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SIMULATION MODELING OF DEPARTING PASSENGER FLOWS FROM METRO STATION

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Abstract

Simulation modeling has been a very important tool to study the passenger flows in transport. The aim of the simulation reserch was to evaluate the passenger flows in metro station. A methodology for processes simulation has been developed by using a direct-event approach and theory of queuing. In this study was investigated the departing passenger flows from metro station with two platforms. The passenger flow was investigated with multi-level model in four stages: entrance of the metro station, entrance-hall, validating machines, escalators and stairs. In the study was observed the number of passenger out system, total time in system, number of passenger waiting in queue, waiting time in queue, unavailable device probability. The simulation modelling has been applied to examine the Metro Station Stadium „Vasil Levski" from Sofia's metro system.The research has been conducted by using a fully licensed software Arena Enterprise Suite Academic Rockwell, version 14.

Introduction

Simulation models have important implications to solve problems and decision-making. The simulation of processes in metro stations is important for making management decisions related to transportation. Metro stations is an intresting subject for simulation modelling and that is the reason why some authors have conducted studies in this area. A queuing network analytical model of station is created in [10] for calculating subway station capacity, which is built by M/G/C/C state dependent queuing network and discrete time Markov chain. In [7] is elaborated a simulation model of the rail network including a group of four consecutive stations for simulation the vehicle operating and compute special system performance parameters. In [8] a simulation model for streams of passengers has been designed for metro stations. In [1] three stations from the Montreal's metro system are taken for simulation with simulation software Arena. The study simulated an interdependent transit system comprising metro and bus. Principal states of queuing systems in transport have been developed in [1,4,5,6,9].

A detailed simulation of the processes in the entrance-hall, validating machines and subway leading to platforms, has not been conducted in the studies mentioned above.

The aim of this study is to develop a methodology of simulation modeling for departing passenger flows from metro station.

1. A presentation of a metro station as the queue theory

The metro station has usually two entrance-hall (vestibule) - East and West. The approaches for entering in in each of the vestibules may be one or more. It depends on the design of the metro station. The metro stations may be with one (common) platform or with two platforms. In the first case the entry of passenger flows to the platform is carried out in total validators for both directions. In the second case, however, the entry of passenger flows takes place in specialized validators for each direction, which point to the appropriate platform. This article has been made research for the case of metro station with two platform. In figure 1 is presented a scheme for metro station with two platforms.

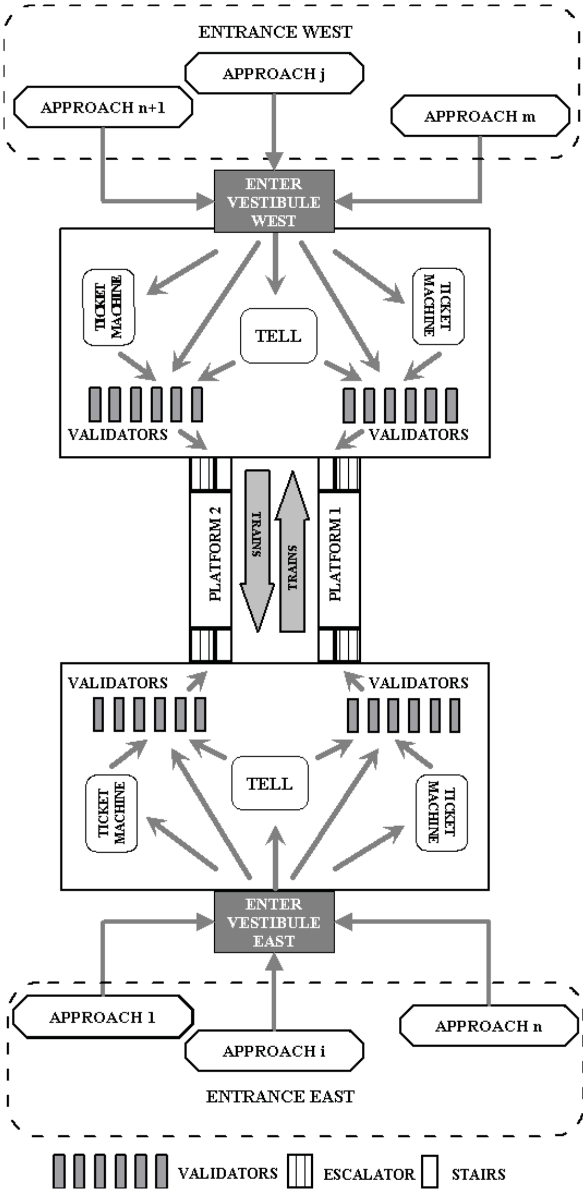

Fig.1 Scheme for metro station with two platforms

A metro station is presented by queueing theory as a multi-level open system without priority with four consecutive servicing devices which have their own characteristics. In fig.2 is presented a scheme of multi-level system for metro station with two platforms. The stages of the multi-level model are:

