Methodology for generating a comprehensive assessment criterion for passenger traffic conditions in the space of roofed communication elements of intermodal transport hubs

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Abstract

The paper considers an assessment methodology for pedestrian environment in the space of communication elements related to intermodal transport hubs, which planning is performed by construction of transfer unit. Pedestrian environment is proposed to be assessed using an integral criterion that comprises quantitative features of the main parameters for passenger traffic by analogy to the practice applied in foreign experience.

1. Introduction

Under condition of high-intensive passenger flows being generated in the major cities, and against the background of deficient area for development, and strict requirements for the distance of pedestrian approach when transferring between transport types, native town-planning school, by analogy to the global experience, considers a possibility of planning development for transport hubs using construction of transfer unit [1–3].

Figure 1. Transfer unit distribution level arrangement flow chart [4]
Fundamental provisions that ensure an efficient function of a transport and transfer hub is a possibility to ensure passengers that use municipal and individual transport transfer with the maximum possible comfort, and in the shortest possible time. The maximum comfort for passengers may be provided by ensuring spatial and functional interconnection between any basic elements related to TTH within a common unit, comfort and transfer time in such facilities is ensured by a developed system of pedestrian links, the core of which is a distributed pedestrian level also called as communication area of transport hub. TTH communication area shall implement the main task when developing pedestrian link system related to the unit i.e. distributing passenger flows by directions and levels minimizing conflicts at crosses (Fig. 1).

Basic communication elements of TTH distribution level that ensure distribution of pedestrian flows, and those considered by the authors is a system of pedestrian galleries, stairs descents, and off-street pedestrian crosses.

The main issue related to such a way to develop TTH in our country is a complete absence both of transfer units, and mechanisms that allow for assessing their pedestrian environment from the point of passenger servicing quality.

2. Study overview
Passenger servicing quality in the space of roofed communication elements of transfer hub in general, and especially the distribution level is understood by the authors as a condition of pedestrian environment, under which the following traffic provisions shall be implemented for each individual participant:
- possibility to move along the entire distance of communication element section at a velocity that conforms to individual psychophysiological condition at this moment of time;
- possibility of unhindered overtaking of passengers that move at a less velocity;
- contact to other passengers with body parts or clothes elements is practically excluded when moving forward and overtake;
- possibility to select freely movement direction at any moment of time [5, 6].

In the paper, the authors propose assessing pedestrian environment of transfer units using an integral criterion (servicing level) that comprises quantitative features of main parameters for passenger traffic by analogy to Level of Service (LOS) a practice applied in the US. As the main element of assessing function of transport infrastructure facilities that embraces any phase of their lifecycle [7–9].

LOS assesses various movement and access types being supported by a clear hierarchy, priority in which is given to comfort and safety of road traffic. The main advantage of such approach is a possibility to acquire as soon possible and assess the data required at any phase of lifecycle related to transfer hub at a minimum amount of assessment criteria. As the assessment criteria, the authors consider the main parameters for the passenger flow taking into account their mutual dependencies [10].

Since earlier passenger traffic in native transport facilities was assessed exceptionally from the point of safety and evacuation, no general conditions for comfortable transfer of passengers in TTH, and quantitative values for the passenger flow related parameters were proposed [11]. In this context, the authors, based on mass service theory, developed a theoretical model for passenger flow traffic in communication area of transport and transfer hub being expressed via a multi-channel mass service system, which efficiency factor is characterized by the quantitative value for estimated possibility of fault in passenger movement through the functional space of structural element related to communication area.

The model implements a probabilistic assessment format for functional efficiency of structural elements related to communication area [12].

Passenger flow mathematics model schematic as a service processing system comprising several service channels (Fig. 2).
Accordingly, as the main criterion for functional efficiency of transfer unit system it is expedient to utilize service failure probability indicator, or a possibility of such an event when any service channel available are occupied when a passenger approaches the functional space of structural element related to communication area in interest:

\[ p(n) = \frac{(H \cdot t_{so})^n \cdot \frac{1}{n!}}{\sum_{m=1}^{n} (H \cdot t_{so})^m \cdot \frac{1}{m!}} \]  

(1)

where:
- \( p(n) \) – estimated fault probability for passenger's movement through the functional space of structural element related to communication area (zone II, Fig. 1), when the system has \( n \) service channels available;
- \( t_{so} \) – average time for passenger movement
- \( n \) – number of service channels
- \( l_h \) – hourly amount of passenger transport in the transfer unit system.

