SIMPLIFIED BORDER CHECKPOINT SIMULATION MODEL

assist. prof. dr. eng. Dimitrov S. D.
Faculty of Transport Management, Higher School of Transport "Todor Kableshkov", Sofia, Bulgaria

Abstract: *This paper presents a simplified simulation model of a border checkpoint developed using well-known simulation system GPSS. The main objective is to model the behavior of the system "border checkpoint", considered as a two-phase single-server queueing system with refusals, operating under various characteristics of the incoming traffic flow and operating modes of the system's servers.*

Keywords: *SIMULATION, MODEL, BORDER CHECKPOINT, QUEUEING SYSTEM, GPSS, SCENARIO, QUEUE LENGTH, WAIT TIME, SYSTEM TIME, TRANSPORT*

1. Introduction.

Border checkpoints (BCs) serving as a gateway to neighboring countries have strategic importance for the implementation and maintenance of foreign trade and tourism relations. They play a key role as a connecting link between two states and as a such they serve for the organizing and controlling of the crossing mode of the transport vehicles (autos) from different transport types: trains and automobiles – trucks, buses, minibuses, motorcycles as well as cars (for private and business purposes), used for both freight and passenger transportation. To perform its function in the exercise of customs control of each party and ensure smooth passage of checked vehicles with the least possible waiting and inhibitions, work in the system "border checkpoint" must be organized so that its elements – border crossing point *1* (BCP *1*) and border crossing point *2* (BCP *2*) to work in sync.

2. Nature of the problem.

Sometimes because of the influence of random factors the organization of work in the border is deteriorating or is distorted. Such important factors can be insufficient number of open border crossing points, organizing strikes blocking working border crossing points and their work, harsh weather conditions and heavy snowfalls, strong seasonal fluctuation and "peak" of the shopping and vacation travels of the population by months of the year and days of the week, etc. The impact of some of these factors leads not only to delay but and stopping the access regime in both countries. The interruption of work of the border crossing points leads to blocking the entire system. Consequently, the impact of these factors forms queues of freight and passenger transport vehicles to checkpoints. Often these queues are the reason for increased waiting times and hence increased total time for crossing the border. Additionally spent waiting times entail the realization of high costs of stay, delayed courses for delivering goods or perishable foods. The search for solutions to overcome such obstacles raise the need for creating and implementing a rational organization of work of the subsystems "border crossing points" and of the system "border checkpoint" as a whole. Appropriate in such cases tool for resolving problems of similar character is the method of simulation modeling[3]. The method gives an opportunity to create simulation model [3,5] and with small expenditure of machine time, resources and insignificant efforts to model the work of the studied system, to calculate averaged values of its parameters and to make analyses, in result of which to give guidance for its future operation.

3. Problem solution.

To create a simulation model of the system "border checkpoint", allowing to simulate the processes taking place in it is used widespread simulations system GPSS World(tm) Student Version [2], which is the product of the Minuteman Software and belongs to systems for discrete event simulation. Specific to GPSS(General Purpose Simulation System) is that the dynamic components in the model, i.e. requests for service, which in this case are the autos, are represented by transactions [2,3], which as described in the modeling algorithm logic successively pass from one block to another in a block scheme[1,4] in which each block performs specific function.

Developed using GPSS simulation model describes system "border checkpoint" as a two-phase queueing system with refusals of type *M/M/n* (fig. 1) with Poisson incoming flow of vehicles, having according to the original intent single-channel service facility of each phase.

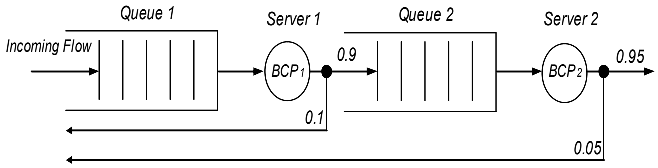

Fig. 1.Scheme of the two-phase single-server queueing system

The model was built by the following model segments:

- model segment "Inter arrival times", simulating Poisson flow of autos arriving at the entrance of the system;
- model segment "Border crossing point *1*" (phase *1*), simulating the process of checking the flow of autos entering first phase;
- model segment "Border crossing point *2*" (phase *2*), simulating crossing mode of the entering second phase autos;
- model segment "Simulation clock", performing function of model clock controlling the length of the simulation.

Structural block-scheme of the modeling algorithm of the developed border checkpoint simulation model is shown in fig. 2 and its implementations written using the built-in GPSS programming language - in fig. 3.