- 1st stage: Entrance of the metro station. At this stage, passengers' waiting in the entrance-hall has been observed. When the entering a metro station is accomplished from two directions (East, West) therefore, entrance-halls are two. Because of that in the next stages servicing devices are examined for both directions separately.
- 2nd stage: Entrance-hall. Here, processes of servicing passengers from the entrance hall to the validating machines have been observed. The focus is on ticket offices and ticket machines.

- 3rd stage: Validating machines. Passengers' going through validating machines is observed closely at this stage.
- 4th stage: Escalators and stairs. Passengers' transition from validating machines to a platform.

In the defined multi-level system, there is not any buffers and that's why it could be seen as compounded of separate single-level systems taking into account the transformations of streams of passengers between them. When the incoming stream of passengers is Poison, and the time of service is exponential and the system is without failures, then the outgoing stream of passengers is also Poison's, [3]. In the study, the system M/M/S has been taken for all stages, e.g. Poison's incoming stream of passengers, exponential time for service, and multi-channel system with a number of channels S. When a metro station as only one entrance then for the first level the system is M/M/1.

The intensity of a stream of passengers λ, coming in the metro station is formed by a stream of passengers which enter the entrance-hall from the two entrances of the metro station- East λ_1 and West λ_2.

$$\lambda = \lambda_1 + \lambda_2 \text{, passengers per hour} \qquad (1)$$

$$\lambda_1 = \gamma_m.\lambda \text{ , passengers per hour} \qquad (2)$$

$$\lambda_2 = (1-\gamma_m).\lambda \text{ , passengers per hour} \qquad (3)$$

where: γ_m is the coefficnent which shows the relative part of a stream of passengers coming in a metro station from an entrance with direction West. Dependng on the way of suppliment of tickets, a part of the stream of people goes directly to the validating machines (passengers provided with monthly passes or electronic tickets), another part of the stream of passengerts goes to places issuing tickets (ticket offices and ticket machines).

The intensity of the stream of passengers from an entrance with direction East λ_{1v} which goes directly to the validating machines is:

$$\lambda_{1v} = \alpha_{1m}\lambda_1 \text{, passengers per hour} \qquad (4)$$

where: α_{1m} is a coeffient which shows the relative part of a stream of passengers for direction East that goes directly to the validating machines.

The passenger flows who go directly to the validators in metro station with two platform are divided to validators for platform 1 and for platform 2, which provide traffic in opposite directions.

The intensity of the passengers flow from the East entrance, which are directly to the validators for platform 1 is:

$$\lambda_{1v}^{p1} = \alpha_{1m}^{p1}\lambda_{1v} \qquad (5)$$

where: α_{1m}^{p1} is a coeffient which shows the relative part of a stream of passengers λ_{1v} that goes directly to the validating machines for platform 1. α_{1m}^{p2} is a coeffient which shows the relative part of a stream of passengers λ_{1v} that goes directly to the validating machines for platform 2.

