The method of expert assessments as applied to the ranking of technical solutions in the design of a tractor gearbox

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Abstract. The purpose of this work is to select a rational concept of the transmission of the tractor being created on the basis of an objective quantitative comprehensive assessment of the considered possible design options. The object of research is the transmission of wheeled tractors of 4 and 6-8 traction classes and forest machines based on their chassis. Making a decision on the principles of building a transmission is an important stage that requires a proper analysis of known theoretical developments, production experience, competitors' achievements, market conditions and other factors. The decision is based on the ranking of the options available for implementation of the object. It is advisable to support such a ranking with the results of an objective quantitative comprehensive assessment of the compared options. The key points in this case are the formation of a nomenclature of objective private performance indicators and the choice of a data processing method. The paper considers the issue of applying the method of expert assessments when choosing the concept of constructing a transmission and the type of transforming mechanism of a tractor. The algorithm of the method, initial data, and evaluation results are presented. The main solutions for the construction of the transmission of tractors of 4 and 6-8 traction classes have been formulated.

1. Introduction
The nomenclature of performance indicators is built primarily on the basis of an analysis of literature sources and available practical experience of the industry. In the particular case of the problem of choosing the concept of constructing the transmission of agricultural and industrial tractors, as literary sources, fundamental works were primarily used on the theory and foundations of designing wheeled and tracked transport and technological machines [1-7]. When choosing a mathematical method for constructing a generalized performance indicator, the data published in [8] were used. This article formulates criteria for the selection of methods for constructing responses of complex systems and carried out such a selection.

This article provides a solution to the following tasks:
• selection of competing technical solutions and the formation of a list of particular indicators for comparing transmission options.
• selection and application of the method of ranking the compared options.
• selection of options for further development.

2. Results of theoretical research
In [8] it is shown that the most rational in the formation of an objective complex assessment of technical solutions in transport engineering are the Harrington method [9] and the method of expert assessments [10,11]. The choice was made in favor of the method of expert assessments, since in this case it is enough to work with rank estimates of particular indicators and the mathematical apparatus of the Harrington method turns out to be redundant. Harrington’s method is advisable to use at other stages of work, for example, when analyzing the energy efficiency of a tractor. The proposed model for constructing a comprehensive assessment satisfies all the requirements listed in [8] and can be applied when comparing competing concepts for constructing a transforming mechanism for a promising tractor.

It is advisable to compare technical solutions on the basis of a single nomenclature of parameters characterizing the main aspects of the production and operation of machines.

The list of operational properties, developed for the general assessment of the efficiency of tractors, is taken as a basis [1]. The nomenclature of estimated indicators proposed for consideration is given in table 1. Indicators characterizing the level of safety of operation of a structure and issues of protecting the environment (in the context of the task of comparing schemes and types of transforming mechanisms, it is assumed that at different costs for organizing a control system, which will be taken into account in the cost of manufacturing a tractor, the same level is provided for indicators of this group and can be excluded from consideration).

The following is a sequence of steps when comparing options.
1. The input parameters are divided into basic groups (in this case, the number of groups is three) (table 1). Each group is associated with the value of the weight coefficient, in accordance with the experts’ assessment of its significance in the context of the problem being solved. The sum of the coefficients for the entire system must be equal to 1: \( \sum_{i=1}^{3} k_{1i} = 1 \).

The level of implementation of the parameter under consideration for the version of the transforming mechanism is assessed on a five-point scale:

• 5 – maximum assessment;
• 1 – minimum assessment.

Variants of technical solutions accepted for comparison:

• A – mechanical automated transmission with a shaft as part of a single-stream transmission [12,13]; B – mechanical planetary automated gearbox as part of a single-stream transmission [4];
• C – use of full flow hydrostatic transmission [7];
• D – hydrostatic-mechanical two-line transmission [7,14]; E – mechanical variator (CVT) [4];
• F – electromechanical transmission [15,16];
• G – mechanical automated transmission with a shaft in a two-way transmission with control of the power distribution over the driving wheels of at least the front axle [17-21];
• H – mechanical planetary automated gearbox in a two-way transmission with control of the power distribution over the driving wheels of at least the front axle [17-21].

2. Each parameter within the group is assigned a weighting factor (table 1), in accordance with the experts’ assessment of its significance in the context of the problem being solved. The sum of the
coefficients within the group is 1: \( \sum_{j=1}^{p} k_{2j} = 1 \), \( p = 5 \) (for the first and second groups), \( p = 3 \) (for the third group of parameters).

3. For all parameters, the product is calculated \( k_{1l} \cdot k_{2j} \) (table 1).

4. Pairwise comparison of options is performed (table 2) and intermediate marks are given according to the following principle. Option with a design advantage, they give him a full point \( t_{lm} = k_{1l} \cdot k_{2j} \), \( m = 1,2, ..., i \cdot j \). The “loser” option gets \( t_{lm} = 0 \). In case of equality of marks, the score is divided in half between the compared options: \( t_{lm} = 0,5 \cdot k_{1l} \cdot k_{2j} \). The index \( l \) is assigned to the compared options: \( l = A, B, C, D ... \)

An example of pairwise comparison is shown in table 3.