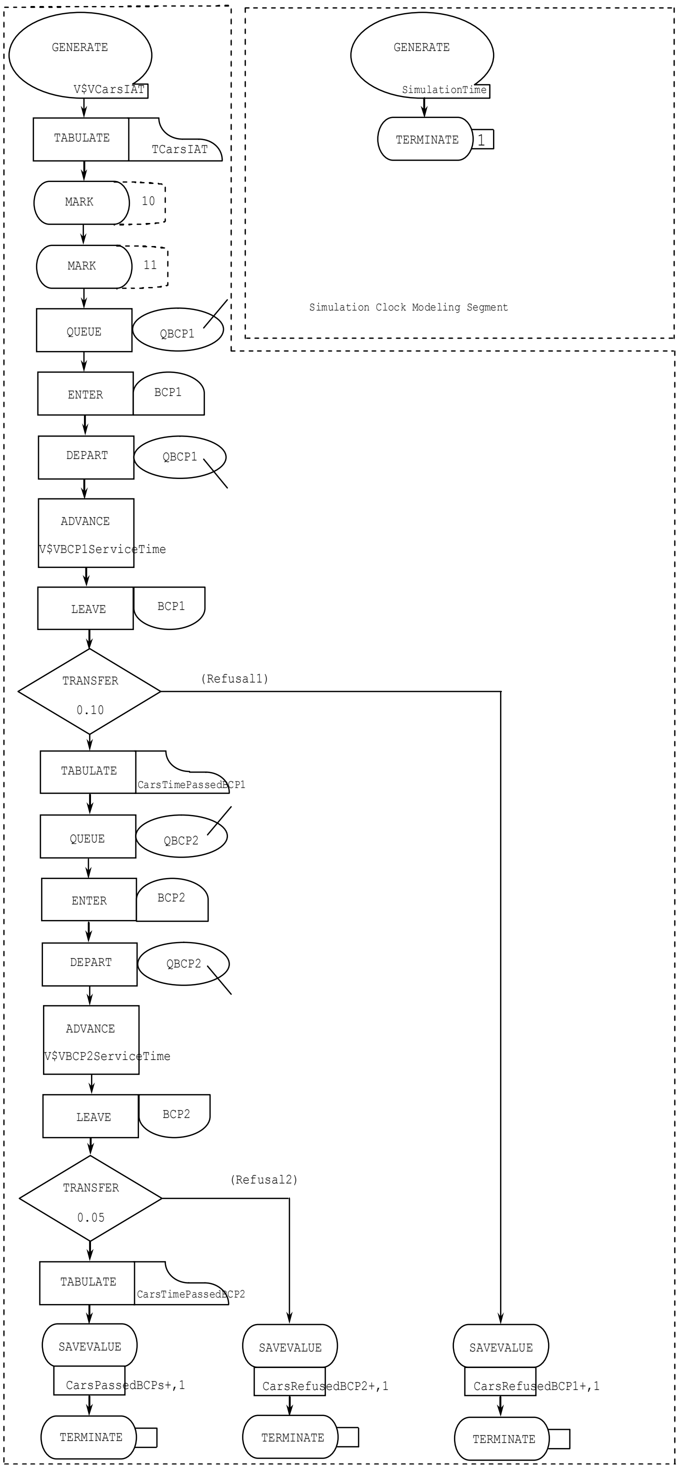

Fig. 2. Structural block-scheme of the modeling algorithm of the border checkpoint simulation model

```
                  ********************************************************************
                  *           Simplified Border Checkpoint Simulation Model          *
                  ********************************************************************
                  *                    1 unit model time = 1 second                  *
                  ********************************************************************
                  *                        Declaration Segment                       *
                  ********************************************************************
                  *           Setting Seeds for Random Number Generators 1, 2 & 3    *
                  ********************************************************************
                       RMULT               101,102,103
                  ********************************************************************
                  *                        Constants                                 *
                  ********************************************************************
SimulationTime         EQU                 604800.0
                  *-------------------------------------------------------------------
CarsIAT                EQU                 120.0
                  *-------------------------------------------------------------------
BCP1ServiceTime        EQU                  90.0
BCP2ServiceTime        EQU                  60.0
                  ********************************************************************
                  *                        Variables                                 *
                  ********************************************************************
VCarsIAT               VARIABLE            (EXPONENTIAL(1,0,CarsIAT))
                  *-------------------------------------------------------------------
VBCP1ServiceTime       VARIABLE            (EXPONENTIAL(2,0,BCP1ServiceTime))
VBCP2ServiceTime       VARIABLE            (EXPONENTIAL(3,0,BCP2ServiceTime))
                  ********************************************************************
                  *                        Storages                                  *
                  ********************************************************************
BCP1                   STORAGE             1
BCP2                   STORAGE             1
                  ********************************************************************
                  *                        Savevalues                                *
                  ********************************************************************
                       INITIAL             X$CarsRefusedBCP1,0
                       INITIAL             X$CarsRefusedBCP2,0
                  *-------------------------------------------------------------------
                       INITIAL             X$CarsPassedBCPs,0
                  ********************************************************************
                  *                        Tables                                    *
                  ********************************************************************
TCarsIAT               TABLE               V$VCarsIAT,60,60,12
                  *-------------------------------------------------------------------
CarsTimePassedBCP1 TABLE                   MP10,120,120,14
CarsTimePassedBCP2 TABLE                   MP11,120,120,15
                  ********************************************************************
                  *                        Modeling Segments                         *
                  ********************************************************************
                  *                        Inter-arrival times                       *
                  ********************************************************************
                       GENERATE            V$VCarsIAT
                  *-------------------------------------------------------------------
                       TABULATE            TCarsIAT
                  *-------------------------------------------------------------------
                       MARK                10
                       MARK                11
                  ********************************************************************
                  *                        Border Crossing Point 1                   *
                  ********************************************************************
                       QUEUE               QBCP1
                       ENTER               BCP1
                       DEPART              QBCP1
                       ADVANCE             V$VBCP1ServiceTime
                       LEAVE               BCP1

                       TRANSFER            0.10,,Refusal1

                       TABULATE            CarsTimePassedBCP1
