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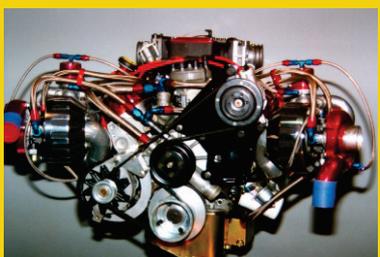
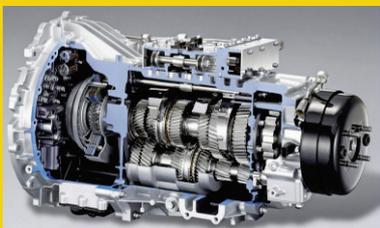
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APPLICATION OF ARENA DISCRETE EVENT SIMULATION TOOL IN THE MODELING OF TECHNOLOGICAL PROCESSES ON DEPARTURE OF PASSENGERS IN SOFIA 'S METRO STATIONS

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Abstract:

In this study has been developed a methodology for processes simulation in a metro station by using a direct-event approach. 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. In the study has been elaborated the simulation models for metro station with common and two platforms. These models have universal characters and could be used for simulations for each metro station of two types. In research have been investigated the metro station SU "Kliment Ohridski" and G.M.Dimitrov. The research has been conducted by using fully licensed software Arena Enterprise Suite Academic Rockwell, version 14.

Keywords: *subway, metro station, simulation modelling, passenger flows, tell, queue theory, ARENA software*

1. 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. 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.

Metro stations are an interesting 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 queuing systems 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 objectives of this research are:

- To develop a methodology of simulation modelling for technological processes with departing passengers in a metro station.

- To elaborate simulations models with ARENA Discrete Event Simulation Tool.

- To investigate the parameters of queuing theory such as number of passenger out system, total time in system, number of passenger waiting in queue, waiting time in queue, unavailable device probability, necessary number of tells.

2. Modelling metro station with queuing theory

The metro station has usually two entrance-halls (vestibule) - East and West. The approaches for entering 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. In figure 1 is presented a scheme for metro station with common platforms, in figure 2 is presented a scheme for metro station with two platforms.

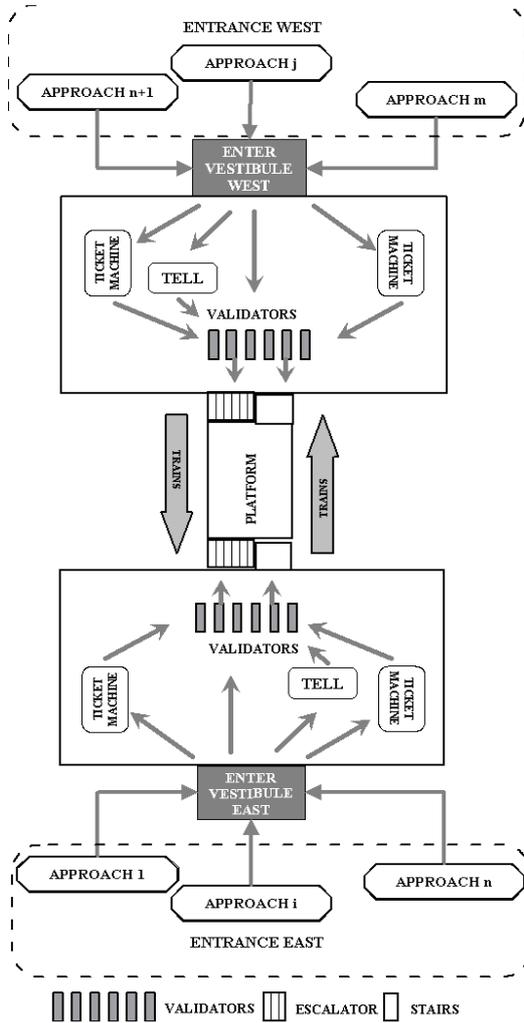


Fig.1 Scheme for metro station with common platform

A metro station is presented by queuing theory as a multi-level open system without priority with four consecutive servicing devices which have their own characteristics. 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.

