Research on the Intensity of Incoming and Outgoing Requests for Services during Maintenance of Mobile Machinery Used in Production

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Abstract: *Maintenance management system has a significant impact on the organization of machinery maintenance for providing and rational use of personnel, means for performing operations and maintenance of machines, formed on the basis of rational structure of the maintenance service shops, which is a special issue and requires separate research. An important issue in organization of maintenance is determining the optimal size of the service shops, the degree of concentration and its specialization. In this regard, the results of these study are used as input data for determining the parameters of the studied service firms for maintenance of given enterprises for the research period in order to scientifically substantiate their optimal size.*

Keywords: *maintenance, repair-servicing system, agricultural machinery, intensity of incoming flow of orders, intensity of out-going flow of orders, service parameters, service workshop, maintenance model, maintenance optimization.*

INTRODUCTION

Maintenance is one of the technological process in production enterprises. It has a significant influence on reducing the cost of production and the harmful impact of machines on the environment. Maintenance and remanufacturing are the means of natural conservation as they reduce the use of excessive natural resources. The way maintenance services are conducted the above-mentioned advantages are multiplied.

Agricultural machinery service companies are trying to use industrial methods for machine maintenance activities, based on specialization, automation and computerization for maintenance purpose. In Bulgaria the problem for maintenance service of older agricultural and motor transport equipment has not been solved yet and this requires to perform research and optimization of these activities. Modern systems for servicing of agricultural and transport equipment are complex organizational systems "man - machine", and the management of such a systems are targeted development or maintenance of systems and the introduction of their repair and improvement of various kinds. To solve the problem of managing such a system, the necessary use of technical means and the rational use and expenditure of material, human and financial resources are efficient and purposeful.

The rational application of machinery maintenance operations has an extremely large impact on their reliability and efficiency of utilization, and therefore on the productivity and profitability of production machinery.

THEORETICAL APPROACH

In the process of using machines under the influence of various random factors, the performance of individual elements goes beyond certain limits, individual elements or entire units fail, which reduces their quality of operation.

Naturally, the aim is to restore the machine's main function as quickly as possible, which is done through adjustments, restoration or replacement of failed elements or whole units. Often there are cases where failures of complex systems, such as tractors and automobiles, are hidden and require the use of special diagnostic devices and complex diagnostic equipment to detect the failure (Tasev G, 1995).

This requires to develop service systems that include functions such as diagnosis, repairing activities, refurbishing various equipment, which will regulate their diversity.

A system in the general theory of systems is understood as an organized set of interacting elements, forming a single component (Tasev G, 1995 and Novikov O, Petuhov C 1969).

The concepts of system and object are not identical (Tasev G, 1995 and Novikov O, Petuhov C 1969), i.e., the system should not be confused with the site for which it is being built. Different objects can have the same system and one object many different systems (Novikov O, Petuhov C 1969).

One of the main properties of the systems is the property of divisibility, i.e., the system can be divided into systems and subsystems, and the element is part of the system performing certain functions. Each system is made up of elements that form a certain structure (Tasev G, 1995). Now a day's multiple systems can system of systems.

Each element of the system can be considered as a system, depending on the goals and objectives of the study, which consists of elements and subsystems. At the same time, each system can be considered as a separate element of a super system. Therefore, in the process of research and separation of the level of management, as principle, it is the determination of the primary system of positions listed by the researcher depending on the goals and objectives of the study. The structure of the system is called a certain interconnection (interposition) of its elements, characterizing the structure and construction of the system (Tasev G, 1995).

A maintenance system, such as the service of mobile equipment is a set of interconnected elements (funds, maintenance documentation, contractors and etc.) needed to maintain and restore the quality of equipment's included in this system - Fig. 1. (Research Centre… Sofia, 1979)

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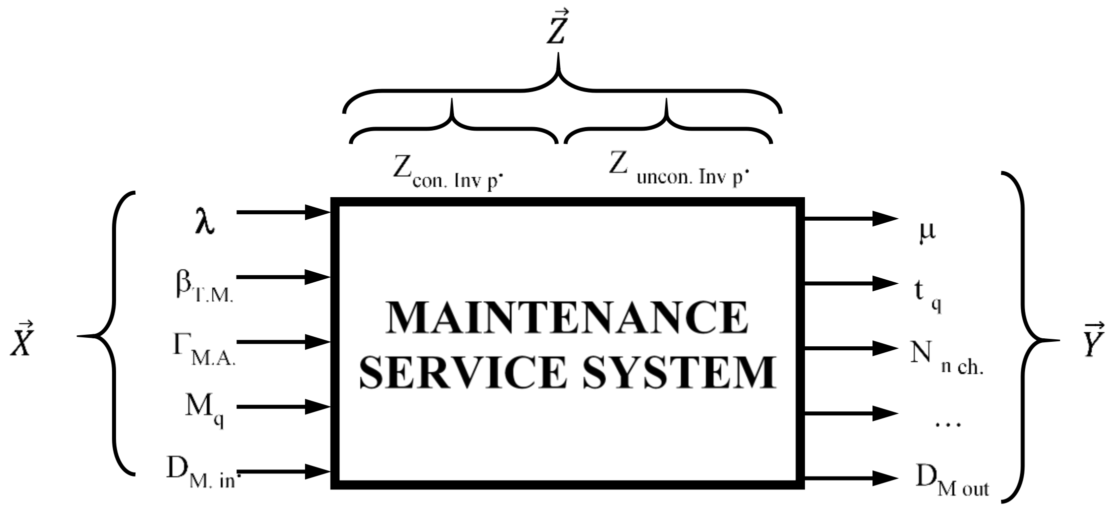