                  ********************************************************************
                  *                        Border Crossing Point 2                   *
                  ********************************************************************
                       QUEUE               QBCP2
                       ENTER               BCP2
                       DEPART              QBCP2
                       ADVANCE             V$VBCP2ServiceTime
                       LEAVE               BCP2

                       TRANSFER            0.05,,Refusal2
                  *-------------------------------------------------------------------
                       TABULATE            CarsTimePassedBCP2
                       SAVEVALUE           CarsPassedBCPs+,1
                       TERMINATE
                  *-------------------------------------------------------------------
Refusal1               SAVEVALUE           CarsRefusedBCP1+,1
                       TERMINATE
                  *-------------------------------------------------------------------
Refusal2               SAVEVALUE           CarsRefusedBCP2+,1
                       TERMINATE
                  ********************************************************************
                  *                        Simulation Clock Modeling Segment         *
                  ********************************************************************
                       GENERATE            SimulationTime
                       TERMINATE           1
                  ********************************************************************
                       START               1
                  *-------------------------------------------------------------------
                       CLEAR
                       RMULT               101,102,103
CarsIAT                EQU                 90.0
                       START               1
                  *-------------------------------------------------------------------
                       CLEAR
                       RMULT               101,102,103
CarsIAT                EQU                 90.0
BCP1                   STORAGE             2
                       START               1
                  ********************************************************************
                  *                        END                                       *
                  ********************************************************************
```

Fig. 3.GPSS program code of the border checkpoint simulation model

4. Results and discussion.

By means of the created simulation model, with preliminary assigned for the *3* played out scenarios values of input parameters(table 1) – duration of simulation, type and intensity of the incoming flow of vehicles, number of servers in each phase, probability distributions and mean service time in each phase, is simulated the operation of the system "border checkpoint" in duration of a *7*-days workweek with *24*-hour working time(*60480*sec.) with the assumptions, that the intensity of the incoming flow (arrival rate) remains constant throughout the day and the average service time on the first phase (out of the home country) is greater than the service time of the second (entrance in the host country).

Table 1.Input data

Scenario №	Duration of the simulation, sec.	Type of the incoming flow	Arrival rate of the traffic flow, autos/h	Phase №	Number of servers	Probability distribution of the service times	Average service time, sec.
1	604800	Poisson	30	1	1	Exponential	90
				2	1		60
2			40	1	1	Exponential	90
				2	1		60
3			40	1	2	Exponential	90
				2	1		60

Three scenarios have been played out as follows:

Scenario 1 – simulation of the system "border checkpoint" as a two-phase queueing system having Poisson incoming flow with an average inter-arrival time of the transport vehicles equal to *120* sec., working with one server on each phase, having exponentially distributed lengths of service with an average value *90* seconds on 1^{-st} phase and *60* seconds on the 2^{-nd} respectively;

Scenario 2 – simulation of the system "border checkpoint" as a two-phase queueing system with reduced from *120* to *90* seconds average time interval between incoming autos due to the "peak" of the seasonal touristic trips, working with one server on each phase, having exponentially distributed service times with average value *90* seconds on the 1^{-st} phase and *60* seconds on the 2^{-nd};

Scenario 3 – simulation of the system "border checkpoint" as a two-phase queueing system with reduced in connection with the observed "peak" in the seasonal touristic trips average inter-arrival time equal to *90* seconds, but working with two servers on the 1^{-st} phase and with one on the 2^{-nd}, serving the traffic flow of autos with exponentially distributed service times, having average value *90*sec. and *60* sec. on the 1^{-st} and the 2^{-nd} phases respectively.

