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Optimization of the Composition of the Harvesting and Transport Complex

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Abstract: This study systematizes information on the topic "Optimization of the harvesting and transport complex". A lot of research work was carried out to collect statistical data on the functioning of harvesting and transport complexes over the past 3 years. Based on the results of this research, recommendations on the acquisition of harvesting and transport complexes were prepared. The essence of this research is as follows: at the time of the set of the hopper of the combine grain yield is determined by the yield of crops, the yield is determined by the number of vehicles necessary for the transportation of grain to the warehouse, depending on the distance to the warehouse when, determining the number of vehicles, correction factors are used.

Key words: Management, optimization, probability theory, harvesting, methodology, yield, number of vehicles

INTRODUCTION

Research on this topic began with the study of the possibility of using probability theory to identify certain patterns of occurrence of any result in the test or study. In our research we used the theory of probability to form the optimal composition of the harvesting and transport complex. One of the most important concepts of probability theory is the concept of a random variable which can be discrete or continuous (Anonymous, 2019; Bastian *et al.*, 2017).

In our case, the discrete value is for example, the number of bunkers assembled by various combine harvesters for a certain period of time. The continuous value is for example, the filling time of one bunker, the waiting time for a vehicle to unload the bunker. We present the numerical characteristics of a random variable it is the mathematical expectation, variance and standard deviation.

MATERIALS AND METHODS

To form the optimal composition, the analysis of the harvesting and transport complex consisting of six combine harvesters and three KAMAZ trucks with trailers was carried out. Combine harvesters "ACROS-580"-5 units, "ACROS-585" -1 unit (Semin and Novoselov, 1994).

When calculating the intensity of receipt of requirements for unloading filled bins, the following data were used: the time of filling the bunker, vehicle waiting time to unload the bunker, bunker unloading time, time of movement of the combine harvester to the pen (when harvesting "directly").

To calculate the intensity of transport service, the following data were used: the waiting time for loading the first bunker after the car returned from the warehouse, travel time to the first combine harvester, unloading time of the first combine harvester, the time to receive the second bunker (it consists of the waiting time for filling the 2nd bunker and the driving time to the second combine harvester) unloading time of the second combine harvester, time to receive the nth bunker, unloading time of the nth combine harvester time of the transport cycle (summed up of the time of the vehicle's movement before the grain storage, unloading of the vehicle, the time of the vehicle's movement from the grain storage to the field). Based on statistical data (a total of 361 measurements were taken) the following were calculated:

- For bunker filling time: expected value = 44 min, dispersion-26.9 min, standard deviation-5.2 min
- For a vehicle load waiting time, the expectation is 1.2 min

RESULTS AND DISCUSSION

From the point of view of random variables analysis, according to the intensity of the demands for unloading filled bunkers, consider the "fill time of the combine harvester" and "vehicle waiting time" which significantly affect the performance of the harvest transport complex.

Based on the processed statistical data, we construct graphs and preliminarily determine the law of distribution of random variables (Semin and Novoselov, 1994) (Fig. 1-3).

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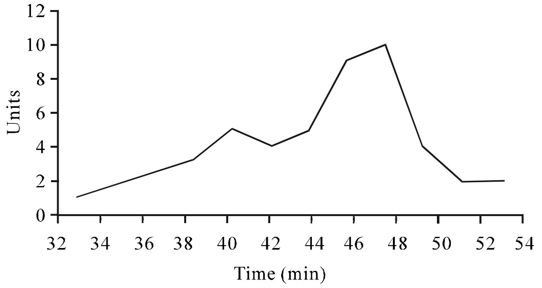

