SIMULATION MODELING OF VEHICLE MAINTENANCE SYSTEM

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***Abstract**: A model of vehicle maintenance system, realized trough simulation modeling is presented in this article. The model covers all routine activities related to movement, maintenance and regulations. Activities are done by a certain number of specialists. The result of the model is obtaining information about the workload of the specialists, queuing time of vehicles and other statistical information*

***Key words**: SIMULATION MODELING QUEUING MODEL; MAINTENANCE;*

1. Introduction

The long-term exploitation of vehicles nowadays requires the precise accomplishment of the regulated activities and procedures related to the maintenance and repair of the vehicles as well as the covering of all processes and interrelations of the separate elements of the technical maintenance system (TMS). The purpose of this analysis is the optimization of the procedures, the number of maintenance staff and the quantity of the necessary equipment. One of the methods of achieving this objective is the simulation modeling of the maintenance system and the processes in incorporates.

2. Simulation modeling and research results

The paper presents a model of a vehicle maintenance and repair unit that has been realized through simulation modeling. As basis for the statistical data the authors have used information from the documentation of an Army unit that has participated in missions abroad. The model contains the unit's vehicles' movement, their daily maintenance upon return to the depot, regulated activities and current repairs of technical failures due to the exploitation of the machines.

The procedures are carried out by a certain fixed number of specialists. As a result of the functioning of the model data is collected about the individual workload of the different specialists, the queuing time of the vehicles and other information about the system as a whole.

The simulation modeling of the maintenance system has been realized in MATLAB program environment [3].

Taking into account that the TMS is a dynamic system, the simulation modeling has been carried out as a function of time. The duration of one iteration is estimated to be 1 hour since most of the operations take one or more hours. The model covers a period of 151 days non-stop, 8 working hours a day, hence the duration of the whole simulation being 1208 hours. This corresponds to one rotation within a mission.

Two software classes have been created for the realization of the simulation modeling: a machine and a technical maintenance system labeled as *machine* and *smo* respectively. These are the main objects participating in the process of exploitation and repair of the vehicles. Each of them generates and processes certain activities. The interaction between the machines and the maintenance system comprise the simulation.

Class "*machine*"– From the point of view of the technical maintenance system, the machines possess the same type of characteristics which have different values in the different types and brands of vehicles. This allows for their formal description through one virtual class which later serves as a basis for creating objects with fixed values of the characteristics corresponding to the respective types and kinds of vehicles. In the process of the simulation each vehicle performs certain tasks and various events occur with it, and they can be grouped and classified as follows:

– vehicle movement;

– generating the necessity of technical maintenance after covering certain mileage;

– malfunctioning of the vehicle;

– restoring its roadworthiness through the technical maintenance system.

The input data for the simulation model includes certain characteristics of vehicles as mentioned in Table 1.

Table 1

Input data for modeling of vehicle maintenance system

quantity	ЗИЛ-131	УАЗ-469	HUMMER	CHEVROLET	Other
P_{rem}	12,5%	15,7%	0,8%	0,8%	16,6%
P_{tp}	1,1%	0,4%	8%	-	-
K_{out}	5,34 pcs	4,94 pcs	3,91 pcs	3,42 pcs	0,54 pcs
Tr_{Min}	1 hr	1 hr	1 hr	1hr	1 hr
Tr_{Max}	8 hrs	8 hrs	hrs	2 hrs	2 hrs.
Speed	25 km/h	25 km/h.	25 km/h	25 km/h	25 km/h
λ	0,0217 km	0,0565 km	0,0060 km	0,0382 km	0,0296 km
s	545,4 km	180 km	858 km	318 km	300 km
ETM	1,3 ч.ч.	0,8 ч.ч.	1,3 ч.ч.	1,3 ч.ч.	1,2 ч.ч.
TM1	6 ч.ч.	4 ч.ч.	-	-	-
TM2	27 ч.ч.	13 ч.ч.	-	-	-
period TM1	1500 km	1500 km	-	-	-
period TM2	6000 km	6000 km	-	-	-
TM	1;1;1;2.	1;1;1;2.	-	-	-

Where:

P_{rem} – Probability for repairs.

