Research on losses of technical preparedness of forage harvesters combines by level of seasonal service accumulation

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Abstract. The results of experimental studies are presented in article. It is established that minimal total costs for ensuring the technical preparedness of forage harvesters combines are possible to create using the optimal number of service activities. Formation of suboptimal number of service activities results in 27% and 18% losses (1 and 7 years of operational term of forage harvester). The article considers the graph of state of technical preparedness of forage harvester combines and develops an algorithm that calculates for each year of operation and for annual operating time the following indicators: average queue length; average number of pending requests; average number of service free channels; queue idle ratio; order utilization rate; idle ratio of servicing units; complete average losses due to idle queue requirements and less channel workload; time of waiting in line. The optimum number of channels was assumed to be the number with minimal total average cost of simple queuing requirements and no channel workload. The authors found out that the cost of ensuring of technical preparedness of forage harvesters depends on year of operation of harvesters and their annual loading. These costs reduce from 13.63% to 3.12%, for the accumulation of 150-180 hectares and from 6.5% to 3.98% (181-220 hectares). Therefore, with the increasing number of harvesters and their annual loading, the change in total costs is almost offset. The fluctuations in the total costs, depending on annual operating time and service assimilation of forage harvester, are less – 13.62% (150-180 ha) and 6.5% (221-330 ha).

1. Introduction

In modern countries, there is such a price policy of agricultural machinery, spare parts for it, and despite the fall in prices for black gold, the prices of fuel and lubricants that agricultural producers, realizing the obtained products, are not able to fully update outdated machines for new ones, which leads to even more aging of the park and increasing the cost of maintaining it [1]. In general, the average load on combine for 2019 was 285 hectares or 822 tons (with a yield of 3.03) [2], and considering the technical condition (79% of serviceable ones) [3], respectively, 358 hectares or 1035 tons [4].
Taking 1815 combines as a basis, Ukraine lost almost 5400 combines in 3 years [5]. This, in turn, leads to increasing the load on the combine. In developed countries, with the aging of technology, seasonal load on equipment decreases. In modern countries, on the contrary, machinery, including combines, is working, aging, and the seasonal load is constantly increasing. A formed vicious circle, the way out of which can be only through a change or policy, or the search for different optimization approaches to the operation and service of the remaining one [6]. Considering that the first is hardly expected for the next 5 or even 10 years, optimizing the composition of the service of the forage harvesters with different annual load is a relevant task [7].

The purpose of the research is to optimize the composition of the service of the forage harvesters service at different annual load based on queuing theory, using data obtained from the results of the collection and mathematical processing of statistical information. Modern farms have virtually no repair service base of their own [8]. According to the literature data [9], the number of those who have is between 15 and 23%. Insufficient provision of farms with high-performance forage harvesters, their low renewability, and poor quality (about 70% of machines have a life span of more than 8-10 years) have led to an excessive load on the combine [10]. Under these conditions, it helps to delay time frames of harvesting operations, violation of the requirements of agricultural technology and, as a consequence, a significant crop failure. With an existing harvester park of 70% of the CIS countries with a lower reliability factor (about 0.6), this load leads to a delay time frames of 25 or more days [11]. The delay of time frames of harvesting is explained by the poor availability and organization of the repair and maintenance base. At the same time with rational organization of work of service department, time for service is reduced by 8-12%, repair – by 20-25% [12]. There is a need for a new approach to the organization of technical service of machines in the agroindustrial complex, including forage harvesters [13]. In this case, it is worth using the experience of both – ours and foreign ones.

The efficiency of using forage harvesters depends essentially on the organization of the maintenance system [14]. The need for technical service for forage harvesters depends on many circumstances: they require periodic refuelling and lubricants; in the process of operation they lose their work capacity, and for its restoration they require repair on request; they require periodic maintenance to prevent failures and malfunctions provided by such types of work as inspection, cleaning, lubricating, regulating, diagnostic and fixing [15]. Maintenance of forage harvesters is performed by the maintenance service. In order for this service to function effectively, it is necessary to optimize the number of the main system-forming objects, which include maintenance units, gas stations and field repair machines.