Fig. 1: Filling time of combine harvester; Number of events

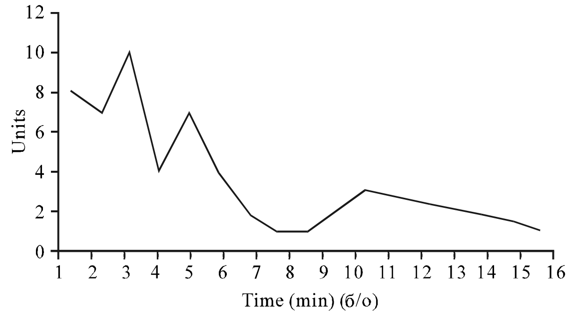

Fig. 2: Vehicle waiting time; Number of events

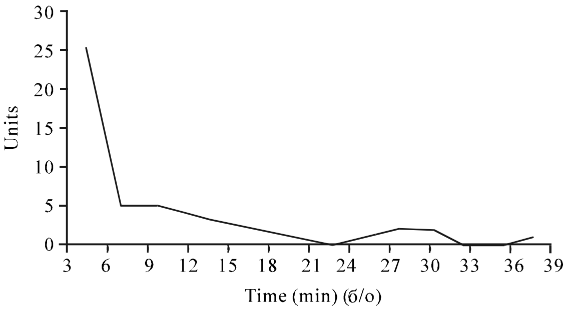

Fig. 3: Vehicle load waiting time; Number of events

The filling time of the combine harvester (Fig. 1) obeys the law of normal distribution with negative asymmetry, the waiting time of the vehicle (Fig. 2) the law of exponential distribution. According to the intensity of receipt of requirements for transport services, we consider the indicators: "load waiting time", "transport cycle time". The results of the analysis will be presented in the form of graphs presented in Fig. 3 and 4.

As can be seen from Fig. 3 and 4, the waiting time for a vehicle to load (Fig. 3) obeys the law of exponential distribution, the law of the distribution of the transport cycle time (Fig. 4) is difficult to determine from an empirical curve. For this, it is necessary to select matching criteria. But presumably, this will be the law of normal distribution with positive asymmetry or the Weibul-Gnedenko law.

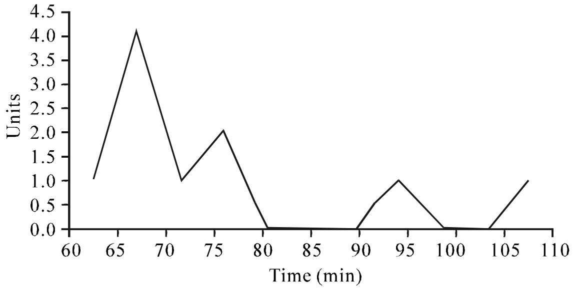

Fig. 4: Transport cycle time; Number of events

From the graphs shown in Fig. 1-4, the following conclusion can be made: the waiting time of the vehicle for unloading the bunker and the waiting time for loading the vehicle have opposite properties. If, we take the waiting time of the vehicle, then the indicator "w/w" (without waiting) has a positive meaning, since, combine harvester does not lose time on waiting and immediately starts working. The waiting time for loading a vehicle with a "w/w" indicator has a negative meaning, since, at this time the combine harvester was waiting for the vehicle.

In accordance with the research and the theory of probability, the probability of an event occurring in the "w/w" interval is 5 min is 0.66, in the range of 6-10 min-0.15 in the range of 11-16 min-0.19.

The mathematical expectation for a random variable of the vehicle waiting time for unloading the bunker is 5.8 min. Those in the area of mathematical expectation, the probability of an event occurring is 0.69. Almost 70% of the waiting time for the vehicle to unload the bunker suits us. The 30% falls on a time interval from 7-16 min. With an increase in the number of vehicles, it is possible to increase the probability of an event occurring in the "w/w" interval -6 min and decrease in the range of 7-16 min. But the recommendations for increasing the number of vehicles, we will do after analyzing the waiting time for loading the vehicle.

