Program for Modelling Queuing Systems in Transport

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This paper presents an example application of a software program developed using the programming language VBA and designed for modelling queuing systems in the field of transport. The program enables users to quantitatively determine the indicators of the queuing systems. In order to show the program's capabilities and how it can be used, two scenarios have been considered - modelling single-server and multi-server queuing systems of type M/M/1 and M/M/S, respectively, having a Poisson incoming flow of requests and exponentially distributed service times.
Keywords: transport, process, service, queuing theory, queuing system, modelling, software program, programming language, VBA, Microsoft® Office Excel

1. INTRODUCTION.

The main goal of the transport sector of the economy is to meet the requirements and needs of its customers. In order to achieve this goal the entire transportation process passes through consecutively or simultaneously running processes for customers' service.

2. NATURE AND WAYS TO SOLVE THE PROBLEM.

The random nature of some processes creates phenomena such as traffic jams, queues and delays, leading to loss from complementary stay, refusals of customers, non-compliance of predetermined deadlines, payment of defaults and others such as losses from stay of vehicles waiting processing, loss of customers due to insufficient number of buses serving routes of the public transport, penalties for stay of cars, trucks, wagons and ships above the normatively determined time [4], etc.

The application of the existing methods – plan scheduling, network planning, theory of schedules and graph theory, solving wide range practical tasks – in order to describe the running processes in the transport is relatively limited [4]. This is mainly due to the inability by using these methods to create models [4,6] describing in full all elements of the transportation process.

Suitable for description of the transportation processes is the queuing theory [4] applied in various fields, including in transport. Queuing theory allows describing in detail the running processes in diverse complex systems [6]. The usage of the queuing theory for modelling [6] is connected with knowledge about the probability distributions of the incoming flow of requests and service times that must be established by collecting and processing large enough volume of data.

Main task of the queuing theory is to identify the working indicators of its object – the queuing systems [4], which systems could be classified [4] by the number of simultaneously working serving devices (single-server and multi-server systems), according to the way of forming of queues in front of the systems' entrance (systems with refusals, with limited or infinite queue), according to the discipline of service (service with priority – with relative or absolute priority, arbitrary service), according to the number of serving devices the customers successively pass through under servicing (single-phase and multi-phase queuing systems) and according to the source of requests – closed systems (finite source) and opened systems (infinite source).

Irrespective of its type each queuing system is defined by incoming flow of requests, a mechanism (server) for their servicing and discipline of the queue according to which the arriving requests are processed – FIFO (First-In, First-Out), LIFO(Last-In, First-Out) or arbitrary selection of the requests for servicing.

Often due to the complexity of the modelled systems, in order to accurately calculate their working indicators, automated tools such as specialized software designed for modelling queuing systems is suitable to be used.

3. MAIN PURPOSE AND PROBLEM SOLUTION.

The main purpose of this paper is to present the developed by the author software program as a possible alternative for modelling queuing systems and calculating their indicators of work. This program was developed by using *VBA* (*Visual Basic for Applications*) [2,3,5,7] that is built-in programming language in the office application *Microsoft® Office Excel*. The program allows, by using preset values for the input parameters of the modelled systems - intensity of the incoming flow of requests, number of the serving facilities and average service times, to model the work of single-phase, single- or multi-server queuing systems. It provides the user an opportunity to export to the working environment of *Microsoft® Office Excel* and *Microsoft® Office Word* the output results in a print-ready form. The developed program also has functionality that graphically visualizes the modelling results about the average queue length in function of the servers' utilization.

4. APPLICATION OF THE PROGRAM AND MODELLING RESULTS.

In order to demonstrate how the developed software program works, simple example was described presenting program's application for modelling queuing systems in the field of transport.

The solution is shown through applying the well-known "*Step-By-Step*" method.

Program can be started after opening the *Excel* file with name "*Queuing system.xls*". As a result the main program's window appears (fig. 4.1).