2. Materials and methods
To determine the number of refuellers it is necessary to have data on fuel consumption by forage harvesters per hectare of collected area $Q_{ga}$. Knowing the maximum variable productivity $W_v^{\text{max}}$ for the harvest period, the capacity of the refueller $V_z$, the number of routes of the refueller per shift $n_p$, it is possible to determine the number of filling units for one combine by the formula:

$$N_z = Q_{ga} \cdot W_v^{\text{max}} \cdot (V_z \cdot n_p \cdot \Delta V)^{-1},$$

where $\Delta V$ – is the coefficient of use of the volume of the refueller (we accept 0.95).

As a result of processing the collected statistics on the farms of Kyiv and Cherkasy regions, the average fuel consumption per hectare of collected area was determined. In this case, the farms had a different load on one forage harvester. It should be noted that the fuel consumption was determined by taking into account the cost of unloaded relocations, turns, stopping and carrying out the maintenance or repair. In general, the data showed that the minimum operating cost of fuel forage harvesters was typical of those farms that had a single combine harvester load of 600-800 ha per harvest. In such farms one of the components of the time of change, the time for technological relocation, is used. Small farms are characterized by significant time-consuming efforts to eliminate technological failures (clogging), most of which are eliminated when the engine is working. These reasons also had a significant impact.
on changes in fuel consumption. Other collected statistical information was the analysis of fuel consumption of forage harvesters, taking into account the year of operation. Based on this analysis, it can be noted that for combines with a throughput of 7 to 9 kg/s, fuel consumption is reduced only in the first three years of operation. At the same time the highest expense was in the first year of operation. Most likely, it was influenced by the engine parts and the number of failures and malfunctions, which affected the overall performance and operating time of the combine. The results of the calculations show that for farms with a small number of combines up to 3, it is not efficient to have mechanized refuelers such as MZ-3905T or others. And conversely, when the number of combines is 20 or more, it is sufficient to have two refuelers with loads on the combine from 150…800 ha.

3. Results and discussion

In order to identify the most efficient system of maintenance, the calculation of the total cost of maintenance of forage harvesters was performed. At the same time the variants of different intensity of combines use (operating time at harvest) were simulated at variations in the model of the number of service channels of the system. For this purpose, the state graph of the system (forage harvesters) was considered (figure 1: 0 – all combines are in order; 1 – the combine refused, the refusal is in progress; 2 – one combine is being serviced, another is waiting for service; m – refused all combines, one on service.).

In accordance with figure 1, the density of the flow of requirements \( \lambda \) and service intensity \( \mu \) for farms with different annual load on one combine and different number of combines in the farm were calculated (table 1). To implement this model, an algorithm was developed (figure 2), which calculated for each of the years of operation and annual operating time: average queue length; the average number of failures of 1 and 2 complexity groups; the average number of service free channels; coefficient of use of orders; coefficient of simple servicing units; complete average losses from simple queuing requirements and no channel load; waiting time in line. For the optimum number of channels, the number with minimal total average losses from simple queue requirements and non-congested channels was taken. To calculate the density of the flow of requirements \( \lambda \) and the intensity of maintenance \( \mu \), it is considered that: \( \lambda = r_{-1}^{-1}. \) Time between failures for 7 years was respectively 12, 25, 22, 16, 13, 12.5 and 11 hours. All failures were distributed into groups of 1, 2 and 3 group.

The first group of complexity is the failures, which are eliminated by repair or replacement of parts, located outside the assembly units and units without assembly of the latter, as well as failures, the elimination of which requires extraordinary maintenance operations. The second group of complexity is the failures, which are eliminated by repair or replacement of readily available prefabricated units, the elimination of which requires the opening of the internal cavities of the main units without their disassembly or extraordinary carrying out of maintenance operations. The third complexity group is the failures that require the disassembly of the main units. In the calculations it was assumed that up to 70% of failures of 1 and 2 complexity groups are eliminated by the exit links. The solution of the main
equations of the queuing system according to the algorithm (figure 2) was realized with the help of Mathcad 15 mathematical package through the development of the program. From schedules and calculations, it follows that using a queuing system to calculate the required number of service links is appropriate and economically justified. At the same time, analysing the results obtained, it can be seen that the dependence of the total costs on the year of operation of the combine decreases in the range from 13.63% to 3.12%, or (UAH 11.81-1.12) for the operating time of 150-180 ha and accordingly by 6.5% and 3.98. That is, with the increase in the number of combines and their annual loading, the change in total costs is almost offset.