Based on the simulation data, the authors produced theoretical conditions for passenger movement in the space of communication of area related to transport and transfer hub. In passenger flow related studies conducted earlier, a regularity of interconnection between passenger flow velocity \( V \) (m/min) and passenger flow density \( D \) (m²/pass) – \((V=f(D))\) was proved, increase in passenger flow velocity reduces the space for movement, and a sequence results in reduce in velocity.

The authors in order to assess comfort of movement in passenger flow propose to use \( M \) (m²/pass) parameter i.e. a free space per a passenger in a communication element, a value reciprocal to density \( D \) (pass/m²). In our opinion, \( M \) parameter reflects more precisely traffic conditions from the point of passenger servicing quality, and fits better for estimations by analogy to LOS.

Taking into account that under the most favorable traffic conditions \( D \) and \( M \) indicators fails to impact the average passenger flow velocity, then it is proposed to be deemed a free movement velocity, length of separate sections of communication element will not impact significantly passenger floe parameters subject to conditions, where \( t_{so} \leq 5 \) min, and the total maximum length of

**Figure 2.** Passenger flow mathematics model schematic
Legend: I – incoming flow formation zone; II – incoming flow service zone; III – outgoing flow zone
communication element will satisfy \( S \leq 150 \text{m} \) condition, the lower threshold value for the average passenger flow velocity shall comply with \( V \geq 30 \text{ m/min} \) [13].

In the global experience, it is believed that the free movement velocity for horizontal paths, in apertures and when moving on stairs downward may fluctuate within 48 m/min and 155 m/min. Based on the estimation that a velocity below 48 m/min will be deemed a limited one, shuffling movement, and over 155 m/min will be already running movement. According to native and foreign studies, a velocity of passenger flow for horizontal paths within 90 and 155 m/min is deemed a movement of high activity degree, and observed at emergencies, or under conditions when the most pedestrians in the flow is limited by a strict time specific frameworks, which conforms to movement conditions for passengers at transfer. Ascend on staircase is characterized by velocity range between 12 and 80 m/min, where an interval between 50 and 80 m/min in conforms to the movement having a higher activity degree [14–16].

The authors propose to take a velocity for movement on horizontal paths at \( V \geq 80 \text{ m/min} \), velocity of upward movement on stairs, as the lower threshold for theoretical values for the average passenger flow \( V \geq 40 \text{ m/min} \).

To conduct theoretical estimation for \( M \), averaged geometrical parameters for communication area sections were selected based on existing inter-station passages in Moscow underground as the closest with respect to passenger flow level and a set of communication elements to pedestrian environment related to TTH transfer units.

Charging of a communication element by passenger flows is taken minimum possible one, which complies with the moment between first 15 minutes from the opening of underground station, and according to the data submitted by this institution, passenger flow velocity will be 110 pass/15 min.

From the point of practical application of estimation results obtained, the authors also propose considering such a significant parameter related to passenger flow as 'flow in section' \( P \) (pass*min/m) i.e. passenger flow in section that passes through a meter of width of communication element to be estimated by formula:

\[
P = V / M \tag{2}
\]

where:
- \( V \) – average passenger flow velocity, m/min;
- \( M \) – pedestrian space m²/pass;

