Improvement of the system of transport-transfer hubs on the example of St. Petersburg agglomeration

M. Gorbunova¹* and A. Novichikhin¹

¹St. Petersburg State University of Railway Transport of Emperor Alexander I, 9 Moskovsky pr., 190031, St. Petersburg, Russia

Abstract. The article proposes a conceptual framework with empirical foundations, prerequisites, theoretical foundations and implementation, and validity criteria. It also presents methods to improve transport and interchange hubs on the example of the St. Petersburg agglomeration, aimed at improving the efficiency of hubs operation, developing infrastructure and stations, improving the capacity of the transport network, achieving uniform loading system and traffic safety, increasing the attractiveness of rail transport for the population, increasing the index of passenger satisfaction. The analytical review of normative documents, theoretical provisions, programs and measures, carried out and planned for implementation for the development of St.-Petersburg railway junction has been made. The existing models of transport-transfer hubs in the St.-Petersburg agglomeration were investigated and the directions for their improvement were revealed by creating the concept. On the basis of the proposed synergistic-logistic concept, the provisions to ensure the improvement of transport-transfer hubs (on the example of the St. Petersburg agglomeration) have been developed. Keywords: transport-transfer hub, agglomeration, passenger transportation, subway, rail and surface transport, concept.

1 Introduction

The concept [1] with implementation until 2030 is the basis for the formation of an integrated approach to the development of the St. Petersburg agglomeration, which is expressed in providing a safe and convenient unified transport network for city residents, taking into account the provision of passenger transfers between different types of transport.

The urgency of the topic of the research is conditioned by active development and expansion of Saint-Petersburg agglomeration at the expense of new building up of city zones which will lead to population mobility growth, increase of load on the transport system of the city and necessity of development of logistic systems.

A transport and transfer hub (TPU) is one of the main elements of the urban public transport system, consisting of a complex of real estate objects, designed for safe and comfortable passenger service, which provides redistribution of passenger flows between
different modes of transport and traffic directions.

The most important factor in the use of the TPU is the quality of user service. It is determined by a combination of the following indicators [2]:
- quality of basic infrastructure;
- spatial integration (average distance between platforms and average transfer time);
- accessibility for people with limited mobility;
- ease of orientation in space;
- personal safety;
- safety of traffic;
- informative;
- additional facilities for passengers.

Modern provisions and aspects of transport system elements are considered in national studies [3-14]. In order to solve intra-nodal transport problems in organizing and coordinating the work of all types of transport in the TPU, it is proposed to consider the logistical management of passenger flows in the node, ensuring a high level of passenger service, as well as their reliable, safe and continuous "seamless" movement.

2 Materials and methods

As an example, let's consider the location of the current TPU in St. Petersburg. Figure 1 shows the scheme of St. Petersburg with the marked existing transport hubs.

St. Petersburg's transportation infrastructure consists of the following elements - subway, railroad, streetcar, trolleybus, bus, cab, personal car, "carsharing", commercial transport, bicycle. From this list, we can distinguish the main types of TPU according to their intersection with modes of transport:
1. Subway + railroad + ground mode of transport;
2. Subway + ground mode of transport (bus stations);
3. Railroad + ground mode of transport.

Based on Figure 1, Table 1 was formed, and the TPU were selected by type of subway + rail + ground mode of transport and subway + ground mode of transport.

Table 1. Existing TPU with subway crossings in the St. Petersburg agglomeration.

