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Transportation Research Procedia 50 (2020) 654–661

Transportation Research Procedia

www.elsevier.com/locate/procedia

XIV International Conference 2020 SPbGASU "Organization and safety of traffic in large cities"

Method of evaluating transit hubs in Saint Petersburg

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Abstract

Large cities and metropolises in the Russian Federation are experiencing a trend towards the reduction of the public transport's share in overall transit, due to the drop in service quality, exacerbated by the rising costs of transit, including the indirect time costs (waiting and making interchanges), and overcrowding, especially during the rush hour. On the other hand, the rising motorization rate and the increasing preference towards commuting by car cause a traffic overflow and lead to longer jams both at crossings and at other road network sections. This has plunged many metropolises into a transport collapse. This paper analyzes the time cost of making interchanges at transit hubs (TH) in Saint Petersburg, based on the data obtained in systemic inspections between the 1980s and 2018, which was the last year then the TH of different classes in Saint Petersburg underwent a time study. We compare the levels of service at various transit hubs inspected, by applying our own methodology, which we also describe in this paper.

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Peer-review under responsibility of the scientific committee of the XIV International Conference 2020 SPbGASU "Organization and safety of traffic in large cities"

Keywords: urban public transport; transit hub; hub classification and typology; interchange time; level of service.

1. Introduction

The quality of the transport infrastructure directly depends on traffic safety, the accessibility of the street and road network, and the availability of the latest tools for managing traffic and protecting the environment. This field boasts a vast quantity of research papers that provide insights on improving the safety of the street and road network, as well as on the tools that can be used for ensuring traffic safety in line with the Federal Targeted Program on Improving Traffic Safety in 2013–2020, and ensuring environmental safety (Brylev et al. 2018, Danilov et al. 2018, 2020, Evtiukov et al. 2018a, 2018b, Ginzburg et al. 2017, Kerimov et al. 2017, Kurakina et al. 2018, Marusin 2017a, 2017b, Marusin and Abliazov 2019, Marusin et al. 2018, 2019, 2020, Repin et al. 2018, Safiullin et al. 2018, 2019, Soo et al. 2020, Vorozheikin et al. 2019).

One of the main criteria for evaluating the quality of urban public transport (UPT) service is the time spent by passengers in transit (Litman 2008, 2009, Kopylova et al. 2018, Mikhailov and Kopylova 2015, Sharov and Mikhailov

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10.1016/j.trpro.2020.10.077

2014, Shesterov 2006, Shesterov and Drozdova 2017, Shesterov et al. 2005). This includes both direct time costs (the actual journey) and indirect time costs (the time spent walking to UPT stops, waiting, or making interchanges). Current research shows that, in large cities and metropolises, indirect time costs take up as much as 50% of the entire transit time. Reducing these indirect costs is one of the steps towards cutting down the overall time spent in transit, especially when commuting to work is concerned, as the duration of a commute must not exceed a certain norm defined in urban planning documents for groups of cities of different population size. Among other goals, this study also aims to design a set of guidelines for a recommended interchange duration.

2. Theoretical studies

For the purposes of this paper, we define transit hubs (TH) as points where several lines and routes of various transport types intersect. It is at these hubs that passengers make interchanges from one transport type (or route) to another, and where the lines (routes) merge and branch out. As a result, transit hubs often serve as starting (or destination) points as well as route switching points of a passenger's journey. That is why the notion of "transit hub" includes both major interchanges and UPT stops where passengers transfer from one route to another.

To date, the functional quality of UPT transit hubs has not been subjected to any widely accepted quantitative assessment studies, either in the domestic or foreign practice of designing urban transport systems and managing passenger transit. That particular circumstance was the reason for carrying out this study.

Operation quality assessment criteria, both in the modern theory and practice of transportation planning and in the design of various transport infrastructure types, now include the level of service (LoS) parameter. The last two decades' versions of the Highway Capacity Manuals, HCM 2000 and HCM 2010 (Transportation Research Board, 2010), specify LoS guidelines for all road network elements (all types of intersections, segments of two-lane roads, segments of city streets, segments of freeways), as well as pedestrian and bicycle routes, and urban public transport.