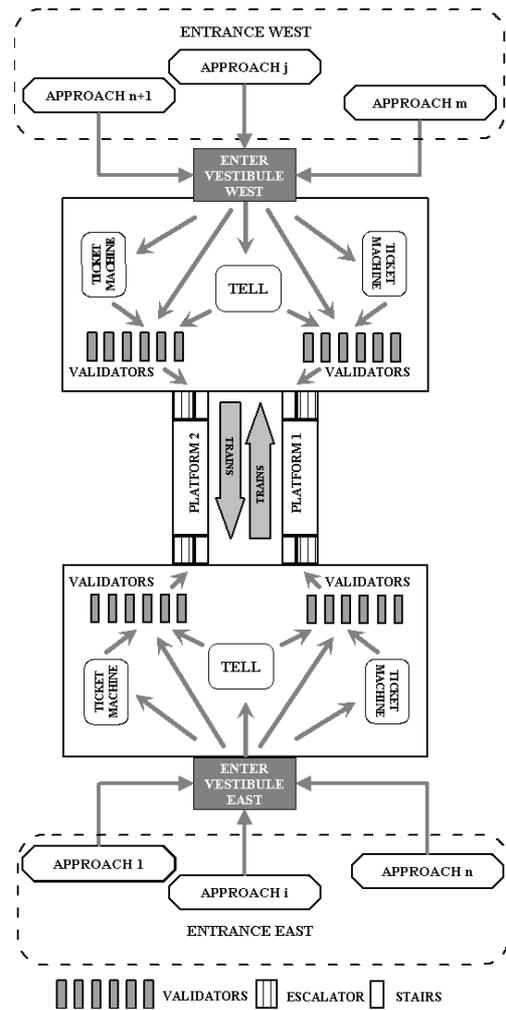


Fig.2 Scheme for metro station with two platforms

In the defined multi-level system, there are 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 Poisson, and the time of service is exponential and the system is without failures, then the outgoing stream of passengers is also Poisson's, [3]. In the study, the system M/M/S has been taken for stages 1, 2 and 3, e.g. Poisson's incoming stream of passengers, exponential time for service, and multi-channel system with a number of channels S. When a metro station is only one entrance then for the first level the system is M/M/1. In the 4th stage the system has been examined by M/D/1 for escalators, e.g. Poisson's incoming stream of passengers, constant time for service, and one channel, and M/M/1 for stairs.

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 .

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

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

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

where: γ_m is the coefficient which shows the relative part of a stream of passengers coming in a metro station from an entrance with direction West depending on the way of supplements 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 passengers 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:

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

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

The passenger flows that go directly to the validating machines in metro station with two platforms are divided to validating machines 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:

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

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

The intensity of the passengers flow from the East entrance, which is 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:

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

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

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

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

The coefficient which shows the relative part of the whole stream of passengers that goes in enters 1 to ticket offices only is $\alpha_{1m} \cdot \beta_{1m}$, 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.

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

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

The intensity of service of a stream of passengers by servicing machines is: μ_1, μ_2 is the intensity of service at an 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 with common platform; 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 with two platforms; 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 with two platforms.

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

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 are 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:

$$\lambda_1 \leq \lambda_c \text{ и } \lambda_2 \leq \lambda_c \quad (13)$$

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.

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

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 . ($p_m = 7 \text{ pass./m}^2$). F_m is the area that could be used by passengers freely (without stepping on any restrict lines). For example, the Metro Station Sofia's University "Sv.Kliment Ohridski" has $\lambda_c = 3350$ pass./hour for common platform; the Metro Station "G.M.Dimitrov" has $\lambda_c = 1675$ pass./hour per a platform.

The parameters of the metro station presented by queuing theory are shown in table 1.