<table>
<thead>
<tr>
<th>Name</th>
<th>Types of transport</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Subway</td>
</tr>
<tr>
<td>Devyatkin</td>
<td>+</td>
</tr>
<tr>
<td>Finlyandsky railway station</td>
<td>+</td>
</tr>
<tr>
<td>Moskovsky railway station</td>
<td>+</td>
</tr>
<tr>
<td>Vitebsky railway station</td>
<td>+</td>
</tr>
<tr>
<td>Baltiysky railway station</td>
<td>+</td>
</tr>
<tr>
<td>Parnas</td>
<td>+</td>
</tr>
<tr>
<td>Udelnaya</td>
<td>+</td>
</tr>
<tr>
<td>Moskovskaya</td>
<td>+</td>
</tr>
<tr>
<td>Kupchino</td>
<td>+</td>
</tr>
<tr>
<td>Staraya Derevnya</td>
<td>+</td>
</tr>
<tr>
<td>Obvodny Kanal</td>
<td>+</td>
</tr>
<tr>
<td>Obukhovo</td>
<td>+</td>
</tr>
<tr>
<td>Rybatskoye</td>
<td>+</td>
</tr>
<tr>
<td>Ladozhsky railway station</td>
<td>+</td>
</tr>
</tbody>
</table>
The most important factor in the use of the TPU is the quality of user service. It is determined by a combination of the following indicators:

1. Quality of basic infrastructure;
2. Spatial integration (average distance between platforms and average transfer time);
3. Accessibility for people with limited mobility;
4. Ease of orientation in space;
5. Personal safety;
6. Safety of traffic;
7. Informative;
8. Additional facilities for passengers.

Modern provisions and aspects of transport system elements are considered in national studies [3-14]. In order to solve intra-nodal transport problems in organizing and coordinating the work of all types of transport in the TPU, it is proposed to consider the logistical management of passenger flows in the node, ensuring a high level of passenger service, as well as their reliable, safe and continuous “seamless” movement.

### Materials and methods

As an example, let’s consider the location of the current TPU in St. Petersburg. Figure 1 shows the scheme of St. Petersburg with the marked existing transport hubs.

St. Petersburg’s transportation infrastructure consists of the following elements: subway, railroad, streetcar, trolleybus, bus, cab, personal car, “carsharing”, commercial transport, bicycle. From this list, we can distinguish the main types of TPU according to their intersection with modes of transport:

1. Subway + railroad + ground mode of transport;
2. Subway + ground mode of transport (bus stations);
3. Railroad + ground mode of transport.

Based on Figure 1, Table 1 was formed, and the TPU were selected by type of subway + railroad + ground mode of transport and subway + ground mode of transport.

#### Table 1. Existing TPU with subway crossings in the St. Petersburg agglomeration.

<table>
<thead>
<tr>
<th>Name</th>
<th>Types of transport</th>
<th>Subway</th>
<th>Bus</th>
<th>Railroad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Devyatkino</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Finlyandsky Railway Station</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Moskovsky Railway Station</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitebsky Railway Station</td>
<td>+</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baltiysky Railway Station</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parnas</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Udel’naya</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kupchino</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Staraya Derevnya</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obvodny Kanal</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ladozhskaya Railway Station</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. Existing transport-transfer hubs in the St. Petersburg agglomeration.

To determine methods to improve the system of TPU, this paper analyzed passenger traffic by rail, both long-distance and suburban traffic on existing TPU in St. Petersburg for 2015, 2016, 2017, 2018 and 2019 (Figure 2), 2020 and 2021 are not considered, due to the decline in passenger traffic on all modes of transport, as this period of time is a pandemic.
Fig. 2. Passenger traffic by railroad in comparison 2015-2019.

It follows from the data presented on it that over the 5 years from 2015 to 2019 passenger traffic significantly increased at the railway stations Rybatskoye, Ladozhsky, Baltiysky, Finlandsky, Vitebsky and Moskovsky.

There is an increased passenger flow in 2015 compared to 2019 at Devyatkino, Udelnaya, Kupchino, Staraya Derewnya and Obukhovo stations, but despite this fact, the passenger flow has significantly increased over 4 years from 2016 to 2019. In 2016 there was a redistribution of passenger flow from railway to other modes of transport, but passenger flow on railway transport grows every year, therefore, this passenger flow also grows on other modes of transport in TPU.

The current subway network mainly serves radial directions between the outskirts and central districts of the city, and due to the lack of chord and ring lines, the population is not transported via latitudinal connections between the densely populated areas of St. Petersburg's suburbs. The time it takes to travel one way in the subway is 35-40 minutes.

The branch scheme of development of the St. Petersburg subway with the prospect up to 2025 [15], provides a significant expansion of underground lines and construction of infrastructure facilities of the subway, aimed at satisfying the needs of the population.