To present the extended functionalities of the program two scenarios are considered - modelling the work of a single-server queuing system (in our case *ticket machine*) of type *M/M/1* [1,4] and modelling of a multi-server queuing system of type *M/M/S* [1,4], both the systems having a *Poisson* arrivals and exponentially distributed service times:

Scenario 1: After pressing the button "*Enter the program*" (fig. 4.1) a window opens (fig. 4.2) in which parameters such as number of servers, customers' arrival rate and average service time must be entered.

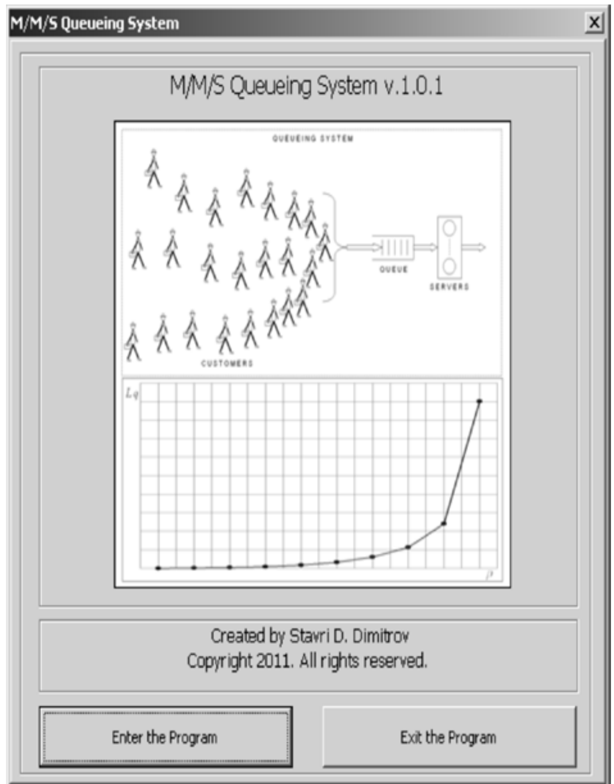


Fig. 4.1. Main window

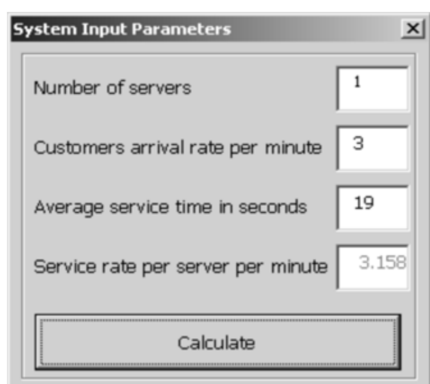


Fig. 4.2. Window "System Input Parameters"

On the basis of the average service time the service rate per server *miu* is calculated. Then by pressing the button "*Calculate*" in the same window the program, using the formulas [4] valid for *M/M/S* queuing system which in scenario *1* has $S = 1$ number of servers, calculates all system output parameters (fig. 4.3) - utilization of one server R_{ho}, average number of customers in the queue L_q, average time spent by one customer waiting in the queue T_q, average number of customers in the system L_s, the time that each customer on average spends in the system T_s, the probability that all servers will be idle P_o and the probability that an arriving customer at the entrance of the system will have to wait in the queue P_w [4].