Tab.1. Parameters of system

System queue	Parameters	
	Direction East (1)	Direction West (2)
Entrance: M/M/1	$\lambda_1, \mu_1, 1$	$\lambda_2, \mu_2, 1$
Tells: M/M/s	$\lambda_{1t}, \mu_{1t}, n_{1t}$	$\lambda_{2t}, \mu_{2t}, n_{2t}$
Ticket machines: M/M/s	$\lambda_{1a}, \mu_{1a}, n_{1a}$	$\lambda_{2a}, \mu_{2a}, n_{2a}$
Machines for validation for metro station with common platform: M/M/s	$\lambda_{1v}, \mu_{1v}, n_{1v}$	$\lambda_{2v}, \mu_{2v}, n_{2v}$
Machines for validation for metro station with two platforms: M/M/s	$\lambda_{1v}^{p1}, \mu_{1v}, n_{1v}^{p1}$ $\lambda_{1v}^{p2}, \mu_{1v}, n_{1v}^{p2}$	$\lambda_{2v}^{p1}, \mu_{2v}, n_{2v}^{p1}$ $\lambda_{2v}^{p2}, \mu_{2v}, n_{2v}^{p2}$
Escalators: M/D/1 -metro station with common platform:	$\lambda_{1v}, \mu_e, 1$	$\lambda_2, \mu_e, 1$
-metro station with two platforms:	$\lambda_{1v}^{p1}, \mu_e, 1$ $\lambda_{1v}^{p2}, \mu_e, 1$	$\lambda_{2v}^{p1}, \mu_e, 1$ $\lambda_{2v}^{p2}, \mu_e, 1$
Stairs M/M/1 -metro station with common platform:	$\lambda_{1v}, \mu_s, 1$	$\lambda_2, \mu_s, 1$
-metro station with two platforms:	$\lambda_{1v}^{p1}, \mu_s, 1$ $\lambda_{1v}^{p2}, \mu_s, 1$	$\lambda_{2v}^{p1}, \mu_s, 1$ $\lambda_{2v}^{p2}, \mu_s, 1$

For escalators and stairs the intensity of service of

system is: μ_e is the intensity of service of escalators, passengers per hour; μ_s is the intensity of service of stairs, passengers per hour.

3. Variants of simulations

Simulations of processes with departing passengers from metro form of rush hour in amending the distribution of passengers traveling with a map (they go directly to the validators) and passengers who buy tickets. For each of these sub-options form for passengers who buy tickets - purchase of cash and ticket machines.

The scheme of variants of simulations is shown in fig.3.

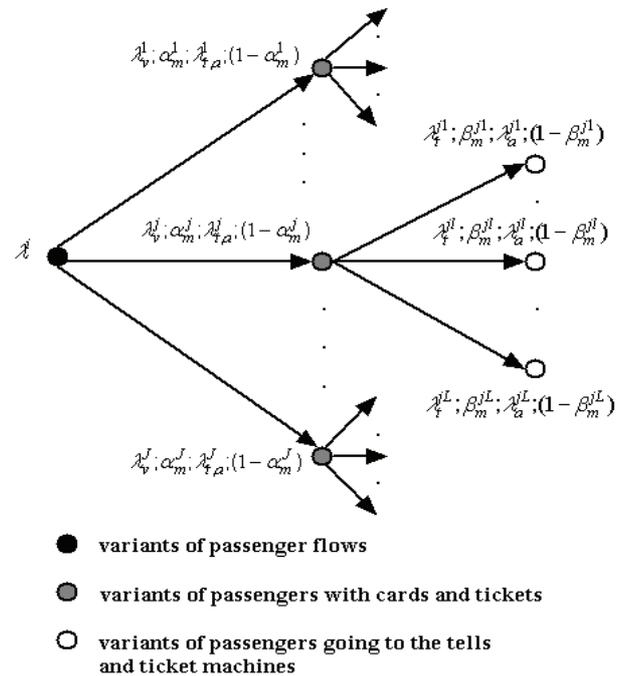


Fig.3. Scheme of tree of variants of simulations

In fig.3 $i = 1, \dots, I$ are the variants of passengers flow entering in metro station; $j = 1, \dots, J$ are the variants the relative part of a stream of passengers with cards; $l = 1, \dots, L$ are the variants the relative part of a stream of passengers that going to the tells.

4. Simulation models whit ARENA discrete event simulation tool

The system for imitation modelling Arena allows us to shape dynamic model for heterogeneous processes which could be optimized [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.

The main modules included in the simulation models for metro stations are CREATE, DECIDE, PROCESS, DISPOSE, etc.

The CREATE module is the generator of passengers, which can simulate passengers to enter into the system. In this module, the initial creating times, the max number of passengers, the time between arrivals and the basic unit of time can be set. This module have name in simulate model:

- "ENTRANCE 1,2 ";
- "THE ORLOV BRIDGE";
- "SOFIA UNIVERSITY";
- "BLV. G.M. DIMITROV 1";
- "G.M. DIMITROV 2"

The DECIDE module is used to determines the percentage of passengers who have more than one choice. This module is used to select the transport document, the selection device for the purchase of transport document, choice of direction, and for the selection of a device for transfer.

