Decision theory for choosing the best machine from alternative options

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Abstract. The studied factors characterizing each machine are taken with real values of the estimated indicators, for which desirability functions and weight coefficients have been developed using the method of pairwise comparison of estimated indicators of absolute and relative rank places using the percentile function. The dependence of the translation of the estimated indicators of the machine with real values into dimensionless ones for the scale $y'$ is obtained, according to which the desirability function is calculated, and then the generalized indicator characterizing the complex assessment of the machine. The advantage of a methodological approach to making an objective decision for each machine using the weight coefficients of each estimated indicator is substantiated, which for the problem under consideration vary in the range of 0.06-0.44. According to the maximum value of the generalized indicator of a comprehensive assessment, preference was given to the KShU-12 cultivator.

1. Introduction

Making an objective decision is very important for both science and production. It is determined by the methods used, on which the final result depends. For this purpose, Harrington's desirability function [1], the method of expert assessments [2], experiment planning [3, 4], and others [5, 6] are widely used. It is very important to use a reliable method in making decisions on the technical equipment of agricultural enterprises. It largely determines the efficiency of crop production and competitiveness. The cost of production, its quality and labor productivity depend on what machines are used in the technologies of cultivation of field crops. Currently, the market is saturated with a wide variety of agricultural equipment. You can buy the most productive machines, ensure that field work is carried out in the optimal time frame and with high quality, but they can be too expensive and not provide the necessary competitiveness of agricultural enterprises.

The purchase of less expensive machines will cause an increase in the demand for machine operators, which is also not rational. The existing methods of optimization of the composition and structure of the machine and tractor fleet [7, 8, 9] are laborious and cumbersome and are practically not used in production and perform technical equipment at the discretion of individual specialists without proper justification of the expected efficiency. All this negatively affects the cultivation technologies being introduced and, ultimately, the competitiveness of agricultural enterprises.

The purpose of this article is to propose a theoretical justification for the modernized desirability function for making a decision on choosing the best machine from alternatives.
2. Materials and methods
The work was carried out on the basis of the analysis of the estimated indicators of six brands of cultivators for continuous tillage, serially produced by the plant. Cultivators are equipped with the same working bodies and differ in working width for tractors of different traction classes. The challenge is to select the best cultivator from the six alternatives using a generalized integrated assessment indicator.

The decision is made according to the maximum value of the generalized indicator of the comprehensive assessment. The decision is made on the basis of the maximum value of the generalized indicator approaching one.

We have proposed four estimated i-indicators \((i = 1...4)\) with their own units of measurement (table 1):

1 - unit price of 1 m of cultivator, \(K_c\) (thousand rubles/m);
2 - energy consumption of the cultivation process, \(K_u\) (MJ/ha);
3 - metal consumption, \(K_g\) (kg/ha);
4 - direct labor costs for the cultivation process, \(K_w\) (man-h/ha).

| Cultivator | Cultivator brand | Name of i-x-indicators | unit price of 1 m of cultivator, \(K_c\) (thousand rubles/m) | energy consumption of the cultivation process, \(K_u\) (MJ/ha) | metal consumption, \(K_g\) (kg/ha) | direct labor costs for the cultivation process, \(K_w\) (man-h/ha) |
|------------|-----------------|------------------------|------------------------------------------------------------|------------------------------------------------------------|----------------------------------|-------------------------------------------------|
| 1          | KSHU -4.8       |                        | 104.8                                                      | 73.2                                                       | 2.9                              | 0.21                                            |
| 2          | KSHU -6.4       |                        | 105.0                                                      | 62.2                                                       | 2.7                              | 0.15                                            |
| 3          | KSHU -8.0       |                        | 103.4                                                      | 56.3                                                       | 2.9                              | 0.13                                            |
| 4          | KSHU -10        |                        | 102.4                                                      | 61.5                                                       | 3.1                              | 0.10                                            |
| 5          | KSHU -12        |                        | 97.6                                                       | 60.7                                                       | 3.1                              | 0.08                                            |
| 6          | KSHU -14        |                        | 130.8                                                      | 53.0                                                       | 3.1                              | 0.07                                            |

The values \((x_{ij})\) of each i-indicator vary in a wide range (table 1):

- the first indicator - from 97.6 (min) to 130.8 (max);
- the second - from 53 to 73.2;
- the third - from 2.7 to 3.1;
- the fourth - from 0.07 to 0.21.

