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RESEARCH AND OPTIMIZATION OF AGRICULTURAL MACHINERY MAINTENANCE SERVICE

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ABSTRACT:
In this paper a method and research on optimization of maintenance serves parameters for agricultural machinery is presented. Parameters of the maintenance service for a period of time which is 2003 to 2005 are given. Statistical distributions for intensity of orders for maintenance service are determined. Research is conducted on different models of maintenance service. Comparative analyses were made for some of the maintenance service parameters. Optimization was made on the numbers of maintenance service groups (channels). The results were analyzed at the end of this work.
KEYWORDS:
Maintenance service parameters, maintenance service models, maintenance service optimization.

1. INTRODUCTION

The cost of maintenance service for agricultural machinery is one of the main expanses in this business. For this reason it is necessary to find new solution regarding maintenance of agricultural machineries that corresponds to the industrial machinery maintenance. In the past periodic maintenance was the main strategy in agricultural machinery maintenance. Periodic maintenance strategy is one of the strategies that have given contribution to the development of different strategies such as preventive maintenance, predictive maintenance, Reliability Centered Maintenance (RCM), Total Productive Maintenance (TPM), proactive maintenance [1, 6 and 13].

Planning of agricultural machinery maintenance is based on the type of service model, strategy and optimization. Using mathematical statistics and queuing theory it is necessary to determine problems related to maintenance service optimization.

The aim of this research is to develop a method for agricultural machinery maintenance service optimization and determine optimal servicing model.

The aim that is formulated above can be achieved by solving the following problems: determining maintenance serves parameters, which is the objective of this research, comparative analysis of different maintenance service models.

Stages of research method:

1. Determining average value of maintenance service parameters: λ – intensity of orders for maintenance service; μ - intensity of maintenance service accomplished;
2. Establishing statistical probability distribution of λ – intensity of orders for maintenance service;
3. Research on maintenance service models on the bases of establishing statistical probability distribution of λ – intensity of orders for maintenance service;
4. Comparative analysis of maintenance service model parameters;
5. Optimization of maintenance service groups (channels) by maintenance service parameters.

This research was conducted in North Bulgaria, Ruse region. The subject of this research is mainly the intensity of maintenance service orders for universal tractors with 55 kW (80 HP), for the period 2003 to 2005.

2. EXPOSITION

Step I. Determining the average diamantine of intensity of request for maintenance service and intensity of processing the request (maintenance of agricultural machineries) for the period 2003-2005 [1,5].

For the detail description of intensity of request (λ) for servicing agricultural machinery it is necessary to determine probability of occurrence of λ for certain period of time. It is obvious that λ and t (duration of time for maintenance activity) are random (stochastic) variables and that means for the full determination of this discrete random process for continues period of time it is necessary to study the request stream for servicing agricultural machinery in the corresponding workshop. The hypothesis is that the request stream has a Poisson distribution, i.e. the following conditions are fulfilled: the order stream for service is ordinary, stationery and without consequence [6, 7, 9, 10].

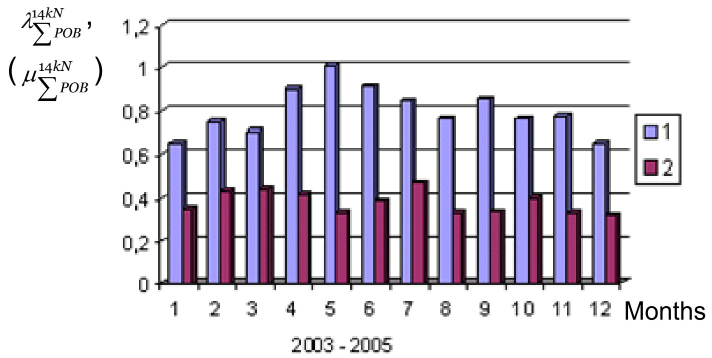

Fig.1. Variation of intensity of request for maintenance service in relation to the period of time for agricultural tractors 14 kN power: 1 – intensity of request for maintenance service ($\lambda^{14kN}_{\sum POB}$); 2 - intensity of maintenance service ($\mu^{14kN}_{\sum POB}$)

The hypostasis for probability density is checked by comparing the research results from the actual data of the service workshop for the past years. In this research the monthly request for service are presented by service type and quantity [2]. The result from this research is shown in fig. 1.