The PROCESS module can implement the process of passengers waiting for tells, ticket machines, validators machines and the check-in process. Besides, the waiting queue length and waiting time reflected in the report ultimately are also run in the module. Therefore, this module is the core of the simulation. In this module, the queuing rules, the resources and delay types, etc. This module have name in simulate model:

- "TELL";
- "TICKET MACHINE";
- "VALIDATOR";
- "ESCALATORS";
- "STAIRS".

The function of DISPOSE module is to exit of the simulation environment for passenger entities. In this simulation, the module is set in two positions: one position is used for receiving the passengers who miss the check-in time; the other one is used for receiving passengers who get on the platform, to finish the simulation process. This module have name in simulate model: "PLATFORM 1, 2, etc.

In fig.4 are shown the main modules for simulations models for metro station in ARENA. Fig.5 and fig.6 show the simulation models for metro station with common platform and with two platforms.

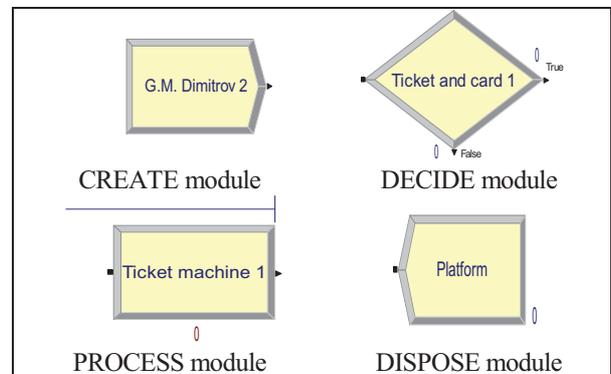


Fig.4. Modules in ARENA simulation model

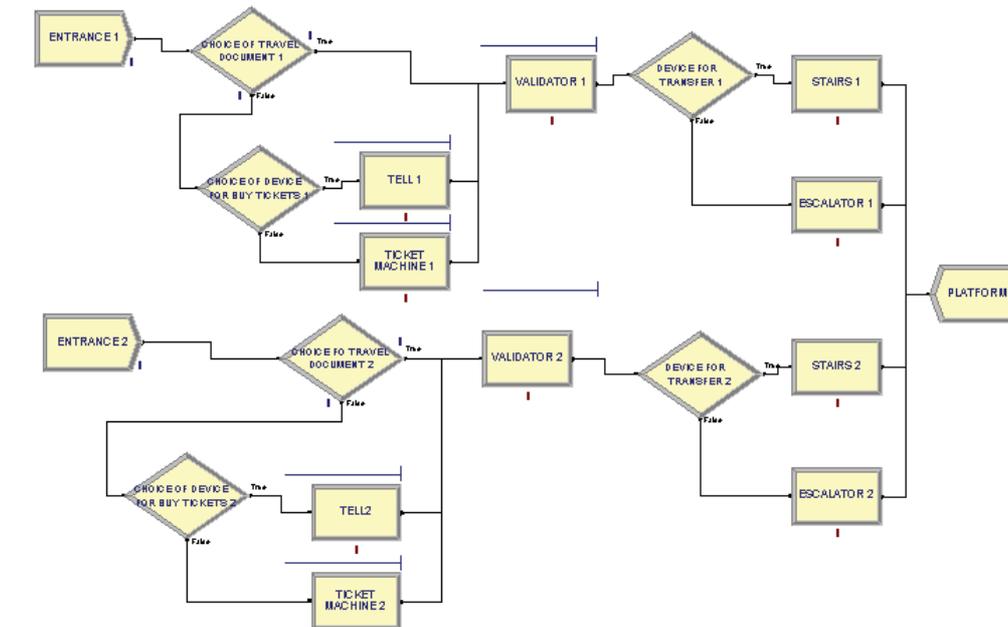


Fig.5. Simulation model in ARENA for metro station with common platform

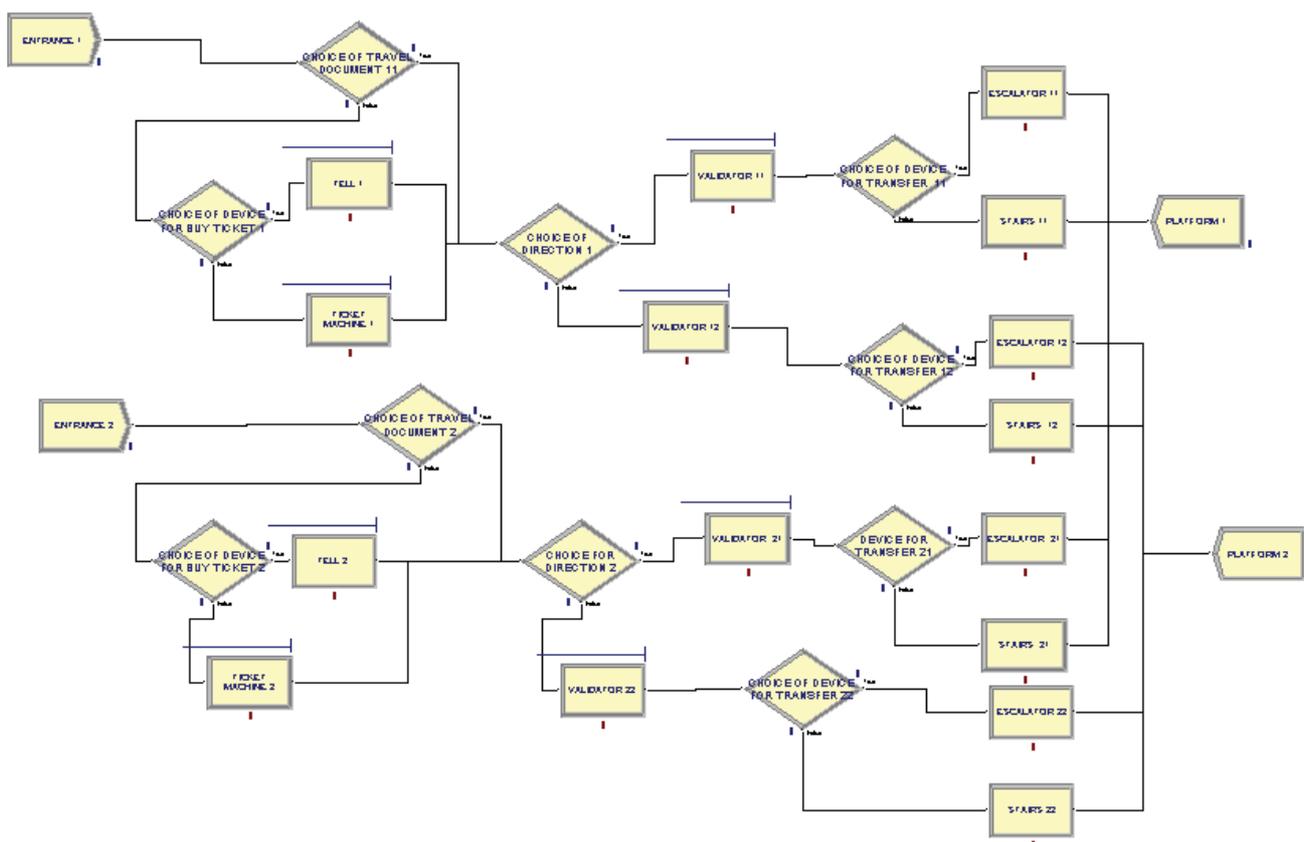


Fig.6. Simulation model in ARENA for metro station with two platforms

The simulations could be performed for all day, for peak period, or others periods.

The models presented in fig.5 and fig.6 can be used to make simulations for all metro stations. In the application of simulation models for a specific subway station is necessary to set the parameters: number of cases, number of ticket machines, number of validators.

In this research was elaborated the simulation models for Metro Station Sofia's University "Sv.Kliment Ohridski" (common platform) and Metro Station "G.M.Dimitrov" (two platforms). These ones were investigated for hour peak period. Near to these metro stations are located major universities. These metro stations are characterised with big passenger flows with students.

The variants of research taking into account of fig.3 are:

- Variants group 1. Separation of passenger flows between card and ticket: Variants of percentages of card: 10%; 20%; 30%; 40%; 50%; 60%; 70%; 80%; 90%. In this case the separation was accepted for 50% for passengers going to tells and 50% going to ticket machines.

- Variants group 2. Separation of passenger flows between tells and ticket machines: Variants of percentages of passengers going to tell are: 10%; 20%; 30%; 40%; 50%; 60%; 70%; 80%; 90%. In this

case the separation was accepted for 50% for card (they go directly to validators) and 50% for ticket.

