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Estimation of the influence of the interaction of factors pairs on the coefficient of route execution possibility

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Abstract. Successful execution of a route by a locomotive can depend on the combination of various operational factors. As an indicator that characterizes the reliable operation of locomotives in exploitation, the coefficient of route execution possibility is proposed to use. The task is to get a formula by which it would be possible to obtain the value of the coefficient of route execution possibility with different combinations of factors. As a tool for obtaining an interpolation formula for determining the coefficient of route execution possibility, a full factor experiment was chosen. The calculations of the model coefficients were carried out with a pairwise combination of four factors: the profile of the area, experience of the driver, the length of the shoulder, the weight of the train. The obtained models were checked for adequacy by F-test. On the received models in three-dimensional coordinates surfaces, reflecting the value of the coefficient of route execution possibility in the intervals of factorization, were constructed. An analysis of the obtained surfaces and the distribution of the selected factors by the degree of impact on the coefficient of route execution possibility were carried out.

1. Introduction

The analysis of the reliability of the work of locomotives in the operation indicates a rather high level of their failures in the route. It indicates that before the departure of the locomotive to the route, there is no assessment of its ability to successfully complete the route under the influence of various factors. Denials on the route may result in significant material losses that could have been avoided even at the stage of route preparation.

First, before sending the locomotive to the route, it is necessary to analyze its actual technical condition and to ensure that the state of its nodes allows executing the route without fail [1]. For this purpose an electronic passport of the locomotive can be used [2].

Secondly, it is necessary to make sure of sufficient qualification of the locomotive crew in order to avoid the failure of the locomotive due to improper actions of the locomotive crew.

Thirdly, it is necessary to take into account the influence of operational parameters of the future route to change the technical condition of the locomotive and its knots.

As a tool that will allow simulating and analyzing the interaction of various factors, the method of a full factor experiment can be used [3, 4].

Methods of the theory of experiment are used to find optimal conditions and obtain formulas reflecting the interaction of factors. Experiment planning applies for searching for optimal conditions, building interpolation formulas, choosing significant factors [5-8].

2. Purpose

The purpose of this article is to analyze the influence of the interaction of a pair of factors on the coefficient of route execution possibility and ranking of selected factors by degree of influence.

3. Main body

As factors that influence on the value of the coefficient of route execution possibility were selected: x_1 – the profile of the area, x_2 – experience of the driver, x_3 – the length of the shoulder, x_4 – the weight of the train.

Accepted values of the zero level, the interval of variation, the upper and lower levels of factors are given in Table 1.

Table 1. Values of variables and variables range.

Levels and interval of variation of factor	Factors			
	x_1	x_2	x_3	x_4
	i, ‰	T, years	L, km	Q, t
Zero level	0	10	300	4000
Interval of variation	10	10	200	2000
Lower level	-10	0	100	2000
Upper level	10	20	500	6000

For the transition from real values to values of ± 1 encoding of the factors is performed. Encoding is determined by the ratio

$$x_i = \frac{\tilde{x}_i - \tilde{x}_{i0}}{J_i}, \quad (1)$$

where x_i is the coded current value of the factor, $\tilde{x}_i$ is the natural current value of the factor, $\tilde{x}_{i0}$ is the natural value of the zero level and J_i is the natural value of the interval of variation.

The values of coded variables are

$$x_1 = \frac{i-0}{10},\ x_2 = \frac{T-10}{10},\ x_3 = \frac{L-300}{200},\ x_4 = \frac{Q-4000}{2000}$$

The matrix of a full factor experiment for interaction of profile of area and experience of the driver is given in Table 2.

Table 2. Matrix of a full factor experiment.

Experiment	Factors and their interaction				Coefficient				
	x_0	x_1	x_2	$x_1 x_2$	y_1	y_2	y_3	y_{cep}	$\hat{y}$
1	1	-1	-1	1	0.91	0.89	0.87	0.89	0.9044
2	1	1	-1	-1	0.89	0.88	0.87	0.88	0.8945
3	1	-1	1	-1	0.92	0.9	0.87	0.90	0.9112
4	1	1	1	1	0.88	0.94	0.93	0.92	0.8988

In this table, y_1, y_2, y_3 are the results of parallel experiments (obtained by simulation). Using them dispersions for each of the series of experiments were calculated by the formula

$$\sigma_i^2 = \frac{\sum_{j=1}^{m}\left(y_{ji} - \overline{y_i}\right)^2}{m-1} \tag{2}$$

where σ_i^2 is the dispersion at the *i*-th point, *m* is the number of parallel experiments, y_{ji} is the value of the optimization parameter in the *j*-th parallel experiment and $\overline{y_i}$ is the average value of the optimization parameter in this series of parallel experiments.

$$\sigma_1^2 = \frac{(0.91-0.89)^2 + (0.89-0.89)^2 + (0.87-0.89)^2}{3-1} = 0.0004$$

Analogically determined $\sigma_2^2 = 0.0001$, $\sigma_3^2 = 0.0006$ and $\sigma_4^2 = 0.001$.

