Calculation of service devices in the projected traffic-transfer hub

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Abstract. The object of the work is the projected traffic-transfer hub (TTH) in the area of station B. Based on the passenger flows between all modes of transport present in the transport hub, the parameters of service devices are determined by simulation modeling. The obtained data will allow organizing the necessary capacity of the hub during "peak hours", at the same time during the period of decreasing passenger traffic flow there will be no significant idle time of the passenger devices. Based on the data obtained, technical and economic comparison of options for equipping the transport hub with service devices was made, as a outcome of which the most optimal number of devices was identified.

1 Introduction

The priority direction of development of the transport system of St. Petersburg and the Leningrad Region until 2030 is to improve the quality of transport services to the population. It must meet modern requirements of safety, accessibility, comfort, efficiency, and environmental friendliness. This problem is urgent, taking into account the high rate of population growth in the St. Petersburg agglomeration.

It should be noted that during the last ten years there has been a significant growth of motor vehicles on the roads of the Russian Federation, including St. Petersburg and the Leningrad region. This is due to a large number of car offers on the market. In this regard, a significant number of people have the opportunity to buy a vehicle, and this in turn leads to a sharp decrease in the capacity of the road network. The outcome is the appearance of traffic jams on the roads, which creates obstacles to the movement of passengers [1].

There are two ways to solve this problem.

1. Increasing the capacity of the transportation system. This includes designing new roads, widening existing ones, and creating new parking spaces.
2. Preference for public transport over personal transport.

In the first case, the solution is unpromising due to the subsequent increase in demand for cars after the increase in infrastructure capacity. At the same time, colossal funding will be needed for the construction and repair of roads, and the statistics of accidents associated with numerous road accidents will go up, and the environment will suffer greatly [2].

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In the second scenario, the flow of vehicles will decrease due to the preference of some urban passengers for public transport over private ones. To increase the flow of passengers on public transport it is necessary to ensure a safe, comfortable, and fast trip by using innovative rolling stock, as well as to build an infrastructure that allows unimpeded transfer from one mode of transport to another. To this end, traffic-transfer hub, TTH are being designed.

To take into account such aspects as the flow of passengers and their transfer times, it is advisable to apply a simulation of traffic flows. Modeling is a process of systems research, which is used to identify its patterns and properties, for further development of recommendations to improve the existing or design a new system. The outcome of modeling is a model, which can be deterministic or stochastic.

Transport systems or traffic flows are most appropriately studied by simulation modeling, which allows the implementation of computational experiments and does not resort to the use of natural due to safety or costliness.

This problem has been considered by various specialists in foreign sources. [3-9]

The purpose of this work is to make calculations of the main parameters of the designed TTH by simulating its operation.

2 The order of building a simulation model of the transport hub

To implement the TTH simulation modeling process in Any Logic, a simulation model was built.

To build the simulation model in Any Logic, the pedestrian library was used because it makes it possible to implement processes where a single passenger is marked with a model unit that moves along a given path and is named Agent, so it is possible to monitor the movement of an individual pedestrian and collect data about his total transfer time. Blocks with the names redSource and redSink, respectively, are responsible for the start and end points of the pedestrian path. The first block allows you to enter parameters such as the nature of the arrival of pedestrians, as well as the speed of their movement along the entire path, which is set by the block redGoTo. If the pedestrians need to pass any service device, such as the primary inspection, the purchase of travel documents at ticket offices or vending machines, then for the parameters of the above devices, such as the number of queues, the intensity of service, the choice of the pedestrian queue is responsible block redService, which is placed before the block redGoTo. It determines the passenger service time according to the law of uniform distribution. It was found using timing observations. This time is shown in Table 1.

Table 1. Passenger service time

Servicing device	Minimum service time, s	Maximum service time, s
Frames of metal detectors	1,0	2,0
Ticket offices	20,0	30,0
BPA	10,0	15,0
Turnstiles at the entrance	3,0	5,0
Exit turnstiles	0,8	1,3
Elevators for MGH	7,0	8,0

When pedestrians move through devices to increase their speed, such as travellators or escalators, the parameters of their functioning are determined by the movement between the target lines crossed by pedestrians. This looks like the disappearance of pedestrians in one target line and their appearance in another, which realizes the increase in the speed of their movement in a particular section. Because the speed of movement of passengers is given by the law of uniform distribution and varies from 1.1 to 1.3 m/s, the speed of escalators in their projection on the horizontal plane takes 0.75 m/s and travellators-2 m/s.