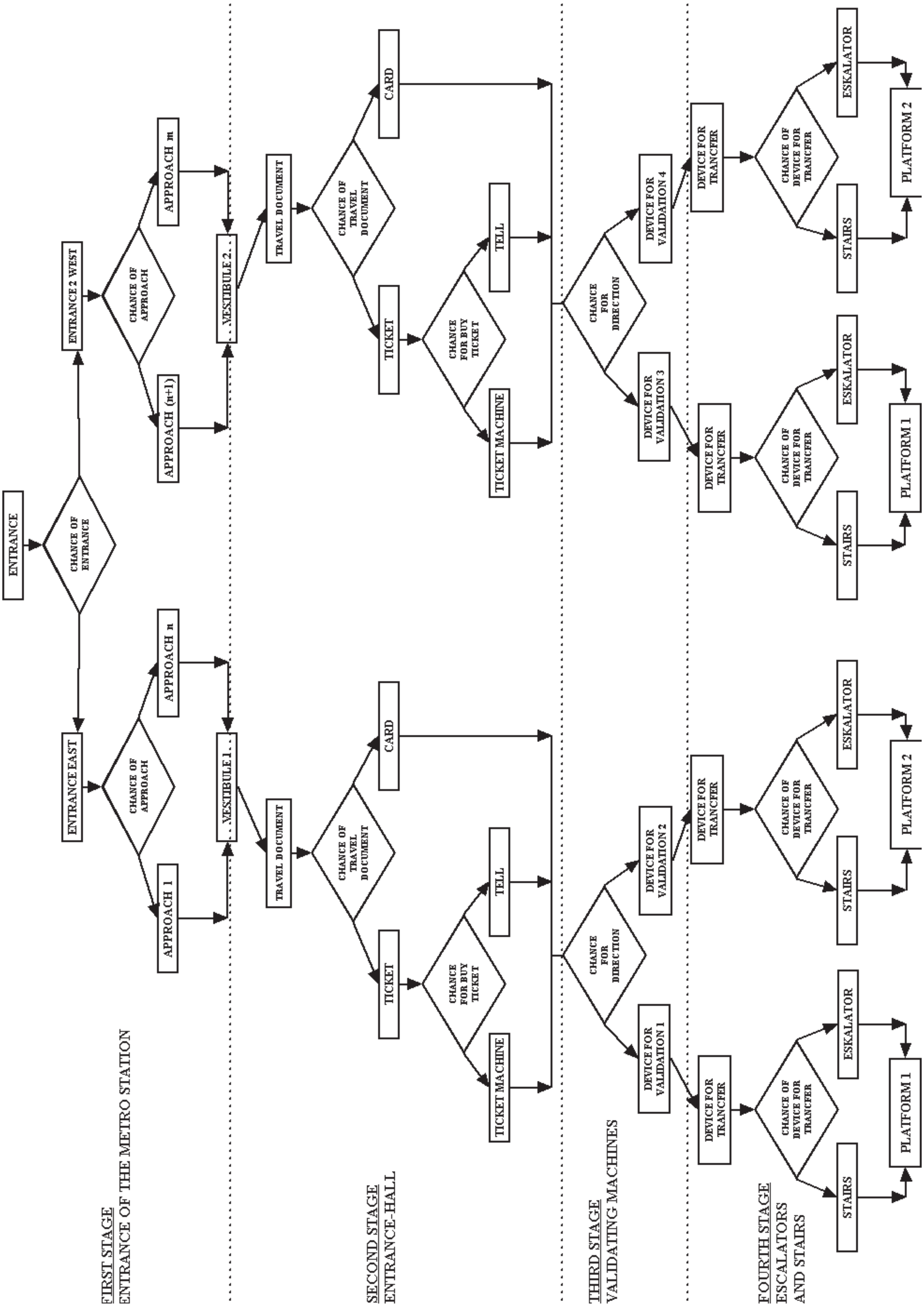

Fig.2 Scheme of multi-level system for metro station with two platforms

The intensity of the passengers flow from the East entrance, which are directly to the validators for platform 2 is:

$$\lambda_{1v}^{p2} = \alpha_{1m}^{p2} \lambda_{1v} \quad (6)$$

$$\alpha_{1m} = \alpha_{1m}^{p1} + \alpha_{1m}^{p2} \quad (7)$$

The intensity of a stream of passengers $\lambda_{1t,a}$ from entrance East which goes to buy tickets from ticket offices or ticket machines is:

$$\lambda_{1t,a} = (1 - \alpha_{1m}).\lambda_1 \text{ , passengers per hour} \quad (8)$$

$$\lambda_{1t,a} = \lambda_{1t} + \lambda_{1a} \text{, passengers per hour} \quad (9)$$

The intensity of the stream of passengers λ_{1t} from entrance East which goes to buy tickets from ticket offices or ticket machines is :

The coefficient which shows the relative part of the whole stream of passengers that goes in entiers 1 to ticket offices only is $\alpha_{1m}.\beta_{1m}$, where β_{1m} is the coefficient which shows the relative part of the whole stream of passengers that goes to ticket offices and ticket machines with a focus on the part that goes to ticket offices only.