The functionality of each suburban and intracity rail transport TPU is determined on the basis of three factors: the needs of a particular area, the congestion of the transport network and the needs of passengers.

Based on Figure 1, the presence of the following nodes on the range:
- inter-regional - the TPU where long-distance (external) and suburban passengers are transferred between each other and to other modes of land transport. These TPU are formed on the basis of such railway stations as Moskovsky, Vitebsky, Ladozhsky, Baltiysky and Finlyandsky;
- regional - the TPU, which provide transfer of passengers from suburban railway transport to ground modes of transport and subway. For example, in St. Petersburg these TPU are formed on the basis of Devyatkin, Obukhovo, Rybatskoe and Kupchino subway stations;
- urban - TPU that provide transfer of passengers from ground mode of transport to the subway. For example, in the St. Petersburg agglomeration we can highlight the TPU formed on the basis of subway stations, such as Parnas, Moskovskaya, Obvodny Kanal.

Currently, there are two main types of TPU - planar and multilevel [16]. Historically, the most widespread type of TPU in Russia is the planar one. However, it is more expedient to organize a multilevel TPU. A positive experience of multilevel TPU is presented at Ladozhsky vokzal in St. Petersburg. However, given the high construction costs, such hubs
are implemented only during new construction and reconstruction of existing stations.

In order to organize a comfortable TPU for passengers it is necessary to have intercepting parking lots, where passengers can leave their personal vehicles and transfer to the railway transport, ground or subway. Currently, in the St. Petersburg transport hub there are intercepting parking lots for private vehicles, but not on all of the hubs. For example, as a positive experience is the Moscow railway station, there is no intercepting parking at the railway station Krasnoye Selo.

Thus, the practical experience of using intercepting parking lots as part of transport hubs shows that they become a necessary element of creating a rational transport system in the agglomeration, increase the level of transport services for the population, provide an opportunity to regulate and improve the work of public transport. In addition, they have an impact on the economic development of individual city districts and can themselves be a source of income through an associated range of services. An important factor in the popularity of intercepting parking lots is that they can have a significant impact on the ecological environment of the city, for example, by reducing the amount of pollutants emitted into the atmosphere by intercepting vehicles.

The solutions to the urgent problems of the effective functioning of logistics systems and transport network have been proposed in scientific papers [17-20].

The problem of modern construction and organization of transport flows in the TPU is acutely felt at the busy railway and subway stations - Devyatkin, Kupchino, Rybatskoe, Parnas - due to increasing passenger traffic, load on the unified transport system, thereby logistic systems are not ready to carry out quality work with passengers.

In accordance with the concept [1], by 2030, new diameter railway routes in St. Petersburg D-1 "Beloostrov - Oranienbaum" and D-2 "Toksovo - Gatchina - Varshavskaya" will be launched. Table 2 provides information on the prospective passenger traffic and its structure at the key interchange hubs that are planned to be organized on the new intracity routes.

**Table 2.** Structure of passenger flow by modes of transport at the main transfer stations in 2030, pas/day [1].

<table>
<thead>
<tr>
<th>Name TPU</th>
<th>Total passenger traffic from the TPA to the railway</th>
<th>Subway</th>
<th>Land transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chernaya Rechka</td>
<td>9626</td>
<td>7686</td>
<td>1930</td>
</tr>
<tr>
<td>Staraya Derevnya</td>
<td>5793</td>
<td>4728</td>
<td>1065</td>
</tr>
<tr>
<td>Lesnaya</td>
<td>22784</td>
<td>6285</td>
<td>16499</td>
</tr>
<tr>
<td>Ladozhskaya</td>
<td>65869</td>
<td>34753</td>
<td>31116</td>
</tr>
<tr>
<td>Volkovskaya</td>
<td>18850</td>
<td>15317</td>
<td>3533</td>
</tr>
<tr>
<td>Moskovskaya (Electrosila railway station)</td>
<td>28098</td>
<td>21954</td>
<td>6144</td>
</tr>
<tr>
<td>Bronevaya</td>
<td>23234</td>
<td>20719</td>
<td>2515</td>
</tr>
<tr>
<td>Oranienbaum I</td>
<td>6818</td>
<td>-</td>
<td>6818</td>
</tr>
<tr>
<td>Devyatkin</td>
<td>7372</td>
<td>2179</td>
<td>5193</td>
</tr>
</tbody>
</table>

The greatest load under existing conditions falls on the Ladozhskaya station, where passengers transfer to all modes of transport (Figure 3).
Fig. 3. Comparative analysis of the congestion of the TPU by 2030 with the launch of intracity routes.

