schedule is an independent external factor. The results of solving such a problem can be used to base planning and architectural solutions for new or reconstructed stations / hubs during their development.

– in case of an existing railway station / hub, the task of optimizing (adjusting) the passenger traffic schedule, parameters, and layout of the station / hub entrances / exits, which determine the strategy of minimizing the time spent by the passenger in the system, can be set. This problem can be considered when assessing and optimizing the train timetable on the directions and in the regions.

– in the study of emergencies, it is advisable to set the task of determining rational (optimal) parameters and layout of existing and emergency entrances / exits of stations / transport hubs in conditions of extreme passenger traffic according to the criterion of minimizing the average (specific) number of critical situations (congestion and downtime) at the entrances / exits of stations and in a hub.

Patterns of passenger flow

The practice of designing and operating transport hubs around the world shows that it is required to identify the patterns of passenger movements to determine the impact of movements on the transport and planning structure of the transport hub.

The experiments carried out on the simulation model built using the AnyLogic program revealed the main dependencies between the parameters of the movement of passenger traffic. Restrained movement can be with little influence of contact interference, with significant influence and continuous movement. The dependence of the speed of movement of interchange flows on the density is shown in Figure 1a. The dependence of

the traffic intensity of interchange flows on the density of passenger traffic is shown in Figure 1b.

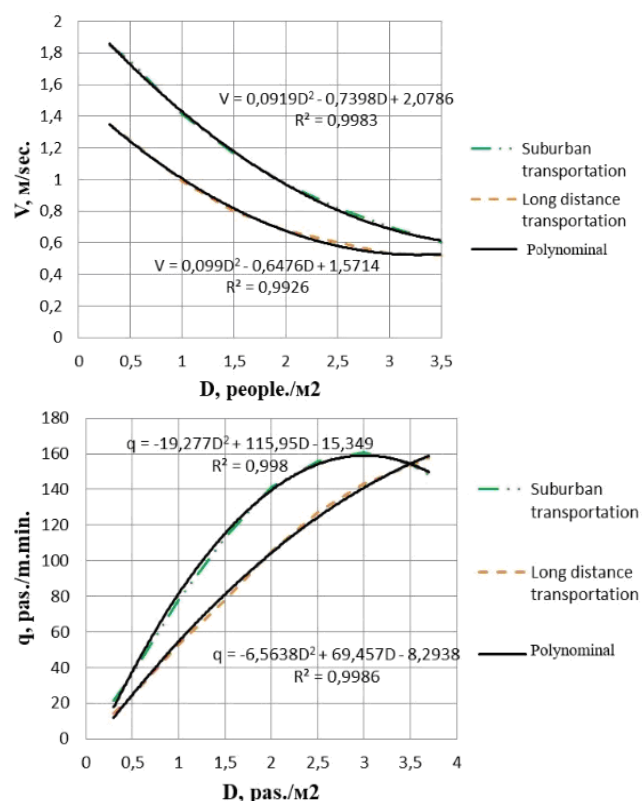


Fig. 1. Dependence of passenger traffic density:
a – on the speed of movement; b – on the intensity of traffic

It is proposed to consider the transport service system of the transfer hubs in the form of a queuing network, for which the main parameters are incoming and outgoing flows. The incoming flow of passengers at hubs is characterized by a ripple caused by the uneven arrival of various modes of transport at the hub and in this case, should be investigated: the occupancy rate of arriving rolling stock (public and individual transport), the arrival interval, the number of passengers coming to stops per unit of time and their arrival time.

The incoming flow is the flow of urban transport. As the investigated parameter of the incoming flow, we take the interval of movement of the rolling stock of urban transport, i.e., the time of arrival of its unit to the stopping point.

The obtained dependencies between the parameters of movement of passenger flows make it possible to determine the throughput capacity of the main elements of transport hubs formed with the participation of railway transport, and other parameters of communication routes. The use of simulation models makes it possible to obtain several options for the routes of passenger traffic and to choose a rational one.

Modelling passenger flows at passenger transport infrastructure facilities

The complexity and stochastic nature of the dynamics of the movement of passenger traffic, the need to determine the desired characteristics and analyse the situations that arise at any mo-

ment of time led to the use of the simulation method when choosing a mathematical method for studying the system” hub – passenger flow”.