Fig. 1 Cybernetic model of a maintenance service system for mobile machinery: $\vec{X}$ is vector-function of the input controlled factors (λ - intensity of the flow of requests for maintenance function); $\Gamma_{A.\ M.}$ - grouping of repair function by complexity and frequency of implementation; M_q - the average length of the queue of machines at the entrance to service shape; $D_{M.\ in}$ - other input factors); $\vec{Z}$ - vector-function of the environmental factors ($Z_{con.\ inv\ p}$ – controlled and non-manipulated; $Z_{uncon.\ inv\ p}$ - uncontrolled and non-manipulated); $\vec{Y}$ - vector-function of quality and reliability (output parameters) of maintenance service shape (μ - parameter of indicator for the law of the time distribution for servicing the requests in the system; t_q - the average waiting time for maintenance service orders; $N_{n\ ch}$ – average number of channels that are loaded; $D_{M\ out}$ – other exit factors)

The state of the systems is judged by their parameters, i.e. a system's parameter is a qualitative measure that characterizes the structure or properties of the system and its elements, and the quantitative measure of the parameter is its value (Tasev G, 1995, Novikov O, Petuhov C.1969).

The state of a system can vary because of a various actions, including human activities or action (maintenance or repair process). The nature of these changes is judged mainly by the state of the system outputs. The set of variables with which the output of the system can be brought to the desired state will be called management, and some general features of management - management strategy or just strategy (Novikov O, Petuhov C 1969).

In order to model a given service it is necessary to determine maintenance service parameters. These parameters can be optimized by means of optimization methods and approaches developed in the form of models. These models characterize to some extent the most important aspects of the maintenance service, which in this case is considered as a technical and economic system. The modelling is performed according to a certain mathematical scheme, as the variables used reflect the main economic indicators of the system (Tasev G, 1993).

With the help of machinery maintenance service parameters quantitative assessment of service activities are performed. Therefore, their knowledge and definition are of particular importance (Mitkov A, Minkov D. 1993).

With the help of queuing theory, maintenance service can be presented as a Queuing system (QS) with the relevant parameters that identify it.

The activity of the service is related to the admission and processing of requests for machinery maintenance service. The random nature of the admission of requests requires their servicing to be random.

Analysis of the machinery maintenance process can be successfully performed using mathematical methods, such as queuing theory. Queuing systems, which are directly affected by the processes of machinery maintenance in this case mobile units for the implementation of maintenance operations or stationary posts - service workshops (Tasev G. et.al 2022).

Requests for maintenance form a flow of requests that arrives at the input of the maintenance system. Maintenance operations are essentially the process of restoring their working capacity.

The maintenance duration time depends on many random factors such as: the content of the maintenance operations, type and model of machinery and there specific feathers, etc., the qualifications of the service workers, etc. In this regard, we can summarize that the duration of maintenance, as well as the time of receipt requests arrival for maintenance in the technical services are random variables.

Significant influence on the organization of machinery maintenance has the system for providing and rational use of repair and maintenance workers, the means to perform operations and maintenance of machines, formed on the basis of a rational structure of the maintenance workshop, which is a special issue and requires another independent research. (Chernoivanov V.I. 1993 and 1997).

An important issue in the organization of maintenance is determining the optimal size of the service shop, the degree of concentration and its specialization.

OBJECT OF THE RESEARCH

The object of these research are three service bases for mobile machinery of the companies Service № 1 ("Agrotime Technik" Ltd); Service № 2 ("Port Complex - Ruse" Ltd); Service № 3 ("Niki - 5") from Ruse region.

SUBJECT OF THE RESEARCH

The subject of this research is the intensity of the incoming flow of requests (λ) and the intensity of the outgoing flow of requests (μ) in these services.

PURPOSE AND TASKS

The research that was being conducted aim's to scientifically study and justify the optimal choice of model and quantity of channels (workplace or group) for mobile machines of the surveyed services of enterprises depending on the average monthly total intensity of their requests for maintenance activates for the research period. From the goal that is set in this way, some of the main tasks of the study, reflected in this material are: determining the average monthly total values of the intensity of the incoming flow of requests (λ) and the intensity of the outgoing flow of requests (μ) for maintenance activities of these machines, which are input data in determining the parameters of the studied service activities of the enterprises.

RESULTS OF THE STUDY

Determining probability distribution of intensity of request for maintenance service which is random variable.

According to Queuing theory it is proved that the probability distributions of maintenance service requests are characterized with Poison distribution. It is necessary to determine the probability distributions of maintenance service request and to compare the hypothesis with the research result for three discreet period of time, whether they correspond to Poison distribution.

The data for maintenance service request intensity for the period 2018 – 2020 for mobile machines in the loaded operation period that is three months for each year are given. The data that is collected is given graphically Fig. 2 and 3.