The variants of research of passenger flows in peak hour for metro station SU Kliment Ohridski are:

- Approach Sofia university: 2300 pass./h; 2000 pass./h; 1700 pass./h;
- Approach The Orlov bridge: 1200 pass./h; 1000 pass./h ; 800 pass./h

For metro station G.M.Dimitrov the variants of passenger flows are:

- Approach blv. Kl. Ohridski: 1500 pass./h; 1300 pass./h; 1100 blv.G.M.Dimitrov:
- Approach 1100 pass./h; 1000 pass./h; 900 pass./h.

These passenger flows are simulated with ARENA software by variants of percentage that is determined above. The models have been simulated with 100 replications.

In fig.7 is shown the necessary number of tells according to number of passengers waiting in queue and passengers per hour.

In fig.8 and fig.9 is shown the total time in system for different variants of group 1 and group 2. The results of two groups are identical.

Table 2 show a comparison for results for metro station SU Kliment Ohridski. In table 3 is shown the results for metro station G.M. Dimitrov.

Tabl.2. Results for metro station SU Kliment Ohridski, approach Sofia University, variants group 1

Percentage of ticket	2300 pass./hour				2000 pass./hour				1700 pass./hour			
	Pass./hour	Number waiting in queue for tells per minute	Necessary number of tells	Number waiting in queue for ticket machines per	Pass./hour	Number waiting in queue for tells per minute	Necessary number of tells	Number waiting in queue for ticket machines per	Pass./hour	Number waiting in queue for tells per minute	Necessary number of tells	Number waiting in queue for ticket machines per
90	1035	8	3	4	900	6	3	1	765	6	3	1
80	920	7	3	2	800	5	3	1	680	5	2	0
70	805	6	3	1	700	5	2	0	595	5	2	0
60	690	5	2	1	600	4	2	0	510	4	2	0
50	575	4	2	0	500	3	2	0	425	3	2	0
40	460	3	2	0	400	2	2	0	340	2	1	0
30	345	2	1	0	300	1	1	0	255	1	1	0
20	230	1	1	0	200	0	1	0	170	1	1	0
10	115	0	1	0	100	0	1	0	85	1	1	0

Tabl.3. Results for metro station G.M.Dimitrov, approach blv. Kl.Ohtidski, variants group 1

Percentage of ticket	1500 pass./hour			1300 pass./hour			1100 pass./hour					
	Pass./hour	Number waiting in queue for tells per minute	Necessary number of tells	Number waiting in queue for ticket machines per minute	Pass./hour	Number waiting in queue for tells per minute	Necessary number of tells	Number waiting in queue for ticket machines per minute	Pass./hour	Number waiting in queue for tells per minute	Necessary number of tells	Number waiting in queue for ticket machines per minute
90	675	5	2	4	585	4	2	0	495	3	2	0
80	600	4	2	2	520	4	2	0	440	2	2	0
70	525	4	2	1	455	3	2	0	385	2	2	0
60	450	3	2	1	390	3	2	0	330	2	1	0
50	375	2	1	0	325	2	1	0	275	1	1	0
40	300	2	1	0	260	1	1	0	220	1	1	0
30	225	1	1	0	195	1	1	0	165	0	1	0
20	150	0	1	0	130	1	1	0	110	0	1	0
10	75	0	1	0	65	0	1	0	55	0	1	0

The necessary number of tells for each of two approaches is determined by formula:

$$\frac{\lambda_{11}}{\mu_{11} \cdot n_{11}} \leq 1 ; \frac{\lambda_{12}}{\mu_{12} \cdot n_{12}} \leq 1 \quad (14)$$

The 70% or above of incoming passengers flow in a subway station should have transport document, i.e. to go directly to validators. At that percentage or above will not need of infrastructural changes in the vestibule of a subway station. When that percentage decreases is necessary infrastructure changes such as adding a new tell or adding a ticket machine. In the developed model is a delay in servicing passenger with tells, so it could be replaced by a ticket machine. The performance at the ticket machine as much significantly and she is nearly equivalent to that of validators.