We use the selected values of the i-indicators for evaluating machines to build scales \(A\) (figure 1) with their real values and dimensionless \(y'_{ij}\). First, we find the scale \(m\) for converting the values \(x_{ij}\) into dimensionless ones on the scale \(y'_{ij}\):

\[
m = \frac{y'_{ijmax} - y'_{ijmin}}{x_{ijmax} - x_{ijmin}},
\]

Where:

- \(y'_{ijmax}\) – a value of 3.5 on the \(y'\) scale if desired \(d = 0.8\);
- \(y'_{ijmin}\) – a value of 1.524 on the \(y'\) scale if desired \(d = 0.2\);
- \(x_{ijmax}, x_{ijmin}\) – the maximum and minimum values of the i-index with their own units of measurement and their own scale for the compared machines.

We have obtained dependencies (2...5) in the form of a straight line BC (figure 2) for converting the actual values of the i-indicators \(x_{ij}\) into dimensionless ones on the scale \(y'_{ij}\) for each \(j\) machine:
1) for unit price \( y'_{1,j} \):

\[
y'_{1,j} = -0.595 \cdot x_{1,j} + 9.31
\]  

(2)

2) for specific energy consumption \( y'_{2,j} \):

\[
y'_{2,j} = -0.098x_{2,j} + 8.69
\]  

(3)

3) for specific metal consumption \( y'_{3,j} \):

\[
y'_{3,j} = -4.94x_{3,j} + 16.84
\]  

(4)

4) for unit labor costs \( y'_{4,j} \):

\[
y'_{4,j} = -14.12x_{4,j} + 4.49
\]  

(5)

Using the obtained values of the dimensionless exponents \( y'_{i,j} \), we find their desirability by the Harrington function (6):

\[
d_{ij} = e^{-e^{-(y'_{ij} - 2)}}
\]  

(6)

Based on the found dimensionless desirability values of all four indicators for six machines, we find the value of the generalized indicators of a comprehensive assessment of all machines, taking into account the weighting coefficient (7):

\[
D_j = \sqrt[4]{\prod_{i} d_{ij}^{ki}}
\]  

(7)

Where:

- \( D_j \) – generalized i-index of complex assessment for each j machine;
- \( d_{ij}^{ki} \) – the desirability of each \( i \)-indicator for each \( j \) machine, taking into account the weighting coefficient \( k_i \) for each \( i \)-indicator.

Without taking into account the weight of \( i \)-indicators, the generalized \( D_j \) is determined by the formula (8):

\[
D_j = \sqrt[4]{\prod_{i} d_{ij}}
\]  

(8)

The highest value of the generalized indicator \( D_j \) gives priority to the \( j \)-th brand of the studied machines.

The weighting index of each \( i \)-indicator is determined by the paired comparison method (table 2) with further determination by the method of the absolute and relative rank place of each \( i \)-indicator of the percentile function \( P_i \) and then - the weighting coefficient \( K_i \) of each \( i \)-indicator (table 3).

**Table 2.** Matrix of paired comparison of partial estimated \( i \)-indicators of compared machines.

| Private estimated i-scores | 1     | 2     | 3     | 4     | Points |
|----------------------------|-------|-------|-------|-------|--------|
| Unit price of 1 m of cultivator, \( K_c \) (thousand rubles/m) | 1.0   | 1.5   | 1.1   | 3.6   |
| Energy consumption of the cultivation process, \( K_u \) (MJ/ha) | 0.9   | 0.9   | 1.0   | 2.8   |
| Metal consumption, \( K_g \) (kg/ha) | 0.5   | 0.6   | 1.0   | 2.1   |
| Direct labor costs for the cultivation process, \( K_w \) (man-h/ha) | 1.0   | 1.4   | 1.1   | 3.5   |


Table 3. Percentage rank indicator and weight coefficients of private estimated indicators.

| Indicator scales | $i$ | Points | The absolute rank of the $i$-indicator | The relative rank of the $i$-indicator $K$ | Percentile $P_{R_i} \%$ | The coefficient of weighting of the indicator $K_i$ |
|-----------------|-----|--------|--------------------------------------|------------------------------------------|------------------------|------------------------------------------|
| 1               | Kc  | 3.6    | 1                                    | 4                                        | 87.5                   | 0.44                                     |
| 4               | Kw  | 3.5    | 2                                    | 3                                        | 62.5                   | 0.31                                     |
| 2               | Ku  | 2.8    | 3                                    | 2                                        | 37.5                   | 0.18                                     |
| 3               | Kg  | 2.1    | 4                                    | 1                                        | 12.5                   | 0.07                                     |

As follows from table 3, the highest ranked place is occupied by the unit price of the machine ($K_1=0.44$), then the unit direct labor costs (weight coefficient $K_2=0.31$), in third place is energy consumption ($K_3=0.18$), in the last with the lowest weight metal consumption ($K_4=0.07$). In our opinion, such a method for determining the weight of $i$-indicators is more objective than the method of expert assessment [2].