**Table 1. Optimum functional conditions for structural elements of transfer unit communication area**

| Element description                        | Flow parameter values                           | Estimated value \( p(n) \) |
|--------------------------------------------|------------------------------------------------|-----------------------------|
| Stairs upward                              | \( M > 2.3 \text{ m}^2/\text{pers} \); \( P \leq 21.7 \text{ pass*min/m} \); \( V \geq 40 \text{ m/min} \); | 0.022 ≤                    |
| Horizontal paths with double direction movement | \( M > 2.7 \text{ m}^2/\text{pers} \); \( P \leq 33.0 \text{ pass*min/m} \); \( V \geq 80.0 \text{ m/min} \); | 0.040 ≤                    |
| Horizontal paths with single direction movement | \( M > 3.8 \text{ m}^2/\text{pers} \); \( P \leq 23.7 \text{ pass*min/m} \); \( V \geq 80.0 \text{ m/min} \); | 0.034 ≤                    |

Parameters of theoretical model were validated and specified based on 4 inter-station passages of Moscow underground determined by the outcomes of representative sample.

The outcomes of field investigations after statistical and quartile analysis were summarized in tables for each communication element.

Conducted quartile analysis for distributions determined quantitative values for \( P \) indicators in each equal part of 4 communication element groups.

When comparing the outcomes of quartile analysis to theoretical values for movement conditions, one can conclude that movement conditions obtained from theoretical estimations comply with the value range between the first and second quartiles, which, according to analysis outcomes, conform to the passenger movement conditions during off-peak time intervals having possibility to overtake freely other passengers, and select freely the velocity of movement on flow.
The most favorable service level that conforms to the first quartile is characterized by a possibility to select freely by passenger the velocity and direction of movement in flow not considering movement of other passengers (Fig. 3a).

A favorable service level that conforms to the second quartile is characterized by a possibility to select freely by passenger the velocity and possible overtake considering movement of other passengers (Fig. 3b).

An optimum service level that conforms to the third quartile is characterized for passenger by a free selection of velocity (Fig. 3c).

A restricted service level that conforms to the fourth quartile is characterized for passenger by a limitation on selection of velocity and possibility to overtake, through a forward movement only by minor pace (Fig. 3d).

Thus, once can say that the borders to applying the service levels generated comprise any phase of TTH lifecycle, except for disposal.

When developing regulatory documents related to planning, engineering and reconstruction of transport and transfer units, the authors propose utilizing an assessment procedure for the required width of communication element i.e. it will allow for generating the maximum comfortable conditions at the planning phase with respect to passenger movement in the space of transfer unit considering prospective development of TTH adjacent area.

| Service level        | Stairs descent | Horizontal paths with double direction movement | Horizontal paths with single direction movement |
|----------------------|----------------|-----------------------------------------------|-----------------------------------------------|
|                      | Passenger flow in section, pass*min/m | Free room, m²/pas | Passenger flow velocity, m/s | Passenger flow in section, pass*min/m | Free room, m²/pas | Passenger flow velocity, m/s | Passenger flow in section, pass*min/m | Free room, m²/pass | Passenger flow velocity, m/s |
| The most favorable   | ≤19.4          | >2.4                                         | ≥46.0                                        | ≤19.4          | >5.4                                         | ≥94.0                                        | ≤17.5          | >6.2                                         | ≥97.0                                        |
| Favorable            | ≤31.5          | >1.1                                         | ≥35.0                                        | ≤36.1          | >2.3                                         | ≥74.0                                        | ≤25.8          | >3.5                                         | ≥70.0                                        |
| Optimum              | ≤41.5          | >0.8                                         | ≥23.0                                        | ≤49.6          | >1.4                                         | ≥60.0                                        | ≤36.8          | >2.2                                         | ≥62.0                                        |
| Restricted           | >41.5          | <0.8                                         | <23.0                                        | >49.6          | <1.4                                         | <60.0                                        | >36.8          | <2.2                                         | <62.0                                        |

To ensure comfortable conditions for passenger traffic in the space of roofed communication elements related to transport and transfer unit, the authors recommend applying characteristics of an optimum service level and higher.
3. Conclusion
Thus, generating a service level system in communication elements related to transport and transfer hubs, and quantitative values for the passenger flow parameters may be utilized when determining a sufficient width of communication elements at planning, engineering or reconstruction phase, further investigation of passenger flows in transport and transfer hubs will generate assumptions for developing native regulations that determine practices for assessing passenger servicing quality at any level of TTH native system.

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