Classification of transport-transfer hubs, taking into account the interaction of modes of transport in cities with million-strong cities

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Abstract. During the period of active urbanization and the strengthening of the connection of large cities with suburban areas, there is a great need to develop transport systems that connect industrial centers with residential areas, gravitating to them. Transport congestion, the development of rapid off-street transport, the growth of agglomerations, the lack of sufficient parking spaces lead to the need to develop public transport, and as a consequence of the development of transport hubs. In the study, by the method of analysis of variance, the selection of factors affecting the development and formation of transport hubs was carried out. Based on the significant factors, a cluster analysis was carried out to identify groups of TIHs in cities with a population of more than 1 million people. The study is conducted on the example of two cities: Voronezh - 1.06 million people, Ufa - 1.13 million people. As a result, a table with the types of transport-transfer hubs on the basis of interacting modes of transport in cities with a population of more than 1 million people is proposed.

Keywords: Transport hubs, cluster analysis, classification, connectivity analysis, interacting modes of transport.

1 Introduction

In the period of active development of urbanization and strengthening of connection of large cities with suburban areas, there is a great need to develop transport systems that connect industrial centers with residential areas, gravitating to them.

The modern stage of urban transport development is characterized by the following features: a) the use of different types of transport with the predominance of individual automobile transport; b) the development of off-street modes of transport; c) the need to strengthen the development of public transport; d) the strengthening of transport links within the agglomeration.

The importance of a particular type of transport in different cities is different and depends on the historical development of the city and its planning features [7].

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As mentioned above, the development of the agglomeration plays a major role in the development of transport. The movement of individual transport within the agglomeration is complicated by the fact that due to a large increase in the level of motorization, the traffic on the main transport arteries increases, which leads to the formation of traffic jams. Also one of the main reasons for the inconvenience of individual transport is the lack of parking space in the areas of attraction.

In this regard, the development of high-speed off-street modes of transport, which will quickly get passengers to their destinations, is required. However, off-street transportation, in most cases, cannot develop enough for passengers to make trips without transferring.

These reasons have led to the need for the development of transfer hubs (hereinafter referred to as TTH). Thanks to the TTH, it is possible to form a sustainable transportation network. The formation of a sustainable transport system is a complex task that requires the implementation of infrastructure projects (construction of city streets and roads, subways, development of urban railroads, etc., etc.) and organizational measures (coordination between modes of transport, the formation of a single parking space, control over the observance of traffic rules, etc., etc.). [4].

In the current federal Code of Practice SP 42.13330.2016 "Urban Planning. Planning and development of urban and rural settlements". [1] the classification of interchanges is not presented. In 2019 introduced SP 395.1325800.2018 "Transport interchange hubs. Design rules". [2], which presents the classification of transfer hubs [8]. The classification is based on the functional (transport) purpose and interacting modes of transport. In addition, when determining the composition of a settlement's TPU system, its size is taken into account [6, 7].

The practice of applying the standards shows that the structure of the system of interchange hubs presented in SP 395 works well in metropolitan cities (Moscow and St. Petersburg), but needs to be specified when it is used in other types of settlements, including the largest cities.

2 Methodology

The study conducted a cluster analysis to identify groups of TTH in cities with a population of more than 1 million people. The study is based on the example of two cities: Voronezh - 1.06 million people, Ufa - 1.13 million people.

The peculiarities of the planning structure of Voronezh are determined by the location of the city on the two banks of the Voronezh Reservoir. The historic part of the city with a radial layout was formed on the high right bank of the tributary of the Don - the Voronezh River. Development of the city of a narrow strip along the left bank began much later, only in the 20th century, due to the transformation of Voronezh in the industrial center. At the same time to the west of the historic center, on the high bank also emerged large industrial zones along the railroad, chaotically alternating with areas of residential development, both apartment and individual, emerging as workers' camps with factories. In the era of industrial housing has formed a large array of residential development in the northern part of town, with a rectangular layout. Connected to the historical part by a major thoroughfare, crossing the production belt - Moscow Avenue, it was actually detached from the main public center.

