SIMULATION OF PASSENGER FLOWS IN TRANSPORT INTERCHANGE HUBS

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ABSTRACT

The authors consider a descriptive part of passenger flows simulation in a transport interchange hub, which takes into account the logical dependencies in organizing relocation of passenger flows, individuals and groups. All possible types of operations observed in the simulated space and assuming the reaction of control devices are shown and get their own interpretation. Different complexity of the situation with the organization of passenger traffic is estimated given architectural and planning decisions and the size of the complex.

ENGLISH SUMMARY

Background. *Transport interchange hub (hereinafter-TIH) is a complex system consisting of a discrete set of passengers traveling in a discrete space at discrete time, and thus taken separately, each passenger can autonomously, independently of the others make a decision on what needs to be done in the next step based on the analysis of his own behavior or state of the entire system. For the simulation of such a system certain principles are required, taking into account that the basis of the organization of movement of passenger and movement of individual parts of the overall process are logical dependencies [1].*

Objective. *The objective of the authors is to provide a descriptive part of passenger flows modeling in a transport interchange hub.*

Methods. *The authors use mathematical method, modeling, analysis and descriptive method.*

Results. *Solution of a task to build a mathematical model of TIH functioning is illustrated by pre-design studies. Axonometric scheme of TIH is shown in Pic. 1. Its second level (Pic. 2) is of particular interest, because it is the area with the largest percentage of technological areas. For the considered pre-design option in TIH space the following passenger flows are formed:*

V^u – passengers with travel documents that come to the 2nd floor of TIH via escalators and move in the direction of the turnstiles of the entrance to a passenger platform to commuter trains;

V^m – passengers with travel documents moving for an interchange from a monorail transport in the direction of the turnstiles at the entrance to a passenger platform to commuter trains;

V^p – passengers with travel documents, using parking and moving towards the turnstiles to commuter trains;

C^{uk} – passengers arriving at the 2nd floor of TIH via escalators and moving to ticket desks and then to the turnstiles of commuter trains;

C^{mk} – passengers, moving for an interchange from monorail transport to the ticket desks and then to turnstiles of commuter trains;

C^{pk} – passengers using parking and moving to ticket desks and then to turnstiles of the entrance to a passenger platform;

W^u – passengers arriving in commuter electric trains and moving through the turnstiles of the exit from passenger platforms to the escalator;

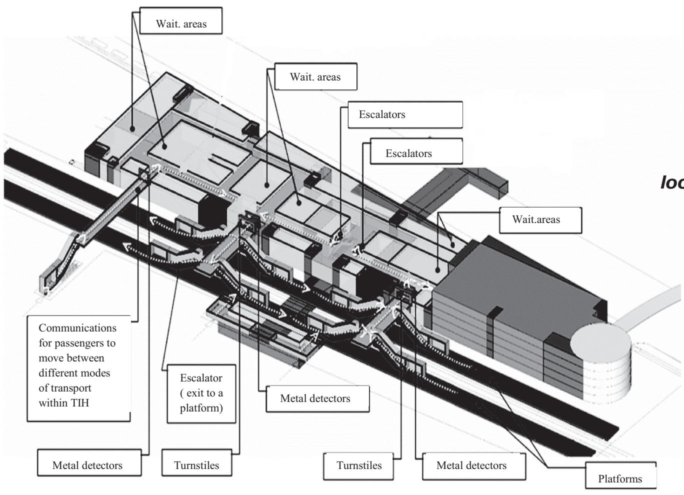
W^{pu} – passengers arriving with private vehicles and moving to the escalator;

W^{mu} –passengers arriving with monorail transport and moving to the escalator;