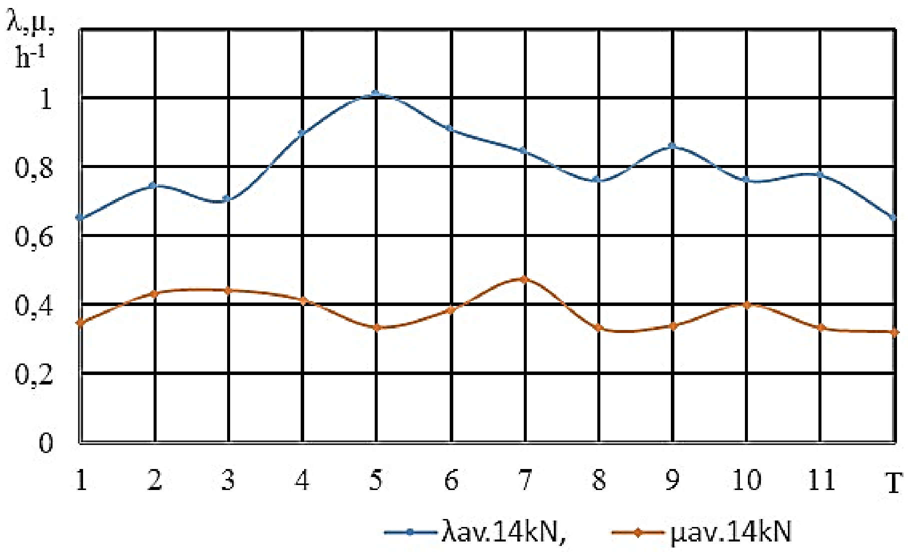


Fig. 2 The average intensity of request - $\lambda_{av.}$ and average intensity of servicing - $\mu_{av.}$ monthly for the period 2018 to 2020 for mobile machines with 14 kN (80 hp)

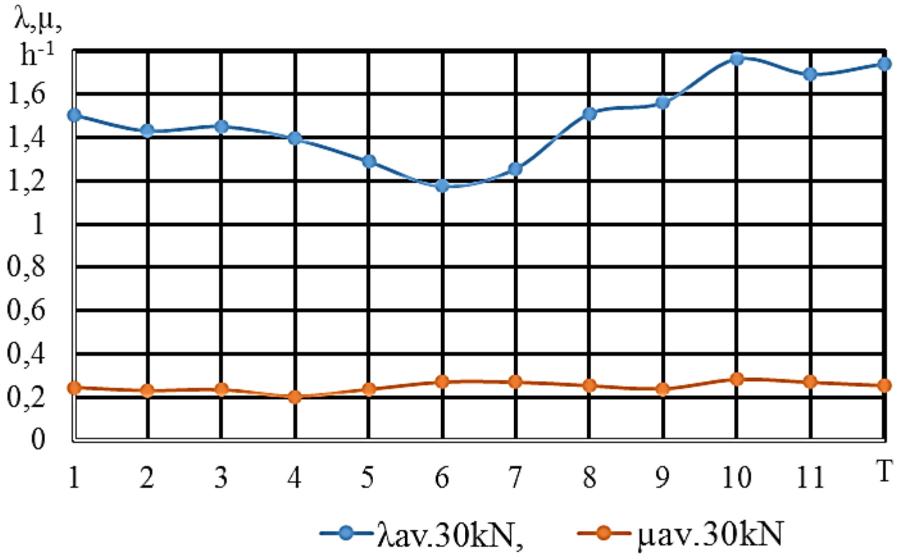


Fig. 3 The average intensity of request - $\lambda_{av.}$ and average intensity of servicing - $\mu_{av.}$ monthly for the period 2018 to 2020 for mobile machines with 30 kN (150 hp)

DETERMINING STATISTICAL PARAMETERS OF THE SERVICE REQUEST

Details of this research include determining statistical parameters which are necessary for the letter stage. For this purpose, it is necessary to determine the probability of existents of maintenance service request in the system for a given period of time, that means 1, 2 … m, number of machines will be in the queue for service. The hypothesis imagines that service need as stream of request for servicing for a given period of time is random intensity λ that characterizes the average maintenance request intensity for that period. Moment need and the duration of service at a certain time is random and this means that in the long run there will be moments of high and low maintenance service intensity. High intensity means the queue will be longer or low intensity refers to idle service channels and workers in the service workshop. This means the maintenance service is a random process that at a certain stage it transfers from one state to another: the number of engaged with maintenance work channels will change and number of machines that are diagnosed will change.

Transition of the system from one state to another is a leap, where one of the events occurs (for example, new request for maintenance service in one of the channels of the workshop). In this case the number of machines in the researched company is definite; therefore the maintenance service system is regarded as definite number of state. For such system the sum of all states at a certain moment is equal to 1, (1), (Tasev G. et.al 2022).

$$\sum_{k=1}^{m} P_k\,(t) = 1 \qquad (1)$$

$P_K\,(t)$ is the probability of k maintenance service request waiting for maintenance service in the workshop.

In order to determine the details of this random process, as a discrete system with continues time. It is necessary to analyze the cause of transition of the system from one state to another. For maintenance service system, the maintenance service request can be regarded as main factor. The maintenance service request consists of different individual and small in volume requests, i.e. the process is discrete, stationery and with no memory. Therefore, the process is Poisson.

Maintenance service request intensity is a function of agricultural activity intensity, in the researched maintenance workshop, the load of the machines can be accepted as uniform i.e. λ = const. In this case determining the process is much simple.

In order to determine the expected value of maintenance service request per day, distribution law of random variable X (number of maintenance service per day) is determined, (2), Tab. 1.

$$M[x] = \sum_{k=0}^{m} x_i \frac{n_i}{n}, \tag{2}$$

Where x_i is the quantity of maintenance request per day;

n_i - number of days with xi, maintenance request per day;

n - number of working days for the corresponding period.

