Modeling of Normativity of Criteria of Technical Level of Forage Harvesters Combines

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Abstract. The article presents the results of analytical calculations of methods for assessing the technical level of agricultural machinery products with their prospective standardization of forage harvesters combines. From the author's point of view, it would be rational to assess the technical level as a function of the rate of change of indicators that determine the development of this type of equipment over a limited period of time, for example, over the life of the forage harvesters combines. During this period, as a rule, you can consider the performance of two or three generations of this type of forage harvesters combines. Investigating the rate of change of parameters of a certain chronological series of analytical objects as an indicator of technical level, we can conclude that the difference in the rate of change of an indicator has the degree of influence of each indicator on the formation of initial properties that determine the ability of this technique at each stage of its development to meet the specific requirements of consumers. That is, only important indicators are subject to improvement or development. If the indicator is improving at an accelerated pace, it means that the importance of factors such as manufacturability or world conditions.

1. Introduction
Carrying out such a comparison in practice contains additional difficulties [1]. This is due to the fact that the indicators of the object are compared, as a rule, which differs in the beginning and resource of its life cycle from other objects of analogues [3]. In addition, the indicators of the evaluated object may be stable throughout the resource [4] or only slightly change within the design or technical solution embedded in the object [5], and indicators, in general, determine the level of world achievements (this type of forage harvesters combines), acquire significant changes over time [6], reproducing the continuous process of selecting optimal technical solutions [7].

Thus, the ratio of relatively stable indicators of the object being evaluated and continuously updated over time indicators of the level of world development of science [8] and technology will always be a function of time [9]. This means that the assessment of the technical level of the object can be reliable only at a specific point in time, which refers to the existence of objects of analogues, selected as a comparison [10]. At any time, the assessment of the technical level of the object will not be completely reliable due to the error caused by changes in the technical level during the time that has elapsed since the existence of the analogue object [11]. In the general case [12], the error in estimating
the technical level of the object $\delta$ will be equal to [13]: $\delta = k_i \cdot \Delta t$, where $k_i$ – the coefficient of change of the $i$-th indicator of the technical level; $\Delta t$ – time discrepancy between the moment of determining the technical level and the moment of assigning the object of analogue to the best world achievements. A similar type of error can occur when the moments of selection of several objects of analogues do not match (not the coincidence of the moments of their development in production). Its value $\overline{\delta}$ will be equal to [14]: $\overline{\delta} = \sum_{n=1}^{n} (k_j \cdot \Delta t \cdot n^{-1})$, where $n$ – is the number of analogous objects accepted in the evaluation. The difficulty of taking into account this type of error is also due to the fact that to assess the technical level of the object have to operate with a set of unit indicators of the types of objects analogous [15].

According to the values of the time indicators located in time, it is necessary to find at each given moment such a calculated state of the generalized indicator, which would reproduce the general trend of its change over time [7], which will express through the regularity of this type of objects [16]. One of the acceptable methods is to solve such problems by comparing the economic efficiency of analogous objects, taking into account the combined effect of all parametric and functional properties of the object [17]. However, such methods have clearly limited properties within the comparison of already optimized variants within themselves and it is impossible to extend them to the synthesis of new variants [18]. Thus, before determining one of the two objects that do not coincide according to the principle of technical solution of analogues, there is a problem of preliminary optimization of design, manufacturing technology and methods of operation of each object to solve the evaluation of their properties and efficiency. Using the dependence [19], which determines the economic efficiency of the ratio of savings to costs. It is considered the most appropriate in the overall set, which characterizes the object of indicators. This methodological approach provides the possibility of system-integrated analysis of the technical level, the content of which is to summarize the individual indicators through a set of unit indicators of the object, which evaluates the economic performance of the entire object. The complexity, and sometimes the impossibility of such an analysis, given the need to use data on world counterparts, require justification of other approaches [20].

2. Purpose of research
From the author’s point of view, it would be rational to assess the technical level as a function of the rate of change of indicators that determine the development of this type of equipment over a limited period of time, for example, over the life of the object. During this period, as a rule, you can consider the performance of two or three generations of this type of equipment (predecessor, existing and projected). Develop methodological provisions for assessing the technical level of agricultural machinery with their subsequent standardization of forage harvesters combines.