In accordance with the studies carried out on the intensity of receipt of requirements for transport services, we consider the indicator "waiting time for loading a vehicle". The probability of an event in the interval "w/w"-6 min is 0.69 but the probability of an event occurring at a random "w/w" value is 0.49, i.e., almost 50%. As mentioned above-this is a negative point in terms of optimization of the cleaning complex. Those combine harvesters will stand idle while waiting for a vehicle.

In the range from 7-20 min the probability of an event will be 0.2, in the range of 21-39 min-0.11. The mathematical expectation for a random variable on the vehicle loading waiting time is 1.2 min. In the time interval from the “w/w” -2 min the probability of an event will be 0.53. It does not suit us because for optimal performance of the cleaning complex, it is necessary to have an event probability of at least 0.69. By increasing the number of vehicles by one unit, we will be able to increase the probability of an event occurring in the “w/w” interval of -6 min to 0.72.

Based on the research, to optimize the work of the cleaning complex, you need to add one unit of transport which will increase the productivity of the complex by 30% by reducing downtime of combine harvesters in anticipation of vehicles, reducing the time of movement of the combine harvester before the piling to continue.

The duration of the transport cycle from a specific field, provided that it is well organized cannot be influenced. Therefore, to optimize the work of the harvest-transport complex, you need to add vehicles. Adding one car with a trailer, we got the following: the waiting time of the vehicle for unloading within 4 min was 77.7% of the number of events that occurred. The remaining 22.3% of events will occur in the range of 5-12 min, rather than 5-16 min with 40.5% of the events occurring in three vehicles (Fig. 5).

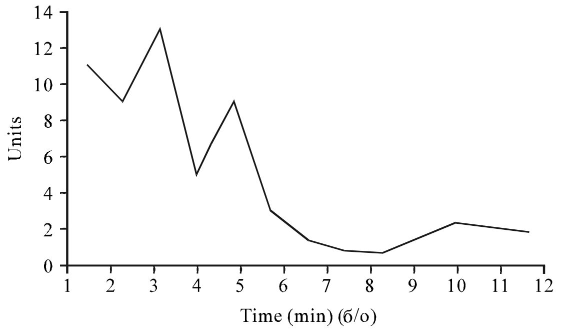

Fig. 5: The number of events (unloading) and the waiting time for unloading combine harvesters with four vehicles; number of events

In addition, according to the experimental data, on the basis of the “Bunker fill time”, the current yield of the harvested crop can be calculated and monitored which also, makes it possible to quickly optimize the work of the harvesting complex, operational management of its work. To calculate the yield we take the following Eq. 1:

$$l_p = 10^{-4} \frac{Q_{\bullet} \rho_3 \lambda_{\bullet}}{B \beta u} \tag{1}$$

Where:

l_p = The length of the working path of filling the combine bunker (m)

Q. = Bunker capacity (m^3) Q. = 9 m^3 (from the instruction manual for the combine harvester ACROS-580)

$\bullet_3$ = Bunker grain bulk mass (t/m^3) for wheat and rye $\bullet_3$, respectively, 0.78 and 0.72 (t/m^3)

•. = Bunker fill factor. •. = 1.1 (with a transforming roof)

B = Header cutting width, m. B = 7(m)

u = Yield (t/ha)

• = Header width utilization factor. • = 0.96

In addition, the length of the working path of filling the combine bunker can be calculated by the following Eq. 2:

$$l_p = V \times t_{3\bullet} \tag{2}$$

where, V is the working speed of the combine harvester when harvesting grain, km/h. V = 7-13 km/h (from the ACROS-580 combine harvester instruction manual). $t_{\bullet\bullet}$ bunker filling time, h. $t_{\bullet\bullet}$ = take 0.73 h (44 min), the mathematical expectation of the filling time of the combine harvester’s bunker, Eq. 1 and 2, we find the yield of an agricultural crop:

Table 1: The ratio of the time of filling the hopper combine harvester and crop yields (wheat)