P_{tp} – Probability for technical check-up.

K_{out} – Average number of the used machines.

Tr_{Min} – Minimum time for completing the repair work.

Tr_{Max} – Maximum time for completing the repair work.

Speed – Average driving speed.

λ – Parameter of the exponential law of distribution of kilometers per day covered by a single vehicle.

s – Average square deviation from kilometers covered per day.

Order for TM – Cyclic recurrence of the regulated procedures of TM1 and TM2.

The movement and exploitation of the vehicles are not directly linked to the functioning of the technical maintenance system but each usage of the machines inevitably leads to the carrying out of certain regulated maintenance activities of TMS such as:

– technical check-up before the vehicles leave the depot;

– daily technical servicing (DTS) of the vehicles when they return to the depot).

– TM1 or TM2 after covering certain mileage.

Parts of all activities, DTS in particular, are to be performed by the driver or the vehicle crew. However, practice shows that when the units are on missions abroad, most of the maintenance activities are carried out by the specialists from the maintenance sections. When the vehicles have traveled and been used, each of them covering a certain distance in kilometers and driving hours and utilizing certain resources [1, 6, 7] they are to undergo certain specified partial technical servicing. The collected data about the movement of the vehicles and the workload of the maintenance units during the particular period show that the majority of the machines from each type have been partially serviced at least once during the specified period.

The simulation model presumes that the movement of the machines starts at the start of the working day. In each iteration of the major simulation cycle, where the subsequent number of the hour is divisible by 8, the Monte Carlo Method [2] is used to determine which vehicles will be used during the day.

For each vehicle that has been determined for use, the number of kilometers it has to cover is generated on a random principle. This number is also generated on the basis of statistical processing of the data about the real distances covered by these vehicles. In order to obtain realistic simulation results, analysis has been made of the law of distribution of kilometers covered by the vehicles per day, and the generated quantity obeys this law. The law of distribution of the kilometers covered by the vehicles comes close to an exponential law. To confirm these hypotheses, a test has been done on the basis of the Pearson criterion. [5]. These raised hypotheses about the type of the laws of distribution of the different types of vehicles do not disagree with the experimental data, therefore the obtained laws can be used to simulate the movement of the vehicles, as a result of which realistic results are expected.

In the process of the simulation with every hour i.e. with every iteration of the main cycle, the kilometers of the used machines are reduced with a certain number, corresponding to the average speed of the respective type of vehicles. When this number of kilometers drops down to zero, we assume that the vehicle has returned to the depot and is to undergo DTS by the maintenance system.

For each vehicle a record of the covered kilometers during the day is made, the numbers are calculated as a variable and when they reach certain pre-defined values the vehicle is to undergo partial servicing in the maintenance system. The type, the sequence and time for the different servicing activities is defined on the basis of regulations adopted by the Bulgarian Armed Forces and on the basis of technical maintenance manuals for the different types of vehicles.[1, 6, 7].

It is only normal that different malfunctions occur in the process of exploitation of vehicles. Handling these malfunctions is one of the main tasks of technical maintenance units. The probability of malfunctions in different types of vehicles is defined on the basis of statistical data for the real repairs and technical checkups conducted. Because of lack of information about the duration of the really conducted repairs during the mission, for the simulation is usual that this durationis generated as a random number with a uniform probability within a defined interval of time through parameters such as minimum and maximum time for repairs. The technical maintenance system comprises two basic elements: queue and service canals. [2, 4]. Each vehicle that is in need of servicing or repairs waits in a queue to be serviced. Moving of the vehicles from the queue to the servicing canals is one of the procedures of TMS.

The fields of the "*machine*" class are as follows: Constant parameters as shown in Table 1. Variable parameters – kilometers covered by the respective vehicle on the day in particular; the number of kilometers covered since the last partial TM of the vehicle; the total number of TM1 or TM2 given to the respective machine, etc.

