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SIMULATION MODELING OF TECHNOLOGICAL PROCESSES IN SUBWAY STATION

Svetla STOILOVA [1]
Veselin STOEV [2]

Abstract *– A methodology for processes simulation in a metro station has been developed by using a direct-event approach. A metro station has been represented as a multi-level system for mass service. The research has been conducted by using a fully licensed software Arena Academic Rockwell. The exploiting criteria resulted from the simulation are such as time for passengers waiting at the different stages of servicing, availability of servicing machines, etc. Simulation modelling gives very useful information for exploitation of a metro station which could not be observed or gained otherwise such as an average time for passengers waiting at metro stations, an average time of available subsystems. This allows us to suggest technological decisions to improve service. The simulation modelling has been applied to examine the Metro Station Serdika from Sofia's metro system.*

Keywords – subway, subway station, simulation modelling, queue theory, ARENA software.

1. INTRODUCTION

A metro network system represents an ecological and high-speed rail transport which takes an important role helping public transport satisfy any needs for transportation in cities. Metro stations are places where incoming stream of passengers should be served quickly. 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. 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 [1] for calculating subway station capacity, which is built by M/G/C/C state dependent queuing network and discrete time Markov chain. In [2] 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 [3] a simulation model for streams of passengers has been designed for metro stations. Principal states of systems for mass service have been developed in [4,5,6].

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 technological processes in a metro station.

2. A PRESENTATION OF A METRO STATION AS THE QUEUE THEORY

A metro station is presented as a multi-level open system for mass service without priority with four consecutive servicing devices which have their own characteristics, fig.1.

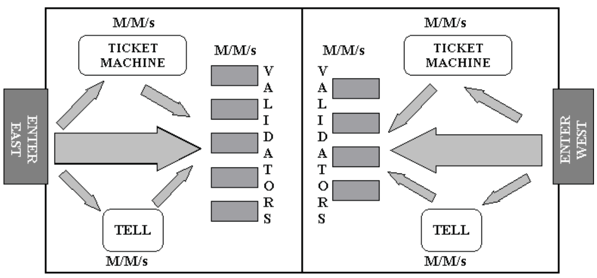

Fig.1. Sheme of metrostation

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. As a matter of principle, metro stations might have one or two entrances. In the second case, entering a metro station is accomplished from two

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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. 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.

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

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

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

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 te validating machines is:

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

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

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:

$$\lambda_{1t,a} = (1-\alpha_{1m}).\lambda_1 \text{, passengers per hour;} \quad (5)$$

$$\lambda_{1t,a} = \lambda_{1t} + \lambda_{1a} \text{, passengers per hour;} \quad (6)$$

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

$$\lambda_{1t} = \beta_{1m}.\lambda_{1t,a} \text{, passengers per hour;} \quad (7)$$

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.

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

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

The intensity of service of a stream of passengers by servicing machines is as follows:

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.

A mathemathical presentation of the intensity of a s tream of passengers from entrance West is identical to the formulation shown above.

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

$$\lambda_1 \le \lambda_c \text{ и } \lambda_2 \le \lambda_c \quad (9)$$

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.

$$\lambda_c = p_m.F_m \text{, passengers per hour;} \quad (10)$$

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 Serdika has λ_c=6706 passengers per hour.

The parametres of the system for mass service are shown in table 1.

Tab. 1. Parameters of system

System queue	Parameters	
	Direction East (1)	Direction West (2)
Entrance: M/M/1	λ_1, μ_1, 1	λ_2, μ_2, 1
Tells: M/M/s	λ_{1t}, μ_{1t}, n_{1t}	λ_{2t}, μ_{2t}, n_{2t}
Ticket machines: M/M/s	λ_{1a}, μ_{1a}, n_{1a}	λ_{2a}, μ_{2a}, n_{2a}
Machines for validation: M/M/s	λ_1, μ_{1v}, n_{1v}	λ_2, μ_{2v}, n_{2v}

3. APROBABTION OF THE METHODOLOGY

3.1. Basic parameters

A simulation model of the Metro Station Serdika which is a part of Line 1 (Obelya-Tsarigradsko shose) has been shown in the study. The station is one of the busiest metro stations of Sofia's metro system.

The study is conducted for a peak period in three different ways shown in table 2:

Tab. 2. Cases for simulation

Case	1	2	3
Incoming stream of passengers	λ = 3600 Passengers per hour		λ =6000 Passengers per hour
Coefficients	γ_m =0,70; α_{1m} =0,85; α_{2m} =0,75; β_{1m} =0,7; β_{2m} =0,7		
Tell	$\mu_{1t} = \mu_{2t}$ =360 Passengers per hour		
Ticket machine	$\mu_{1a} = \mu_{2a}$ =1000 Passengers per hour		
Machine for validation	$\mu_{1v} = \mu_{2v}$ =1800 Passengers per hour		
Number of tells	n_{1t} =1 n_{2t} =1	n_{1t} =2 n_{2t} =1	n_{1t} =2 n_{2t} =2
Number of ticket machine	n_{1a} =2; n_{2a} =2		
Number of machine for validation	n_{1v} =5; n_{2v} =4		