The result from the research shows that: intensity of request for service is λ=0,797 per hour; intensity of maintenance service μ=0,379 per hour; average time for maintenance service for each request $t_{s.}$ = 2,639 hour, for tractors (14 kN), corresponding to the tractors that inters and leave the service workshop

In order to take a decision for selection of optimal maintenance service model for agricultural machinery in North Bulgaria, Ruse Region for maintenance workshops which are engaged with maintenance of agricultural tractors (14 kN). For this purpose it is necessary to determine parameters of maintenance service of the models and analyse the results.

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

Queuing theory proves that the probability distributions of service requests are characterized with Poison distribution. The first stage of this research is to determine the probability distributions of maintenance service request and it is necessary 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 2003 – 2005 for agricultural tractors in the loaded operation period that is three months for every year. The data that is collected is given in graphically fig. 2.

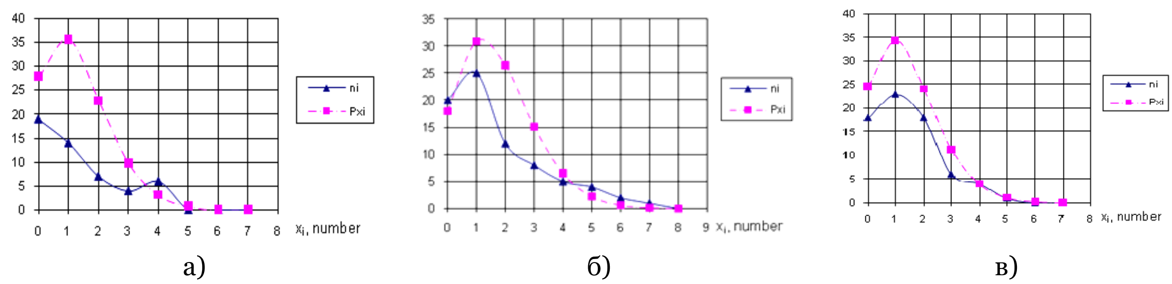

Fig.2. Empiric - ▲ - (n_i) and theoretical - ■- (P_{xi}) distribution curve of average request for service per day, that are interring the workshop for tractors maintenance per month: a) May; b) Jun and c) July, from 2003 to 2005

Details of this research include determining statistical parameters which are necessary for the second 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 service for a given period of time is random intensity λ that characterizes the average maintenance request intensity for a given period of time. Moment need and the duration of service at a certain moment 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 in the service workshop. This means the maintenance service is a random process that at a

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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 tractors in the researched farm 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), [1,3,6,7].

$$\sum_{k=0}^{m} P_k(t) = 1 \tag{1}$$

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 simpler.

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 x_i, 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) [1,3,6]:

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

where d = M[x] is a parameter for Poison distribution

Table 1 . Evaluation of intensity of maintenance service λ for agricultural tractors (14 kN)

Model of tractors	Evaluation of average value of $M\{x\} = \lambda$ per month for maintenance service in the workshop			Average value of λ_{avrage}
TK – 80, MTZ – 80.1 UMZ – 6AK	May 2003÷2005	Jun 2003÷2005	July 2003÷2005	1,464
	1,280	1,714	1,399	

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, $\left(\frac{n_i}{n} - P_{xi}\right)^2$, (4) [1,3,6].

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

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

n_i - Experimental absolute frequency of class "i" after incorporation;

k - Number of class after incorporation.

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

Step III. Maintenance service models, on the bases of probability distributions of maintenance service request intensity.

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Probability distributions of maintenance service request intensity is Poisson distribution. □oi t is possible to use Queuing Theory Model for this purpose. This is necessary to present the maintenance workshop working process. The main parameters of these models are studied in detail and analyzed comparatively.

Parameters of four 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 agricultural machinery is an open service model (without restriction) is characterized as a queuing system with a limited number of channels "n", in which ,maintenance service of agricultural machineries are 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 finish 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.3) [1, 4, 5, 8, and 11].

The source of maintenance service request is unlimited capacity, while intensity of request λ 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 μ .

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).