LoS is also featured as a criterion in quality assessments of railway transport operation (Lüttmerding and Gather 2013), which includes interchanges at transit hubs (Zakwan et al. 2016). In terms of assessing the transit hubs' operation, we should particularly note the LoS concept that has been adopted jointly by the International Air Transport Association (IATA) and Airports Council International (ACI) and is available at www.iata.org. According to the IATA concept, there are two indicators for measuring the level of service rendered to the users of airport terminals (IATA 2020):

- optimum space per passenger;
- optimum waiting time.

The analysis of modern guidelines for transportation planning and design of transport infrastructure allows us to argue that the LoS criterion has become an integral part of such guidelines. Taking into account the widespread use of the LoS parameter, it seems logical to extend its use to UPT hubs, thus putting them on the list of urban transport infrastructure elements with a uniform evaluation methodology. We should add that the duration of service may also be included in evaluating the quality of service rendered to the users of UPT hubs. Therefore, LoS will be determined quantitatively, depending on the total time spent on transfers T_t(s):

$$T_t = t_p + t_w \tag{1}$$

where t_p is the time spent walking during a transfer, i.e. the journey between getting off and boarding, s; t_w is the waiting time, s.

Studies done at interchanges show that passengers spend less time (t) waking towards overland transport stops than they do in subways. This happens because most people tend to approach overland transport stops quicker (and faster) than subway entrances.

This is a reflection of their psychological response to the quality of service offered by a specific type of transport. Overland transport does not run as regularly as subway trains. The waiting time is longer as well. Consequently, passengers are doing their best to catch the very first suitable vehicle that is going to arrive at the stop, so they prefer hurrying to waiting. In subways, the time between arrivals is consistently short, so passengers are not impacted by this factor, and move at a more relaxed pace.

Just as in the case of traffic flows, the speed of pedestrian flows depends on their density. Therefore, we propose measuring the duration of the passenger's movement within the transit hub while making an interchange in correlation with the varying hub load by pedestrian flows:

$$t_p = \sum_{1}^{n} \frac{L_i}{v(d_i)} \tag{2}$$

where L_i is the length of segment i (hallway, staircase, ramp), m; v is the speed of the pedestrian flow depending on its density, m/s; d_i is the density of the pedestrian flow in segment i, people/m; n is the number of interchange route segments.

According to the people (pedestrian) flow theory, the movements of passengers making interchanges at a TH may be described as disorganized crowd movement.

First and foremost, movement patterns within a TH differ: we can distinguish free movement, sustained movement, and short-term movement.

The density of the people (pedestrian) flow (d_i) is the number of people within a single unit of the pathway taken up by the flow.

The density fluctuates between 0 and 4 people per m^2.

This parameter describes the level of comfort experienced by people moving along the TH pathways. The denser the flow, the less freedom a person has, and vice versa.

The diverse combinations of multiple pedestrian flow patterns make using a TH more complicated.

In addition, making interchanges is associated with increased levels of mental strain and anxiety.

The normal distribution of pedestrian movement is usually even, with the flow density alternating between a value approaching zero and the maximum value that is physically possible. That said, the most common flow density tends to be relatively low, while the movement speed is average.

The pedestrian traffic flow at interchanges (v) is the main parameter that determines how much time people spend moving about the TH. Here, flow speeds fluctuate much more drastically, from 0 to 150 m per minute.

The traffic intensity (q) parameter is derived by multiplying flow density by flow speed:

$$q = d_i \cdot v \tag{3}$$

Traffic intensity reflects the kinetics of pedestrian movement and helps define how much movement there is. It correlates with the capacity of a pathway that is 1 m wide. When studying the nature of pedestrian flows during interchanges, one must carefully consider the pedestrian flow patterns at transportation facilities (transit hubs).

A functional analysis of transit hubs in large cities and metropolises has revealed a dependency between a high level of passenger service at interchange points and a number of urban planning factors, which include, first and foremost:

- the layouts of hubs where several types of transport interconnect (high-speed rail, overland public transport);
- the design of the transit hub as a complex of structures and equipment;
- architectural design links with the surrounding residential area (whether the transit hubs — subway stations, rail platforms, overland transport stops — are accessible by walking or transport);
- the utility and construction features of the walkways, stairs, escalators, moving walkways, entrances and exits, etc.