The city of Ufa is located on the bank of the Belaya River, at the confluence of the Ufa and Dema rivers into it. Ufa received the status of the city in 1586. During the XIX and XX centuries, the city has grown rapidly, becoming a city of "millionaires". Ufa occupies an extremely favorable geo-strategic position on the connection lines between two largest economic systems of Russia: the Volga region and the Urals, the whole mentioned area is a hinterland of Ufa business center, a place of application of its capitals, interests and energy. In this regard, the role of Ufa as a financial and economic center of the vast region - from
Samara and Ulyanovsk in the west to Chelyabinsk and Yekaterinburg in the east - will only increase in time, as well as the role and importance of its business center. The railway line runs through the city along its entire length, including the Severnaya industrial zone and nearby settlements - Urshak (airport), Dema, Shaksha.

Currently, there are 23 TTH in Voronezh and 19 TTH in Ufa. In order to conduct a cluster analysis, it is necessary to conduct an on-site survey of the currently operating TTHs.

При проведении натурного обследования были рассмотрены следующие факторы:
1. Planning factors:
   - Size of the TTH impact area (area served);
   - Size of the TTH area;
   - Location relative to the city center;
   - Remoteness of the TTH from existing buildings.
2. Functional factors:
   - Maximum parameters of building height (in accordance with the rules of land use and development);
   - The need to develop the adjacent territory (in accordance with the general plan of the city).
3. Factors of security:
   - Availability of related services (stores, hotels, etc.).
4. Factors of transport infrastructure development:
   - Size of passenger traffic during "peak" frequencies;
   - Types of transport interacting in the hub and their characteristics;
   - Frequency of public transport (units per hour);
   - Interchange distance in the TTH;
   - Transfer time;
   - Capacity of parking space;
   - Density of the public transport network in the zone of the TIU’s influence.

After collecting baseline data, it is necessary to determine which of the factors should be taken into account in the formation of the classification of transport hubs. One of the methods of factor selection is a one-factor analysis of variance [3].

A factor is considered strongly connected if two conditions are fulfilled: $F > F_{critical}$ and $P-value < 0.05$ (Table 1), if one of the conditions is not met the factor is considered weakly connected (Table 2). Weakly coherent factors are not considered in the TPU classification.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>$F$</th>
<th>$P$-value</th>
<th>$F$ critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis of variance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Single-factor analysis of variance (both conditions are met)
The analysis of the connectivity of TPU factors in Voronezh and in Ufa showed identical results. Thus, the weakly connected factors are:

- Limit parameters of building height;
- Availability of related services;
- The need to develop the surrounding area.

In connection with the above, the following factors must be considered in order to conduct a cluster analysis:

1. Planning factors:
   - Size of the TTH impact area (area served);
   - Size of the TTH area;
   - Location relative to the city center;
   - Remoteness of the TTH from existing buildings.

2. Functional factors:
   - Maximum parameters of building height (in accordance with the rules of land use and development).

3. Factors of transport infrastructure development:
   - Size of passenger traffic during "peak" frequencies;
   - Types of transport interacting in the hub and their characteristics;
   - Frequency of public transport (units per hour);
   - Interchange distance in the TTH;
   - Transfer time;
   - Capacity of parking space;
   - Density of the public transport network in the zone of the TIU's influence.
Classification of transport-transfer hubs in large cities was carried out by cluster analysis, according to the factors listed in Table 4, as the cluster analysis allows based on given characteristics to form groups (clusters), united by common characteristics. More often the cluster analysis is used in the absence of the hypothesis of cluster formation [3, 9].

In this study, the classification of TTH was carried out in the software package STATISTICA. When processing the data in the program STATISTICA we get the following hierarchical tree cluster analysis for the city of Voronezh (Figure 1) and the hierarchical tree cluster analysis for the city of Ufa (Figure 2).

Figure 1: Hierarchical cluster analysis tree for Voronezh

Figure 2: Hierarchical cluster analysis tree for the city of Ufa
To determine the clusters in the hierarchical tree, it is necessary to carry out the merging process. In the unification process, the break point corresponds to step 18, and the number of objects considered is 23. Accordingly, the cluster cut-off line must pass at step 5. It follows that the number of clusters in the considered tree corresponds to 4 [2] (Figure 3).