3. Materials and methods
In the general case, the task of obtaining for each fixed point in time a generalized indicator of the technical level of the object is to determine the regression function of time:

$$K_{TP_j} = \sum_{j=1}^{m} [k_{mj} \cdot K_j(t)]$$

(1)

where $K_{TP_j}$ – the generalized value of one $j$-th type of indicators at a given time $t_r$; $K_j(t_r)$ – values of unit indicators; $k_{mj}$ – weighting factor of each indicator $j$-th type; $m$ – the number of indicators of one $j$-th type.

At small intervals of evaluation, covering two or three changes of generations of this type of technology, the function $K_j(t_r)$ for each one $j$-th type of unit indicator $K$ can be approximated with sufficient accuracy by a linear relationship:

$$K_{jtr} = K_{j0} + k_i \cdot t_r$$

(2)
where $K_{jir}$ – the value of the $i$-th indicator of the technical level of the $j$-th type at a given time $t_r = \tau$, which is taken as the base, i.e. $K_{jir} = K_{0jr}$. $K_{j0r}$ – the value of the $i$-th indicator of the technical level of the $j$-th type at the initial time $t_r = 0$.

4. Results and discussion

Using the mathematical apparatus of the least squares method, we obtain:

$$K_{j0r} = \sum_{i=1}^{n} (K_{ji} \cdot t_r) \cdot \sum_{r=1}^{w} t_r - \sum_{i=1}^{n} K_{ji} \cdot \sum_{r=1}^{w} t_r^2 \cdot \left(\left(\sum_{r=1}^{w} t_r\right)^2 - w \cdot \sum_{r=1}^{w} t_r^2\right)^{-1}, \quad (3)$$

$$k_i = \sum_{i=1}^{n} \Delta K_{ji} \cdot \left(\sum_{r=1}^{w} \Delta t_r\right)^{-1}, \quad (4)$$

where $K_{ji}$ – the value of the $i$-th indicator of the technical level of the $j$-th type at a given time $t_r$; $t_r$ – time value from the total set $w$.

If the accuracy of the calculation is not required or if the duration of the evaluation (number of analogues and time) is insufficient to perform calculations by the method of least squares, the corresponding calculations can be performed with less accuracy by a simplified formula $K_{j0r} = \bar{K}_j$:

$$k_i = \sum_{i=1}^{n} \Delta K_{ji} \cdot \left(\sum_{r=1}^{w} \Delta t_r\right)^{-1}, \quad (5)$$

where $\Delta K_{ji}$ – change the value of the $i$-th indicator of the technical level of the $j$-th type at the time $\Delta t_r$. Due to the fact that the change $\Delta K_{ji}$ in time is determined by analogous objects (A1–A9) in the sequence, obtained for the durability of combine harvesters (figure 1).

![Figure 1. Changing the value of a single indicator of objects of analogues in retrospect.](image)

Substituting the value of figure 1 in expression (5) we obtain:

$$K_{j0r} = (412.6 \cdot 100 - 33 \cdot 1584) \cdot (10000 - 9 \cdot 1584)^{-1} = 2.35, k_i = (33 \cdot 100 - 9 \cdot 412.6) \cdot (10000 - 9 \cdot 1584)^{-1} = 0.098.$$

These data allow you to get the most likely value $K_{ji}$ at a given time $t_r$. If we calculate at five-year intervals, then according to formula (4) we obtain (figure 2). The obtained regularities (figure 1 and figure 2) bear the middle position of the approximation in retrospect of the parameter $K_{ji}$ within its actual values. Therefore, it is necessary to consider these methodological provisions not as a replacement for mathematical optimization of the technical level, but the integration of analog objects with the location of the optimal curve, which is approximated within the laws at the moment. In this regard, the task is to select and process or summarize the individual indicators of the assessed object.
According to the results of our own research, we find that successfully competing in the market objects that represent the best achievements of technical progress, as a rule, have no absolute analogues in terms of values. Each of these objects has advantages in one or another single indicator or even a combination of several of them, which will satisfy the needs of certain consumers or are more rational in solving certain constructions of the object. Thus, the identification of the optimal object by the dominance of a single indicator, which is accepted in the assessment of the main for a particular consumer, has a subjective context in relation to another consumer.