When the parameter of Poisson distribution probability is equal to the expected value (*M[x]*) random value, therefore the empirical distribution can be compared to the Poisson distribution of probability of occurrence (3) (Dudushki Iv. 2008, Tasev G. 1995 and 1993):

Probability of occurrence (3):

$$P_{x_i} = \frac{d^{x_i}}{x_i} e^{-d}, \tag{3}$$

Where $d = M\,[x]$ is a parameter for Poison distribution

Table 1. Evaluation of intensity of maintenance service λ for agricultural machines

Class of tractors, [kW] (hp)	Evaluation of average value of $M\{x\} = \lambda$ per month for maintenance service in the workshop			Average value of λ_{avrage}
	May	Jun	July	
60 (80)	1,280	1,714	1,399	1,464
150 (120)	1,529	1,471	2,043	1,681

The hypothesis is proved with χ^2 criteria (Person criterion) that the distribution is **Poisson distribution**. Testing for coherence of hypothesis between the theoretical and experimental distribution includes determining the magnitude of difference, that the sum of square of the standard deviation, $\left(\frac{n_i}{n} - P_{x_i}\right)^2$, (4) (Dudushki Iv. 2008, Tasev G. 1995 and 1993).

$$U = \sum_{i=1}^{k} \frac{\left(n_i - nP_{x_i}\right)^2}{nP_{x_i}}, \; \chi^2 = U = \sum_{nP_{x_i}}^{k} \frac{(n_i - nP_i)^2}{nP_{x_i}} \tag{4}$$

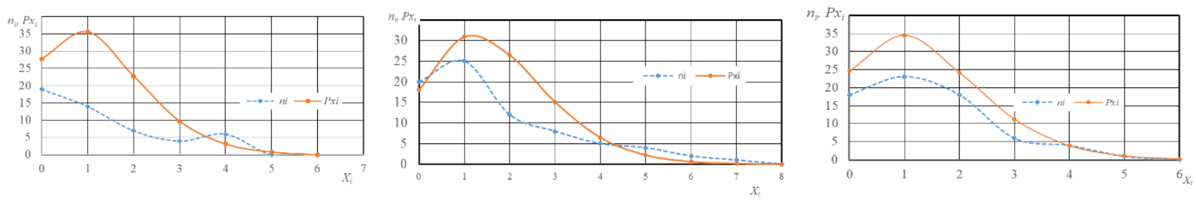
Where $n.P_{x_i}$ is the theoretical absolute frequency of class "*I*" after incorporation;

n_i - Experimental absolute frequency of class after incorporation;

k - Number of class after incorporation.

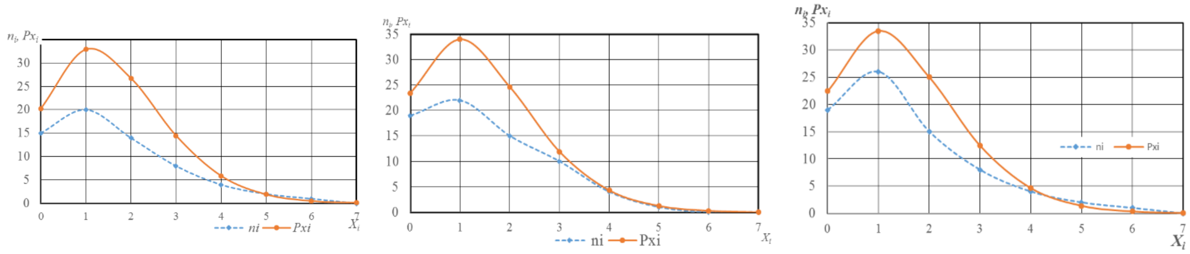
Testing the hypostasis proves that $x^2 < x^2_{\text{кр}} = x^2_{\alpha;k}$, i.e., the hypothesis doesn't contradict with the research results.

In determining the average values of the intensity of the incoming flow of maintenance by type (by elements, units and aggregates), received in the surveyed maintenance service shop for three years (2018-2020) monthly quantity per hour mobile machines class 14 kN (80 hp) or 30 kN (150 hp) $\lambda_{\text{mt vt}}$ and road vehicles $\lambda_{\text{mt rvt}}$. are presented on Fig. 4 and Fig.5.



May Jun July

Fig. 4 Empirical (n_i) and theoretical (P_{xi}) distribution curves number of requests for mobile machines type 14 kN (80hp) maintenance per month for the period 2018 - 2020



October November December

Fig. 5 Empirical (n_i) and theoretical (P_{xi}) distribution curve of average request for service per day, that are interring the workshop for mobile machines of class 30 kN (120 hp) maintenance per month for the period 2018 - 2020

From the summation of the values of $\lambda_{\text{av.}}$ for the respective month the average total intensity of the incoming flow of requests for maintenance of vehicles of the two mobile machin classes (14kN and 30kN) of the respective enterprises was obtained. – $\lambda_{\text{Smt vt}}$ by months of the studied period.

The value of the average total monthly intensity of the incoming flow of requests for maintenance for the period (2018-2020) that are characterized with their engine power 14kN (80 hp.) and 30kN (150 hp.) $\lambda_{\text{mt S}}$, received in the respective surveyed service workshope of enterprises are the sum of the values of all $\lambda_{\text{mt S}}$ for each month for the period divided by the number of calendar months of the year, i.e.:

$$\lambda_{av.M\ mt} = \frac{\sum_{i=1}^{12} \lambda_{i\sum mt\ av.}}{12}, \text{ n /h} \qquad (5)$$

$$\alpha_{av.M\ mt} = \lambda_{av.mt.(3\ years)} t_m, \text{ Number.} \qquad (6)$$

Where $\lambda_{\text{av.mt (3years)}}$ is the average intencity of incoming order for maintenance;

$\alpha_{av.Mmt}$ - determinable parameter;

t_m - the time for carrying out one repair operation (by elements, units and aggregates) or one preventive function according to the type of the respective request for mobile machine of class 14kN, 30kN or automobiles and is accepted under condition of partial mechanization of the repair and maintenance works performed in service workshops of enterprises and is determined by standard regulations for the hour.