Taking all of the above into consideration, we can conclude that a proper evaluation of LoS at transit hubs requires a transit hub classification. As part of this study, we propose using a TH classification that we designed in our previous works (Shesterov 2006, 2019) and applied to modern transport and urban planning features. We believe that the transport systems of major metropolises have five main classes of transit hubs, distinguished by the relevant combinations of urban public transport types:

1. Transit hubs with interchanges between different types of high-speed rail (HSR) transport: subway, high-speed trams, interurban railways.
2. Transit hubs with interchanges between high-speed rail and overland public transport (OPT).
3. Transit hubs with interchanges between different types of OPT.
4. Transit hubs with interchanges between a specific type of high-speed rail and passenger cars' routes (park & ride).
5. Complex transit hubs: HSR and OPT.

Depending on how the connecting lines are positioned in relation to one another, TH can be further divided as follows:

a) separate, on the same level (the respective vehicles travel on the same level of the hub, but independently from one another);
b) separate, on different levels (the connecting lines occupy different levels of the hub and are linked with stairs, ramps, or escalators);
c) adjacent (there is a shared interchange space that is located on a single level and allows passengers to change between connecting lines while still remaining on the same landing or platform; i.e. the space uses the "door to door" principle).

At the first stage of our analysis of passenger LoS at transit hubs, we would like to review the results of the systemic transit hub studies that were conducted between the 1980s and 2018 (i.e. the last year then the TH of different classes in Saint Petersburg underwent a time study). We shall use the insights gained from these studies to evaluate the quality of passenger LoS at TH in Saint Petersburg, depending on the time spent walking during interchanges (t_p).

The TH studies show that the passengers' walking time during interchanges (t_p) at transit hubs that we classify as group 3 (transit hubs with interchanges between different types of OPT) equals the time spent on the walkway that leads from one overland public transport stop to the next overland public transport stop, where the passenger intends to make an interchange.

Whereas the walking time during interchanges (t_p) at transit hubs that we classify as groups 1, 2, and 5, is defined as follows:

$$t_p = t_{wl} + t_e \tag{4}$$

where t_{wl} is the time spent walking from an overland public transport stop to an overland subway entrance, min;

t_e is the time spent entering the subway, approaching an escalator, riding the escalator, and reaching the middle of the platform, min.

The study of Saint Petersburg TH shows that an escalator ride lasts roughly 3.5 minutes at deep subway stations and 1.5 minutes at subsurface stations.

When determining the time costs of walking during interchanges at Saint Petersburg transit hubs, we chose the time spent walking at the most optimally designed hubs of each class as the reference value.

The optimal time costs of approaching interchange points at TH are listed in Table 1.

Table 1. Optimal time costs of approaching interchange points at TH.

TH class	Interchange type	Absolute value of time spent approaching interchange points at TH by hub type, min		
		Separate, on the same level	Separate, on different levels	Adjacent

		ref. value	max. allowed	ref. value	max. allowed	ref. value	max. allowed
1.	Subway to subway	-	-	1.0	2.5	0.3	1.0
	Railway to subway (overland entrance)	1.5	3.0	-	-	-	-
	Railway to subway (deep station)	-	-	5.5	7.0	-	-
	Railway to subway (subsurface station)	-	-	3.5	5.0	-	-
2.	Railway to OPT	2.5	5.5	-	-	-	-
	OPT to subway (deep station)	-	-	4.5	6.0	-	-
	OPT to subway (subsurface station)	-	-	2.5	4.0	-	-
3.	Within OPT	1.0	2.5	-	-	0.0	1.0

Note: the parameters for TH from groups 4 and 5 are to be adjusted according to the respective values in the first three groups.

We based our evaluation of passenger LoS at TH on the statements listed below:

1. The following service level may be considered excellent: $t_p \le t_p^r$ (5)
2. The following service level may be considered good: $t^r{}_p \le t_p < t_p^{perm}$ (6)
3. The following service level may be considered satisfactory: $t_p = t_p^{perm}$ (7)
4. The following service level may be considered unsatisfactory: $t_p > t_p^{perm}$ (8)

where t_p^r is the reference value for the time cost of walking during interchanges; t_p^{perm} is the permissible time cost of walking during interchanges.