To determine the homogeneity of dispersions, the Cochran's G-test is calculated by the formula

$$G = \frac{\sigma_{i\max}^2}{\sum_{i=1}^{n}\sigma_i^2} \tag{3}$$

where $\sigma_{i\max}^2$ – the largest value of the dispersion.

$$G = \frac{0.001}{0.0004 + 0.0001 + 0.0006 + 0.001} = 0.47$$

Table value is $G_{table} = 0.68$.

Since $G < G_{table}$, the dispersions are homogeneous.

The experimental error is determined by the formula

$$\sigma_y^2 = \frac{\sum_{i=1}^{n}\sigma_i^2}{n} \tag{4}$$

$$\sigma_y^2 = \frac{0.0004 + 0.0001 + 0.0006 + 0.001}{4} = 0.0005.$$

The coefficients of the model are determined by the formula

$$b_j = \frac{\sum_{i=1}^{n} x_{ij} y_i}{n} \tag{5}$$

$$b_0 = \frac{1\cdot 0.89 + 1\cdot 0.88 + 1\cdot 0.9 + 1\cdot 0.92}{4} = 0.8958$$

Analogically determined $b_1 = 0.0025$, $b_2 = 0.0108$ and $b_{12} = 0.0075$.

Knowing the coefficients of the model, it is possible to calculate the value of the coefficient of route execution possibility and to examine the adequacy of the model.

The Fisher's F-test is used to check the adequacy of the model

$$F = \frac{\sigma_{ad}^2}{\sigma_y^2} \tag{6}$$

where σ_{ad}^2 – the dispersion of adequacy.

$$\sigma_{ad}^2 = \frac{\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)^2}{n-k-1} \tag{7}$$

where $\hat{y}_i$ – the value of the optimization criterion provided by the equation for the *i*-th experiment.

If for the selected level of significance $\alpha = 0.05$ the calculated value of Fisher's F-test does not exceed the table value, then the model is considered adequate.

$$\sigma_{ad}^2 = \frac{(0.89-0.9044)^2 + (0.88-0.8945)^2 + (0.9-0.9112)^2 + (0.92-0.8988)^2}{4-2-1} = 0{,}00094$$

$$F = \frac{0.00094}{0{,}0005} = 1.75$$

Table value is $F_{table}\left(k_1 = 4, k_2 = 4\right) = 6.39$.

Since $F < F_{table}$, the model is adequate.

The formula for determining the coefficient of route execution possibility with the interaction of factors x_1 and x_2 will have the following form

$$k = 0.8958 + 0.0025x_1 + 0.0108x_2 + 0.0075x_1x_2 \tag{8}$$

On the received formula in three-dimensional coordinates it is possible to construct a surface that will reflect the value of the coefficient of route execution possibility in the intervals of variation the factors x_1 and x_2 (Figure 1).