The arrival of passengers exiting the platforms of urban and suburban electric trains is defined relative to the arrival schedule of these electric trains by [10], as well as the population of an individual electric train.

In the process of model building, the process modeling library was also applied, in particular, the TimeMeasureStart and Time MeasureEnd blocks were applied, with the help of which it is possible to determine the passage time of pedestrians on a particular section of their way. Passenger passage times for service devices (excluding escalators, moving walkways, and elevators for MSM) were measured, as well as passage times from the target lines of passenger traffic origination to the transfer lines for subway, city, and suburban electric trains. The final target line for measuring transfer times to suburban trains was the platform farthest from the pedestrian tunnel.

Based on the measured target values, the diagrams of the density distribution of passengers over time were constructed. The order in which the diagram is built is shown in Figure 1.

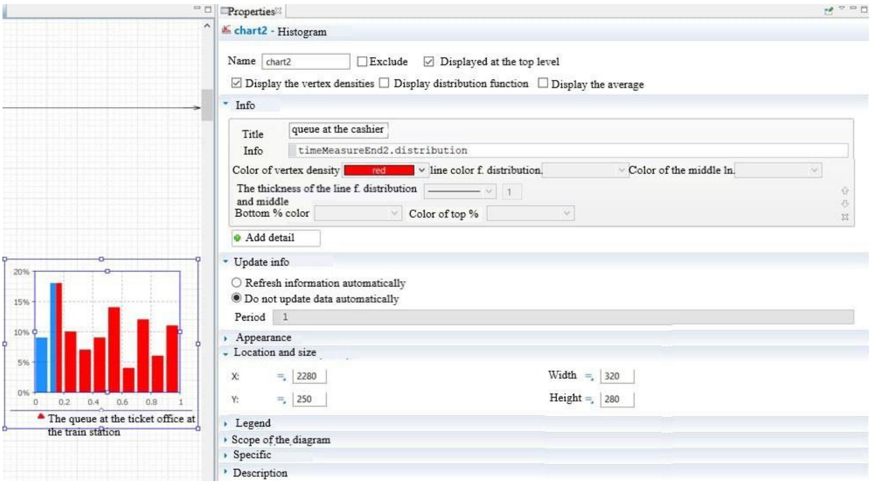

Fig. 1. Construct a distribution density diagram.

3 Calculation of savings in capital costs and operating costs associated with maintenance devices

In the process of constructing a transfer hub, capital investment should be minimized, including the provision of service equipment. At the same time, its throughput capacity should not be reduced, otherwise, there is a potential for congestion, such as when pedestrians enter the station building or lobby, purchase fare documents at the ticket office or BPA, and move through the turnstiles.

The optimal number of service devices was determined using simulation modeling, taking into account passenger flows and passenger passage time of a single device. The design scheme of the TTH was chosen as the basis, and after the simulation model was completed, the number of service devices was calculated on its basis.

The cost of turnstiles, ticket booths, and BPAs are shown in Table 2.

Table 2. Cost of service devices in 2018 prices excluding VAT

Product name	**Price excluding VAT, rub.**
Reversible luggage/passenger turnstile	1188,9
"Ticket-cashier workstation" with "Prim 08F" control and cash machine	100,9
Self-service terminal "Is-kra-201P" with KKM Prim-21F	280,2
Self-service terminal "MGG-01" with KKM Prim-21F (for low-mobile passengers)	288,1

Because this cost-of-service device in Table 1 is presented in 2018 prices, it is necessary to determine the inflation factor to translate it into 2021 prices. To find the k_{inf} coefficient we will use the formula 1.

$$k_{inf} = \prod_{i=n}^{m-1} \left(1 + \frac{u_i}{100}\right). \quad (1)$$

where n–the year in whose prices the original cost is stated;
m–current year;
u_i–the value of inflation rate in the i-th year, %.

With the given initial conditions as part of the k_{inf} coefficient, we define inflation for the period from 2018 to 2021. The magnitude of inflation in these years, according to [11], is presented in Table 3.

Table 3. Inflation in the Russian Federation in 2018-2021.

The Year	2018	2019	2020
Inflation rate, %	4,27	3,05	4,91

The value of the inflation coefficient is found by formula 1 [12]:

$$k_{inf} = \left(1 + \frac{4{,}27}{100}\right) \cdot \left(1 + \frac{3{,}05}{100}\right) \cdot \left(1 + \frac{4{,}91}{100}\right) \approx 1{,}13$$

After the calculation, we can get the cost of service devices in prices of 2021, including VAT according to formula 2.

$$C_k = C_{\text{н}} \cdot k_{inf} \cdot 1{,}2, \quad (2)$$

Where $C_{\text{н}}$–initial prices in 2018, thousand rubles;
1,2–VAT rate;

The cost of service devices in 2021 prices, including VAT, is shown in Table 4.