Service model with restriction of service request (closed model)

Service model with restriction of service request (closed model) is presented on fig.4. [1,4,5,8,10].

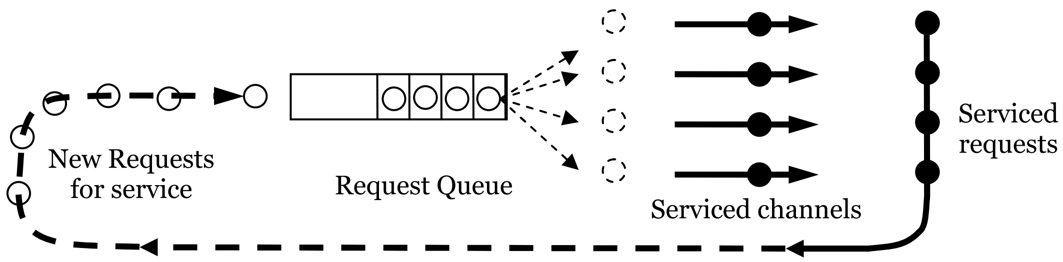

Fig.4. Closer Maintenance Service Model (Without Requests)

If the maintenance service workshop is presented with closed service model request consist of "n" – service channels. Each channel can serve only one request. The machines that inter the service are characterized with simple stream intensity of request λ . The request stream has limited source, there fore in the service system the maximum number of request is "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 wait in the queue. After the maintenance service the machines return to their normal agricultural work and become potential maintenance service request.

The parameters of service of this two maintenance service models rare given in the next table Tab. 2.

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Table 2. Service Parameters of Model of Service with Non - Preemptive Priority (Open Model) and Model of Service with Preemptive Priority (Closed Model)

№	Service Parameters	Model of Service without restriction (Open Model)	Model of Service with restriction (Closed Model)
1	2	3	4
1.	α – Determinable Parameter	$\alpha = \frac{\lambda}{\mu}$, $\mu = \frac{1}{\bar{t}_{serv.}}$	
2.	P_o – Probability for system load, for $\frac{\alpha}{n} < 1$ for Open Model	$P_o = \frac{1}{\sum_{k=0}^{n-1} \frac{\alpha^K}{K!} + \frac{\alpha^n}{(n-1)!(n-\alpha)}}$	$P_o = \left[\sum_{k=0}^{n} \frac{m!}{k!(m-k)!} \alpha^k + \sum_{k=n+1}^{m} \frac{m!\alpha^k}{n^{k-n}.n!(m-k)!} \right]^{-1}$
3.	P_K - Probability of “k” orders in the system	$P_K = \frac{\alpha^K}{K!} P_o$ for $1 \le K \le n$	$P_k = \frac{m!\alpha^k}{n^{k-n}.n!(m-k)!}.P_o$, for $n \le k \le m$
4.	Π - Probability that the system is loaded fully, $(K \ge n)$.	$\Pi = \frac{\alpha^n.P_o}{(n-1)!(n-\alpha)}$, $\frac{\alpha}{n} < 1$	
5.	P_{n+S} - Probability that the system is loaded fully and “S” orders are waiting in the queue to be served	$P_{n+S} = \frac{\alpha^{n+S}}{n!n^S}.P_o$, for $S > 0$	
6.	$P(\tau > t)$ - 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	$\bar{t}_{del.} = \frac{\Pi.\bar{t}_{serv}}{(n-\alpha)}$, for $\frac{\alpha}{n} < 1$	
8.	$M_{que.}$ - Average queue length, at the entrance of the system.	$M_{expected} = \frac{\alpha.P_n}{n(1-\frac{\alpha}{n})^2}$	$M_{expected} = \sum_{k=n+1}^{m} \frac{(k-n)m!\,\alpha^k}{n(1-\frac{\alpha}{n})^2} P_o$
9.	M – Average number of order in the system	$M = M_{очакв} + \frac{n.P_n}{1-\frac{\alpha}{n}} + P_o \sum_{k=1}^{n-1} \frac{\alpha^K}{(k-1)!}$	$M = M_{очакв.} + \sum_{k=1}^{n} \frac{\alpha^k m!}{k!(m-k)!}.P_o$
10.	N_o – Average number of free server channels	$N_o = \sum_{k=0}^{n-1} \frac{n-k}{k!} \alpha^K.P_o$	$N_o = \sum_{k=0}^{n-1} (n-k) p_k = \sum_{k=0}^{n-1} \frac{(n-k).m!\alpha^k}{k!(m-k)!}.p_o$
11.	$K_{del.}$ – coefficient of delay of order in the channel	$K_{del.} = \frac{N_o}{n}$	
12.	N_3 – average number of busy channels with maintenance service work	$N_3 = n - N_o$	
13.	K_{load} - load coefficient of channels	$K_{load.} = \frac{N_3}{n}$	
14.	G_{loss} – Economic indicator that evaluates the project choice variant of service model for designing maintenance service system.	$G_{zag} = (\lambda.q_{expected} + q_{n.k}.N_o + N_3.q_k).\bar{t}_{expected}$	