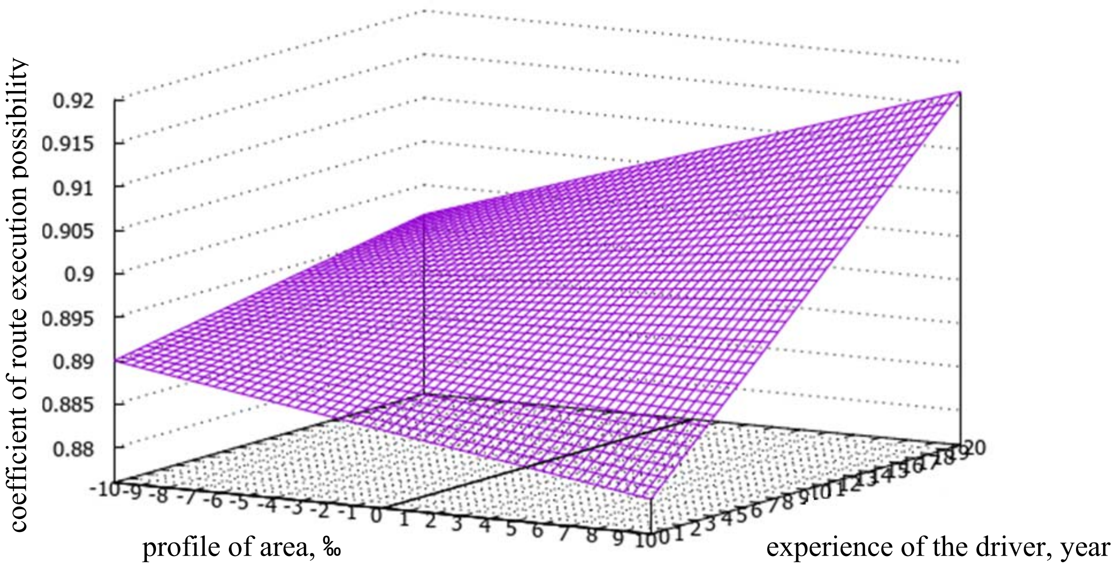

Figure 1. Dependence of the coefficient of route execution possibility on the profile of the area and experience of the driver.

The analysis of the graph shows that in the interaction of factors x_1 – the profile of the area and x_2 – experience of the driver the coefficient of route execution possibility varies from 0.88 to 0.916. The minimum value of the coefficient corresponds to the interaction of the maximum value x_1 and the minimum value of x_2, and the maximum value of the coefficient corresponds the interaction of the maximum values x_1 and x_2.

The next was a full factor experiment with the interaction of factors x_3 – the length of the shoulder, x_4 – the weight of the train. In this case, the matrix of the complete factor experiment was compiled, the dispersions, the coefficients of the model, the experimental error were calculated and the verification of the model for adequacy were made according to the methodology given above.

The formula for determining the coefficient of route execution possibility with the interaction of factors x_3 and x_4 will have the following form

$$k = 0.8715 - 0.0057x_3 - 0.0014x_4 - 0.0033x_3x_4 \qquad (9)$$

The surface, which reflects the value of the coefficient of route execution possibility in the intervals of variation of factors x_3 and x_4 is shown on Figure 2.

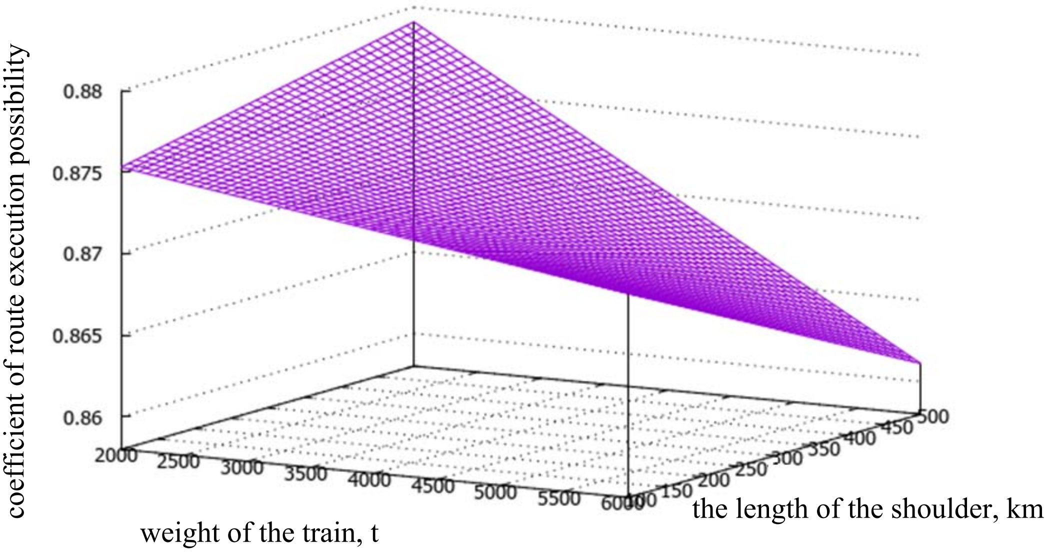

Figure 2. Dependence of the coefficient of route execution possibility on the weight of the train and the length of the shoulder.

In the interaction of factors x_3 – the length of the shoulder, x_4 – the weight of the train coefficient of route execution possibility varies from 0.862 to 0.878. The minimum value of the coefficient corresponds to the interaction of the maximum values x_1 and x_2, and the maximum value of the coefficient is the interaction of the maximum value of x_3 and the minimum value of x_4.