5. The sum of the points scored in the course of pairwise comparison for each option is calculated \( T_i = \sum_{m=1}^{13} t_{lm} \). The winner is the option, the value of the accumulated amount for which is greater. Table 4 shows the codes of the "winners" in pairwise comparison.

6. Based on the table 4, ranking positions are distributed. In the case of the same frequency of "winning" for two competitors, preference is given to the option that wins in a pairwise comparison between competitors (table 5). Table 5, the preference for the option grows with an increase in the rating position number.

**Table 1.** Nomenclature of parameters and weighting factors of parameters and groups.

| Parameter group, parameters / Code | A   | B   | C   | D   | E   | F   | G   | H   | k₁  | k₂  | k₁×k₂ |
|-----------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
| Agrotechnical indicators:         | -   | -   | -   | -   | -   | -   | -   | 0.40| -   | -   |       |
| Smooth torque change              | 4   | 4   | 5   | 5   | 5   | 4   | 5   | 5   | 0.30| 0.12|       |
| Efficiency when ensuring          | 5   | 5   | 3   | 4   | 3   | 4   | 5   | 5   | 0.30| 0.12|       |
| speed ranges when aggregated      |     |     |     |     |     |     |     |     |     |     |       |
| with implements                   |     |     |     |     |     |     |     |     |     |     |       |
| Controllability                   | 4   | 4   | 4   | 4   | 4   | 5   | 5   | 5   | 0.15| 0.06|       |
| Stability of movement             | 4   | 4   | 4   | 4   | 4   | 5   | 5   | 5   | 0.15| 0.06|       |
| Prospects as part of an           | 5   | 5   | 3   | 5   | 3   | 4   | 5   | 5   | 0.10| 0.04|       |
| unmanned complex                  |     |     |     |     |     |     |     |     |     |     |       |
| Technical and economic            | -   | -   | -   | -   | -   | -   | -   | 0.35| -   | -   |       |
| indicators:                       |     |     |     |     |     |     |     |     |     |     |       |
| Work performance                  | 5   | 5   | 4   | 4   | 4   | 5   | 5   | 5   | 0.30| 0.105|0.30\times0.105 |
| Economy                           | 5   | 5   | 3   | 4   | 3   | 4   | 5   | 5   | 0.30| 0.105|       |
| Versatility of application        | 5   | 5   | 5   | 5   | 4   | 4   | 5   | 5   | 0.20| 0.070|       |
| Manufacturing cost                | 5   | 4   | 3   | 3   | 3   | 2   | 4   | 4   | 0.10| 0.035|       |
| Cost of operation                 | 5   | 5   | 3   | 3   | 3   | 4   | 4   | 4   | 0.10| 0.035|       |
| General technical indicators:     | -   | -   | -   | -   | -   | -   | -   | -   | 0.25| -   |       |
| Reliability                       | 5   | 5   | 4   | 4   | 3   | 3   | 4   | 4   | 0.33| 0.083|       |
| Durability                        | 5   | 4   | 3   | 3   | 2   | 3   | 4   | 4   | 0.33| 0.083|       |
| Maintainability                   | 4   | 3   | 2   | 2   | 2   | 2   | 4   | 3   | 0.33| 0.083|       |

**Table 2.** Coding of options for pairwise comparisons.

| A   | B   | C   | D   | E   | F   | G   | H   |
|-----|-----|-----|-----|-----|-----|-----|-----|
| A   | -   | AB  | AC  | AD  | AE  | AF  | AG  | AH  |
| B   | -   | -   | BC  | BD  | BE  | BF  | BG  | BH  |
| C   | -   | -   | -   | CD  | CE  | CF  | CG  | CH  |
| D   | -   | -   | -   | -   | DE  | DF  | DG  | DH  |
| E   | -   | -   | -   | -   | -   | EF  | EG  | EH  |
| F   | -   | -   | -   | -   | -   | FG  | FH  |     |
|     | -   | -   | -   | -   | -   |     |     | GH  |
Table 3. Example of pairwise comparisons: AC pair.