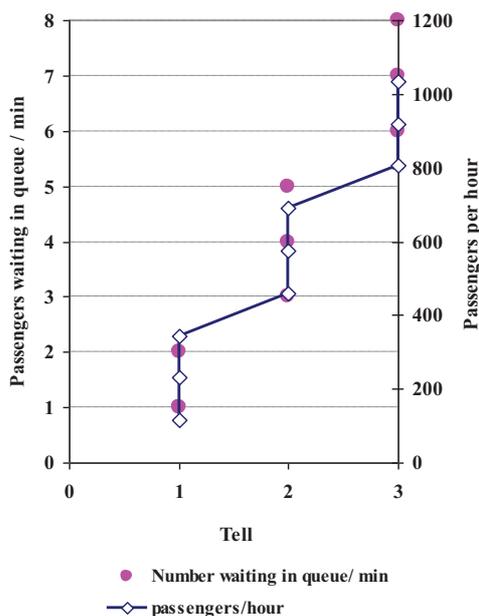


Fig.7. Necessary number of tells

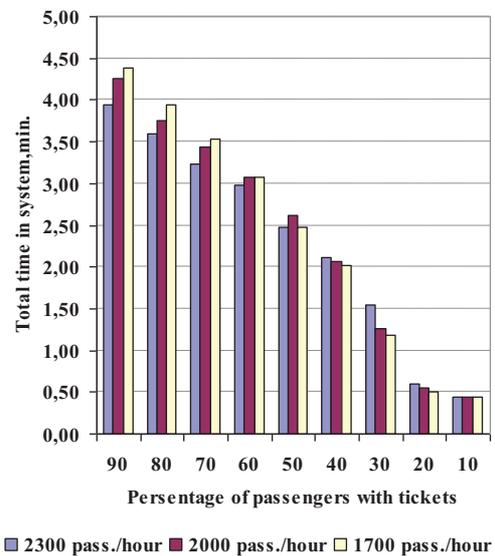


Fig.8. Metro station SU Kliment Ohridski, approach "The Orlov bridge" – variants group 1

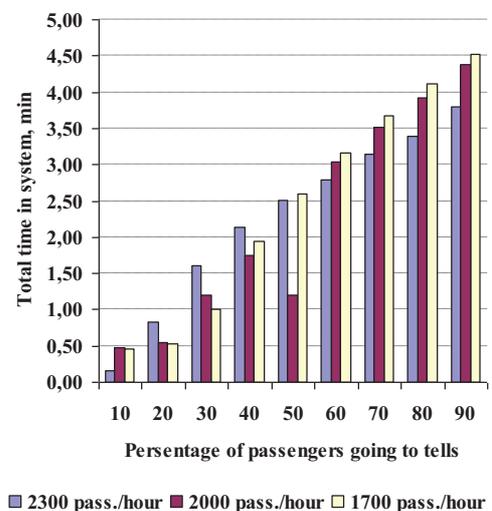


Fig.9. Metro station SU Kliment Ohridski, approach "The Orlov bridge" – variants group 2

Conclusions

The conducted research allows to make the following conclusions:

- A methodology for presenting a metro station as a multi-level system has been developed.
- A multi-level system is examined as a compounded of separate single-level systems with Poisson's incoming stream of passengers, exponential time for service and a 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), validators, escalators and stairs.
- A simulation models for metro station with common and two platforms has been elaborated. These models could be used to simulate and investigated each station from these types.
- In the study has been defined the number of passengers in which should introduce an additional tell.
- The simulation models of a metro stations have been developed with Arena software.

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ПРИЛОЖЕНИЕ НА СОФТУЕРА ЗА ДИСКРЕТНО-СЪБИТИЙНО СИМУЛИРАНЕ ARENA ЗА МОДЕЛИРАНЕ НА ТЕХНОЛОГИЧНИТЕ ПРОЦЕСИ ПРИ ЗАМИНАВАНЕ НА ПЪТНИЦИТЕ ОТ МЕТОСТАНЦИИТЕ НА СОФИЙСКИЯ МЕТРОПОЛИТЕН

В изследването е разработена методика за симулиране на технологичните процеси свързани със заминаващите пътници от метростанция с прилагане на дискретно-събитийния подход. Пътникопотоците са изследвани с многофазен модел, състоящ се от четити фази: вход в метростанцията; вестибюл; валидатори за преминаване; ескалатори и стълби. Чрез симулиране са наблюдавани броят на пътниците, които излизат от системата, т.е. достигат до перона; общо време в системата; брой пътници, чакащи в опашка; вероятности на системата. Разработени са симулационни модели на метростанция с общ и с два перона. Тези модели имат универсален характер и могат да се използват за симулиране в коя да е метростанция от двата типа. Изследвани са метростанциите Софийски Университет „Св. Климент Охридски” и „Г.М.Димитров”. Изследването е проведено с използване на лицензиран софтуер Arena Enterprise Suite Academic Rockwell, версия 14.