Then there was a full factor experiment with the interaction of factors x_4 – the weight of the train, x_2 – experience of the driver. In this case, the matrix of the complete factor experiment was compiled, the dispersions, the coefficients of the model, the experimental error were calculated and the verification of the model for adequacy were made according to the methodology given above.

The formula for determining the coefficient of route execution possibility with the interaction of the factors x_4 and x_2 will have the following form

$$k = 0.8837 - 0.0218x_4 + 0.0315x_2 - 0.0089x_4x_2 \qquad (10)$$

The surface, which reflects the value of the coefficient of route execution possibility in the intervals of variation of factors x_4 and x_2 is shown in Figure 3.

In the interaction of factors x_4 – the weight of the train, x_2 – experience of the driver coefficient of route execution possibility varies from 0.866 to 0.926. The minimum value of the coefficient corresponds to the interaction of the maximum values of x_4 and x_2, and the maximum value of the coefficient is the interaction of the maximum value of x_2 and the minimum value of x_4.

The next pair of factors was chosen x_2 – experience of the driver and x_3 – the length of the shoulder. After carrying out a full factor experiment, the following formula was obtained for determining the coefficient of route execution possibility with the interaction of factors x_2 and x_3.

$$k = 0.8948 - 0.0253x_2 - 0.0071x_3 - 0.0105x_2x_3 \tag{11}$$

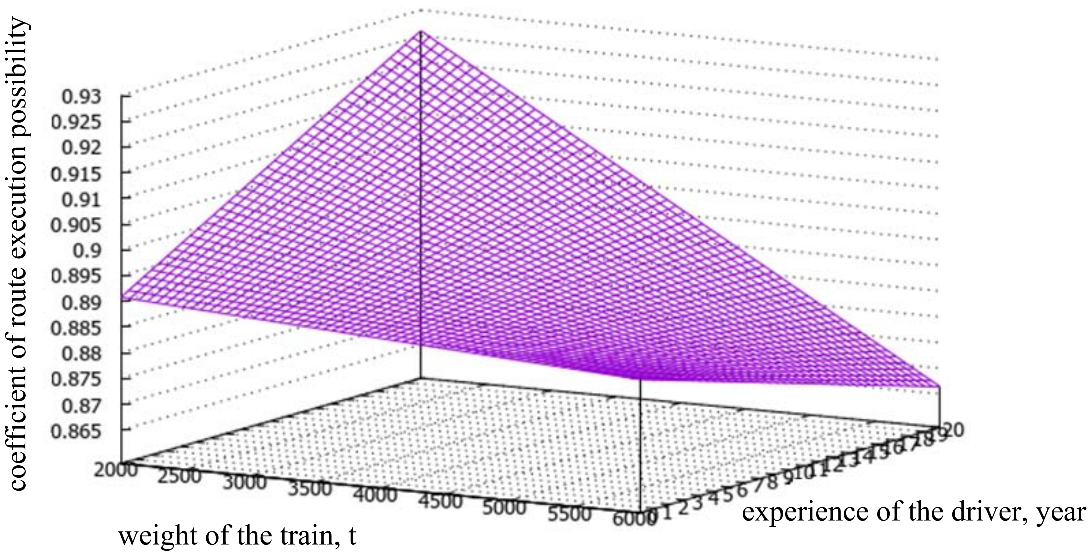

Figure 3. Dependence of the coefficient of route execution possibility on the weight of the train and experience of the driver.

According to the obtained formula, a surface that reflects the value of the coefficient of flight fulfillment in the intervals of the coagulation of the factors x_2 and x_3 (Figure 4).