$$\lambda_{1t} = \beta_{1m}.\lambda_{1t,a} \text{, passengers per hour} \quad (10)$$

The intensity of the stream of passengers λ_{1a} from entrance East that goes to buy tickets from ticket machines is :

$$\lambda_{1a} = (1 - \beta_{1m}).\lambda_{1t,a} \text{, passengers per hour;} \quad (11)$$

The intensity of service of a stream of passengers by servicing machines is: μ_1, μ_2 is the intensity of service at a entrance of an entrance-hall of a metro station with direction East/West, passengers per hour; μ_{1t}, μ_{2t} is the intensity of service of ticket offices at an entrance-hall with direction East/West, passengers per hour; μ_{1a}, μ_{2a} is the intensity of service of ticket machines at an entrance-hall with direction East/West, passengers per hour; μ_{1v}, μ_{2v} is the intensity of service provided by one validating machine at an entrance-hall with direction East/West, passengers per hour.

The number of servicing devices for each stage is: n_{1t}, n_{2t} is the number of ticket offices at an entrance-hall with direction East/West; n_{1a}, n_{2a} is the number of ticket machines at an entrance-hall with direction East/West; n_{1v}, n_{2v} is the number of validating machines at an entrance-hall with direction East/West at a metro station; n_{1v}^{p1}, n_{1v}^{p2} is the number of validating machines at an entrance-hall with direction East for platform 1(2) at a metro station; n_{2v}^{p1}, n_{2v}^{p2} is the number of validating machines at an entrance-hall with direction West for platform 1(2) at a metro station.

$$n_{1v} = n_{1v}^{p1} + n_{1v}^{p2};\ n_{2v} = n_{2v}^{p1} + n_{2v}^{p2} \quad (12)$$

A mathematical presentation of the intensity of a stream of passengers from entrance West is identical to the formulation shown above.

In cases where there is only one metro station entrance formulas for determining the intensity of passenger flow in subsystems are identical.

To avoid detention at an entrance of a metro station the condition must be met:

$$\lambda_1 \le \lambda_c \text{ и } \lambda_2 \le \lambda_c \qquad (13)$$

where: λ_c is the limit intensity of the incoming stream of passengers where there would be observed a passengers waiting at an entrance of a metro station.

$$\lambda_c = p_m.F_m\text{, passengers per hour} \qquad (14)$$

where: p_m is the coefficient showing the optimal number of passengers per m^2 when conditions of comfort and safety are met, pass./m^2. (p_m =7pass./m^2.). F_m is the area that could be used by passengers freely (without stepping on any restrict lines). For example, the Metro Station Stadium "Vasil Levski" has λ_c = 3350 passengers per hour per platform.

2. Simulation modelling with Arena Software

The system for imitation modelling Arena allows us to shape dynamic model for hereogeneous processes which could be optimased [11]. Modelling is conducted by using the modelling language SIMAN and an animation system. It has been used blocks for modelling which connect to each other in accordance to dependences as well as operations in the studied system. The Arena building blocks used are Create, Waiting, Assign, Signal, Split, Hold, Delay and Dispose. Modules are divided in two categories: flowchart modules and data modules. Flowchart modules describes the dynamical processes of movement and changes in the module. Data modules are defining the characteristics of the various objects like entities, resources and queues. In fig.3 is presented a simulatin model in Arena of metro station Stadium "Vasil Levski" which is a part of Line 1 (Obelya-Tsarigradsko shose) and has been shown in the study. This metro station is situated in centre of Sofia and there are a big passenger flow. It has only one entrance and one approche for entrance in vestibule. This metro station has two platforms. The study is conducted for a peak hour period. Model is developed in the simulation software Arena Enterprise Suite Academic version 14.0.by Rockwell Software.