Filling time of the hopper of the combine (min)	Yield (c/ha)
26	38.4
28	35.1
30	33.0
32	31.2
34	29.0
36	27.5
38	26.2
40	24.7
42	23.6
44	22.9
46	21.5
48	20.6
50	19.9
52	19.0

$$u = 10^{-4} \frac{Q_{\bullet} \rho_3 \lambda_{\bullet}}{l_p B \beta} \tag{3}$$

As a result of the calculations made on the basis of the above initial data, we obtain the desired yield of 22.9 centners per hectare. We will make similar calculations for the following time intervals for filling the combine harvester’s bunker: 26; 28; 30; 32; 34; 36; 38; 40; 42; 46; 48; 50; 52. We will present the data in the form of a Table 1 and a graph presented in Fig. 6.

Analyzing Fig. 6 with the graph of the ratio of yield and filling time of the combine harvester bunker, we see that three components make up the optimal work of the harvest-transport complex: yield, number of combine harvesters, number of vehicles. Under this yield with a constant number of combine harvesters, it is possible, on the basis of probability theory, mathematical calculations

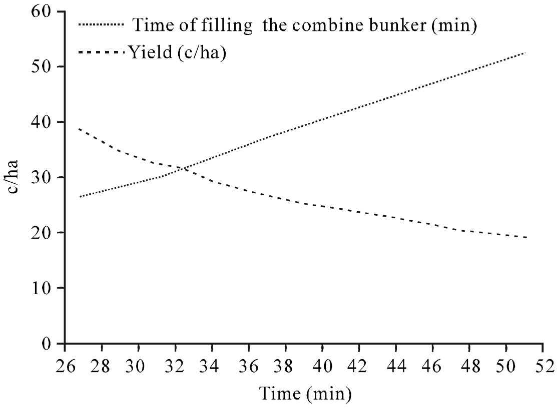

Fig. 6: Graph of the ratio of yield and filling time of the combine harvester

and practical experience, to choose the number of vehicles to ensure optimum performance of the harvest transport complex.

Using in Eq. 2, 3 and the graph presented in Fig. 6, it is possible to control the work of the harvesting complex operatively that is to make certain corrective actions both by the number of combine harvesters and by the number of vehicles. To determine the number of vehicles required to ensure optimal (without downtime) work harvest transport complex use the following Eq. 4 (Pyakurel *et al*., 2018):

$$n_{Tp}^{13yk} = \frac{C_1 \times T_p}{q_1 \times T.} \tag{4}$$

Where:

n_{Tp}^{13yk} = The number of vehicles required for servicing one combine harvester, units
C_1 = The mass of grain in the bunker of the combine harvester (t)
T_p = The duration of the transport cycle (h)
q_1 = Car load capacity (t)
$T.$ = Time of filling the hopper with grain (h)
n_{Tp}^{13yk} = $7.06\times1.21/28.3\times0.73 = 0.41$ units
C_1 = $V\times\bullet = 9\times0.785 = 7.06$ (t)

where, V the volume of the bunker of the combine harvester, m^3. In accordance with the ACROS-580 combine harvester's instruction manual, the bunker capacity with a bunker filling factor of 1.1 (with a transforming roof) the bunker capacity is 9 m^3. •-volume weight of wheat 0.785 t/m^3.

The load capacity of the KAMAZ-55102 with a trailer is 28.3 tons. To ensure the operation of the harvesting and transport complex (6 harvesters), 2.5 units are required, i.e., three cars. To increase the productivity of the harvesting and transport complex using elements of the probability theory, it was proposed to increase the number of cars to four. As a result, the waiting time for the combine harvester unloading into the vehicle was reduced, the time of movement of the combine to the "padding" was reduced (Huang *et al*., 2018; Jodlbauer *et al*., 2018).