Where λ is intensity of request (interance stream) for servicing; μ - intensity of servicing (exiting stream); n – number of servicing channels; $t_{obs.}=1/\mu$ – average time of servicing; $G_{zag.}$ – lose caused by delay of service for $t_{ochk.}$; $q_{ochk.}$ - lose caused by delay of service when the machine is in the queue; q_{nk} – 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.

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Step IV. Comparison analyses of serves parameters for Open and Closed Queuing System Service Models.

4.1. Probability of all service channels to be free that is (P_o) for $\frac{\alpha}{n} < 1$ varying the number of channels n. Variation of P_o is shown on fig 5.

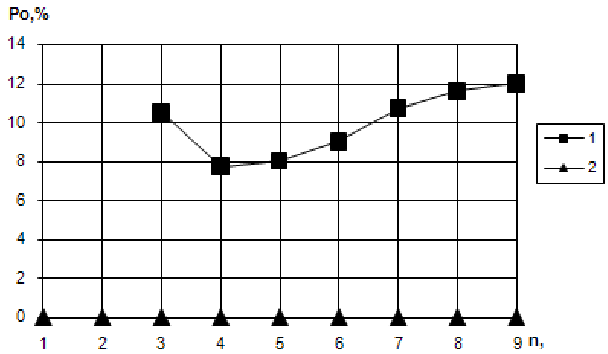

Fig.5. Variation of Probability of all service channels to be free (P_o) depending on the quantity of channel n: 1 - For channels with open (unlimited) stream of queuing for service and 2 - For channels with closed (limited) stream of queuing for service;

From fig.5, it is obvious that the average vale of λ, μ, t_{obs} and α, for the closed model $\mathbf{P_o}$ 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_o have no value (undetermined) up to n = 2, because the condition $\frac{\alpha}{n} < 1$ 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 of n = 4 channels. With the increase of n, P_o increase.

4.2. Probability of "K" quantity channels to be loaded for servicing the machines P_k from all the channels of the given Service workshop. Variation of P_k from n is shown on fig.6 for both closed and open models of service.

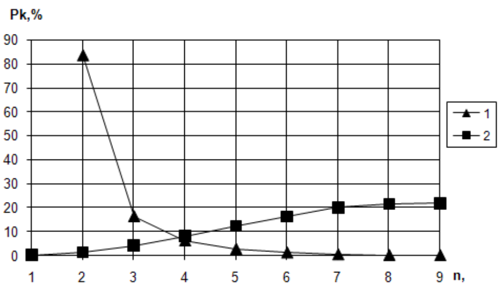

Fig.6. Variation of P_k probability of channels to be free in relation to n number of all channels: 1 - For channels with open model for service (limited model) and 2 - For channels with closed model for service (unlimited model)

The probability P_k some of the channels to be free for open service model can be divided conditionally in to two parts fig.6. The first part is n = 2 to n =4 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) for the service workshop, when n increase the newly added channels will also serve eventual orders, which are placed in the queue. In this way serving time in the channels will decrease. The second part is with bounders from n = 4 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 can not 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 P_k curve for closed service model increase corresponding to the growth of n (number of channels). This shows that for a given data for: λ, μ, for work 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.

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4.3. Variation of queue length that is formed at the entrance of the service workshop (M_{ochk}) in relation to n number of service channels of the workshop. The result of this research is given on fig. 7.