Methods of the "*machine*" class:

– *machine* – This function creates an object for the respective vehicle from the class.

– *mstatus* – This is the basic working function of the "*machine*" class. It is conducted with each iteration of the main cycle. The input of the function includes the current time and a specific object of the "*machine*" class. The output is a "*machine*" object with altered data. Figure 1 shows the flow chart of the algorithm underlying this function;

– *qstatus* – This is the basic working function which is conducted on an hourly basis for all vehicles in the queue waiting to be serviced.

There are other methods incorporated in the "*machine*" class but they are of auxiliary nature.

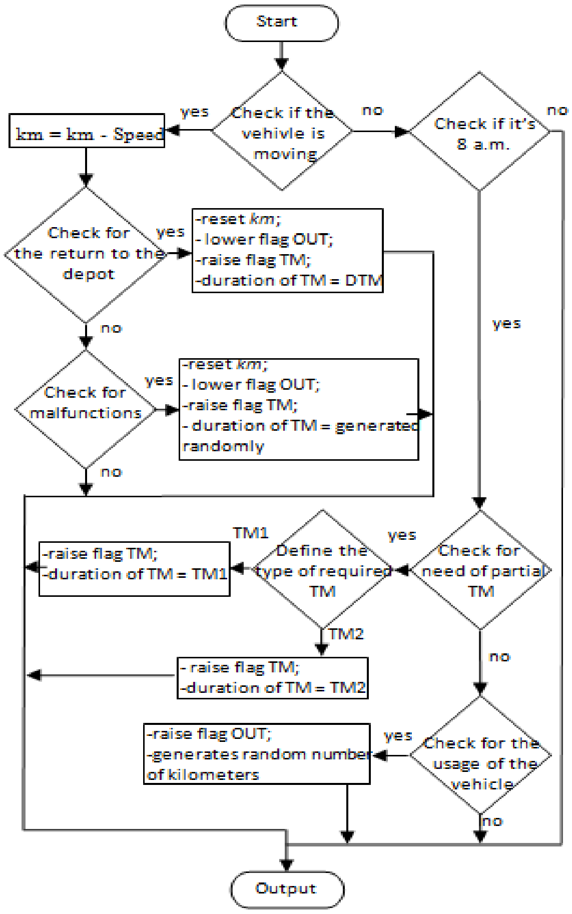

Fig. 1 *Flow chart of mstatus method algorithm*

The SMO model (Class "*smo*") performs the following basic operations:

– In the event of available unoccupied servicing canal and vehicles queuing to be serviced, the first of them moves to the canal and its servicing begins;

– For vehicles that are currently on the servicing canal, the time for servicing is reduced;

– Upon completion of the servicing process (when the servicing time gets down to 0), the vehicle is moved from the canal to the group of the serviced vehicles;

– Data is collected about the work load of the servicing canals, the duration of the vehicles' repairs, etc.

The "*smo*" class only includes two data fields as follows:

– *n* – number of the canals included in the TMS – it corresponds to the number of the specialists in the respective maintenance unit. This field is of constant nature and has the same value throughout the whole simulation. It is usually defined with the creation of an object from the "*smo*" class;

– *chan* – initially this field is empty and it presents the servicing canals.

The basic methods of the "*smo*" class are as follows:

– *smo* – this is a function which generates objects from the "*smo*" class. The input parameter is represented by the number of the canals of the TMS. The output is the created object;

– *smo_work* – this is the basic function simulating the work of the system of mass servicing. It is conducted with each iteration of the main cycle of the simulation. The flow chart of the algorithm underlying this function is shown on fig. 2

There are other methods incorporated in the "*smo*" class but they are of auxiliary nature.

Along with the above-described classes and the objects constructed by them, the work of the simulation requires some other data structures. The main structures of the central script of the model are as follows:

– *bmash* – database containing the objects from the *"machine"* class which are currently in good condition;

– *queue* – database containing the objects from the *"machine"* class which are not in good condition and are awaiting servicing from SMO;

– *data* – database containing information about the work of the model in every hour of the central cycle.