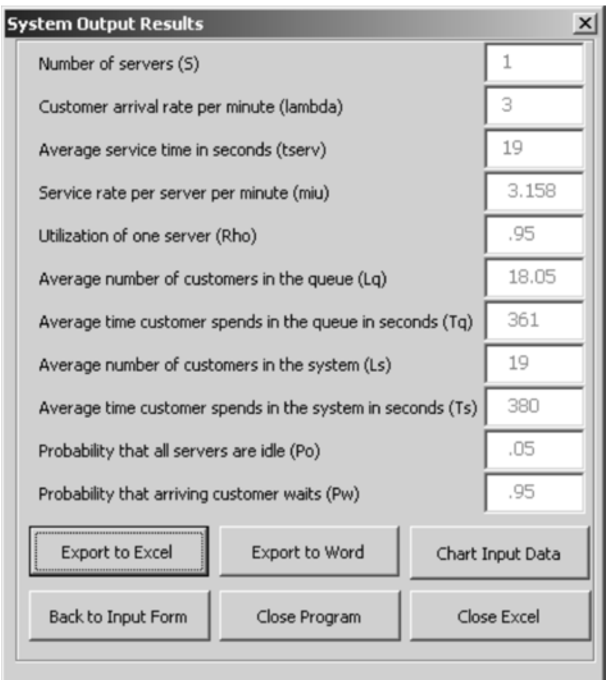


Fig. 4.3. Window "System Output Results"

As it can be seen on fig. 4.3 the intensity of the incoming flow of passengers, which for example during the peak hours when people make mainly work trips, is on average *3* passengers per *1* minute on the one hand and on the other hand - having in mind the service rate of *3,158* passengers per minute calculated for service time of *19* seconds per request, are both leading to a rate of utilization of the system ($R_{ho} = 0{,}95$) that is close to its capacity. The high capacity utilization rate is the cause for the appearance of long queues (on average $L_q = 18$ passengers in the queue). In this case the average waiting time in the queue is $T_q = 6$ minutes and the total passenger's stay in the system is $T_s = 6$ minutes and *20* seconds. That is why the probability that an arriving passenger will wait in the system's queue is close to *1* ($P_w = 0{,}95$). Summarizing the above values we may conclude that an optimization of the system's functioning needs to be done. An optimization can be achieved by opening a second serving facility (machine, issuing tickets to passengers) – a subject to scenario *2* discussed below.

Scenario 2: In order to play this scenario the user must press button "*Back to Input Form*" located on window "*System output results*" (fig. 4.3). As a result opens the window "*System Input Parameters*" (fig. 4.4) that is already known.

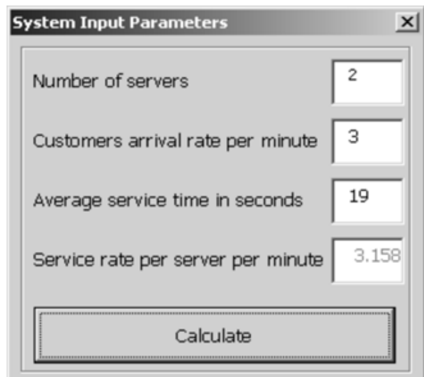


Fig. 4.4.Window "System Input Parameters"

After pressing "*Calculate*" again the program re-calculates output parameters' values (fig. 4.5).

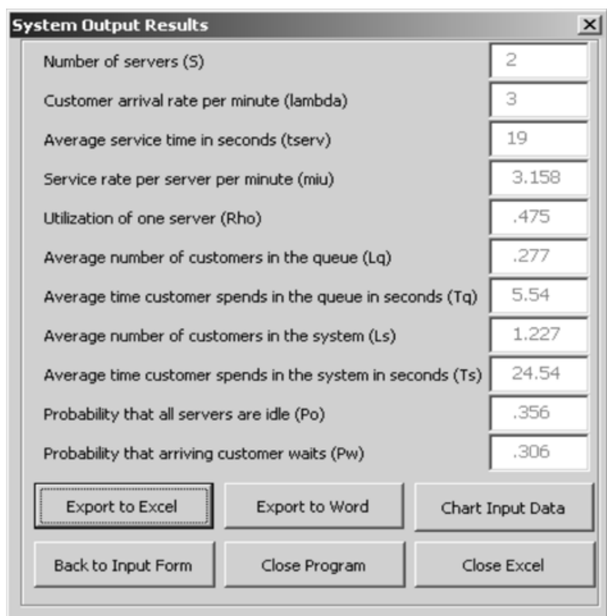
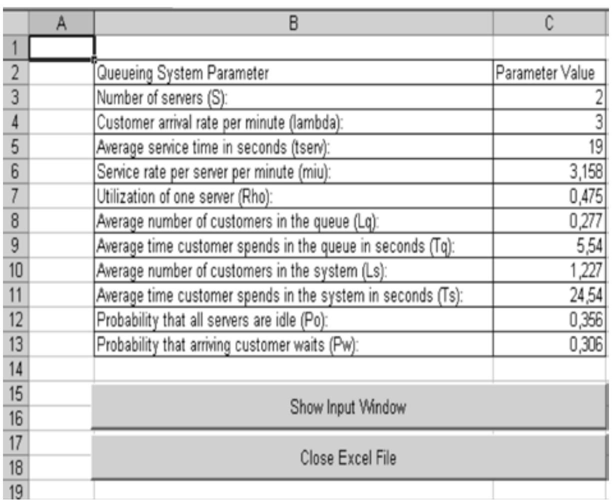