Investigating the rate of change of parameters of a certain set (chronological series) of analytical objects as an indicator of technical level, we can conclude that the difference in the rate of change of an indicator has the degree of influence of each indicator on the formation of initial properties that determine the ability of this technique at each stage of its development to meet the specific requirements of consumers. That is, only important indicators are subject to improvement or development. If the indicator is improving at an accelerated pace, it means that the importance of factors such as manufacturability or world conditions. Therefore, the value of the weight $m_{ji}$ of each indicator $K_{ji}$ is determined by the expression through the coefficient $\nu_{ji}$ of the rate of its change over time, attributed to the original value of the indicator $K_{ji0}$:

$$m_{ji} = \frac{\sum_{t_i}^n K_{ji} \cdot \sum_{t_i}^n t_i - n \cdot \sum_{t_i}^n (K_{ji} \cdot t_i) \cdot \sum_{t_i}^n t_i}{(\sum_{t_i}^n (K_{ji} \cdot t_i) \cdot \sum_{t_i}^n t_i - \sum_{t_i}^n K_{ji} \cdot \sum_{t_i}^n t_i^2)}.$$  (6)

By expression (6), determining the values $m_{ji}$ in fractions relative to $l$ a number $i$ of indicators $K_{ji}$, we obtain the value of the weighting factor $M_{ji} = m_{ji} \cdot (\sum_{i=1}^l m_{ji})^{-1}$. The obtained data $K_{ji}$ and $M_{ji}$ are sufficient to determine the generalized value of the technical level $\bar{K}_{ji}$ indicator at an arbitrary time $t_r$:

$$\bar{K}_{ji} = \sum_{i=1}^l (M_{ji} \cdot K_{ji}).$$

According to the data obtained, the indicator $K_{jir}$ according to formula (4), take as a baseline, then:

$$q_{ji} = \frac{K_{ji} \cdot (K_{ji0})^{-1}}{\sum_{i=1}^l (M_{ji} \cdot K_{ji})}. $$

Let at the time of development of the technical task the objects which characterize a modern level – objects analogs are known (table 1). To determine the technical level, which is set by the following parameters: estimation accuracy – 0.25%, temperature error – 0.20%, number of channels – 6 units, temperature range – 120 °C, gas consumption – 1.8 l/min. Substitute the values $K_{ji}$ (table 1) and summarize them. The value of the technical level according to formula $\bar{K}_{ji} = \sum_{i=1}^l (M_{ji} \cdot K_{ji})$ is equal to 1.14, i.e. the value of exceeding the technical level of 14%. However, the application of the proposed method in solving various types of practical problems of determining the technical level, such as the formation of the technical task for the development of the object, assessing the quality of this development, assessing the compliance of
the object to the criteria of quality category ISO series, we can demolish (year), which will include the technical level of the assessed object. One of the solutions can be to determine the value of the time indicator of the technical level of the object by determining the time intervals of growth of the technical level indicator by the value \( \Delta, \) i.e.: \( \Delta t = \bar{K}_{ji} \cdot \left( \sum_{i=1}^{l} M_{ji} \cdot k_i \cdot \{K_{ji}\}^{-1} \right)^{-1} \), where \( \Delta t \) – the time difference from the moment when the value of the technical level was determined \( \bar{K}_{ji} \).

Table 1. The main indicators of the technical level of the maintenance tool for controlling the heating temperature and crankcase gas flow.

| Indicator               | \( \bar{K}_{ji} \) | Objects |
|-------------------------|--------------------|---------|
|                         | \( K_{ji} \)       | C_1    | C_2 | C_3 | C_4 | C_5 | C_6 |
| Estimation accuracy, %  | \( K_{11} \)       | 1.0    | 1.0 | 0.5 | 0.3 | 0.5 | 0.3 |
| Temperature error, %    | \( K_{12} \)       | 0.6    | 0.6 | 0.5 | 0.3 | 0.3 | 0.25|
| Number of channels, units| \( K_{13} \)       | 1.0    | 2.0 | 2.0 | 2.0 | 2.0 | 5.0 |
| Temperature range, ºC   | \( K_{14} \)       | 45.0   | 45.0| 60.0| 90.0| 105.0| 110.0|
| Gas consumption, l/min  | \( K_{15} \)       | 8.0    | 7.5 | 5.5 | 6.0 | 2.5 | 4.0 |