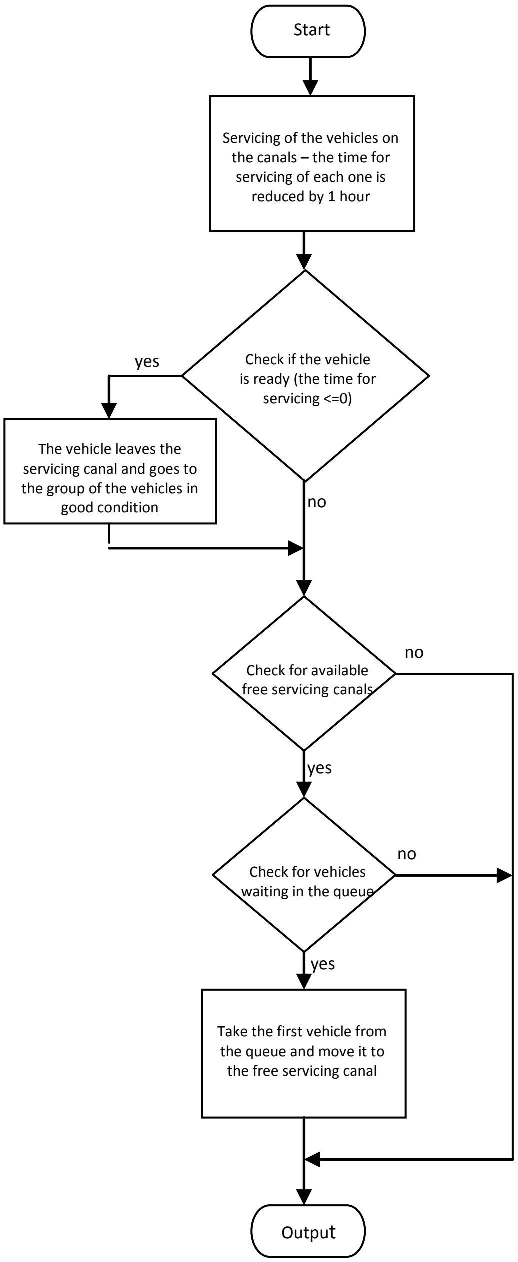

Fig. 2 *Flow chart of the smo_work method algorithm*

The main cycle of the simulation is realized in a separate script. The algorithm underlying the central script of the simulation is a linear one i.e. without branches and logical conditions and can be presented through the following sequence:

1) *Variables' initialization* – this includes creation of all objects and structures on the basis of data described above. It is assumed that at the start of the simulation all vehicles are in order and belong to the group of the serviced ones.

2) *Main cycle* – each iteration of this cycle corresponds to one hour of the mission. The following steps are included in one iteration of the cycle:

a) the *mstatus* method is applied to all the machines from the group of vehicles in good condition (*bmash*);

b) the *qstatus* method is applied to all the machines waiting in the queue (*queue*);

c) all vehicles from the group of those in good condition (*bmash*) are transferred to the queue (*queue*) with a raised flag TM;

d) the *smo_work* method is applied to the *"smo"* object ;

e) information about the current system status is collected in *data* field.

f) *Final processing and visualization* of results of the simulation modeling.

The results of the functioning of the model are graphically presented in fig. 3:

– average number of occupied *SMO* canals per hour;

– frequency of the occurrence of the various statuses of the system – corresponds to the probability of the system being in these statuses;

– average number of the vehicles waiting in the queue per hour;

– histogram of the distribution of the queue length. The y-axis represents the length of the queue and the x-axis - the number of hours (length of time) when the queue has had the respective length.