The remaining values of the definable parameter for the period of these machines are established in the same way for determining the intensity of their incoming flow of activities requests

(Corrective maintenance, preventive maintenance or repair activities), and the indications are similar.

The average total values of the intensity of the outflow of applications for repairs or maintenance by months for the period of three years: vehicles class 14kN or 30kN $\mu_{\text{mt Srv1}}$), mobilemachines (14kN and 30kN) for each month of the period we find from the correlation existing between the intensities of the incoming and outgoing flow of requests of the respective machines:

$$\mu_{\sum mv\ av\ (3\ years)} = \frac{\lambda_{av.M\ mt}}{\alpha_{av.M\ mt}}, \text{ h}^{-1} \qquad (7)$$

The remaining values of the intensity of the outgoing flow of impact requests (Corrective maintenance, preventive maintenance or repair activities) of the same machines for the period of 3 years are determined in the same way to determine the intensity of their incoming flow of applications and their definable parameter for corrective maintenance, preventive maintenance or repair activities, as the indications are analogous.

The obtained average monthly values for the research period (3 years) of the main numerical characteristics of the flow of applications for technical activities of machinery in the studied service shops are presented graphically in Fig. 2 and 3.

DETERMINING THE MAINTENANCE SERVICE MODELS

The above characteristics are used to determine the Maintenance service models, on the basis of probability distributions of maintenance service request intensity. Probability distributions of maintenance service request intensity corresponds to Poisson distribution. So, it is possible to use Queuing Theory Model for this purpose. This is necessary to present the maintenance workshop activities (process). The main parameters of these models are studied in detail and analyzed comparatively.

Parameters of Queuing Theory models for service are studded for various number of maintenance servicing channels (working group). These models are: service model without restriction of service request (open model); service model with restriction of service request (closed model); service model with failure and partial interference of channels for processing request and service model with failure and full interference of channels for processing request. For this purpose, a computer program was developed. With the help of this program important parameters of maintenance service models are calculated for various numbers of channels (n_i). The results show that the last two models (service model with failure and partial interference of channels for processing request and service model with failure and full interference of channels for processing request) for average value of service request intensity and maintenance service rate are equal to zero for various n_i. This shows that these two models cannot be used because of the small scale of maintenance service request intensity. After this conclusion the research is oriented only on the remaining two models i.e., **open and closed service model**.

Service model without restriction of service request (open model): The maintenance service workshop for mobile machinery is an open service model (without restriction) is characterized as a queuing system with a limited number of channels "$\boldsymbol{n_i}$", in which, maintenance service of agricultural machineries is provided. Each channel can serve one machine at a time or one request for service. Each request which is coming for maintenance joins the queue, because the service groups are engaged with the previous request and wait for one of the channels to accomplish the work. If the request arrives and there is a free channel then the request immediately will inter the free channel and get a maintenance service. The pre-condition for the open service model to function is the probability distribution must be Poison distribution (**Fig. 6. a**) [6, 11, 12, 17, and 19].

The source of maintenance service request is unlimited capacity, while intensity of request is with finite dimension. The continuation of maintenance service time t_{serv} is stochastic variable, which is determined with parameters of probability distribution intensity of servicing.

Table 2. Parameters of Maintenance Service Model of without Restriction (Open Model) and Maintenance Service Model with Restriction (Closed Model)

№	Service Parameters	Model of Service without restriction (Open Model)	Model of Service with restriction (Closed Model)
1.	***α***- Determinable Parameter	$\alpha = \frac{\lambda}{\mu};\ \mu = \frac{1}{\bar{t}_{serv.}},$	
2.	***P₀*** – Probability for system load,	$P_0 = \frac{1}{\sum_{k=0}^{n-1}\frac{\alpha^k}{K!} + \frac{\alpha^n}{(n-1)!\,(n-\alpha)}} for\ \frac{\alpha}{n} < 1$	$P_0 = \sum_{k=0}^{n}\frac{m!}{k!\,(m-k)!}\alpha^k + \sum_{k=n+1}^{m}\frac{m!\,\alpha^k}{n^{k-n}.n!\,(m-k)!}$
3.	***P_K*** - Probability of “k” orders in the system	$P_k = \frac{\alpha^k}{k!}P_0, for\ 1 \le k \le n$	$P_k = \frac{m!\,\alpha^k}{n^{k-n}.n!\,(m-k)!}.P_0,$ $for\ n \le k \le m$
4.	***Π*** - Probability that the system is loaded fully, ($K \geq n$)	$\Pi = \frac{\alpha^n.P_0}{(n-1)!(n-\alpha)},\ \frac{\alpha}{n} < 1$	-
5.	***P_{n+s}*** - Probability that the system is loaded fully and “S” orders are waiting in the queue to be served	$P_{n+S} = \frac{\alpha^{n+S}}{n!\ n^S}P_0, \quad for\ S > 0$	-
6.	***P(τ > t)*** - Probability that the delay time of orders in the queue to be greater than the determined value *t*.	$P(\tau > t) = \Pi.e^{-\mu(n-\alpha).t}$	-
7.	$\bar{t}_{del}$ - Average delay time of orders, waiting for service in the system	$\bar{t}_{del} = \frac{\Pi.\bar{t}_{ser.}}{(n-\alpha)}, \quad for\ \frac{\alpha}{n} < 1$	-
8.	***$M_{exp.}$*** - Average queue length, at the entrance of the system.	$M_{exp.} = \frac{\alpha.P_n}{n\left(1-\frac{\alpha}{n}\right)^2},$	$M_{exp.} = \sum_{k=n+1}^{m}\frac{(k-n)m!\,\alpha^k}{n\left(1-\frac{\alpha}{n}\right)^2}P_0$
9.	***M*** – Average number of order in the system	$M = M_{exp.} + \frac{n.P_n}{1+\frac{\alpha}{n}} + P_0\sum_{k=1}^{n-1}\frac{\alpha^k}{(k-1)!}$	$M = M_{exp.} + \sum_{k=1}^{n}\frac{\alpha^k m!}{k!\,(m-k)!}P_0$
10.	**N₀** – Average number of free server channels	$N_0 = \sum_{k=0}^{n-1}\frac{n-k}{k!}\alpha^K.P_0$	$N_0 = \sum_{k=0}^{n-1}(n-k)p_k\sum_{k=0}^{n-1}\frac{(n-k).m!\,\alpha^k}{k!\,(m-k)!}.P_0$
11.	**Кпр.** – coefficient of delay of order in the channel	$K_{del} = \frac{N_0}{n}$	
12.	Nз – average number of busy channels with maintenance service work	$N_z = n - N_0$	-
13.	***K_{load}*** - load coefficient of channels	$K_{load} = \frac{N_z}{n}$	-
14.	*G_{loss}* – Economic indicator that evaluates the project choice variant of service model for designing maintenance service system.	$G_{loss} = (\lambda q_{exp} + q_{n.k}N_0 + N_z q_k).\bar{t}_{exp}$	-