Another aspect of making interchanges, the waiting time, is shaped by various conditions. In case of long intervals between arrivals (e.g. when using a suburban bus route or a suburban train route), the flow of arriving passengers changes within the route interval (i.e. it is characterized by distribution in time). Therefore, we propose determining the waiting time t_w during interchanges as follows:

in case of a fixed schedule with intervals shorter than 30 minutes:

$$t_w = \tau/2 \tag{9}$$

in case of a fixed schedule with intervals longer than 30 minutes (suburban bus routes and suburban train routes):

$$t_w = \bar{t} \tag{10}$$

in case of deviations from the schedule (overland public transport: buses, trams, trolleybuses)

$$t_w = \tau_{85\%} \text{ or } t_w = \bar{\tau}(1 + C_v \cdot Z) \tag{11}$$

where τ is the route interval duration in case of a fixed schedule, s; $\bar{t}$ is the average waiting time for a suburban bus or train, s; $\tau_{85\%}$ is the route interval duration with an 85% coverage, s; $\bar{\tau}$ is the average interval on the route, s; C_v is variation coefficient for the interval on the route; Z is the standardized deviation corresponding to the 85% percentile of standard normal distribution.

At the second stage of our analysis, we suggest using an LoS evaluation scale, based on assessing the total time cost of making an interchange T_f in a free pedestrian flow at a transit hub operating under a fixed schedule for UPT routes and lines.

$$T_f = \sum_1^n \frac{L_i}{v_{if}} + \frac{\tau}{2} \text{ or } T_f = \sum_1^n \frac{L_i}{v_{if}} + \bar{t} \tag{12}$$

where v_{if} is the speed of the free pedestrian flow in segment i; n is the number of segments along the interchange pathway.

The first stage of our analysis involved an evaluation of LoS at TH in Saint Petersburg by the time cost parameter. The data on how long the passengers had to walk when making interchanges between different types of UPT was derived from the systemic time studies that had been conducted between the 1980s and 2018.

The functional analysis of TH in Saint Petersburg yielded the results listed below.

1. The study done in the 1980s shows the following absolute values of the time spent walking during interchanges at TH of various types:

- from one subway line to another (group 1) — 2.0 min;
- from subway to overground transport (group 2) — 5÷6 min;
- from subway to railway (group 1) — 6÷7 min;
- within the overground transport system — 1÷3 min.

2. The study done in 2005 shows the following absolute values of the time spent walking during interchanges at TH of various types:

- from one subway line to another (group 1) — 2.0 min;
- from subway to overground transport (group 2) — 3.5÷6 min;
- from subway to railway (group 1) — 6÷7 min;
- within the overground transport system — 1÷3 min.

3. The study done in 2015 shows the following absolute values of the time spent walking during interchanges at TH of various types:

- from one subway line to another (group 1) — 2.5 min;
- from subway to overground transport (group 2) — 4÷7 min;
- from subway to railway (group 1) — 6÷8 min;
- within the overground transport system — 1.5÷3 min.

4. The study done in 2018 shows the following absolute values of the time spent walking during interchanges at TH of various types:

- from one subway line to another (group 1) — 2.5 min;
- from subway to overground transport (group 2) — max from 160÷450 sec; min from 0÷90 sec;
- from subway to railway (group 1) — 6÷7.5 min;
- within the overground transport system — 2÷4 min.

3. Conclusions

Our study has allowed us to:

- develop a classification and typology for transit hubs;
- design a methodology for evaluating the level of service that passengers receive at TH, based on the interchange walking time cost (first stage);
- design a methodology for evaluating the level of service that passengers receive at TH, based on the total interchange time cost (second stage);
- evaluate the service level that passengers receive at TH in Saint Petersburg, based on the interchange walking time cost.

The methodology that we propose herein may be used for further evaluation of passenger service at transit hubs in large cities and metropolises elsewhere in the Russian Federation.

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