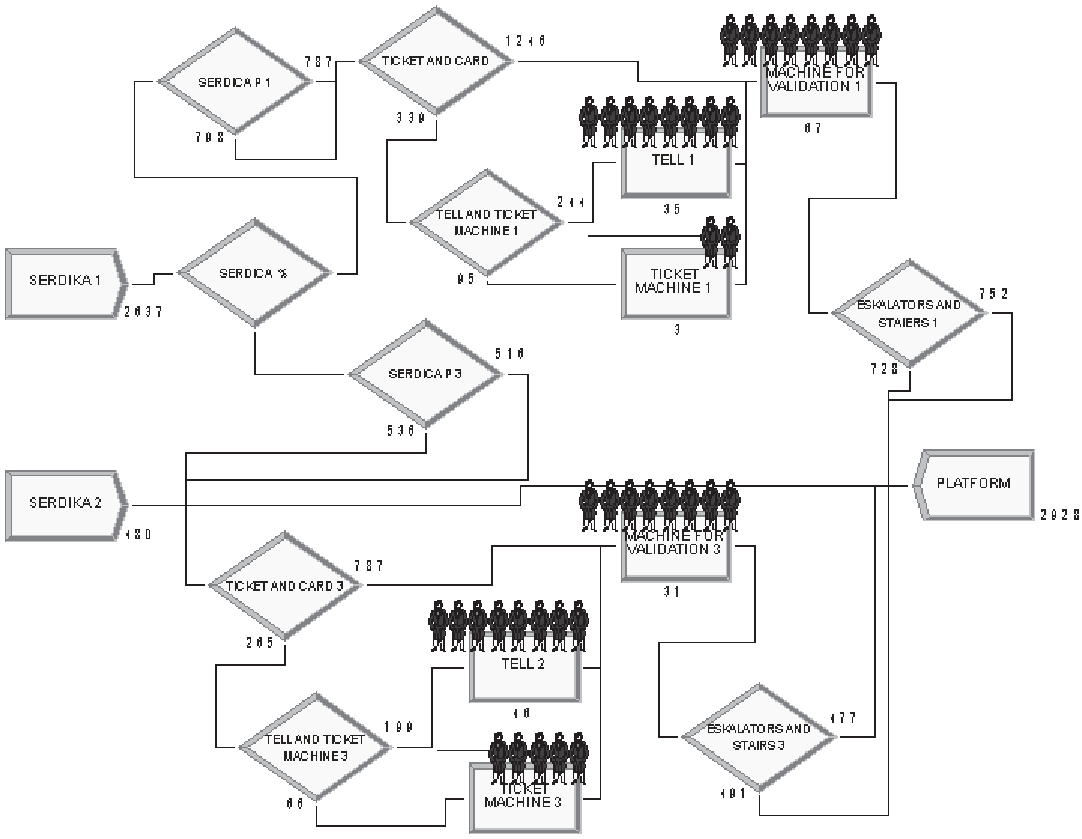

Fig.2. Simulation model in ARENA

3.2. An application of Arena Software for simulation modelling

The system for imitation modelling Arena allows us to shape dynamic model for hereogeneous processes which could be optimased [8]. 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 simulation model for Metro Stattion Serdika of Sofia's Metro System has been shown in figure 2. Ten replications have been done for each of the cases after that an average value for each observed indicator is reported. A comparision of the results has been shown in table 3.

Tab.3. Results of simulations

Indicator	Variant		
	1	**2**	**3**
Number out system, pass.	3608	4061	6511
Total time in system, sec.	37	23	36
Number waiting in queue, passengers			
Machine for validation 1	5	6	20
Machine for validation 2	4	4	8
Tell 1	17	3	21
Tell 2	7	6	9
Ticket machine 1	0	0	1
Ticket machine 2	0	0	0
Waiting time in queue, sec.			
Machine for validation 1	9	10	19
Machine for validation 2	10	10	13
Tell 1	173	29	114
Tell 2	95	84	63
Ticket machine 1	2	2	10
Ticket machine 2	1	2	3
Unavailable device probability			
Machine for validation 1	0,24	0,24	0,40
Machine for validation 2	0,28	0,28	0,31
Tell 1	0,88	0,46	0,78
Tell 2	0,70	0,68	0,63
Ticket machine 1	0,05	0,06	0,18
Ticket machine 2	0,04	0,05	0,08

The maximum number of waiting passengers that would be served at one till in a ticket office is assumed to be ten for the study's purposes.

In the first case, the number of tills in ticket offices is not enough for direction East. When an additional till is opened, system state has been imporved (only three customers are waiting). One the other hand, the third case suggests a situation close to the critical point. In this case, both tills in the ticket office are loaded. Opening an additional till depends on the capailities and the infrastructure of the entrance-hall. In the third case, it is important to redirect customers to ticket machines for issuing tickets. The first and the third cases show situations which could happen during a peak hour in case of additional factors such as bad weather, special occasions and so on.

4. CONCLUSION

The conducted research allows us to make the following conclusions:

- A methodology for presenting a metro station as a multi-level system for mass service 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 of a metro system has been developed with Arena software.

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REFERENCES

[1] Zhang,Q., Baoming, H., Dewei., L., *Modeling and simulation of passenger alighting and boarding movement in Beijing metro stations,* Transportation Research Part C 38, pp. 28–43, 2014.

[2] Martinez, F., *Application of SIMAN ARENA Discrete Event Simulation Tool in the Operational Planning of a Rail System*, University of Puerto Rico, 2002.

[3] Ozturk, G., *Simulation & analysis of Izmir metro transportation system,*Department of Industrial Management and Information Systems, Bornova – IZMIR, p.95, 2012.

[4] Karagyozov, K., *Approximation of the moments of processes of traffic flow arrival, interruption and normalization,* Scientific journal "Mechanics, transport, communications"N3, 2013.

[5] Karagyozov, K, *Hierarchical decomposition and synthesis for logistics systems modeling by closed queuing networks,*Scientific journal "Mechanics, transport, communications"N3, 2013

[6] Razmov, T., *Analysis of the trasnport systems through discrete-event modeling,* Scientific journal "Mechanics, transport, communications"N3, 2013

[7] Kachaunov, T., *Modeling and optimization of the transportation processes*, 2nd edition, Publishing house of Todor Kableshkov University of Transport, Sofia, (written in Bulgarian), 2005

[8] http://www.arenasimulation.com