Table 4. Cost of service devices in 2021 prices, including VAT

Product name	**Price excluding VAT, rub.**
Reversible luggage/passenger turnstile	1612,1
"Ticket-cashier workstation" with "Prim 08F" control and cash machine	136,8
Self-service terminal "Is-kra-201P" with KKM Prim-21F	380,0
Self-service terminal "MGG-01" with KKM Prim-21F (for low-mobile passengers)	390,7

Determination of the annual operating costs of the ticket offices is based on the average monthly salary of a ticket cashier, which is 28182 rubles in St. Petersburg [13], the shift work ratio corresponding to the value of 4.5 since ticket offices don't work every day from 00:00 to 04:00, the tax rate for payroll and the cost of annual maintenance of the premises, which is 10% of the capital costs of its equipment, which is 136711.92 rubles.

Annual operating costs for the maintenance of one ticket office are determined by formula 3.

$$C_{к} = (\alpha \cdot 12 \cdot k_{с}) \cdot 1{,}304 + 0{,}1 \cdot K_{з}, \quad (3)$$

where α–average monthly salary of a ticket cashier, thousand rubles/month.;
12–the number of months in a year;
$k_с$–shift rate;
1,304–payroll tax rate;
Kз-capital costs for the ticket office equipment, thousand rubles.
$C_{к} = (28{,}182 \cdot 12 \cdot 4{,}5) \cdot 1{,}304 + 0{,}1 \cdot 136{,}8$ = 19965,7 thousand rubles/year.

Due to the fact that the cash register premises not used for their intended purpose can be used to obtain income from their rent, let us find it over the annual period according to formula 4:

$$D_{month} \cdot S \cdot 12 - 0{,}02 \cdot C \cdot S, \quad (4)$$

Where D_{month}–cost of rent of commercial premises, thus. rub/month.;
S–sales area, m^2;
12–number of months in a year;
0,02–annual tax rate for the lease of commercial premises relative to their cadastral value [14];
C–cadastral value of the premises, thousand rubles.

The rental cost is determined by the average market in St. Petersburg, which is 1.9 thousand rubles/m2 [15].

Since there is no information about the cost of the construction of the station and its operating costs, let's determine the cadastral value similar to the average market value in St. Petersburg. It is equal to 183.3 rubles/m2 [16].

The area of retail space is determined by the design drawings, it is 7.0 m^2 [17].
P_{year} = $1{,}9 \cdot 7 \cdot 12 - 0{,}02 \cdot 183{,}3 \cdot 7 = 129{,}1$ thousand rubles/year.

To find the annual operating costs in the case of reducing ticket offices, apply formula 5.

$$E_k = n_{pr} \cdot C_k - (n_{start} - n_{pr}) \cdot P_{year}, \quad (5)$$

where n_{pr}–the accepted number of ticket booths, pcs;
n_{pr}–initial number of ticket offices, pcs.

Table 16 shows the initially accepted number of devices.

As a outcome of the changes made based on the outcomes of simulation modeling, the number of service devices has changed relative to the original design option. It is shown in Table 3.

Table 5. Number of service devices in the original project.

Product name	**Quantity, pcs.**	**Capital expenditures, thousand**	**Annual operating costs, thousand rubs. /year**	**Total capital costs, thousand rubles.**	**Total annual operating costs, thousand rubles/year**
Inspection equipment	4	621,6 [18]	62,2	2486,4	248,7
Ticket offices	3	136,8	1998,2	410,2	5994,5
BPA	8	380,0	36,0 [19]	3039,7	288,0
BPA for MGH	2	390,7	36,0 [19]	781,4	72,0
Turnstiles	28	1612,1	42,0 [20]	45138,4	1176,0
Escalators	16	2584,6 [21]	120,5 [15]	41352,4	1928,0
Travellators	2	13486,1 [21]	628,8 [22]	26972,2,0	1257,5
Stairs	12	232,3 [23]	23,3	2787,1	278,8
Elevators for the handicapped	9	1440,0 [24]	48,2 [25]	12960,0	433,8
Total	84	20883,9	2995,0	135927,4	11677,0

Table 6. Number of service devices obtained from the simulation.