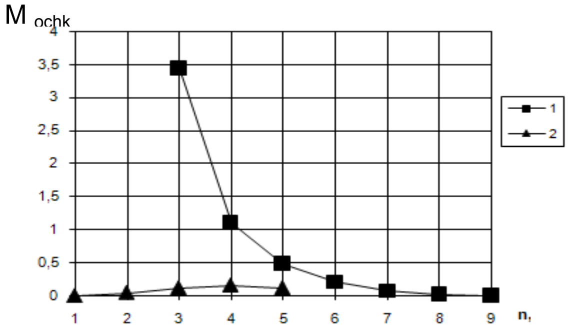

Fig.7. Variation of average queue length M ochk waiting for service machines at the iterance of the workshop in relation to the number of servicing channels (n): 1 - For channels with open model for service (limited model) and 2 - For channels with closed model for service (unlimited model)

Fig7. shows that the average length of queue $\mathbf{M_{ochk}}$ 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 frther increasing of n = 4, 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_{ochk} = 0, 5 or in practise it does not exits.

4.4. The average number of request in the service system M in relation with n is given as variation of this parameter on fig.8.

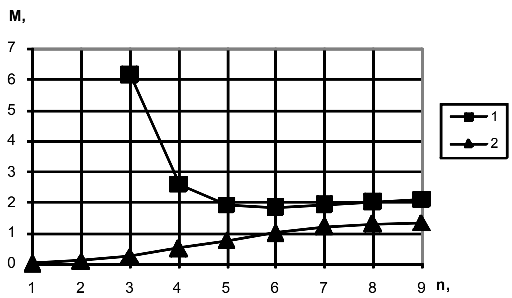

Fig.8. Service request variation in relation to n channels of the service workshop: 1 - For channels with open model for service (limited model) and 2 - For channels with closed model for service (unlimited model)

Fig.8 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 = 6 channels. In this part M is characterized as decreasing function when m = 6, n = 3 and n = 6, for m = 2. This shows that the intercity 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 don'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 increasing characteristics.

Step V. Optimizing the number of servicing channel of the workshop.

Design service workshop productivity in comparison to the actual productivity for servicing agricultural machinery is different and has non constant character. The intensity of maintenance service orders during important agricultural operations can exceed the capacity of servicing in this workshop and the actual activity related to this maintenance service can not satisfy the work orders that are waiting at the entrance. That is why the queue starts growing in front of service channels. The load of the service workshop outside important operations (ploughing, sawing, harvesting and etc.) calendar is lower than the project design of servicing capacity. This means that some of the channels can be idle.

The structure and dimensions of maintenance service workshop can be determined on a base of compromise of real influencing factors. These factors don't have the same influence on the service system and this gives reason for tacking subjective decision to satisfy agricultural operations. In practice this complicated problem is solved with the help of optimization method and means, designed in the form of models, that characterizes at a certain level the most important side of servicing systems, that is technical and economic system [1, 6, 7, 12].

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In this case the solution of the problem related to service optimization is solved with a complex evaluation factor which is monthly budget of the service workshop (G_M). This parameter consist of the following losses: $\mathbf{G_1}$ – loss caused by service delay while machines are waiting in queue; $\mathbf{G_2}$ - loss caused by service delay while machines are in servicing channels of the workshop; $\mathbf{G_3}$ – the real service cost of maintenance in the workshop. In this case the criteria equation will have the following type (5):

$$G_M = G1 + G2 + G3 \rightarrow \min, \quad (5)$$

Where G_1 is loss caused by service delay while machines are waiting in queue,

$$G1 = \lambda .\ q_{ochk}.\ t_{ochk}, \quad (6)$$

λ. – intensity of order foe maintenance service, [number per h]

q_{ochk} – is loss caused by service delay while machines are waiting in queue for unit of time, [EUR];

t_{ochk} – average idle time while machines are waiting in queue

$$G2 = K_{dch}.\ n.\ q_{dch}., \quad (7)$$

K_{dch} – coefficient of delay in the queue;

n – number of channels in the service workshop;

q_{dch} – loss caused by service delay while machines are in servicing channels of the workshop for unit of time;

