Modeling the Technological Process for Harvesting of Agricultural Produce

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Abstract. The efficiency and the parameters of harvesting as a technological process being substantiated make it possible to reduce the cost of production and increase the profit of enterprises. To increase the efficiency of combine harvesters when the level of technical equipment declines is possible due to their efficient operating modes within daily and every season. Therefore, the correlation between the operational daily time and the seasonal load of combine harvesters is found, with the increase in the seasonal load causing the prolonged duration of operational daily time for harvesters being determined. To increase the efficient time of the seasonal load is possible due to a reasonable ratio of crop varieties according to their ripening periods, the necessary quantity of machines thereby to be reduced up to 40%. By timing and field testing the operational factor of the useful shift time of combine harvesters and the efficient modes of operating machines are defined, with the alternatives for improving the technical readiness of combine harvesters being identified.

1. Introduction
The competitiveness of agricultural enterprises is possible to improve due to the substantiation of rational parameters of technological processes of grain production on the basis of mathematical modeling. The need for technical means depends on the harvesting period duration both during the shift and the season. The operating hours of a technological machine during the day are well known to be limited by the moisture level of the grain mass during the morning and evening hours, as a rule, because of dew. In [2, 3] it is determined that the time of the daily work of combine harvesters should not exceed twelve hours under the conditions of the Southern Urals. It is necessary to bear in mind that the work duration will be affected by the level of technical equipment involved in harvesting, which, in its turn, requires reviewing the matter. In the authors’ papers [4, 5] it is recommended to increase the efficient harvesting time due to the sowing of different varieties of wheat according to the length of its growing seasons in equal proportions, but it is known that early varieties have yields lower than late ones, thus, it is necessary to find a reasonable proportion between the sowing area (taking into account the efficiency of machines) and cost indicators. One of the most effective ways to reduce production losses when the level of technical equipment is rather low is to increase the sowing terms of wheat [6].

2. Results and discussion
As for the Ural region of Russia in the State Register there are three groups of wheat varieties according to its earliness: middle-early, mid-season and middle-late [7, 8]. To substantiate the proportion between the areas of different wheat varieties there has been developed an economic and mathematical model with the criterion of the maximum profit taken as the basic one [9, 10]:

\[ P(Q_{me}Q_{ms}) = C_y - L_{me}(Q_{me}) + L_{ms}(Q_{ms}) + L_{md}(Q_{md}) \rightarrow \text{max} \]

where:
C_y is the yield cost, RUB/ha; L_me, L_ms, L_ml are the losses on the area of middle-early (Q_me), mid-season (Q_ms) and middle-late (Q_ml) wheat varieties.

The expanded form of the model is as follows:

\[
P(Q_{ms}) = (P_{ml} (Q_s - Q_{me} - Q_{ms}) + P_{ms} \cdot Q_{ms}) \cdot C_p - \frac{K_{r,i} \cdot K_1 \cdot P_{ms}}{Q_d} \left[ P_{ml} (Q_s - Q_{ms}) (Q_s - Q_{ms} - Q_{me}) + P_{ms} \cdot P_{ms} Q_{ms}^2 \right] \rightarrow \max
\]

where:

- \( P_{ml}, P_{ms}, P_{me} \) are the basic productivity of middle-late, mid-season and middle-early varieties, t/ha;
- \( C_p \) is the price of products RUB/t;
- \( Q_s \) is the seasonal load on a harvester, ha;
- \( K_{r,i} \) is the coefficient of ripening irregularity (\( K_{r,i} = 0.5 \));
- \( K_1 \) is the production loss factor, share/day;
- \( Q_d \) is daily harvester capacity, ha/day.

On the basis of the obtained expression it is established that in the present conditions it is reasonable to cultivate about 20 % of middle-early varieties, 35 % of mid-season and about 45 % middle-late varieties (Fig. 1).

