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Transportation Research Procedia 36 (2018) 303–307

Transportation Research Procedia

www.elsevier.com/locate/procedia

Thirteenth International Conference on Organization and Traffic Safety Management in Large Cities (SPbOTSIC 2018)

A Level-of-Service concept regarding intermodal hubs of urban public passenger transport

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Abstract

With motorization increasing in cities of the Russian Federation, urban public passenger transport can compete with individual automobile transport primarily due to the high quality of passenger services and operational reliability. One of the crucial indicators of urban public passenger transport service quality is total time expenditures on transportation which includes time expenditures on transfers. The quality of transfer hub operation has not gotten any quantitative assessment in the Russian Federation. In this regard, in order to evaluate the quality of transfer hub operation, the following criterion is proposed: the level of service measured by total time expenditures on transfers, including time expenditures on transportation during transfers and transfer waiting time. A scale for levels of service is proposed. The scale is based on distribution quartiles for transfer duration, obtained from the survey data regarding transfer hubs in Irkutsk and Vienna.

*Keywords:*urban public passenger transport; intermodal hub; transfer duration; level of service.

1. Introduction

One of the crucial indicators of urban public transport (UPT) service quality is time spent by passengers on transportation (Litman, 2008, 2017; Mikhailov and Kopylova, 2015; Sharov and Mikhailov, 2014) which includes

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10.1016/j.trpro.2018.12.087

time spent on transfers. A concept of Seamless Transportation System imposing strict requirements for the interaction of various UPT types in intermodal hubs has been formulated and is implemented in EU member states. In Russia, time expenditures on transfers when using UPT are characterized by fairly high figures. For example, average time spent on transfers in Irkutsk (according to surveys of 2008) made up 23% of the average transportation duration.

The present paper refers to intermodal hubs as hubs where users transfer from one means of transportation to another, i.e. from one UPT type to another, or from one UPT route to another. That is why the notion of "intermodal hub" includes both major transfer hubs and UPT stops where passengers transfer from one route to another.

To date, operation quality of UPT intermodal hubs has not gotten any widely accepted quantitative assessment both in domestic and foreign experience of designing urban transport systems and arrangement of passenger transportations. That particular circumstance was a reason to carry out this study.

2. Methodology

The level of service became a criterion for operation quality assessment in the modern theory and practice of transportation planning, as well as design of various types of transport infrastructure (HCM 2010, 2010; TCQSM, 1999). In the last two decades, such versions of Highway Capacity Manuals as HCM 2000 and HCM 2010 were developed for all road network elements (all types of intersections, segments of two-lane roads, segments of city streets, segments of free-ways), pedestrian and bicycle communications, as well as for public passenger transport.

The level of service is also considered as a criterion for assessment of railway transport operation quality (Lüttmerding and Gather, 2013), including that of transfer hubs (Daamen, 2002; Hänseler et al., 2016; Zakwan et al., 2016). In terms of assessment of intermodal hubs' operation, we should particularly note the level-of-service concept adopted jointly by the International Air Transport Association (IATA) and Airports Council International (ACI), published on the website www.iata.org (2017). According to the IATA concept, the level of service rendered to users of airport terminals is assessed by the following indicators:

- optimum space per passenger;
- optimum waiting time.

The analysis of modern guidelines for transportation planning and design of transport infrastructure allows arguing that such criterion as the level of service has become their integral part. Taking into account the wide use of the level-of-service indicator, it seems logical to extend its use to UPT intermodal hubs, thus including those hubs into the list of urban transport infrastructure elements provided with a uniform assessment method. In such case, to assess the quality of services rendered to users of UPT intermodal hubs, service duration can be considered. Therefore, the level of service will be determined quantitatively by total time expenditures on transfers T (s):

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

where t_p is time of transportation from the disembarkation point to the embarkation point, s; t_w is transfer waiting time, s.

3. Case study

By analogy with traffic flows, the speed of pedestrian flows depends on their density. Therefore, it is proposed to determine the duration of transportation during transfer within the hub taking into account the varying hub load with pedestrian flows:

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

where L_i is the length of the i element (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/on the i element, people/m; n is the number of elements on the route during the transfer.