Figure 3: Graph of determining the number of clusters Voronezh

Following the unification process for the city of Ufa, the breaking point corresponds to step 15, and the number of objects considered is 19. Accordingly, the cluster cut-off line should pass at step 4. From this it follows that the number of clusters in the considered tree should be 4. It follows that the number of clusters in the considered tree corresponds to 4 (Figure 4).

Figure 4: Graph of determining the number of clusters Ufa
The resulting clusters of transport and transfer hubs in the cities of Voronezh and Ufa should be compared with the types of transport and transfer hubs in accordance with SP 395.1325800.2018 Transport and Transfer Hubs. Design rules [2, 10] (hereinafter - SP 395) (Table 3).

Table 3. Interoperable modes of transport in transport hubs of different types in accordance with SP 395.1325800.2018

<table>
<thead>
<tr>
<th>Type of transportation hub</th>
<th>N of the TPU group</th>
<th>External transport</th>
<th>Regional transport</th>
<th>City transport</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Railway transportation</td>
<td>Air transport</td>
<td>Water transport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suburban train</td>
<td>Rail</td>
<td>Road</td>
</tr>
<tr>
<td>1. Hubs of interregional significance</td>
<td>1.1</td>
<td>One or several types</td>
<td>One or several types</td>
<td>One or several types</td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>One or several types</td>
<td>One or several types</td>
<td>One or several types</td>
</tr>
<tr>
<td></td>
<td>1.3</td>
<td>One or several types</td>
<td>One or several types</td>
<td>One or several types</td>
</tr>
<tr>
<td>2. Hubs of regional (agglomeration) significance</td>
<td>2.1</td>
<td>One or several types</td>
<td>One or several types</td>
<td>One or several types</td>
</tr>
<tr>
<td></td>
<td>2.2</td>
<td>One or several types</td>
<td>One or several types</td>
<td>One or several types</td>
</tr>
<tr>
<td>3. Regional hubs</td>
<td>3.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4. Local hubs</td>
<td>4.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>4.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

In accordance with SP 395 in Voronezh and Ufa there are 2 types of transport hubs:
1 hubs of interregional significance;
2 hubs of regional significance (agglomeration significance).

However, according to the cluster analysis, it can be seen that TPU's of regional significance are divided into 3 groups. In order to determine the characteristics of the groups of TPU's, an analysis of the interacting modes of transport and the location of the TTHs in the city plan was carried out (Figure 5, Figure 6).
Figure 5. Location of the TTH within the city limits of Voronezh
Figure 6: Location of the TTH within Ufa city limits

The results of the analysis are presented in the form of a proposed classification of TIH, taking into account the interacting modes of transport in cities with populations over one million people on the basis of SP 395.1325800.2018 [11] (Table 4).
Table 4. Proposed Table of Classification of TTH with Regard to Interacting Types of Transport in Cities with Population over a Million People

<table>
<thead>
<tr>
<th>Type of transport hub</th>
<th>N o f t h e T P U g r o u p</th>
<th>External transport</th>
<th>Regional transport</th>
<th>City transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hub s of interregional significance</td>
<td>1.1</td>
<td>One or several types</td>
<td>One or several types</td>
<td>One or several types</td>
</tr>
<tr>
<td>Hub s of regional (agglomeration) significance</td>
<td>2.1</td>
<td>-</td>
<td>-</td>
<td>One type of</td>
</tr>
<tr>
<td></td>
<td>2.2</td>
<td>-</td>
<td>-</td>
<td>One type of</td>
</tr>
<tr>
<td></td>
<td>2.3</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

3 Conclusion
As a result of the cluster analysis, two types of TTHs can be distinguished in cities with "million-strong cities": nodes of interregional significance and nodes of regional (agglomeration) significance.

In turn, nodes of regional significance are divided into 3 subgroups:

First class regional TTH - TTHs located on the basis of bus stations and public transport stops, where commuter buses stop, with a large passenger flow.

Regional TTH of the second class - TTH, based on railway stations with large passenger traffic, interchange between different types of urban transport and private transport. Development of the adjacent territory is envisaged in accordance with the spatial planning documents.

Regional TTH of the third class - TTH based on railway stations with the least passenger traffic and the least prospective development of the adjacent territory of the TTH. In such TTHs, interchanges are often made from personal transport to rail transport.

### References