![Figure 1. Rational ratio of wheat varieties in precocity](image)

In general, the objective function to substantiate the load for a combine harvester, with the production losses during the day [11] and the season [12] being considered, will be:

\[
U_k(Q_s) = \frac{B_h \alpha r \gamma_i}{Q_s \cdot P} \sum_{i=1}^{n} \frac{T \cdot \gamma_j}{Q_s \cdot P} + K_{r,i} K_{crop} K_{var} K_{w,cond} C_p \frac{Q_s}{Q_d} + 0.01 P C_p \left( L_m + k \frac{T_0 \beta}{\beta + 1} \right) \rightarrow \min
\]

where:

- \( B_h \) is the balance price of a combine harvester, RUB;
- \( \alpha \) is the coefficient to include the costs caused by involved machines;
- \( i, j \) is the utilization share of the i-th machine of the j-th combine harvester for the given type of operations;
- \( P \) is the crop productivity, t/ha;
- \( K_1 \) is the production loss factor, share/day;
- \( Q_s \) is the seasonal load on a harvester, ha.
is the seasonal load on a harvester, ha; \( \tau \) is the operation factor of the shift time; \( T_0 \) is the time of combine operation, h; \( H_w \) is the width of the harvesting machine, m; \( K_{\text{crop}} \) is the loss factor reduction due to the combination of crops; \( K_{\text{var.}} \) is the loss factor reduction due to the combination of varieties; \( K_{\text{w.cond.}} \) is the factor of weather conditions; \( T_0 \) is the efficiency rate of the machine operator's work, RUB; \( L_m \) is the minimum loss caused by a combine harvester, %; \( k, \beta \) are the factors that reflect pattern changes of current losses during the day.

The daily output of grain harvesters is determined by the expression [13-15]:

\[
Q_d = 0.1H_w V \tau T_0 K_{\text{w.cond}}
\]  

(4)

where:
\( H_w \) is the width of the harvesting machine, m, \( V \) is speed of motion, km/h; \( \tau \) is the operation factor of the shift time, \( T_0 \) is the time of combine operation, h, \( K_{\text{w.cond.}} \) is the factor of weather conditions during the harvesting period.

For modeling the technological process the statistical data are collected. The daily output amounts to 17 ha/shift, the degree of unevenness of fluctuations and the standard deviation being 1.7 and 6.7, respectively. The coefficient of variation is 38.115.

The average shift is found to be 14 hours, with the maximum being 16 hours 15 minutes and the minimum – 7 hours 45 minutes. The mean-square deviation is 84 minutes. As a result of timing the operation factor of the shift time of combine harvesters is found to be on average 0.62. The economic-mathematical modeling makes it possible to find the efficient time of daily and seasonal operating modes of combine harvesters (Fig. 2, 3).

The modeling shows that the efficiency when using combine harvesters will be significantly higher if the duration of their operation will be within the range of 14–16 hours a day (Fig. 2). With the load of a combine harvester of the 3rd Class being 200 hectares, its operating time is found to be 12...14 hours. When its seasonal load increases up to 300 hectares, the operating time is to be 15...16 hours, when the seasonal load of a combine harvester is 400 hectares, its operating time should be 17...19 hours.

The modeling has found that the combination of three groups of varieties that differ in ripening with their reasonable ratio can increase their seasonal productivity for a combine harvester of the 5th Class from 400 to 600 hectares, when using early maturing crops up to 700 hectares, and when using combine harvesters of the 3rd Class up to 400 hectares.
Figure 2. Dependence of the operating time of the combine harvester of the 3rd Class on the productivity of fields ($C_p = 6800 \text{ RUB/t}; \tau = 0.45; H_w = 6 \text{ m}$)

Thus, when planning the technological processes of sowing and harvesting of crops, there is a need for combining different varieties of spring wheat and early maturing crops. This will reduce the loss of production and a rational amount of technical and human resources up to 40%.
3. Conclusion
The field tests have shown that by changing the structure of sown areas, the use of various crops and varieties that differ in ripening the rational seasonal load on a combine harvester increases up to 725 hectares, which makes it possible to reduce the required amount of technical and human resources up to 40%.

It is found that the largest share of downtime is due to eliminating the consequences of technical failures caused by the reaper elements, thresher and undercarriage of a combine harvester. To reduce the time to eliminate the consequences of technical failures, it is necessary to increase the efficiency of machines due to the aggregate method of repairing in the field and to reduce the delivery time of spare parts due to exchange funds [15-20].

Thus, the economic-mathematical modeling of the technological process of grain crops harvesting made it possible to determine the rational modes for operation of technical means, labour resources and their amounts, taking into account the biological characteristics of agricultural crops.

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