Fig. 4.5.Window "System Output Results"

The output results below show that after the optimization, implemented through opening a second, parallel working server, the functioning of the modelled system was considerably improved:

- servers' utilization decreased twice to a value of $R_{ho} = 0{,}475$;
- the number of passengers waiting in the queue on average is $L_q = 0{,}277$;
- each one of the waiting passengers spends in the queue approximately $T_q = 5$ seconds;
- the average stay in the system per passenger is $T_s = 25$ seconds;
- the probability that all servers are idle is now equal to $P_o = 0{,}356$;
- the probability that an arriving passenger will wait in the queue decreased *3* times to $P_w = 0{,}306$.

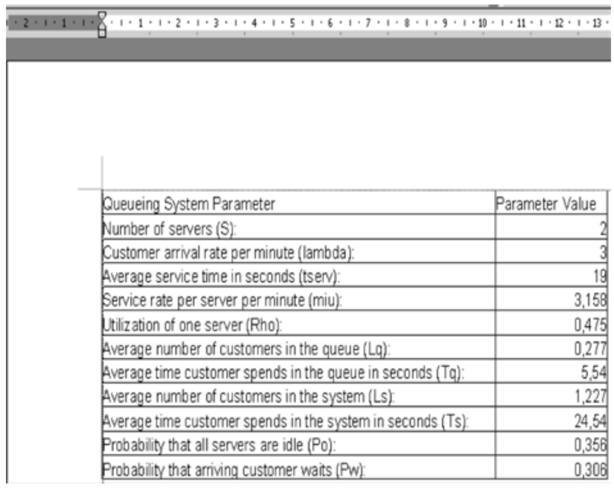
The program provides users with the opportunity by pressing the button "*Export to Excel*" (fig. 4.3) to export the output results to the working environment of the office application *Microsoft® Office Excel* (fig. 4.6) where the data are entered in a formatted table.



Queueing System Parameter	Parameter Value
Number of servers (S):	2
Customer arrival rate per minute (lambda):	3
Average service time in seconds (tserv):	19
Service rate per server per minute (miu):	3,158
Utilization of one server (Rho):	0,475
Average number of customers in the queue (Lq):	0,277
Average time customer spends in the queue in seconds (Tq):	5,54
Average number of customers in the system (Ls):	1,227
Average time customer spends in the system in seconds (Ts):	24,54
Probability that all servers are idle (Po):	0,356
Probability that arriving customer waits (Pw):	0,306

Fig. 4.6. Data exported to Excel

The program also allows the users by pressing the button "*Export to Word*" (fig. 4.3) to export the results to the application *Microsoft® Office Word*(fig. 4.7) where the data are written in a table in the same way as in *Excel* and are ready to be saved and printed.



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Number of servers (S):	2
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Utilization of one server (Rho):	0,475
Average number of customers in the queue (Lq):	0,277
Average time customer spends in the queue in seconds (Tq):	5,54
Average number of customers in the system (Ls):	1,227
Average time customer spends in the system in seconds (Ts):	24,54
Probability that all servers are idle (Po):	0,356
Probability that arriving customer waits (Pw):	0,306

Fig. 4.7. "Data exported to MS Word"

An additional functionality of the program allows the users after they press the button "*Chart Input Data*" (fig. 4.3) to create charts showing the variation of the average queue length in function of the servers' utilization. For this purpose in the opened window "*Chart Input Data*" (fig. 4.8) the user must enter a minimum and a maximum value for customers' arrival rate and a value for the step of its increment.