The system under study consists of two subsystems: static – the area of the station, concourse, passenger platforms, pedestrian crossings, and dynamic – passenger traffic. Until recently, traditional engineering techniques based on the summation of the areas of individual functional rooms, determined based on an estimate of the “average” number of passengers served, were usually used to assess the need for the area of hub premises.

In general, the interior space of a station or any other object of transport passenger infrastructure, “accessible” to passengers, has a complex outline. Entrances/exits are always bottlenecks.

The simulation model of the hub based on the railway terminal of the station “Irkutsk – Passenger” was built using the Russian-made professional package of simulation AnyLogic University (educational version). The logical structure of the work of the simulation model of the hub “Irkutsk – Passenger” is shown in Figure 2. Figure 3 shows the simulation results for a rationalized version of the planning solution.

For hub Irkutsk – Passenger, the following solutions were proposed as a rationalization of pedestrian communications: separation of long-distance and suburban passenger flows, transfer of a luxury hall to the 2nd floor, installation of an elevator to provide access to low-mobility groups to the 2nd floor, construction of a covered pedestrian bridge equipped with lifts for low-mobility groups of the population, opening of exits to the platform in entrances No. 2 and No. 3, redistribution of commercial space, transfer of ticket-printing machines, redistribution of the waiting area in the suburban pavilion, etc.

The probabilistic distribution of the density of pedestrian flows D makes it possible to establish the value of the most probable density of movement of flows along certain pedestrian communications and can be used when calculating the required throughput capacity.

The probabilistic distribution of the speed of movement of pedestrian flows V , respectively, allows us to determine the most acceptable value of the speed of movement of interchange flows in the hub, used to determine the radius of the zone of pedestrian accessibility of the hub.

N.V. Pravdin [1] and other researchers [2-19] note in their works that the speeds of long-distance and suburban passengers are different. They range for long-distance passengers from 33.3 to 66 m/min, and for suburban passengers, respectively, 33.3-100 m/min. Within the limits of pedestrian communications during peak hours, the speed of passenger movement drops sharply to 30 m/min due to an increase in the density of passenger traffic. The most difficult situation arises at the moment of arrival of the most loaded type of transport (railway), which determines the power of the flow passed through pedestrian communications.

A modern hub is a complex queuing system, which can be represented in the form of two functionally interacting subsystems: a multichannel subsystem for servicing (receiving/sending) modes of transport interacting in a hub; passenger service subsystems. Each of these subsystems, in turn, is a complex queuing system.

One of the most important issues in optimizing the processes of interaction between the railway and urban transport modes is the integrated development and placement of transfer stations and hubs. Transport and planning solutions for the development of hubs must be carried out based on a scientifically grounded design base.