Where λ is intensity of request (interance stream) for servicing; μ - intensity of servicing (exiting stream); n – number of servicing channels; $t_{ser.} = 1/\mu$ – average time of servicing; $G_{zag.}$ – lose caused by delay of service for $t_{exp.}$.; $q_{exp.}$ - lose caused by delay of service when the machine is in the queue; $q_{n.k}$ – cost of idle time of channels for unit time and q_k – cost real maintenance work for the machines in the service for unit time.

All the service channels of open maintenance eservice models are with equal productivity. The main parameters that characterize the activity of maintenance service workshop are: the probability all channels to be free or occupied; mathematical expectation for the length of the queue; coefficients that reflects occupation and idle state of maintenance channels (group).

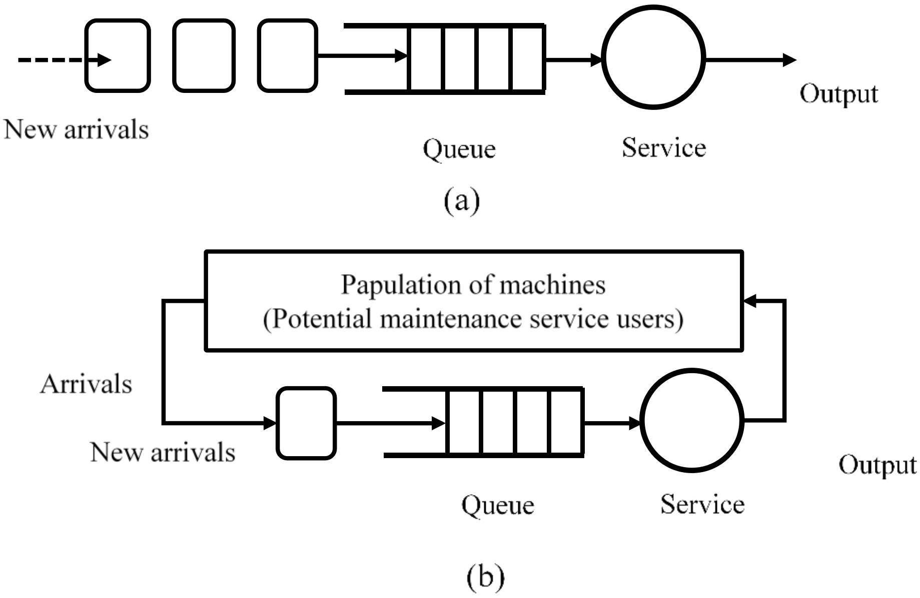


Fig. 6 Illustration of (a) open and (b) Closed queueing model

Service model with restriction of service request (closed model): Service model with restriction for service request (closed model) is presented on **Fig.6. b.**

If the maintenance service workshop is presented with closed service model request consist of "$\boldsymbol{n_j}$" – service channels. Each channel can serve only one request. The machines that inter the service are characterized with simple stream intensity of request. The request stream has limited source, therefore in the service system the maximum number of requests is "$\boldsymbol{m}$". The request that inter the system is serviced immediately when one of the channels is freed and if there is no free channel the requests will wait in the queue. After the maintenance service the machines return to their normal activity and become potential maintenance service requester.

The parameters of service of this two maintenance service models are given in the next table Tab. 2 (Tasev G. et.al.2022).

Comparison analyses of serves parameters for open and closed queuing system service models

Probability for all service channels to be free that is (P_o) for $\boldsymbol{\frac{\alpha}{n} < 1}$ varying the number of channels n

P_o – Probability for system load

Probability of all service channels to be free that is (P_o) for $\boldsymbol{\frac{\alpha}{n} < 1}$ for n number of channels is given on Fig. 7.