Figure 4 shows the layout of new and existing TPU on the planned intracity routes.

Fig. 4. Scheme of the planned TPU at the intersection of suburban routes with the stations of the St. Petersburg subway.

The main methods of developing a system of transport hubs:
1. in new construction of urban transport stations - the formation of TPU, which meet modern planning requirements;
2. cumulative reconstruction of all existing transportation hubs;
3. selective reconstruction of existing hubs, with prioritization of blocks to be reconstructed.

The urgent task in forming new transport hubs and developing the existing ones is to improve the transport situation in large cities and agglomerations, which is aimed at improving the efficiency of passenger transportation, the level of interaction between different types of transport and the quality of passenger services.

In order to improve the system of transport and interchange hubs in the agglomeration of St. Petersburg a concept has been developed (Figure 5).
Fig. 3. Comparative analysis of the congestion of the TPU by 2030 with the launch of intracity routes.

Figure 4 shows the layout of new and existing TPU on the planned intracity routes.

The main methods of developing a system of transport hubs:
1. in new construction of urban transport stations - the formation of TPU, which meet modern planning requirements;
2. cumulative reconstruction of all existing transportation hubs;
3. selective reconstruction of existing hubs, with prioritization of blocks to be reconstructed.

The urgent task in forming new transport hubs and developing the existing ones is to improve the transport situation in large cities and agglomerations, which is aimed at improving the efficiency of passenger transportation, the level of interaction between different types of transport and the quality of passenger services.

In order to improve the system of transport and interchange hubs in the agglomeration of St. Petersburg a concept has been developed (Figure 5).

The presented concept consists of 4 main blocks: empirical foundations and prerequisites, theoretical foundations, implementation and credibility criteria.

These prerequisites lead to the functioning of the TPU at a level that does not meet modern requirements, which leads to the dissatisfaction of the needs of passengers in transportation by rail. The solutions to the above problems are based on the theoretical provisions for improving the system of transport infrastructure specified in the concept.

One of the results of achieving the objectives is a set of indicators to assess the effectiveness of the TPU.

Criteria of reliability of the developed concept:
1. Subjectivity - theoretical foundations aimed at improving the TPU system.
2. Verifiability - results of work, models are possible to compare with existing objects.
3. Reliability - a set of indicators, reflecting changes in the TPU, aimed at improving performance.
4. Consistency - implementation results and changes that do not contradict each other.
5. Interpretability - availability of calculated values.
6. Completeness - effective interaction of all elements of the transport system.

3 Results

On the basis of the proposed concept, it is possible to develop solutions for the improvement of the TPU on the basis of the St. Petersburg agglomeration.

A significant part of the existing TPU has historically been formed on the basis of railway stations as the main type of transport. With the development of other modes of transport, the TPU are beginning to form on the basis of bus stations and subway stations. At the same time, those formed in this way have outdated planning solutions that do not meet modern operating conditions, new requirements and development trends.

When considering the TPU as an element of multimodal transport system of the urban agglomeration it will allow: to reduce time for transferring passengers (which is one of the most important conditions for TPU functioning), thereby reducing total travel time; increase role of rail transport as a part of the route; increase efficiency, coherence and reliability of
TPU in agglomeration; reduce load on single transport system in Saint-Petersburg; improve transport accessibility for city population.