5. Conclusions
1. Since the annual variable value of the technical level is 0.0678, at \( \bar{K}_{ji} \) 14%, we have \( \Delta t = 2.06 \) years. Thus, exceeding the complex indicator of the technical level of 0.14 is a period of two years to catch up with world counterparts. Than applying the developed analytical provisions for the assessment of promising solutions under conditions of changing indicators, we obtain the following tabular data (table 1). Thus, with the proposed technical solutions and the calculated dynamics of changes in the technical level of 0.678, the introduction of object D provides an advance in the technical level for 10.96 years.
2. These examples allow us to assess the correctness of the methodology from the practical significance of the proposed method of assessing the technical level of forage harvesters combines, the advantage of which is the mathematical justification of weighting factors when used in complex assessment, reducing the impact of subjective expert assessments. In the future, the development of industry standardized provisions of the methodology for assessing the technical level of forage harvesters combines products is envisaged.
6. References

[1] Hochstein R R 2018 Forage harvester operation PAMI 85(2) 27-39
[2] Mráž M, Urbanovičová O, Findura P and Prístavka M 2019 Use of information systems to support decision making according to analysis machines Agricultural Machinery 2 89-93
[3] Galimov R, Maksimovich K and Tikhonovskiy V 2020 Evaluation of combines transport support effectiveness for harvesting silage crops in Western Siberia E3S Web of Conferences 175 05030
[4] Dubbini M, Pezzuolo A, De Giglio M, Gattelli M, Curzio L and Covi D 2017 Last generation instrument for agriculture multispectral data collection CIGR Journal 19 158-63
[5] 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
[6] Miu V 2016 Combine harvesters: theory, modeling and design CRC 6 208-24
[7] 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
[8] Smetljkova A, Vaculik P and Prikryl M 2016 Rating of malt grist fineness with respect to the used grinding equipment Research in Agricultural Engineering 62(3) 141-6
[9] Redreev G V, Okunev G A and Voinash S A 2020 Efficiency of usage of transport and technological machines Lecture Notes in Mechanical Engineering ICIE 625-31
[10] Rogovskii I L, Titova L L, Trokhianiak V I, Haponenko O I, Ohienko M M and Kulik V P 2020 Engineering management of tillage equipment with concave disk spring shanks INMATEH Agricultural Engineering 60(1) 45-52
[11] Partko S A and Sirotenko A N 2020 Self-oscillation in agricultural mobile machine units Journal Physics 1515 042084
[12] Šotnar M, Pospíšil J, Mareček J, Dokukilová T and Novotný V 2018 Influence of the combine harvester parameter settings on harvest losses Acta Technologica Agriculturae 3105-8
[13] Nikolaev V A, Voinash S A, Maksimovich K Y, Galimov R R, Sokolova V A and Dolmatov S N 2020 Extraction of grains from ears of grain crops by grinding when opposite moving the conveyor and deck IOP Conference Series: Earth and Environmental Science 548 062039
[14] Rogovskii I, Titova L, Trokhianiak V, Trokhianiak O and Stepanenko S 2019 Experimental study on the process of grain cleaning in a pneumatic microbiocature separator with apparatus camera Bulletin of the Transilvania University of Brasov Series II: Forestry Wood Industry Agricultural Food Engineering 12(61) 117-28
[15] Isaac N, Quick G, Birrell S, Edwards W and Coers B 2006 Combine harvester econometric model with forward speed optimization Applied Engineering in Agriculture 22 25-31
[16] Mashkov S, Ishkin P, Zhiltson S and Mastepanenko M 2019 Methods of determining the need for agricultural machinery IOP Conference Series: Earth and Environmental Science 403 012079
[17] Sirotenko A N, Partko S A and Voinash S A 2020 Research of pneumodrive with energy recovery into additional volume Lecture Notes in Mechanical Engineering ICIE 1325-33
[18] Hrynkv 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
[19] Rogovskii I L, Titova L L, Trokhianiak V I, Marinina L I, Lavrinenko O T and Bannyi O O 2020 Engineering management of machine for formation of artificial shell on seed vegetable cultures INMATEH Agricultural Engineering 61(2) 165-74
[20] Yezekyan T, Marinello F, Armentano G, Trestini S and Sartori L 2020 Modelling of harvesting machines’ technical parameters and prices Agriculture 10 194-203