From Fig.7, it is obvious that the average vale of λ, μ, t_{obs} and α, for the closed model P_o is equal to 0, that means there is no probability all the channels to be loaded for a given time while for the open model P_0 have no value (undetermined) up to n = 2, because the condition $\boldsymbol{\frac{\alpha}{n} < 1}$ is not fulfilled. Increasing the value of n up to 4, the probability all canals to be free of serviced machines increases. The optimal value is n = 4 channels. With the increase of n, P_0 increase.

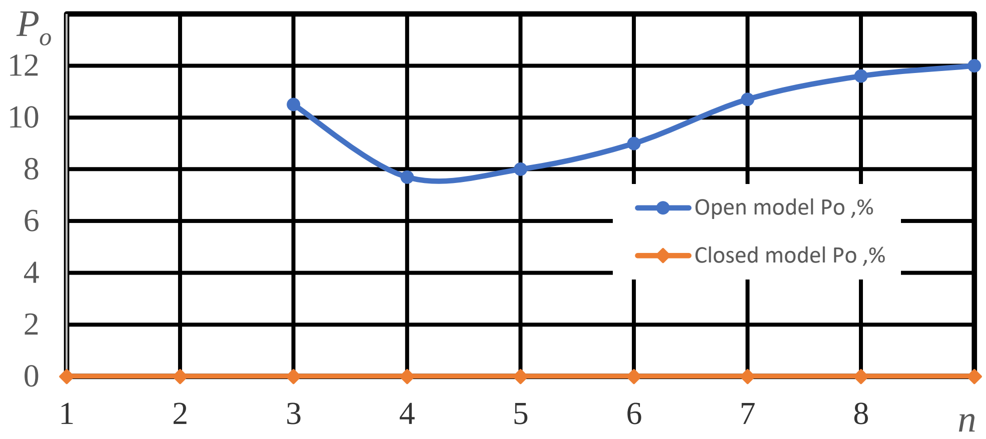


Fig. 7 Graphic presentation of Comparison of serves parameters for Open and Closed Queuing System Service Models

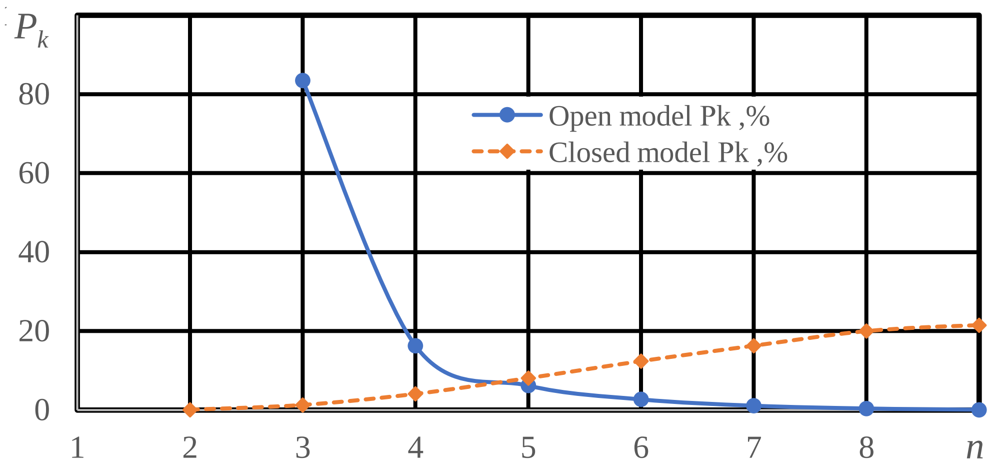


Fig. 8 Graphic presentation of Comparison of P_k which is probability of all channels to be free in relation to ***n*** number of channels: 1 - For channels with **open model** service (unlimited model) and 2 - For channels with **closed model** for service (limited model)

- P_k - Probability of "k" orders are in the service system

The probability of k number of requests (orders) to be present in the service - P_k or some of the channels to be free for open service model can be divided conditionally in to two parts (Fig.8).

The **first part** is *n = 2 to n = 3* channels. In this section the value of P_k decrees sharply with the increase of n. This shows that for certain λ (intensity of order) of the system, when *n* increase the newly remaining channels will also serve eventual orders, which are placed in the waiting queue. In this way serving time in the system will decrease.

The **second part** includes from *n* = 3 to n = 9 channels. In this section of the curve the parameter P_k decreases and slightly inclined to 0, this shows that. With the increasing of *n* all requests will be served and cannot be loaded any more or there will be no more machines left in the queue, so the length of the queue is approximately zero.

The parameter's P_k curve for **closed service model** increase corresponding to the growth of n (number of channels). This shows that for a given value of λ and μ, request of servicing machines where k = 5; m = 10, the growth of n (number of channels) of service workshop increases the possibilities of servicing more machineries (requests). The two curves intercept at the point where n = 4, this means that at this point it is possible to transfer from closed to open model of service and vice versa and it is the optimal value of n.

- Comparison of queue length - $M_{exp.}$

Comparison of queue length that is formed at the entrance of the service workshop ($M_{exp.}$) in relation to *n* number of service channels of the workshop. The result of this research is given on Fig.9.