For all *3* scenarios *10 %* of the entering on 1^{-st} phase automobiles were refused to go through and were returned. *5 %* from those successfully went through 1^{-st} phase were refused to go through the 2^{-nd} and also were returned.

Resulting from the simulation parameter values: maximum and average queue length of waiting vehicles, average waiting time in the queue, average number of autos went through the queue without waiting, server's utilization of each phase, total number of autos entered in each phase, number of autos that were refused to go through the phases and were returned, total number of autos successfully went through each phase, as well as the average system time, are shown in table *2*.

Table 2. Simulation results

Scenario №	Phase №	Number of servers	Maximum queue length, autos	Average queue length, autos	Average queue waiting time, sec.	Autos passed through the queue without waiting	Servers utilization	Autos entered in the servers	Autos received refusal to pass	Autos passed through phase	Average system time of the autos passed through phase
1	1	1	25	2,4	286	1239	0,75	5077	499	4578	376
	2	1	10	0,4	47	2579	0,45	4578	255	4323	483
2	1	1	217	78,7	7007	134	0,98	6586	642	5943	7048
	2	1	15	0,8	84	2527	0,59	5940	282	5657	7176
3	1	2	10	0,4	32	4460	0,51	6839	696	6143	123
	2	1	15	1,0	96	2429	0,60	6143	284	5858	277

From table 2 can be seen that when we have flow of incoming *30 autos/h* (scenario *1*), the service rate on each of the both phases (*40 autos/h* on 1^{-st} and *60 autos/h* on the 2^{-nd}) is sufficient this flow to be served without to overload the servers and to generate long queues in front of the two phases (in our case the maximum queue length is of *15* and *10* autos on 1^{-st} and 2^{-nd} phase respectively), large waiting times in the queues and hence to large residence times in the system.

Unlike scenario *1* in scenario *2* the reduced with 25 % time interval between the arriving autos in "peak" days – from *120* to *90* seconds leads to an increase of the frequency with which they arrive from *30 autos/h* to *40 autos/h* (about *33%* increase), which leads to an increase of the server's utilization on both phases with approximately *30%* (from *0,75* to *0,98* on the 1^{-st} phase and from *0,45* to 0,59 on the 2^{-nd}). The larger utilization affects the maximum queue length in phase *1*, steeply rising throughout the simulation from *25* to *217* autos (fig. *5*) and in phase *2* - from *10* to *15 autos*. The greater queue length affects to waiting time which increased from *286* to *7007* seconds on the queue on phase *1* and from *47* to *84* seconds on phase *2*. In this way the average system time of the autos successfully went through both phases increased from *483* seconds up to *7176* seconds. Such large waiting times of approximately *2* hours from customers' point of view would be unacceptable.

The arisen problem was solved with the developed scenario *3* in which on 1^{-st} phase second server was opened. As a result of the performed organizational change the following improvements in the work of the modeled system were achieved:

- from the critical level of *0,98* server utilization on 1^{-st} phase was reduced to *0,51*, while on the 2^{-nd} phase it remained of the order of *0,6*;
- the maximum queue length in border crossing point *1* was reduced from *217* to *10 autos*, while in border crossing point *2* the queue length remained unchanged – *15 autos*;
- the average queue waiting times were reduced from *7007* to *32* seconds in 1^{-st} phase, while the average waiting time in the 2^{-nd} phase increased insignificantly from *84* to *96* seconds;
- the average system time of the autos passed through both phases was reduced from *7176* seconds to *277*.

Graphically, the simulation results for all *3* scenarios representing the variation of the queue lengths of autos in function of the duration of simulation, are shown in fig. *4 – 6*.