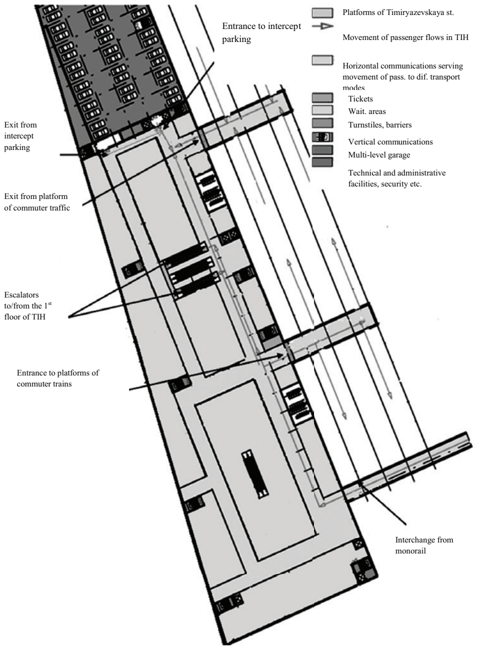
W^p – passengers arriving in commuter electric trains and moving through the turnstiles of the exit from passenger platforms to «intercept”;

W^m – passengers arriving with monorail transport and moving to the «intercept» parking.

In addition to these passenger flows in TIH space there can be a small number of people, moving to or from waiting areas, to or from objects of service, etc. However, their share in the TIH is so small compared with the main passenger flows, that it cannot affect the stability and efficiency of the TIH.



Pic. 1 Axonometric scheme of TIH: location of main facilities and direction of movement of main passenger flows.



Pic.2. Second floor plan and direction of passenger flows within TIH.

To reduce the scope of the description of similar behavior of flows their types will only be mentioned and in case of small differences from each other only their typical features will be reflected. TIH space is represented as a band divided into zones (Pic. 3). In each zone only one symbol of the alphabet Y can be written, containing the following variables [2]:

$$Y = \{S_i, B_j, V_l, R_m, N_p\}. \quad (1)$$

Symbols B_j mean that the zone is not occupied by any object; S_i – addresses of TIH facilities; V_l – transport objects (passengers); R_m – places of possible route changes of a passenger and choice of following direction; N_p – obstacles on the way.

Displacement of the object V_l is performed by a controlling (executive) unit q_j, which can overlook the proximate adjacent areas and move an object forward or backward.

Events that occur in this model and reaction of transport operator are described by the expression:

$$\frac{V_l}{q_j} BST \frac{V_l}{q_k}, \quad (2)$$

where the first three symbols

$$\frac{V_l}{q_j} B \quad (3)$$

characterize an event and the second –

$$ST \frac{V_l}{q_k} \quad (4)$$

characterize one of possible reactions of a transport operator.

A transport operator is a finite set of operations, among which there is no operation with the same initial threes. In general, aggregate (2) means a logical operation which can be used for management of transport process at some stage of its development. When considering all possible types of logical operations a set D is used, which characterizes the response of the controlling unit q_j:

$$D = \{ST, RE, EX, R, L, R(S_k)\}, \quad (5)$$

where ST – a command to move one step in the direction of travel; RE – a command to change a direction of motion; EX – a command to wait or stop; R – a command to change a direction of motion to the right, and L – to the left; $R(S_k)$ – command to perform a single step from zone R to zone S_k.

Using the described technology, the authors consider the behavior of flow V^u. Its description will be:

$$\frac{V_i^{ub}}{q_0^i} BST \frac{V_i^{ub}}{q_1^i}; \frac{V_i^{ub}}{q_1^i} BST \frac{V_i^{ub}}{q_2^i}; \ldots; \frac{V_i^{ub}}{q_{b-1}^i} BST \frac{V_i^{ub}}{q_b^i}; \frac{V_i^{ub}}{q_b^i} BR \frac{V_i^{us}}{q_0^i};$$

$$\frac{V_i^{us}}{q_0^i} BST \frac{V_i^{us}}{q_1^i}; \frac{V_i^{us}}{q_1^i} BST \frac{V_i^{us}}{q_2^i}; \ldots; \frac{V_i^{us}}{q_{s-1}^i} BST \frac{V_i^{us}}{q_s^i}; \frac{V_i^{us}}{q_s^i} Kl_1 L \frac{V_i^{ux}}{q_0^i};$$