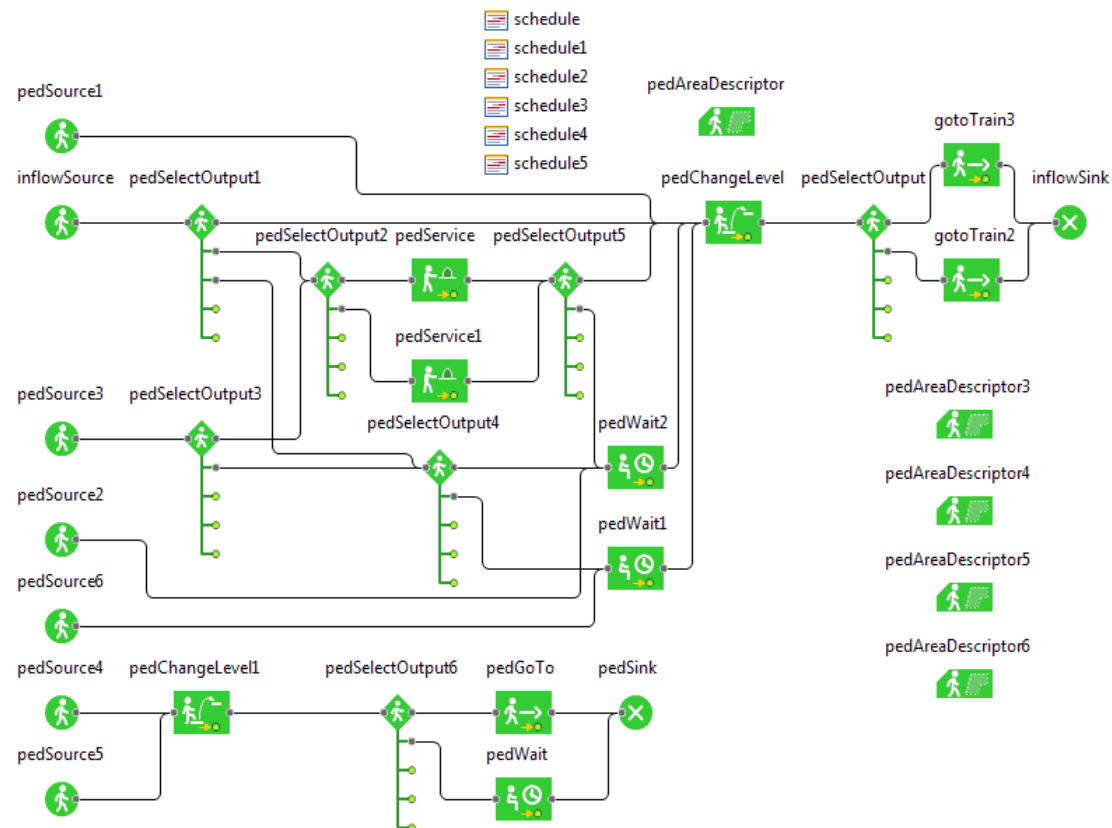


Fig. 2. The logical structure of the work of the simulation model of the hub “Irkutsk – Passenger”