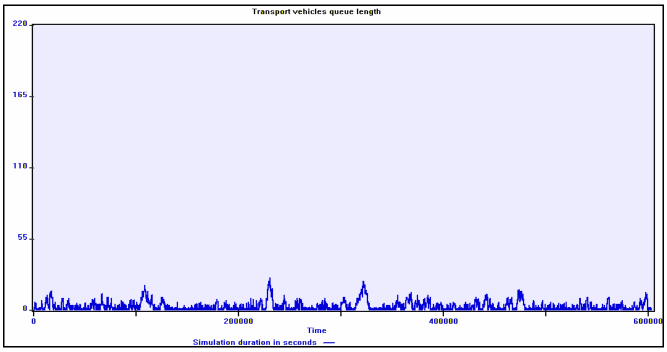

Fig. 4. Transport vehicles queue length in scenario 1

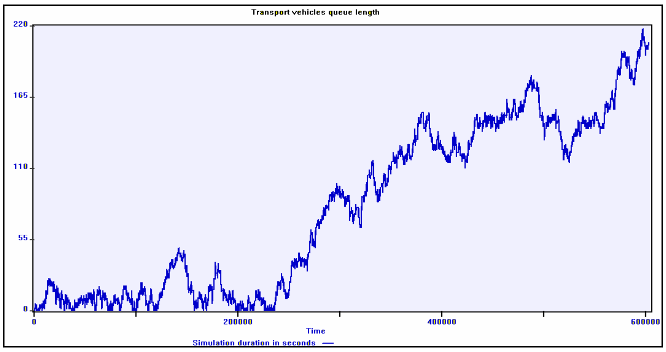

Fig. 5. Transport vehicles queue length in scenario 2

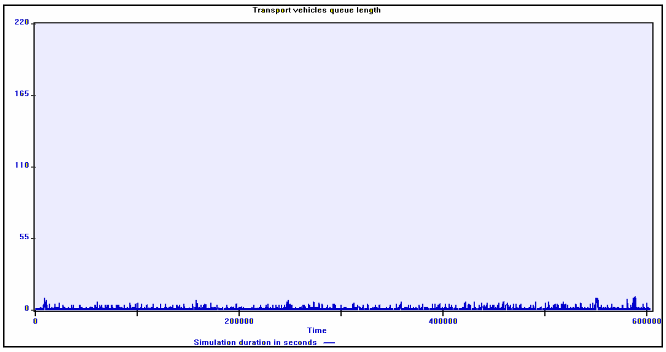

Fig. 6. Transport vehicles queue length in scenario 3

5. Conclusion.

Finally following conclusions can be drawn:

The method of simulation modeling is a powerful tool for creating models when the processes in the studied systems are difficult or impossible analytically to describe, and the simulation system GPSS – a powerful tool for describing models and their program implementation.

The developed simplified simulation model simulating the crossing of the transport vehicles through an illustrative border checkpoint possesses the following special features:

1. The proposed simulation model is relatively flexible because it allows in cases when the intensity of the incoming flow is changing significantly to simulate system performance working as a multi-server in each phase and to explore how this intensity affects servers' utilization on both phases and on the maximum and average queue lengths, as well as on the average waiting time in the queues and the average time spent by vehicles in the system.

2. Although the model does not distinguish the transport vehicles – trucks, buses, cars and the model experiments were made using sample data, after calibrating model with statistical data for a real system with a similar organization of work as in the given example, the obtained from the simulation results could be used as a guidance for making only of an initial recommendations on how the system to operate.

3. As such, the simplified simulation model is suitable to use from university students for training purposes. The model can also serve as a basis for developing practically applicable more complex model allowing to simulate the processes in a border checkpoint, in which:

- as input data are used the established probability distribution of the inter arrival times and their average values for the different types of transport vehicles;
- distinction between the arriving at the entrance of the system vehicles of the various types is made and is taken into account their percentage distribution;
- the various types of vehicles on each phase are served by equipped for this purpose servers with the respective duration of service. However, to be this possible the probability distribution of the service times and their averages for the separate transport modes should be preliminary established;
- it is envisaged a mechanism automatically regulating the number of simultaneously operating servers depending on the length of the queue of autos.

References:

[1] Bobillier, P. A., Kahan, B. C., Probst, A. R., "Simulation with GPSS and GPSS V", Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1976;

[2] GPSS World(tm) Reference Manual, Minuteman Software;

[3] Kachaunov, T. T., Karagyozov, K. St., Razmov, T. K., "Simulation modeling of the transport processes", Higher school of transport, Sofia, 1998 (in Bulgarian);

[4] Schriber, Th. J., "Simulation using GPSS", Moscow, 1980 (in Russian);

[5] Solomon, S. L., "Simulation of waiting line systems", Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1983