Proposed classification of TPU (using the example of planned TPU in St. Petersburg by 2030):

1. Stop or stopping point of a railway line.
   This point will provide a link adjacent to the railway network of the city districts.
   For the effective functioning and creation of a full-fledged TPU it is necessary to: create stop points of urban passenger transport with integration into the railway infrastructure, organization of climatic protection, installation of underground/ground crosswalks, car and bicycle intercepting parking lots.
   Intercepting parking lots are appropriate in low-urbanized areas, where it is possible to fully meet the demand for the proposed transfer: car - rail, as the quality of the transport solution is primarily determined by the guarantee of service.

2. Railroad + subway.
   This type of TPU is characterized by the organization of additional transportation options, which relieve the nearby TPU and reduce travel time. The increased investment attractiveness of the territories adjacent to the transfer transport hub is caused by pedestrian accessibility.
   It is necessary to create a comfortable transition between the two modes of rail transport with mandatory compliance with the "dry feet" principle.

3. a railway node + a railway/metro line + a subway node. This type of TPU consists of a framework of nodes that determine the generalized accessibility of areas. Each node makes a significant contribution to generalized accessibility and reduces travel time for a significant part of the city.
   It will be necessary to create fast, barrier-free movements between three or more platforms within the control perimeter, respecting the "dry feet" principle.

4. Railway junction/railway line + subway junction/ subway line + socially and economically significant function.
   This type of TPU, in addition to the above-mentioned functions, must provide external large or voluminous passenger traffic with a high level of comfort and aesthetic appeal. This will require an individual solution adapted to the specific task.
   The proposed TPU classification expands the toolkit and confirms the necessary measures for the effective operation of transport and interchange hubs.
   The TPU in combination with unified tickets for different modes of transport is the most important and effective tool for forming a "seamless passenger journey".
   When launching D-1 and D-2 routes, it is necessary to pay special attention to existing hubs, such as Udelnaya, Kupchino, Obukhovo, Rybatskoye, Parnas, which are currently located on radial routes. For more effective delivery of passengers in St. Petersburg on D-1 and D-2 routes it is necessary to improve the transport network on radial routes as well.
   Thus, to improve the transport-transfer hubs on the example of St. Petersburg agglomeration, it is necessary to comply with a set of measures:
   1. organization of pedestrian flows;
   2. organization of traffic flows;
   3. consideration of planning solutions for the needs of the disabled;
   4. organization of transport facilities (intercepting parking lots, parking and turnaround areas, passenger platforms, etc.) in the TPU);
   5. covering boarding platforms with canopies to protect passengers from precipitation;
   6. streamlining of small retail trade facilities in the TPU;
   7. the creation of a spatial and functional relationship between the individual elements of the TPU;
   8. taking into account environmental factors, such as - reducing pollution, noise levels, compliance with sanitary norms;
9. digitalization and innovative and logistic technologies of development.
   The novelty of the proposed measures is the optimization and redistribution of passenger traffic in the agglomeration of St. Petersburg on the basis of logistics models and modern digital methods.

4 Discussion

The paper analyzes the transport-transfer hubs of St. Petersburg agglomeration on a practical example, identifies the problems of modern construction and organization of transport flows in the TPU.

The practical significance of the research increases due to the increasing passenger traffic in the agglomeration. Consequently, scientific solutions in the field of transport interchange hubs improvement will allow not only preserving, but also increasing the efficiency of railway transport and attractiveness for passengers.

The proposed classification of transport interchange hubs by 2030 in St. Petersburg expands the toolkit of transport interchange hubs, which allows solving practical tasks of analyzing and designing transport systems.

This article presents methods for improving the system of transport interchange hubs through theoretical foundations and the conceptual structure of the methodological approach, the implementation of which can be confirmed by validity criteria.

In contrast to the existing measures for the effective functioning of the TPU, the proposed ones are based on logistic models and modern digital methods.

In the future the work on this subject will be continued and will be based on the practical application of the proposed concept, the creation of the conceptual structure of the TPU management system.

Reference

1. The concept for the development of railway infrastructure in order to organize suburban and intercity passenger transportation in the St. Petersburg railway hub (Government of the Leningrad Region and the Board of JSC "Russian Railways", 2020)


15. The sectoral development scheme of the St. Petersburg metro with a perspective up to 2025 approved by the Government of St. Petersburg dated 06/28/2011 No. 836.