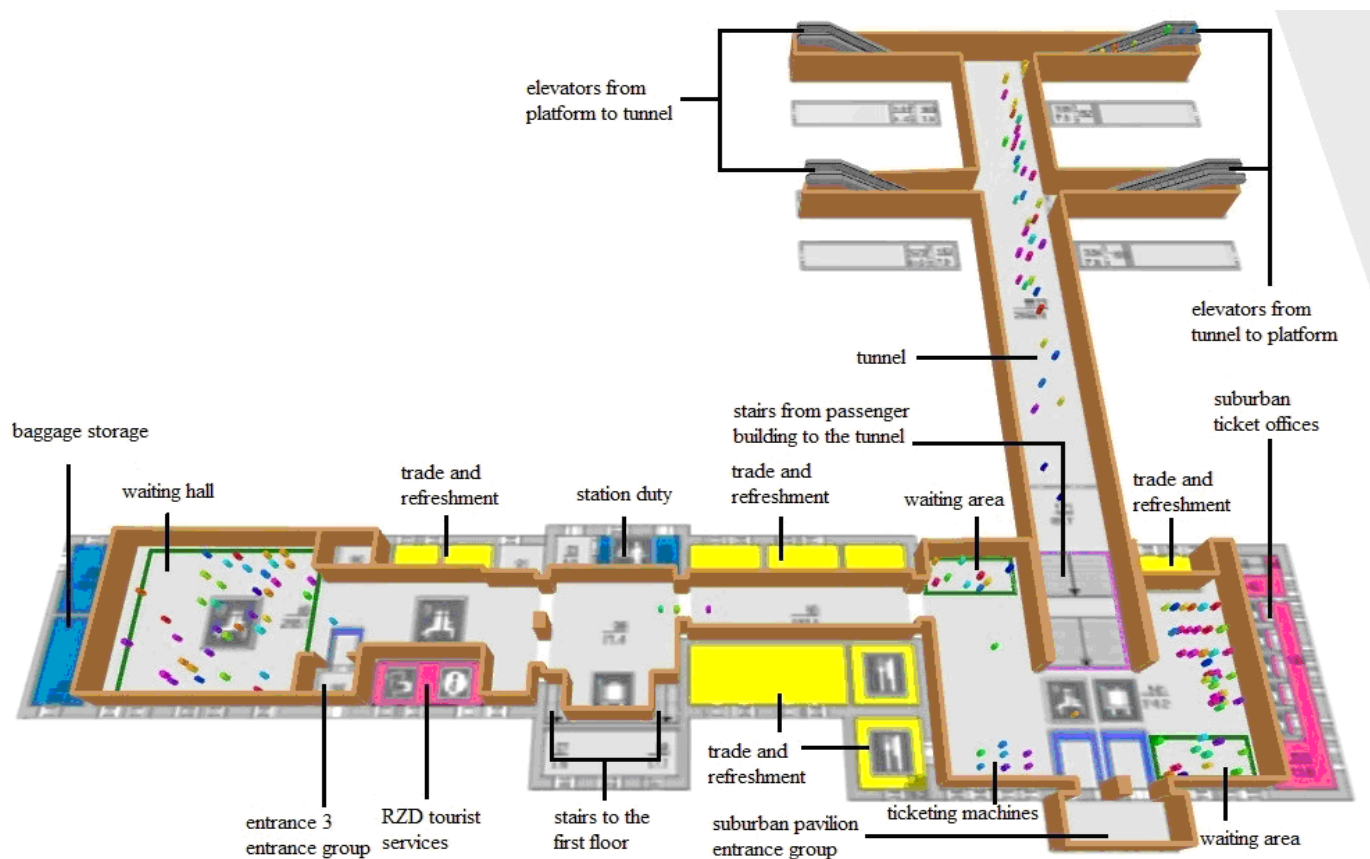


Fig. 3. The results of modelling for a rationalized version of the planning solution of hub “Irkutsk – Passenger”

Analysis of passenger flow management efficiency at the TIH

The following algorithm is proposed for analysing the efficiency of passenger traffic flows in the TIH:

1) Based on a scaled diagram for the TIH and its adjacent territories, a graph of transport links is drawn, in which the following points are marked:

- The main points of passenger interest (vertices of the graph) composing the array $p \in [1, 2, \dots, P]$. The points of interest are the entrances and exits of the main transport communications (underground, stops of urban street and off-street transport, entrances, and exits of the VC in question, parking spaces for private cars and equipped parking spaces for individual mobility vehicles);

- the transport connectivity edges of the points of interest (graph edges) comprising the array $e \in [1, 2, \dots, E]$. Transport connectivity edges connect vertices p if there is a physical possibility to pass between the points under consideration. Transport connectivity edges can be mono-directional and two-way connectivity edges. Mono-directional edges are formed in case of one-way movement with passenger traffic from vertex p_i to vertex p_j , bidirectional edges are formed in case of unimpeded access from point p_i to point p_j and from point p_j to point p_i .

The graph of transport links for the Belorusskaya TPU, including interchanges between all the most common modes of urban transport in Moscow (suburban electric trains, MCD, metro, bus, tram) is shown in Figure 4.

In the presented graph the vertices of the array are marked, their total number was $|P|=47$, the edges of the graph whose number was $|E|=54$, the monodirectional edges are marked with colour (red for incoming traffic and purple for outgoing traffic) and an arrow that denotes the direction of traffic.

2) To analyse the graph and obtain quantitative indicators of TPU connectivity, it is necessary to construct 6 matrices – $a, b, c^{\wedge}, c^{\vee}, d, f$, which show

a) a – initial matrix of passenger transit times from point p_i to point p_j , dimension $P \times P$, each element of which, denoted by $a_{(p_i;p_j)}$, takes values of passenger walking time between considered graph vertices, min.

If $i=j$, $a_{(p_i;p_j)}=0$, if there is no edge e between vertices p_i and p_j , $a_{(p_i;p_j)}=\infty$, in all other cases $a_{(p_i;p_j)}$ takes value:

$$a_{(p_i;p_j)} = l_{(p_i;p_j)} / v_{cp} \quad (1)$$

where $l_{(p_i;p_j)}$ is the reduced distance between the considered vertices p_i and p_j , km; v_{cp} – average walking speed of a passenger, km/h.

The general view of the matrix a is given in Table 1.