Table 1. Density of flow of requirements $\lambda$ and intensity of service by years of operation and annual operating time.

| Years of operation of combines, $\mu$ (1/hour) | Quantity, units | Annual operating hours (ha) intervals and midpoints |
|-----------------------------------------------|-----------------|-----------------------------------------------------|
|                                               |                 | 150-180 | 470-500 | 630-660 | 780-810 | 840-870 | 1000-1030 |
|                                               | 165 | 485 | 645 | 795 | 855 | 1015 |
| 1 year (0.612)                                | 3        | 0.218 | 0.179 | 0.181 | 0.175 | 0.179 | 0.157 |
|                                               | 5        | 0.364 | 0.298 | 0.3025 | 0.291 | 0.298 | 0.262 |
|                                               | 10       | 0.727 | 0.596 | 0.604 | 0.582 | 0.596 | 0.524 |
|                                               | 15       | 1.091 | 0.894 | 0.906 | 0.873 | 0.894 | 0.785 |
|                                               | 20       | 1.454 | 1.193 | 1.208 | 1.164 | 1.193 | 1.047 |
| 2 years (0.3138)                              | 3        | 0.455 | 0.373 | 0.378 | 0.364 | 0.373 | 0.327 |
|                                               | 5        | 0.757 | 0.621 | 0.629 | 0.606 | 0.621 | 0.545 |
|                                               | 10       | 1.515 | 1.242 | 1.259 | 1.212 | 1.242 | 1.090 |
|                                               | 15       | 2.273 | 1.864 | 1.889 | 1.818 | 1.864 | 1.636 |
|                                               | 20       | 3.03  | 2.485 | 2.518 | 2.424 | 2.484 | 2.182 |
| 3 years (0.4)                                 | 3        | 0.4   | 0.328 | 0.332 | 0.32  | 0.328 | 0.288 |
|                                               | 5        | 0.667 | 0.547 | 0.554 | 0.533 | 0.547 | 0.48  |
|                                               | 10       | 1.333 | 1.093 | 1.108 | 1.066 | 1.093 | 0.96  |
|                                               | 20       | 2.667 | 2.187 | 2.216 | 2.133 | 2.187 | 1.92  |
| 4 years (0.4464)                              | 3        | 0.291 | 0.238 | 0.242 | 0.233 | 0.238 | 0.209 |
|                                               | 5        | 0.484 | 0.397 | 0.402 | 0.387 | 0.397 | 0.349 |
|                                               | 10       | 0.969 | 0.795 | 0.805 | 0.775 | 0.795 | 0.698 |
|                                               | 15       | 1.454 | 1.192 | 1.208 | 1.163 | 1.192 | 1.047 |
|                                               | 20       | 1.939 | 1.590 | 1.611 | 1.551 | 1.590 | 1.396 |
| 5 years (0.4256)                              | 3        | 0.236 | 0.193 | 0.196 | 0.189 | 0.193 | 0.170 |
|                                               | 5        | 0.393 | 0.323 | 0.327 | 0.315 | 0.323 | 0.283 |
|                                               | 10       | 0.787 | 0.646 | 0.654 | 0.630 | 0.646 | 0.567 |
|                                               | 15       | 1.181 | 0.969 | 0.982 | 0.945 | 0.969 | 0.850 |
|                                               | 20       | 1.575 | 1.292 | 1.309 | 1.260 | 1.292 | 1.134 |
| 6 years (0.46)                                | 3        | 0.227 | 0.186 | 0.188 | 0.181 | 0.186 | 0.163 |
|                                               | 5        | 0.378 | 0.310 | 0.314 | 0.303 | 0.310 | 0.272 |
|                                               | 10       | 0.757 | 0.621 | 0.629 | 0.606 | 0.621 | 0.545 |
|                                               | 15       | 1.136 | 0.931 | 0.944 | 0.909 | 0.931 | 0.818 |
|                                               | 20       | 1.515 | 1.242 | 1.259 | 1.212 | 1.242 | 1.090 |
| 7 years (0.4488)                              | 3        | 0.2   | 0.164 | 0.166 | 0.16  | 0.164 | 0.144 |
|                                               | 5        | 0.333 | 0.273 | 0.277 | 0.266 | 0.273 | 0.24  |
|                                               | 10       | 0.666 | 0.546 | 0.554 | 0.533 | 0.546 | 0.48  |
|                                               | 15       | 1     | 0.82  | 0.831 | 0.8  | 0.82  | 0.72  |
|                                               | 20       | 1.333 | 1.093 | 1.108 | 1.066 | 1.093 | 0.96  |
The number of service channels ranges from 1 (for 3 combines) to 11 (for 20 combines). The fluctuations in the total costs depending on the annual operating time of one combine have less fluctuations and are 13.62% (150-180 ha) and 6.5% (1000-1030 ha). Evidence of the need to use queueing system to calculate the number of service units in farms can be modelling of calculations not by the optimal number of service channels, but by common sense. In particular, the following data were modelled: for 3 combines – 1 service channel, 5 combines – 2 channels, 10 combines – 3 channels, 15 combines – 4 channels, and respectively 20 – 5 channels. Analysis of these calculations shows that the largest losses from suboptimal number are specific to the largest group of combines 20. The losses
for 1 year of operation amount to 3187 UAH (11.57 times), and for 7 years of operation respectively 1881 UAH (6.87 times).