$$\frac{V_i^{ux}}{q_0^i} BST \frac{V_i^{ux}}{q_0^i}; \frac{V_i^{ux}}{q_0^i} C_f EX \frac{V_i^{ux}}{q_0^i}; \frac{V_i^{ux}}{q_0^i} B(d) ST(d) \frac{V_i^{ux}}{q_0^i};$$

$$\frac{V_i^{ux}}{q_0^i} TU(c) TU(o) \frac{V_i^{ut}}{q_0^i}; \quad (6)$$

$$\frac{V_i^{ut}}{q_0^i} TU(o) ST \frac{V_i^{ut}}{q_0^i}.$$

In (6) Kl_1 – line of the last ticket desk, behind which a passenger turns to the left to one of turnstiles TU_z; s – number of steps that a passenger will make to the first turn to the left; b – number of steps that a passenger will make to the first turn to the right; x – number of steps after the turn to the turnstile z; t – phase of passenger movement after passing the turnstile z; C_f – passengers of a ticket desk f, forming a queue at the entrance to the platforms of commuter trains; TU (c), TU (o) – open and closed turnstiles, respectively.

In the description of behavior of passenger flow (6) not all of them after going down from the escalator, turn to the right to the entrance to commuter trains platforms. They can make a few steps forward, and then turn to the left. This choice depends on many factors: physical, mental state, the state of space (whether it is free), etc., and because of this it is modeled on the basis of a random dependence:

$s_i = 10 \cdot p_i$, (7)

where p_i – a random number between 0 and 1, rounded to the first digit after decimal place.

Given the characteristics of TIH planning structure, it is possible to assume that passenger flows V^u, V^m, V^p, moving past ticket desks to the turnstiles of the entrance to commuter trains platform, when it is large, should move through long queues to ticket desks. This situation in description of a flow (6) is modeled by the following fragment:

$$\frac{V_i^{ux}}{q_0^i} C_f EX \frac{V_i^{ux}}{q_0^i}; \frac{V_i^{ux}}{q_0^i} B(d) ST(d) \frac{V_i^{ux}}{q_0^i}. \quad (8)$$

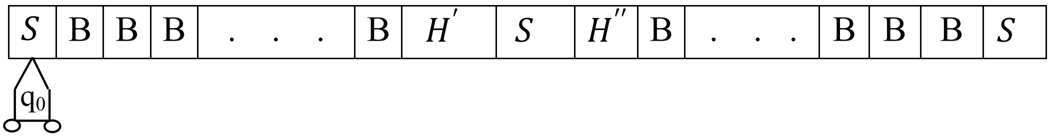
Set of expressions (9) characterize the behavior of a passenger flow $C^{uк}$, the subjects of which need to buy ticket at TIH ticket desks:

$$\frac{C_i^{uk}}{q_0^i} BST \frac{C_i^{ukb}}{q_1^i}; \frac{C_i^{ukb}}{q_1^i} BST \frac{C_i^{ukb}}{q_2^i}; \ldots; \frac{C_i^{ukb}}{q_{b-1}^i} BST \frac{C_i^{ukb}}{q_b^i}; \frac{C_i^{ukb}}{q_b^i} BR \frac{C_i^{uks}}{q_0^i};$$

$$\frac{C_i^{uks}}{q_0^i} BST \frac{C_i^{uks}}{q_1^i}; \frac{C_i^{uks}}{q_1^i} BST \frac{C_i^{uks}}{q_2^i}; \ldots; \frac{C_i^{uks}}{q_{s-1}^i} BST \frac{C_i^{uks}}{q_s^i}; \frac{C_i^{uks}}{q_s^i} Kl_1 L \frac{C_i^{ukf}}{q_0^i};$$

$$\frac{C_i^{ukf}}{q_0^i} BST(f) \frac{C_i^{ukf}}{q_0^i}; \frac{C_i^{ukf}}{q_0^i} C^{kf} EX \frac{C_i^{ukf}}{q_0^i}; \frac{C_i^{ukf}}{q_0^i} B(d) ST(df) \frac{{}_i^{ukf}}{q_0^i};$$

$$\frac{C_i^{ukf}}{q_0^i} K_f EX(t) \frac{C_i^{ukh}}{q_1^i}; \frac{C_i^{ukh}}{q_1^i} K_f R \frac{C_i^{ukh}}{q_0^i}; \frac{C_i^{ukh}}{q_0^i} BST(z) \frac{{}_i^{ukh}}{q_0^i}; \quad (9)$$