Another transfer component is transfer waiting time. This component is formed under various conditions. In case of significant interval duration (e.g. 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, it is proposed to determine transfer waiting time t_w as follows:

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

$$t_w = \tau/2 \tag{3}$$

in case of a fixed schedule with intervals more than 30 minutes (suburban bus routes and suburban train routes (Figure 1)):

$$t_w = \bar{t} \tag{4}$$

in case of deviations from the schedule (street passenger transport: buses, trams, trolley buses):

$$t_w = \tau_{85\%} \text{ or } t_w = \bar{\tau}(1 + C_v \cdot Z) \tag{5}$$

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

It is proposed to create an assessment scale for service levels based on assessment of total time expenditures on transfer T_f carried out in a pedestrian flow in a transfer hub under free conditions and in case of a fixed schedule for UPT routes and lines.

$$T_f = \sum_1^n \frac{L_i}{v_{if}} + \frac{\tau}{2} \text{ or } T_f = \sum_1^n \frac{L_i}{v_{if}} + \bar{t} \tag{6}$$

where v_{if} is the speed of the pedestrian flow in/on the i element in a free flow; n is the number of elements on the route during the transfer.

4. Results

In accordance with the proposed method for assessment of the level of service, all additional time expenditures, such as increase in the duration of transportation under conditions of dense pedestrian flows, increase in the waiting time due to transport deviations from the schedule, lead to decrease in the quality of services in relation to basic conditions.

Experimental measurements of time expenditures on transfer of passengers from one UPT type to another were made during surveys of 13 UPT intermodal hubs in Irkutsk and 20 UPT intermodal hubs in Vienna (Figure 4). The surveys included assessment of total time expenditures on transfer for all possible interaction combinations of UPT lines and routes within intermodal hubs:

- "Off Street–Off Street" (OffSt–OffSt) — transfer from off-street transport to off-street transport (S-bahn, U-bahn, suburban passenger trains);
- "Off Street–Street" (OffSt–St) — transfer from off-street transport to street transport and vice versa;
- "Street–Street" (St–St) — transfer from street transport to street transport (trams, buses, trolley buses).

Following the results of the audit of statistical significance of the differences in average indicators of the duration of transfers with the use the Student's test, it was established that "Street–Street" transfers should be considered a separate group, while "Off Street–Street" and "Off Street–Off Street" transfers should be combined into the second group. The obtained distribution quantiles for transfer duration in both groups are presented in Table 1. The proposed assessment scale for service levels is based on distribution quartiles for transfer duration (for all types of transfers)is presented in Table 2.

Table 1. Statistics of transfer's duration and distribution quartiles.

Transfer type	Transfer duration, s			Distribution quartiles, s		
	Min	Max	Mean	25%	50%	75%
Street–Street	170	1150	450	320	420	540
Off Street–Street Off Street–Off Street	230	2000	730	420	670	990
All transfers	155	2000	640	370	510	980

Table 2. Proposed bounds of the Level-of-Service at intermodal hubs of urban passenger transport.

Level of Service	A	B	C	D
Quality of Service	high comfort	good comfort	adequate comfort	inadequate comfort
Transfer duration, s (min:s)	$T \leq 370$ (6:10)	370 (6:10) $<T \leq$ 510 (8:30)	510 (8:30) $<T \leq$ 980 (16:20)	$T>$ 980 (16:20)

5. Discussion and conclusions

The possibility of criterion application was examined using the example of UPT intermodal hubs of Moscow: Aviamotornaya, Dmitrovskaya, Nagatinskaya subway stations. The time expenditures on transfers between all UPT lines and routes within a transfer transport hub were calculated, the average time expenditures on transfers and the average level of service were determined. In the course of calculations, we considered pedestrian flows moving under free conditions.

The chosen stations were assessed by the level of service; the corresponding assessment scale is presented in Table 2. According to the results of transfer duration calculations, transfer conditions at all three stations were acknowledged as satisfactory. Therefore, in case of a higher load in the hubs under consideration, transfer conditions will be acknowledged as unsatisfactory. The main reason for significant time expenditures on transfers is a large distance between UPT stops (200–700 m).

The authors intend to further develop the technique for assessment of the quality of UPT intermodal hubs. The assessment scale for the level of service will be adjusted with allowance for the data of surveys in intermodal hubs in Saint Petersburg (Shesterov and Drozdova, 2017). By now, 18 hubs in Saint Petersburg, including subway stations and UPT stops, have been already surveyed. New surveys will allow forming representative data samples for all three types of transfers (Off Street–Off Street, Off Street–Street, Street–Street) and develop a more justified scale for the level of service for each of them.

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