Table 1

General view of the travel time matrix a

	p_1	p_2	...	$p-1$	p
p_1	$a_{1;1}$	$a_{1;2}$	...	$a_{1;p-1}$	$a_{1;p}$
p_2	$a_{2;1}$	$a_{2;2}$	...	$a_{2;p-1}$	$a_{2;p}$
...	...	...	...	...	...
$p-1$	$a_{p-1;1}$	$a_{p-1;2}$	...	$a_{p-1;p-1}$	$a_{p-1;p}$
p	$a_{p;1}$	$a_{p;2}$	...	$a_{p;p-1}$	$a_{p;p}$

b) b is a matrix for the passenger's destination from point p_i to point p_j , each element of which, denoted by $b_{(p_i;p_j)}=j$, is a source matrix for construction the matrix d .

A fragment for matrix b is shown in Table 2.

Table 2

Fragment filling in the assignment matrix b

	p_1	p_2	...	$p-1$	p
p_1	1	2	...	$p-1$	p
p_2	1	2	...	$p-1$	p
...	...	...	...	...	...
$p-1$	1	2	...	$p-1$	p
p	1	2	...	$p-1$	p

c) $c^{\wedge}$ is a graph incidence matrix for the incoming stream, which specifies links between incident vertices p of the graph. It has dimension $P \times E$, where P are matrix rows and E are columns. Each element, denoted by $[c^{\wedge}]_{(p_i;p_j)}$, takes values $[c^{\wedge}]_{(p_i;p_j)} \in [0;1]$, where value 0 is assigned in case of no connection between the vertex and the edge in question and value 1 in case it exists. The $c^{\wedge}$ matrix considers only bidirectional edges and monodirectional edges oriented towards the TIH input.

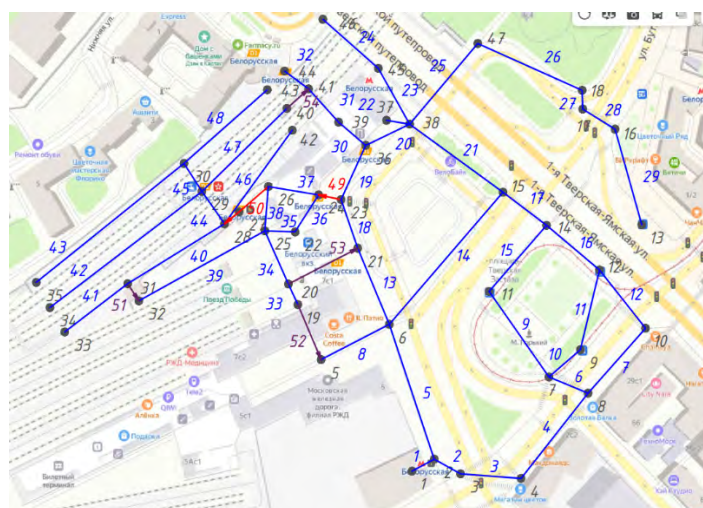


Fig. 4. Transport connectivity graph of the Belorusskaya TIH on the topographical map

A fragment of the incidence matrix $c^{\wedge}$ constructed for suburban passenger platforms at Belorussky Railway Station ($P \in [28, 29, 30, 31, 33, 34, 35, 40, 42, 43]$; $E \in [40, 41, 42, 43, 44, 45, 46, 47, 48]$) is given in Table 3.

d) $c^{\vee}$ is the graph incidence matrix for the output stream. It is compiled similarly to $c^{\wedge}$ matrix, provided that only bidirectional edges and monodirectional ones oriented towards exiting TIH are taken into account.

e) d – general matrix of passenger transit times. Obtained in the course of transformations of initial matrices a and b by Floyd-Worschell algorithm [6, 7]. Thus, for the given task of determining the shortest routes for connecting points of the resulting graph, the transformations should be performed according to the following principle:

- To transform initial matrices of times a and assignments b , auxiliary constructions are performed to check the possibility to reduce travel time by changing the route (via point p_k), then

$k \in [1...P]$ auxiliary constructions should be performed. The scheme of possible change of the route is shown in Figure 5.