| Parameter group, parameters / Code | A  | C  | \( k_1 \) | \( k_2 \) | \( k_1 \times k_2 \) | A  | C  |
|-----------------------------------|----|----|-----------|-----------|-----------------|----|----|
| Agrotechnical indicators:         | –  | –  | 0.40      | –         | –               | –  | –  |
| Smooth torque change              | 4  | 5  | 0.30      | 0.120     | 0               | 0.120 | 0 |
| Efficiency when ensuring speed ranges when aggregated with implements | 5  | 3  | 0.30      | 0.120     | 0.120           | 0.120 | 0 |
| Controllability                   | 4  | 4  | 0.15      | 0.060     | 0.030           | 0.030 | 0 |
| Stability of movement             | 4  | 4  | 0.15      | 0.060     | 0.030           | 0.030 | 0 |
| Prospects as part of an unmanned complex | 5  | 3  | 0.10      | 0.040     | 0.040           | 0.040 | 0 |
| Technical and economic indicators:| –  | –  | 0.35      | –         | –               | –  | –  |
| Work performance                  | 5  | 4  | 0.30      | 0.105     | 0.105           | 0.105 | 0 |
| Economy                           | 5  | 3  | 0.30      | 0.105     | 0.105           | 0.105 | 0 |
| Versatility of application        | 5  | 5  | 0.20      | 0.070     | 0.035           | 0.035 | 0 |
| Manufacturing cost                | 5  | 3  | 0.10      | 0.035     | 0.035           | 0.035 | 0 |
| Cost of operation                 | 5  | 3  | 0.10      | 0.035     | 0.035           | 0.035 | 0 |
| General technical indicators:     | –  | –  | 0.25      | –         | –               | –  | –  |
| Reliability                       | 5  | 4  | 0.33      | 0.083     | 0.083           | 0.083 | 0 |
| Durability                        | 5  | 3  | 0.33      | 0.083     | 0.083           | 0.083 | 0 |
| Maintainability                   | 4  | 2  | 0.33      | 0.083     | 0.083           | 0.083 | 0 |
| Total score                       | –  | –  | –         | –         | –               | 0.783 | 0.215 |

Practical implications and prospects. Table 4 and 5 show the results of a comparative assessment of the options considered.

Table 4. "Winners" of pairwise comparisons.

| A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|
| A | – | A | A | A | A | A | G | A |
| B | – | – | B | B | B | B | G | H |
| C | – | – | – | D | C | F | G | H |
| D | – | – | – | – | D | D | G | H |
| E | – | – | – | – | – | F | G | H |
| F | – | – | – | – | – | – | G | H |
| G | – | – | – | – | – | – | – | G |

Table 5. Final rating.

| A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|
| 7 | 5 | 2 | 4 | 1 | 3 | 8 | 6 |

Thus, based on a comparison of the options, it was concluded that the best concept of the transforming mechanism from the point of view of completeness of ensuring the considered indicators is the option of a two-flow mechanical transmission with an automated shaft gearbox in the main power flow and a frictional power distribution mechanism that ensures control of power flows at least for the front driving wheels (option code G).

This is followed by an option involving the use of a shaft automated gearbox as part of a single-stream transmission.

The advantage of options with a shaft automated transmission over options with a planetary automated transmission within the framework of this comparison model is primarily due to the lower expected cost of the product and, in general, the higher maintainability of the shaft transmission units (option code A).
Industry experience shows that the best control quality in these gearboxes is achieved with electronic hydraulic control. The objects of control are disc friction elements, including those operating in the mode of pulse-width modulation of the control pressure [22, 23], and the control system is closed (feedback on the angular velocity of the gearbox output shaft is provided). The control system must support CAN technology standards [24].

This technical solution, as a compromise allowing the maximum use of the available technological base and ensuring a high level of operational properties, was accepted for implementation: the kinematic diagram of the gearbox was developed, the necessary documentation was prepared, a prototype of the assembly was produced and tested at the original stand [25] (figure 1). The work was carried out by the St. Petersburg Polytechnic University and LLC "Petersburg Tractor Plant" with financial support from the Ministry of Science and Higher Education of the Russian Federation under the project "Development of the design of a new model range of automated gearboxes for agricultural and road construction equipment in the range of 140-440 kW, adapted for use in a complex of unmanned tractor systems" [26].

![Figure 1. Appearance of the tested gearbox. 1 – input shaft, 2 – output shaft.](image)

3. Conclusions

Based on the analysis of trends in modern tractor construction, the best seems to be: for a tractor of the 4th traction class, the transmission should be double-flow, with a shaft gearbox and a frictional power distribution mechanism that ensures control of traction forces on the driving wheels of the front axle; for a tractor of 6-8 traction classes, the transmission should be double-flow, with a shaft gearbox and a friction mechanism in a parallel flow, without traction control.

This solution is recommended as an option. For serial machines in the basic configuration, regardless of the traction class, keep the principle of a single-stream transmission.

The highest energy indicators (specific power, efficiency at operating modes, efficiency at idle, etc.) can be provided by modern planetary gearboxes. However, in the basic configuration, it is recommended to use a shaft transmission with disc frictional controls.

Provide a hydraulic drive for the friction control elements as the executive part of the gearbox control system. Use constant pressure in the hydraulic drive of disc clutches. The logical part of the control system must be based on a microprocessor-based system with support for data transfer protocols via the CAN bus. The control system must be closed.

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