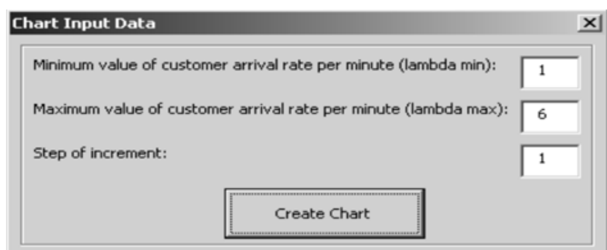

Fig. 4.8.Window "Chart Input Data"

Then the user presses "*Create Chart*". As a result of this action the program creates a chart located in *Excel* worksheet (fig. 4.9).

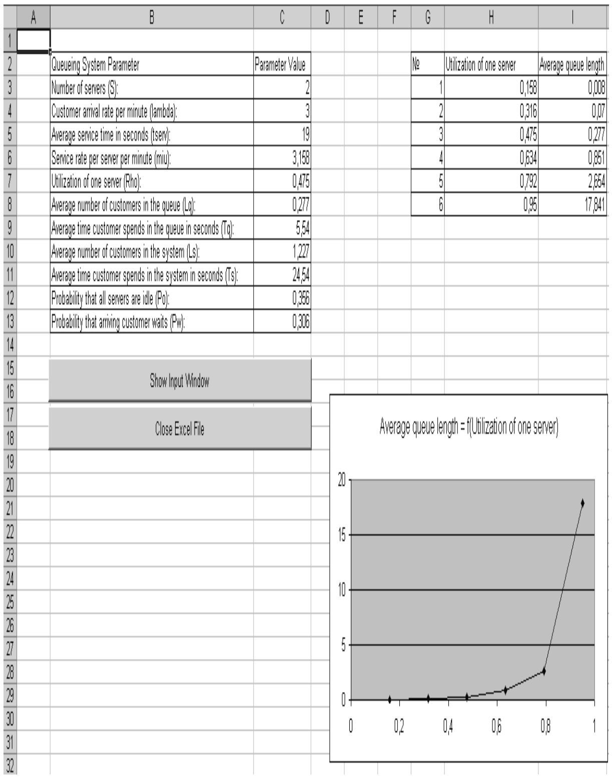

Fig. 4.9.Window "Chart in Excel"

If the user wants to exit the program, then he/she presses the button "*Close Excel File*" accessible in the worksheet shown on fig. 4.9. In this way before closing the *Excel* file and *Excel* application, the program saves the data exported to *Excel's* environment and by showing a message (fig. 4.10) lets the user know that the output results were saved in this file.

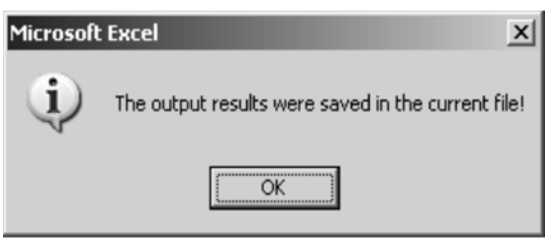

Fig. 4.10. "Information message"

In order to make a check for the accuracy of the calculations accomplished by the developed software program, the program was used (fig. 4.11) for modelling other *M/M/S* queuing system (a company selling top-of-the-line men's and women's clothing) with *S = 2* servers. This system that is presented in example *2* (fig. 4.12) was described in more details in [1].