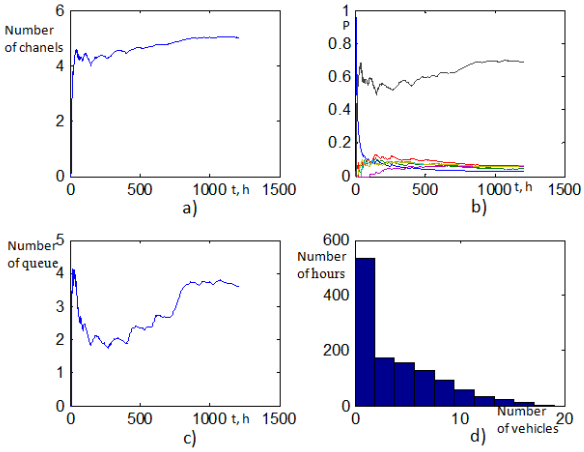

Fig. 3 *Automobile maintenance system*

a) average number of occupied canals

b) frequency of the occurrence of the system statuses;

c) average queue length;

d) histogram of the number of vehicles waiting in the queue.

Upon completion of the work of the model, the following results are calculated and numerically represented:

– frequency of the occurrence of the different statuses of the system;

– average number of the occupied canals;

– average number of vehicles waiting in the queue;

– average waiting time;

– average servicing time – this is the average time the vehicles spend on the servicing canals of the maintenance system;

– number of repairs given to the vehicles;

– number of TM–1

– number of TM–2;

– number of leavings of the depot by the serviced vehicles;

– average value of the kilometers covered by all machines;

– average – square deviation of the covered distances (in kilometers) by all vehicles;

– total number of repairs performed by the TMS;

– average time between two repairs.

Since the simulation model uses a lot of random events and values, the final results vary for each iteration. In order to obtain true and reliable results from the model, it is assumed that 30 experiments are made and the varied values of the different parameters are averaged.

The results of the experiments made and the theoretical model are presented in tables 2 and 3.

Table 2

Comparative results of the simulation model and the automobile maintenance system research through differential equations.

Quantities	Values received on the basis of differential equations	Average values received on the basis of the simulation model	Relative error
M_k	5,3895 items	5,1118 items	5,15%
m_s	3,6486 items	4,0638 items	11,38%
$\bar{t}_{чак}$	1,2856 hrs	1,5525 hrs	20,76%
ΔT	90%	85%	5,56%

Where:

M_k – mathematical prediction for the number of the occupied canals of the TMS;

m_s – mathematical prediction for the queue length;

$\bar{t}_{чак}$ – average waiting time in the queue.

ΔT – coefficient of the workload of one canal from the TMS.

Table 3

Comparative results of the simulation and the empirical values of the automobile maintenance system

Quantities	Empirical values	Average values received from the simulation model	Relative error
O_A	2740 items	2672 items	2,48%
R_A	582 items	746 items	28,18%
TM1	17 items	16 items	5,88%
TM2	20 items	14 items	30%
Σ_{ZA}	3359 items	3448 items	2,65%
$\bar{t}_{обс}$	1,9769 hrs	2,1264 hrs	7,56%
$\overline{T}$	0,3328 hrs	0,3504 hrs	5,29%

Where:

O_A – Total number of the utilizations of automobiles for the particular period;

R_A – Number of the repairs of vehicles done during the particular period;

Σ_{ZA} – Total number of requests for repairs to the TMS for the particular period;

$\bar{t}_{обс}$ – Average servicing time;

$\overline{T}$ – Average time between two requests for repairs.

3. Conclusions:

1. The results of the simulation modeling show that with the particular input parameters, the mathematical predictions for the number of the occupied canals is M_k= 5, 11(items), the average queue length is ms= 4, 06(items), the coefficient of workload of one canal of the TMS is ΔT= 85%, and these are the indexes that the TMS handles its optimum work load.

2. The histogram for the distribution of the queue length shows that its maximum length at certain times can reach 20 vehicles and their waiting time can be up to 6 hours.

3. The comparative analysis of the analytic research data about the system and the data from the simulation model are presented in tables 2 and 3, and the relative statistical error of TMS indexes is 11%, which shoes good coordination between the two modeling methods.

4. The simulation model gives the opportunity for carrying out experiments with varying input data about the system as well as opportunity for researching its behavior over the time, which facilitates the system optimization activities.

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