Table 3

Fragment $c^{\wedge}$ incidence matrix constructed for suburban platforms at Belorussky station

$P \backslash E$		...	40	41	42	43	44	45	46	47	48	...
...		...	...	...	...	...	...	...	...	...	...	...
28		...	1	0	0	0	1	0	1	0	0	...
29		...	0	0	1	0	1	1	0	0	0	...
30		...	0	0	0	1	0	1	0	1	1	...
31		...	1	1	0	0	0	0	0	0	0	...
...		...	...	...	...	...	...	...	...	...	...	...
33		...	0	1	0	0	0	0	0	0	0	...
34		...	0	0	1	0	0	0	0	0	0	...
35		...	0	0	0	1	0	0	0	0	0	...
...		...	...	...	...	...	...	...	...	...	...	...
40		...	0	0	0	0	0	0	0	1	0	...
...		...	...	...	...	...	...	...	...	...	...	...
42		...	0	0	0	0	0	0	1	0	0	...
43		...	0	0	0	0	0	0	0	0	1	...
...		...	...	...	...	...	...	...	...	...	...	...

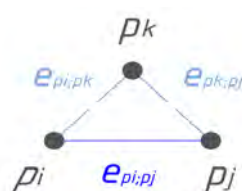


Fig. 5. Diagram of analytical transformations

Then at each auxiliary construction, a logical check of the condition is performed for each element of the sequence time and assignment matrices:

If $a_{(p_i; p_j)} > a_{(p_i; p_k)} + a_{(p_k; p_j)}$, then $a_{(p_i; p_j)} = a_{(p_i; p_k)} + a_{(p_k; p_j)}$; $b_{(p_i; p_j)} = b_{(p_i; p_k)} + b_{(p_k; p_j)}$ (2)

– With all auxiliary constructions, the resulting matrix and is the required matrix d , which denotes the travel times from any point in graph p_i to any point in graph p_j .

(f) f is a connectivity (adjacency) matrix for graph edges, each element of which, denoted by $f_{(p_i; p_j)}$, takes the value of the number the edges from i vertex of the graph to j .

Conclusion

The severity of the transport problem of cities, of course, requires effective digital technologies for predicting the transport situation and means of integrated design of transport systems. In this regard, it is the simulation models that make it possible to adequately reflect the entire complexity of the interaction of complex transport systems and systems of demand for transportation, to assess the influence of various factors on the dynamics

of processes. Experiments with simulation models allow us to evaluate the effectiveness and consequences of various decisions, to get an in-depth understanding of the nature of the interaction of elements and processes of the system, are of great predictive value.

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МОДЕЛИРОВАНИЕ ПЕРЕМЕЩЕНИЯ ПАССАЖИРОПОТОКОВ И ОПТИМИЗАЦИЯ ПАРАМЕТРОВ КОММУНИКАЦИОННЫХ ПУТЕЙ

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Аннотация

Среди проблем крупных городов и агломераций одна из важнейших - транспортная проблема, которая по мере роста городов приобретает все более острый социальный и макроэкономический характер. Транспортно-пересадочные узлы (ТПУ) являются важными структурными элементами транспортной сети города. Они представляют собой сложные комплексные объекты, выполняющие разнообразные социальные функции. Территориальная организация ТПУ должна базироваться на основе нормативов и рекомендаций, учитывающих многофункциональность транспортных сооружений. Градостроительные решения, в частности, по транспортно-планировочной организации ТПУ в настоящее время принимаются без наличия научно обоснованной нормативной базы проектирования таких объектов. При этом недостаточно полно учитывается комплексное влияние различных транспортно-планировочных, социальных и других факторов. Одним из наиболее важных факторов определяющих технико-технологическую структуру ТПУ является пассажиропоток. Особенно это важно, когда ТПУ формируются на пригородном направлении в зоне тяготения пригородного пассажиропотока. В связи с этим возникает необходимость проводить исследования по изучению функционирования ТПУ, закономерностей перемещения пассажиров. В данной работе рассмотрена проблема моделирования пассажиропотоков на объектах пассажирской транспортной инфраструктуры, выявлены закономерности формирования и продвижения пассажиропотоков в ТПУ, приведены полученные с использованием имитационной модели зависимости между основными параметрами перемещения пассажиропотоков в ТПУ.

Ключевые слова: пассажиропотоки, оптимизация, модель, AnyLogic, транспортно-пересадочный узел.

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