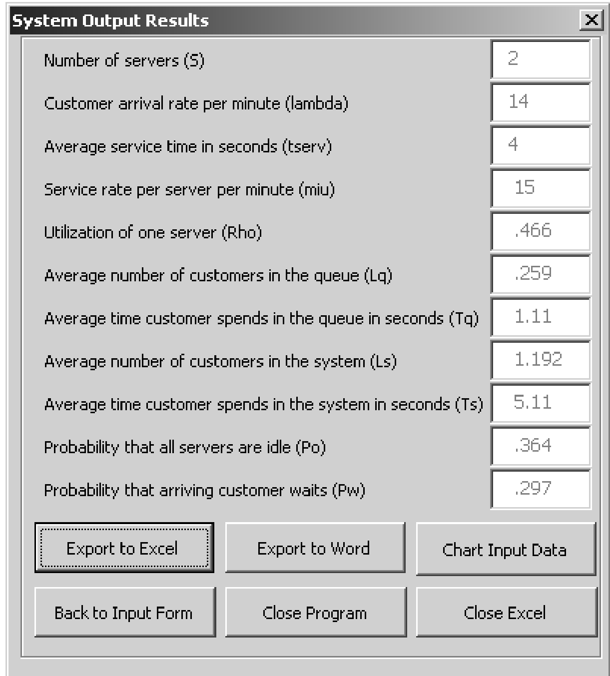

Fig. 4.11. "System output results obtained by the developed program"

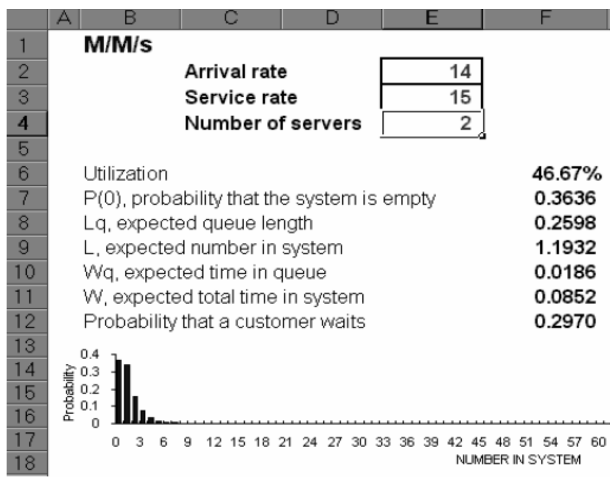

Fig. 4.12. "System output results from the solved in [1] example 2"

The comparison of the output results on fig.4.11 and fig. 4.12 shows that the values of the working indicators for the modelled system obtained by the program are equal to those obtained as a result of the solved example in [1]. This fact leads to the conclusion that the calculations that were accomplished by the developed program in relation to the system "*ticket machine*" are correct.

5. CONCLUSION.

Finally, the following more important conclusions, concerning the developed software program and its application, can be drawn:

1. The disadvantage to determine the working indicators of queuing systems by performing manual calculations, which take a lot of time and resources, can in nowadays be overcame by the existing specialized software programs that automate the whole calculation process.
2. The developed software program possesses the following advantages:
   - the program allows to model both single-server and multi-server queuing systems;
   - the main advantage of this program consists of its ability to automate the process of calculation of all systems' parameters and in this way saving man-hours in performing these calculations by hand;
   - as the program is integrated in *Microsoft Excel* file, it is easy and convenient for the customers to learn on how to use it for their purposes. This fact makes the program especially suitable to apply it at the learning process;
   - it allows the users to export the output modelling results to the working environment of the office applications *MS Excel* and *MS Word*;
   - it has functionality that makes a check for system's overloading and in those cases when the utilization of the modelled system is greater than or equal to *1*, the program shows a warning message.
3. Along with the possibility of graphical representation of the average queue length depending on the utilization of one server, it is planned to be developed functionality allowing the users to create chart representing the queue waiting time in function of server's utilization. Such a chart will show users how the higher utilization, respectively the longer queue affects the length of time that passengers spend inside the queue.
4. The proposed program is designed mainly for training purposes. In this connection, it is envisaged its utilization by university students during the lab exercises in "Operations Research".

6. REFERENCES

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