Product name	**Quantity, pcs.**	**Capital expenditures, thousand**	**Annual operating costs, thousand rubs. /year**	**Total capital expenditures, thousand rubles**	**Total annual operating costs, thousand rubles/year**
Inspection equipment	4	621,6	62,2	2486,4	248,7
Ticket offices	2	136,8	1998,2	273,5	3609,1
BPA	5	380,0	36,0	1899,8	180,0
BPA for MGH	1	390,7	36,0	390,7	36,0
Turnstiles	17	1612,1	42,0	27405,5	714,0
Escalators	13	2584,6	120,5	33598,8	1566,5
Translators	2	13486,1	628,8	26972,2	1257,5
Stairs	11	232,3	23,3	2554,9	255,5
Elevators for the handicapped	9	1440,0	48,2	12960,0	433,8
Total	64	20883,9	2995,0	108541,5	8300,9

It is necessary to find the present annual cost of equipment by service devices for the original and adopted options by formula 6.

$$E_k = K \cdot E_h + C, \tag{6}$$

Where K–capital expenditures on servicing devices, thousand;
E_h–coefficient of capital investments efficiency, thousand rubs. /year;
C–annual operating costs for maintenance devices, thousand

The coefficient of capital efficiency is the value inverse of the normative payback period of investment, which is taken equal to 10 years. The capital efficiency coefficient is determined by formula 7.

$$E_{н} = \frac{1}{Т_{ок}}, \quad (7)$$

where $Т_{ок}$-normative payback period of investment, years.

$$E_{н} = \frac{1}{10} = 0{,}1.$$

Next, we calculate the present finished costs using formula 12.

According to the original version:

$E_{pr1} = 135927{,}4 \cdot 0{,}1 + 11677{,}0$ = 25269,7 thousand rubles/year.

According to the adopted option:

$E_{pr2} = 108541{,}5 \cdot 0{,}1 + 8300{,}9$ = 19155,1 thousand rubles/year.

Savings achieved as a outcome of the adopted design solutions; we determine by formula 8.

$$E_{pr} = E_{pr1} - E_{pr2} \quad (8)$$

$E_{pr} = 25269{,}7 - 19155{,}1$ = 6114,6 thousand rubles/year.

By simulating the operation of the TIH, the number of designed service facilities has been reduced. In this case, the speed of passenger transfer does not change relative to the original variant, because there is a reserve of capacity, as a outcome of which the TIU functions properly, but the economic efficiency of the project increases significantly.

Thus, the savings of reduced costs amounted to 6114.7 thousand rubles/year.

It should be noted that when carrying out technical and economic calculations, it is possible, in addition to simulation modeling, to use the tools and methods of the theory of terminality, logistics, situational, and process management [26-30].

4 Calculation of economic efficiency of replacing the ticket office with a ticket-printing machine

For the convenience of passenger service and economic efficiency, it was decided instead of a fine ticket office in the station building to place a fine BPA in one of the distribution halls of the pedestrian tunnel and to rent out the room designed for the fine ticket office. In this case, the economic efficiency of such a solution will consist of savings from the replacement of the ticket office with the BPA, as well as from the profit from the lease.

Savings of annual present value costs from the replacement of the cash register on the machine we will find by formula 9.

$$E_k = (K_k \cdot E_h + C_k) - (K_b \cdot E_h + C_b), \quad (9)$$

where $K_к$–capital expenditures for the equipment of the cash register;
$C_к$–annual operating expenses for the maintenance of the cash register;
K_b– capital investment for the installation of BPAs;
C_b– annual maintenance costs of the BPA.

$E_3 = (136{,}8 \cdot 0{,}1 + 1998{,}2) - (380{,}0 \cdot 0{,}1 + 36{,}0)$= 1937,9 thousand rubles/year.

The rental income during the year is determined by formula 9.

The area of retail space is determined by the design drawings, it is 11.9 m^2.

P_{year} = $1{,}9 \cdot 11{,}9 \cdot 12 - 1{,}02 \cdot 183{,}3 \cdot 12 = 219{,}5$ thousand rubles/year.

The full cost-effectiveness of such a solution is found by formula 11.

$$E_p = E_3 + P_{year} \tag{10}$$

$E_p = 1937{,}9 + 219{,}5 = 2157{,}3$ thousand rubles/year.

Thus, as a outcome of replacing the penalty ticket office, BPA's economic efficiency will be 1938.3 rubles per year.