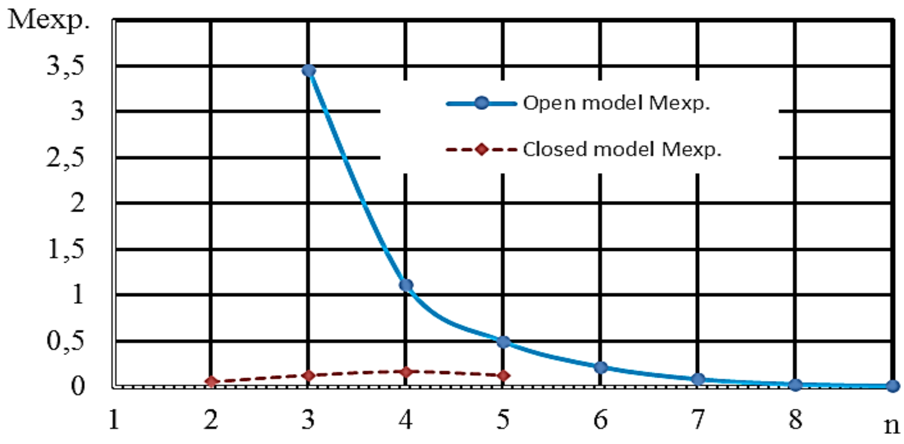


Fig. 9 Graphical presentation of the average queue length $M_{exp.}$ at the inertance of the service system in relation to the number of servicing channels (*n*): 1 - For open model service system (unlimited model) and 2 - For channels with closed model (limited model)

On Fig 9. The average length of queue M_{exp} for open service model decrees with the increase of *n*. This means that the queue that is waiting will be served faster and it will decrease that means more machines are serviced in the workshop. For farther increasing of n = 3, the loss for idle channels will increase because there will be no machines for servicing in the queue.

For closed model of servicing the queue never reaches $M_{exp} = 0,5$ or in practice it does not exist.

- Comparison of average number of requests in the service system *M*

The result is given graphically on Fig.10.

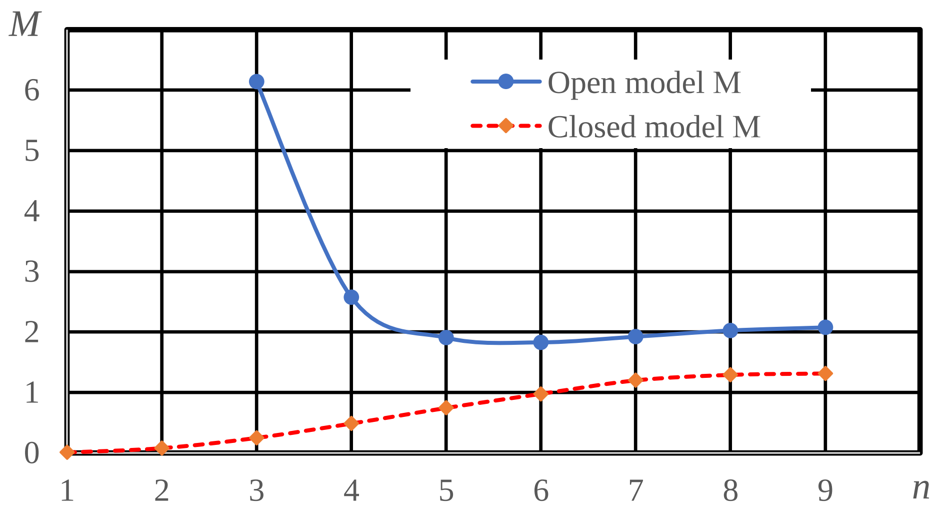


Fig. 10 Service request queue length M in relation to n channels of the service system for channels with: 1 - open model (unlimited model) and 2 - Closed model (limited model)

Fig.10 shows that the average value of requests that is in the system ***M*** for open model can be divided conditionally in to two parts. The first part is from ***n*** = 3 to **n** = 5 channels. In this part ***M*** is characterized as decreasing function when ***m*** = 6, ***n*** = 3 and ***n*** = 5, for ***m*** = 2. This shows that the intensity of request stream is not enough to load the servicing workshop for normal production process as farther increasing of n. The second sector is ***n*** = 6 up to ***n*** = 9 channels. In this section the real average request for servicing in the workshop do not vary with the increasing of n significantly. This average value real of ***M*** request that is in the system don't vary significantly with the increasing of ***n*** number of channels of the servicing workshop. The average request for servicing in the workshop doesn't exceed ***M*** = 2.

The diagram shows that in general, variation of average value of request (***M***) in the service system in relation to the number of servicing channels (***n***) for closed service model has slightly increasing characteristics, but the value of M remains closed to 1.

CONCLUSION

From the suggested maintenance service models and the research in relation with these models on maintenance of mobile machines 80 hp (14 kN) and 150 hp (30 kN) for the period 2018 – 2020, in Ruse Region, the following conclusions are made:

1. Maintenance service models parameters aren't studded enough and this research solves some of the problems related to the validity of these models in relation to mobile machinery maintenance service request intensity for relation to service channel (group) number "**n**";
2. Probability distribution of maintenance service request intensity is Poison distribution with significance level α = 0,1;
3. The relationship between mobile machinery loss depending on the variation of service channel (group) number "n";
4. Applicability of mobile machinery maintenance service models depending on the intensity of maintenance service request and maintenance service intensity were determined;
5. Using Queuing Theory and research data for input factors for the main mobile machinery maintenance service parameters for the two models (open and closed) are determined (P_0, P_k, P_{n+1}, M_{exp}, M, $t_{exp.}$, N_0 and etc);
6. Following the research results a method for determining maintenance service parameters is developed;
7. The research result shows that for the researched Region Open Maintenance Service Model is most efficient and advisable for the given maintenance service request intensity and maintenance service intensity.

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