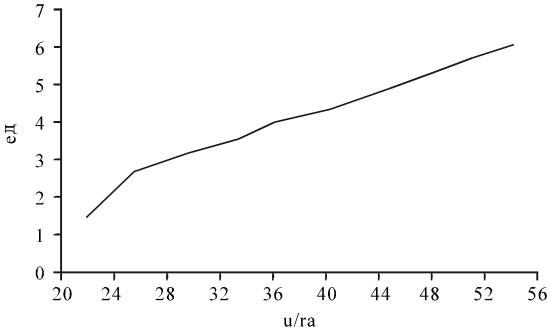

Fig. 7: The number of vehicles to ensure optimal operation of the harvesting complex, depending on the different yields

To derive the dependence of the number of vehicles on yield (time of filling the bunker), we use the data from the graph in Fig. 6 and Eq. 4. These calculations are summarized in a Table 2.

For clarity, the data from Table 2 present in the form of a graph. Calculations on the number of vehicles made at a distance of 10 km from the field to the warehouse. When forming the transport service of the harvest-transport complex at other distances, it is necessary to apply the correction factors given in Table 3. Proper picking and management of the harvest and transport complex affects the economic performance of the use of both combine harvesters and trucks for removal (Qin *et al*., 2018).

Research and analysis showed the following: the transportation cost, at a constant distance from the field to the warehouse is influenced by the loading time of the vehicle with grain from the combine bunker (the unloading time of one bunker is almost the same). In our study, the loading time of one car (4 bunkers) ranged from 15-58 min. Taking the cost of transportation when the vehicle loading time for 15 min (0.25 h) per unit, we derived the following dependence of the cost of transportation on the vehicle loading time and presented in the form of a Table 4 and Fig. 7.

For clarity, the increase in the cost of transportation depending on the load time of the vehicle will be represented as a graph (Fig. 8).

Table 2: The number of vehicles to ensure optimal performance of the cleaning complex, depending on the yield (c/ha)

Indicators	Number of vehicles (units)
20	1.5
24	2.66
28	3.12
32	3.48
36	4.02
40	4.31
44	4.77
48	5.17
52	5.66
56	6.04

Table 3: Correction factors for determining the number of vehicles when servicing the cleaning complex at different distances from the field to the warehouse

Distance (km)	Correction factors
• o5	0.77
10	1.00
15	1.30
20	1.59
25	1.85
30	2.00

Table 4: Correction factors of increase in the cost of transportation depending on the vehicle loading time

Load time (h)	Correction factors
0.3	1.00
0.4	1.03
0.5	1.04
0.6	1.06
0.7	1.08
0.8	1.11
0.9	1.12
1.0	1.15
1.1	1.18

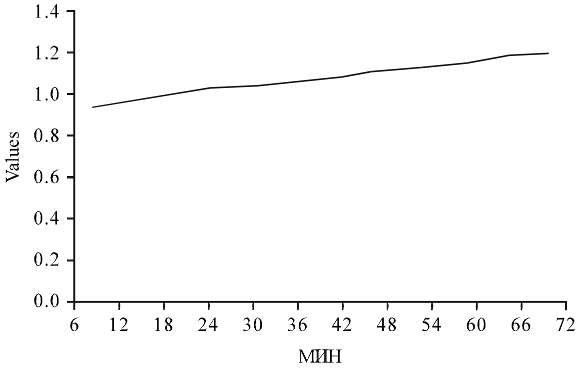

Fig. 8: The coefficients of increasing the cost of transportation depending on the loading time of vehicles

CONCLUSION

The effectiveness of the use of combine harvesters is determined by the acquisition and management of the entire harvest-transport complex which provides minimal downtime of combines while waiting for vehicles to unload grain bins. At the same time, combine harvesters must meet the requirements of intensity, productivity and efficiency (Fu *et al*., 2018; Bastian *et al*., 2017; Li *et al*., 2016; Soucek, 2016). Correction factors of 0.1; 0.2; 1.2 h (6, 12 and 72 min) were obtained by calculation.

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