The total cost savings achieved as a outcome of the design solutions; we determine by formula 12.

$$E = E_{pr} + E_3 \tag{11}$$

$E = E_{pr} + E_3$ = 8271,9 thousand rubles.

5 Calculation of the social and economic effects of the full implementation of electronic travel documents

The economic efficiency can be increased through the purchase of electronic travel documents by passengers and fare payment with the possibility of bypassing ticket offices and BPA, which leads to a reduction in the total transfer time and saves time that the passenger could use as a worker. In the original version of the model, it is assumed that 6% of the incoming passenger flow to suburban electric trains goes through ticket offices and 39% through BPAs. The average monthly salary in St. Petersburg is 45572 rubles, the service time in the ticket office is roughly 25 seconds and the BPA -12 seconds. Using these data, let us calculate the financial efficiency of the full use of electronic travel documents by passengers.

According to Table 10, given in Section 3 of this thesis project, we take the average passenger flow during peak hours to be 1,251 people per hour, and the coefficient of daily irregularity of the passenger flow is 1.67, according to the expert method. The average passenger flow per day α through the TPO will be equal:

$$P_{day} = \frac{P_{month}}{a} \tag{12}$$

where P_{month}–the estimated passenger flow in the "rush hour";
a –coefficient of daily irregularity.
$P_{day} = \frac{1251}{1{,}67}$ = 750 pass/hour.

The average wage per minute in St. Petersburg can be calculated using formula 13:

$$c_{min} = \frac{c_{month}}{30 \cdot n_v} \tag{13}$$

where c_{month}–average monthly salary in St. Petersburg, rubles;
30–the number of months in a year;
n_v–norm of working time per week, min./month.

$$c_{min} = \frac{45582}{30 \cdot 160} = 9{,}5 \text{ rbl./min.} \tag{14}$$

Savings of working time of the passengers who will receive electronic travel documents and will not be served at the ticket offices and BPA, let's calculate by the formula 15.

$$t_{ek} = P_{day} \cdot P_k \cdot t_k + P_{day} \cdot P_{BPA} \cdot t_{BPA} \tag{15}$$

where $P_К$ and P_{BPA}–the share of passengers, respectively, in ticket offices and BPAs;
$t_К$ and t_{BPA}–passenger service time in ticket offices and BPA, respectively, min.

$$t_{ek} = 750 \cdot 0{,}06 \cdot 25 + 750 \cdot 0{,}39 \cdot 124635 \text{ min./day.}$$

Economic efficiency from the introduction of electronic travel documents is determined by formula 16.

$$E_b = c_{min} \cdot t_{ek} \quad (16)$$

$E_b = 9{,}5 \cdot 4635$= 44032,5 rbl. /day. = 16071,9 thousand rubles/year.

Thus, as a outcome of the use of electronic travel documents by suburban passengers, the socio-economic effect due to the saving of working time will amount to 16071.9 rubles per year.

6 Conclusion

The concept of railway infrastructure development for the organization of suburban and intracity passenger transportation in the St. Petersburg railway hub involves the development of high-speed traffic and the introduction of urban electric trains of two diameters. The activities of the Concept include the reconstruction of station B for commuter electric trains and the construction of passenger facilities at the station, which are part of the TPS.

Based on the existing design materials, a simulation model was built in AnyLogic. The advantage of building a simulation model over analytical calculations is that its structure can be easily changed and the TTH operation of almost any complexity can be simulated. The disadvantage, however, is that to analyze statistical data to determine ouTTHt values that are close to the numerical characteristics of analytical calculations with a high degree of accuracy, an electronic computing machine is required, as well as the skills of working in AnyLogic. But these disadvantages can be eliminated.

In the course of this work, by simulating the operation of the designed TTH, the economic costs of equipping the TTH with service devices and their annual maintenance were determined.

Based on the outcomes of the analysis of simulation experiments, it was found that the current throughput and transfer times do not meet the required values, as a outcome of which it was decided to separate passenger flows by specializing the distribution halls for boarding and unloading, and it was also decided to eliminate the turnstile lines for checking travel documents in the station building and perform these actions only in the distribution halls. As a outcome, it was possible to achieve a 25% increase in throughput capacity, while reducing the number of service devices from 84 to 64.

By making changes in the specialization and placement of service devices, as well as by simulating the TTH operation using simulation modeling, it was possible to achieve annual cost savings of 8.3 million rubles/year, as well as a socio-economic effect of 16.1 million rubles/year.

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