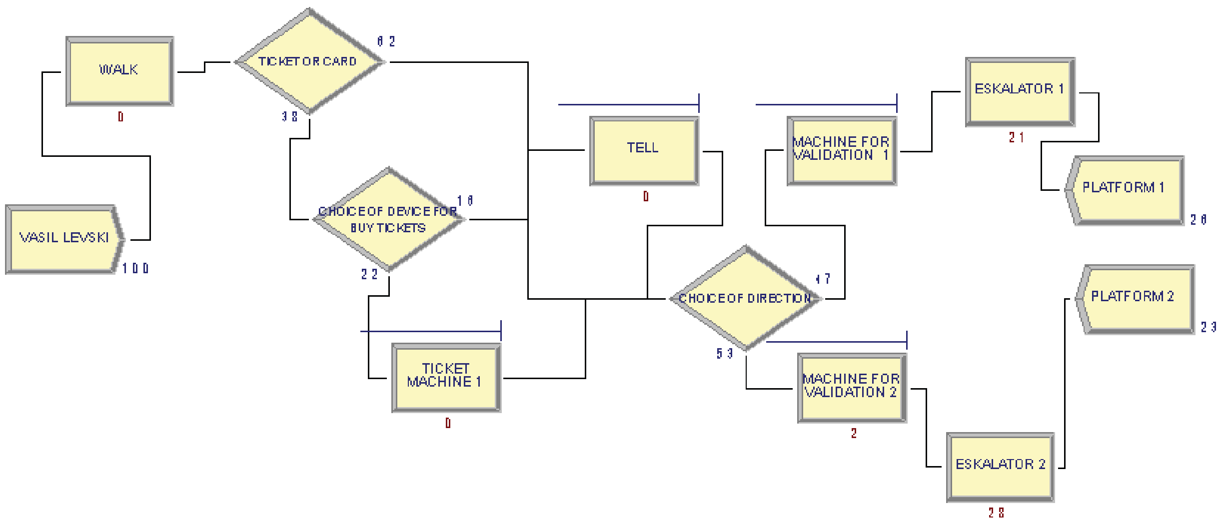

Fig.3 Simulation model for metro station „Vasil Levski" from Sofia's metro system in Arena sofrware

3. Determination the number of replication

One of important steps in simulation process is to determine the number of replications (simulation runs). This affects the accuracy of the results. In this research it is applied two ways to determine the minimum number of replications. The first ways is proposed by [2] for estimating number of replications. The second way is by using the nalf width of the confidence interval. The study was performed for 95% confidential level.

First way. The minimum number of replication $N(n)$ to achieve the desired level of accuracy is calculated by following formula, [2]:

$$N(n)_1 = \left(\frac{t_{n-1,\alpha/2}.s}{\bar{x}.\varepsilon} \right) \tag{15}$$

where $\bar{x}$ is the mean estimate of an initial n number of runs; s is the standard deviation estimate of *n* number of runs; α is level of confidence; ε is allowable percentage of error; $t_{n-1,\alpha/2}$ is critical value from *t*-tables of the two-tailed *t*-distribution at α level of significance, given *n-1* degrees of freedom.

- Second way. The half width says that in 95% of repeated trials, the sample mean would be reported as within the interval sample mean ± half width. The half width is calculated with the equation:

$$h = t_{n-1,\alpha/2} \frac{s}{\sqrt{n}} \tag{16}$$

The requirement is this to half width to be "small". For that it is nessery the calculated half width to be less than a pre-specified one. Taking into account that the minimum number of replication can be determined by following formula:

$$N(n)_2 = n_0 . \frac{h_0^2}{h_1^2} \tag{17}$$

where: h_0 is the half width for initial n_0 runs, calculated by formula (16), h_1 is pre-specified half width which is less than h_0.

4. Results

The model has been investigated of metro station Vasil Levski for peak hour in seven variants of passenger flows. For determined the minimal number of replications is investigated the average total time in system. In table 1 is shown the parameters and cases for simulation. Table 2 presents the results of replications for variant 7 (2000 passengers per hour) and minmal number of replications determined by formulas (15) and (17). In table 3 is shown a comparision of the results for all variants received by Arena simulation with 100 replications and peak hour period of simulation run. The number of replication is bigger than the minimal number $N(n)_1$ and $N(n)_2$.