4. Conclusions
The total costs are insignificant depending on the year of operation of the combines and their annual loading. These costs are reduced accordingly from 13.63% to 3.12%. The number of these combines in the group has more impact on the amount of costs.

Formation of suboptimal number of servicing links gives loss of funds from 3187 to 1881 UAH (1 year and 7 years of operation). For the harvest period, growers should involve additional service professionals for the required optimal number of units, which will allow to offset additional losses and reduce the cost, including the cost of grain quality, due to the timing of the harvest.

References
[1] Minarelli F, Raggi M and Viaggi D 2020 Innovation in European food SMEs: determinants and links between types Bio-based and Applied Economics 4(1) 33-53
[2] Langemeier M and Purdy R 2019 International benchmarks for corn production Farmdoc Daily 9(86) 2-9
[3] Yezekyan T, Marinello F, Armentano G, Trestini S and Sartori L 2020 Modelling of harvesting machines’ technical parameters and prices Agriculture 10 194-203
[4] Sorensen C G and Bochtis D D 2010 Conceptual model of fleet management in agriculture Biosystem Engineering 105 41-50
[5] Hutorov A O, Lupenko Y O, Yermolenko O A and Dorokhov V O 2018 Strategic management of the agrarian sector of economy based on the analysis of value chains Bulletin of the Transilvania University of Brasov Series II: Forestry Wood Industry Agricultural Food Engineering 11(2) 101-14
[6] Hrynkiv A, Rogovskii I, Aulin V, Lysenko S, Titova L, Zagurskiy O and Kolosok I 2020 Development of a system for determining the informativeness of the diagnosing parameters of the cylinder-piston group of the diesel engines in operation Eastern-European Journal of Enterprise Technologies 3(105) 19-29
[7] Bauhus J, Meer P and Kaninen M 2010 Ecosystem goods and services from plantation forage International Journal of Environmental Studies 68(2) 168-75
[8] Parkhomenko G G, Voinash S A, Sokolova V A, Krivonogova A S and Rzhavtsev A A 2019 Reducing the negative impact of undercarriage systems and agricultural machinery parts on soils IOP Conference Series: Earth and Environmental Science 316 012049
[9] Rogovskii I, Titova L, Novitskii A and Rebenko V 2019 Research of vibroacoustic diagnostics of fuel system of engines of combine harvesters Engineering for rural development 18 291-8
[10] Amiama C, Pereira J M, Castro J and Bueno J 2015 Modelling corn silage harvest logistics for a cost optimization approach Computers and Electronics in Agriculture 118 56-65
[11] Yezekyan T, Marinello F, Armentano G and Sartori L 2018 Analysis of cost and performances of agricultural machinery: reference model for sprayers Agronomy Research 16 604-4
[12] Bochtis D D, Sorensen C G and Busato P 2014 Advances in agricultural machinery management: a review Biosystem Engineering 12 669-81
[13] Rogovskii I, Titova L L, Trokhaniak V I, Haponenko O I, Ohienko M M and Kulik V P 2020 Engineering management of tillage equipment with concave disk springs INMATEH Agricultural Engineering 60(1) 45-52
[14] Hochstein R R 2018 Forage harvester operation PAMI 85(2) 27-39
[15] Bietresato M, Pavan S, Giulio C and Sartori L 2013 A numerical approach for evaluating and properly setting self-propelled forage harvesters Transactions of the American Society of Agricultural and Biological Engineers 56(1) 5-14