Pic. 3. Division of TIH space into zones.

$$\frac{C_i^{ukh}}{q_0^i} TU_z(c) TU_z(o) \frac{C_i^{ukh}}{q_0^i}; \frac{C_i^{ukh}}{q_0^i} TU_z(o) ST \frac{C_i^{ukt}}{q_0^i}.$$

Here f is a phase of a passenger movement from the moment of choice of a ticket desk to the purchase of a ticket; $C^{\kappa f}$ – passenger flow, waiting in a queue to be served at a ticket desk; K_f – ticket desk with number f; $EX(t)$ – time, which is taken by a cashier to sell a ticket; h – phase of passenger movement from the purchase of a ticket to the turnstiles.

In describing $C^{u\kappa}$ (9) a passenger after turning to the left to the ticket desks, make a decision to which ticket desk he will move. He makes it, judging from the length of a queue in front of each ticket desk, according to the expression:

$K_i = \min_f \{R_1, R_{2, \ldots,} R_f\}$, (10)

where R_i is a length of the queue in front of i-th ticket desk, and a passenger chooses the one with the minimum queue among f ticket desks. Thereafter C^{ukx} converts to the symbol C^{ukf}, which means the beginning of a new phase – movement ST(f) to the selected ticket desk f occurs. This phase continues until a passenger reaches the «back» of the last person, waiting for a ticket, in this queue.

A passenger, while he is in the queue, cannot make a full step, as the zone in front of him is occupied. Then he begins to move «slowly» making incomplete step. If a part of the zone with the size B (d) is released, and then a passenger respectively makes a step with the size ST (d). Virtually in space there are many grids with different sampling increment d.

Passenger flows C^{mk} and C^{pk} are described similarly.

The simplest flows are flows of passenger arriving at TIH, because they do not have to solve any problem, except one: to exit TIH. For example, passengers W^{pu} from «intercept» parking move directly through the distribution hall to the escalator (11):

$$\frac{W_i^{pu}}{q_0^i} EPST \frac{W_i^{pub}}{q_1^i}; \frac{W_i^{pub}}{q_1^i} BST \frac{W_i^{pub}}{q_2^i}; \ldots;$$
$$\frac{W_i^{pub}}{q_{b-1}^i} BST \frac{W_i^{pub}}{q_b^i}; \frac{W_i^{pub}}{q_b^i} BR \frac{W_i^{pur}}{q_0^i};$$
$$\frac{W_i^{pur}}{q_0^i} BST \frac{W_i^{pur}}{q_0^i}; \frac{W_i^{pur}}{q_0^i} W_l^{pur} EX(r) \frac{W_i^{pur}}{q_0^i};$$
$$\frac{W_i^{pur}}{q_0^i} B(d) ST(d) \frac{W_i^{pur}}{q_0^i}; \quad (11)$$
$$\frac{W_i^{pur}}{q_0^i} ESST \frac{W_i^{pue}}{q_0^i},$$

where EP – line of the entrance to the second floor of TIH from «intercept» parking; $EX(r)$ – time spent by a passenger, waiting to enter the escalator; ES – line of escalators operating in descending direction; e – index of a passenger who has left the second floor of TIH.

Using fragments describing TIH passenger flows it be seen that the most difficult situation for the organization of passenger traffic at a given architectural and planning solution, is in the central part of the 2nd floor of TIH.

Conclusions. *Application of the technology of the formalized description of TIH passenger flows makes it possible to systematize understanding of the processes occurring in TIH and to analyze general properties of transport systems, abstracting from the details specific to each mode of transport or a system, as well as to take into account logical dependencies in the organization of passenger traffic and passenger movement.*

Keywords: transport interchange hubs, passenger transportation, mathematical modeling, passenger flows, passenger behavior logic.

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