Tab. 1 Cases for simulation

Variants	1	2	3	4	5	6	7
Incoming stream of passengers	800	1000	1200	1400	1600	1800	2000
Coefficients	γ_m =1; α_m =0,3; β_m =0,5; α_m^{p1} = α_m^{p2} =0,5						
Tell: μ_t =360 Passengers per hour; Ticket machine: μ_a =1000 Passengers per hour Machine for validation: μ_v =1800 Passengers per hour; Number of tells: n_t =1; Number of ticket machine: n_a =2; Number of machine for validation: n_v^{p1} =6; n_v^{p1} =6							

Tab. 2 Results of replications for variant 7

Replications	**Number out system, number of passengers**	**Average total time in system, min**	**Half width**
1	1844	1,25	0,07
2	1892	1,37	1,52
3	2008	1,34	0,32
4	1961	1,33	0,17
5	2022	1,41	0,24
$\bar{x}$, min=1,34; n_0 =5; s=0,06; t=2,776; ε =0,05; h_0 =0,07; h_1=0,05; $N(n)_1$=7; $N(n)_2$ =11			

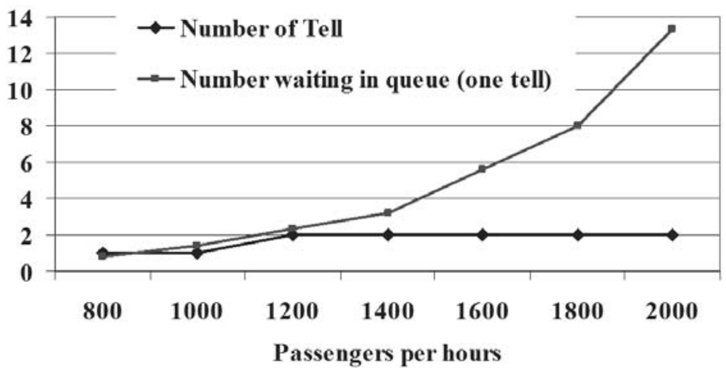

Fig.4 Variation of number of tell and number of waiting in queue

The number of tells depends on the ratio of the input passenger flow and the intensity of the service. If it exceeds value one must be introduce additional tell. In fig.4 is shown the change of the number of passengers waiting at the service depending of number of various passenger flows who enters the metro station. Dependig the studied initial conditions it is necessary to introduce a second tell in the vestibule when the entrance passengers per hour is 1200. Opening an additional till depends on the capailities and the infrastructure of the entrance-hall.

Simulation modelling allows us to examine and analyse many tehnological situations in different time intervals, with different incoming and outgoing streams of passengers and different technological time for service, with different usage of capacity and capabilities of a metro system, which are very hard to be examined in real time.

Tab. 3 Results for variants (number of replications 100)

Number of passengers per hours	**800**	**1000**	**1200**	**1400**	**1600**	**1800**	**2000**
Number out system	779	1012	1185	1339	1565	1766	1972
Total time in system, min.	1,15	1,18	1,21	1,24	1,31	1,36	1,47
Number of passengers waiting in queue							
Machine for validation 1	0,06	0,37	0,21	0,28	0,41	0,53	0,73
Machine for validation 2	0,04	0,09	0,15	0,20	0,30	0,40	0,55
Tell	0,79	1,42	2,36	3,19	5,58	8,02	13,34
Ticket machine	0,01	0,04	0,05	0,07	0,12	0,15	0,20
Waiting time in queue, min.							
Machine for validation 1	0,01	0,02	0,02	0,02	0,03	0,03	0,04
Machine for validation 2	0,01	0,01	0,01	0,02	0,02	0,03	0,03
Tell	0,38	0,53	0,74	0,89	1,32	1,67	2,51
Ticket machine	0,01	0,01	0,02	0,02	0,03	0,03	0,04
Unavailable device probability							
Machine for validation 1	0,04	0,05	0,06	0,07	0,08	0,09	0,10
Machine for validation 2	0,03	0,04	0,05	0,06	0,07	0,08	0,08
Tell	0,34	0,43	0,05	0,58	0,67	0,74	0,82
Ticket machine	0,03	0,04	0,05	0,05	0,06	0,07	0,08

Conclusion

The conducted research allows us to make the following conclusions:

- A methodology for presenting a metro station with two platforms as a multi-level system has been developed sucessfully.
- A multi-level system is examined as a compounded of separate single-level systems with Poison's incoming stream of passengers, exponential time for service and s number of channels (M/M/s).

- The decomposition of levels is consistent with passengers' going through and servicing them by the system: entrance, entrance-hall (ticket offices and ticket machines),escalators and stairs.
- A simulation model for metro station with two platforms has been elaborated.
- In research has been determined the minimal number of replications for simulation model.
- In the study has been defined the number of passengers in which should introduce an additional tell.
- A simulation model of a metro system has been developed with Arena software.

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