3. Results and discussion

The proposed method of modernization of the Harringthorn function for choosing the best machine from the considered family of wide-grip KSHU cultivators for tillage is considered on the example of machines manufactured by OOO Rus Agro [10] (Chelyabinsk, Russia). The KSHU cultivators produced by the company (figure 1) are designed for pre-sowing treatment of all types of soils in the background of plowing and cultivation. They work to a depth of 12 cm, efficiently destroy weeds and level the soil.

![Figure 1. KShU cultivator in operation.](image)

These cultivators (table 1) have proven themselves well in the treatment of various types of soils.

The goal of our task is to calculate using the desirability function for all $i$-indicators for each $j$ machine, taking into account the weight of each $i$-indicator and without it. After that, the generalized $D_j$ indicator is calculated for each $j$ machine and we find the best of them by the maximum value of the $D_j$ indicator. The calculation results are summarized in table 4.

Before calculating the indicator $D_j$, it is necessary to convert each value of the $i$-indicator ($x_{ij}$) for each $j$ machine to a dimensionless one for the scale $y'$, which were calculated by formulas (2...5), their desirability $d_{ij}$ according to formulas (6) and generalized indicators of a comprehensive assessment of $D_j$ for each $j$ machine according to formulas (8).
In Figure 2, the dashed line shows the sequence of calculation, starting with the scales A of all i-indicators of the machine evaluation with their natural values \(x_{ij}\) and ending with the desirability of \(d_{ij}\) of these indicators. Generalized indicators of a comprehensive assessment of \(j\) machine are shown in Table 4.

Table 4. Generalized indicators for evaluating the \(j\)-th indicators.

| Number \(j\)-th machinery | Compared \(j\)-cars brands | Generalized estimates taking into account the weight, \(D_j^k\) | without regard to weight, \(D_j\) |
|---------------------------|---------------------------|-------------------------------------------------|-------------------|
| 1                         | KSHU -4.8                 | 0.78                                            | 0.35              |
| 2                         | KSHU -6.4                 | 0.89                                            | 0.64              |
| 3                         | KSHU -8.0                 | 0.906                                           | 0.65              |
| 4                         | KSHU -10                  | 0.90                                            | 0.50              |
| 5                         | KSHU -12                  | 0.913                                           | 0.53              |
| 6                         | KSHU -14                  | 0.80                                            | 0.40              |

In the best cultivator (KSHU-12), only one estimated indicator, the specific price of the machine (97.6 thousand rubles / m), has the minimum value of all analyzed (Table 4) and, despite this, received priority. The cultivators KSHU-8 and KSHU-10 are close to it in \(D_j\), but they are significantly inferior to KSHU-12 in terms of labor costs with a high weight coefficient (Table 1), which lowered them to the second and third places, KSHU-10 - the second, and priority for KSHU-8, although it does not have a single \(i\)-th estimated indicator (Table 1) with the best value out of the six compared machines.

All this emphasizes the objectivity of the approach to choosing the best car according to the generalized indicator of the assessment \(D_j\), taking into account the weight of each \(i\)-th indicator. Without this approach, it is impossible to choose the best car.

Thus, the significant influence of the weight coefficients of \(i\)-indicators on the value of the generalized and final decision-making has been proved, since without taking into account these coefficients, it becomes different and not objective.
4. Conclusion
As a result of the proposed approach to making an objective decision on choosing the best machine from the alternatives, using the modernized Harrington desirability function, the possibility of its use for evaluating cultivators for continuous tillage has been proven.

Using the method of paired comparison of the estimated $i$-indicators of the compared machines, the coefficients of their weight have been substantiated and the significance of their influence on the objectivity of decision-making has been proved. So, if the best machine out of the compared six brands of KSHU cultivators according to the generalized indicator of a comprehensive assessment, taking into account the weight of the estimated $i$-th indicators, is the KSHU-12 cultivator, then, taking into account the generalized indicator without the weight of the estimated $i$-th indicators, the priority is assigned to the KSHU-8 cultivator, where KSHU-12 took only third place.

For the studied KSHU cultivators, reliable (according to the Cochran's criterion) dependences of converting the values of the $i$-th indicators with their own units of measurement into dimensionless ones for the $y'$ scale and further calculation of the desirability function were obtained.

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