$t_{ochk\,1}$ – average idle time while machines are in service channels.

$$G3 = n.\ q_K., \quad (8)$$

q_K – Service cost of the workshop for machinery maintenance, [EUR per h]

Then the criterial equation will have the follow type (9):

$$G_M = \lambda .\ q_{ochk}.\ t_{ochk}. + K_{dch}.n.q_{dch}. + n.q_K., \quad (9)$$

To calculate the dimension of monthly budget of the maintenance service workshop for agricultural tractor with 14 kN draught force depending on the number of servicing channels, equation (5) is used and by replacing the following research results:

$\lambda_{av.\ 2003-2005г.} = 0{,}797$ per h $\qquad \mu_{av.\ 2003-2005\ г.} = 0{,}379$ h

$\alpha = 2{,}103$, $\qquad t_{serv} = 1/\mu = 2{,}639$ h

$q_{exp.} = 96$ EUR/h, $\qquad q_{ПК} = 320\ 96$ EUR/h, $\qquad q_K = 180$ EUR/h

The results of maintenance service optimization are given in fig 9 and 10.

Increasing the number of service channels where the intensity of request is the same, led's to an increase of loss. Therefore increasing the productivity of maintenance service workshop must be related to a change in the organization and model of the service system and not only increasing the number of service channels.

Results of calculation for monthly expenditures that is necessary for the service workshop depending on the number of channels for servicing machinery shows that optimal variant service model for universal tractors with 14 kN power is n = 3, where the workshop in the researched region consist of n = 4.

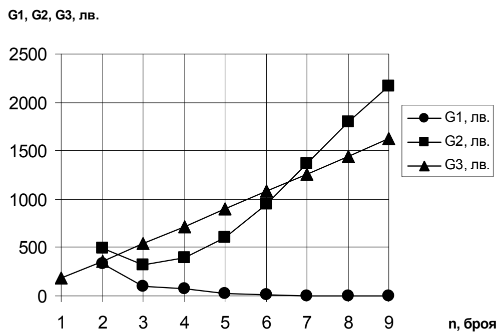

Fig.9. Variation of los for from:
1 -◆- requests, that are in the service queue for a unit of time (G_1); EUR./h
2 -■- delay of machines in the queue per unit of time, EUR./h (G_2);
3 -▲ – the real cost of servicing the machines in the service workshop that are placed in the queue per unit of time, EUR/ h (G_3) depending on the quality of channels of the service workshop (n).

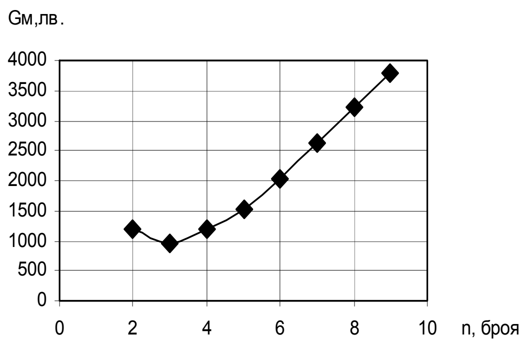

Fig.10. Variation of los dimension related to idle time of machines while they are waiting inside the queue waiting for service per unit of time, EUR/h, (G_M) depending on the quantity of channels of the service woke shop (n).

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3. CONCLUSIONS

From the suggested maintenance service models and the research in relation with these models on maintenance of agricultural tractors (14 kN) for the period 2003 – 2005, 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 agricultural machinery maintenance service request intensity for variation of service channel (group) number "n";
2. Probability distribution of maintenance service request intensity is Poison distribution with significance level $\alpha = 0{,}1$;
3. The relationship between agricultural machinery разходи depending on the variation of service channel (group) number "n";
4. Applicability of agricultural machinery maintenance service models depending on maintenance service request intensity and maintenance service intensity were determined;
5. Using Queuing Theory and research data for incoming factors the main agricultural machinery maintenance service parameters for different models are determined (P_o, P_k, P_{n+1}, M, $t_{ochk.}$, N_o 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.
8. For models that are used in this research, desired function of optimization aims to achieve minimum expenses for agricultural machinery maintenance for the given maintenance service request intensity and maintenance service intensity

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