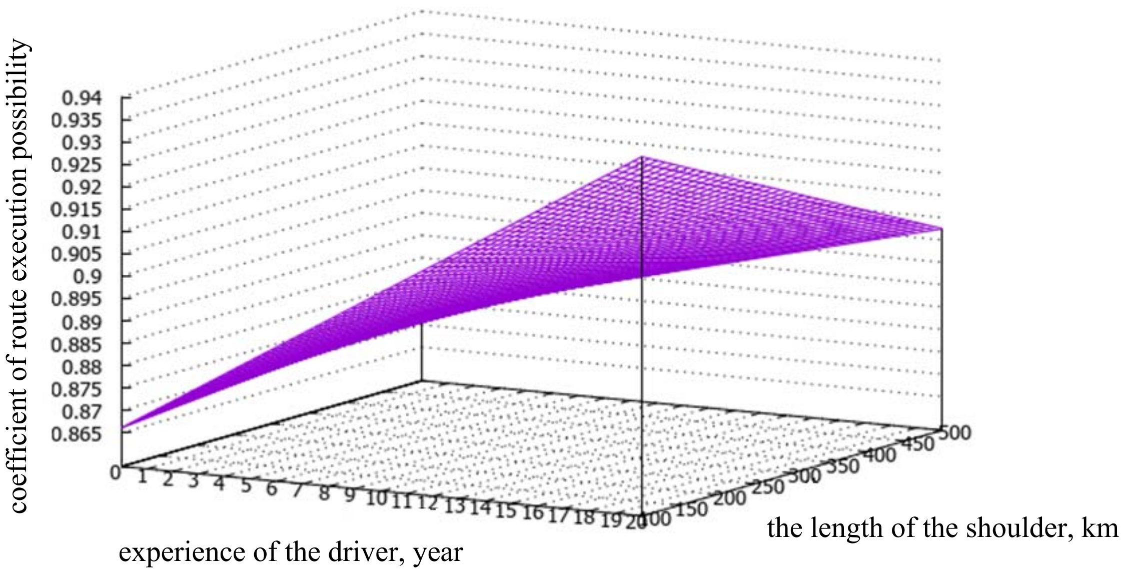

Figure 4. Dependence of the coefficient of route execution possibility on experience of the driver and the length of the shoulder.

In the interaction of factors x_2 – experience of the driver and x_3 – the length of the shoulder coefficient of route execution possibility varies from 0.866 to 0.913. The minimum value of the coefficient corresponds to the interaction of the minimum values x_1 and x_2, and the maximum value of the coefficient corresponds the interaction of the maximum value of x_2 and the minimum value of x_3.

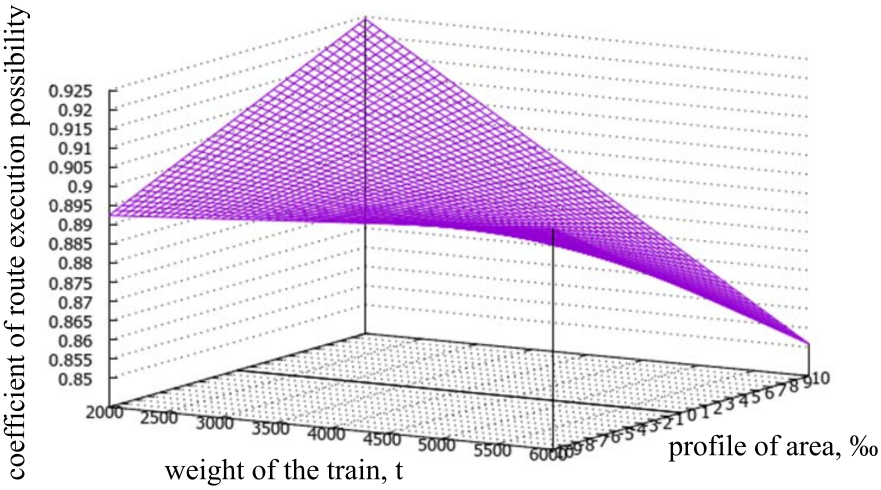

Figure 5. Dependence of the coefficient of route execution possibility on the weight of the train and the profile of the area.

The last group of factors on which the calculations were made were x_4 – the weight of the train and x_1 – the profile of the area. The made calculations showed that the formula for determining the coefficient of route execution possibility with the interaction of the factors x_4 and x_1 will have the following form

$$k = 0.8919 - 0.0165x_4 + 0.0043x_1 - 0.0203x_4x_1 \quad (12)$$

The surface, which reflects the value of the coefficient of route execution possibility in the intervals of the variation of factors x_4 and x_1 is shown in Figure 5.

The analysis of the graph shows that in the interaction of the factors x_4 – the weight of the train and x_1 – the profile of the area the coefficient of route execution possibility varies from 0.85 to 0.925. The minimum value of the coefficient corresponds to the interaction of the maximum values of x_4 and x_1, and the maximum value is the interaction of the minimum value of x_4 and the maximum value of x_1.

4. Conclusion

The obtained formulas are valid for the variables in the intervals of variation given in Table 1. According to them, it is possible to calculate the value of the coefficient of route execution possibility at different combinations of a pair of factors.

In this case, the coefficient of route execution possibility takes the value from 0.85 to 0.926. The minimum value of the coefficient corresponds to the interaction of the maximum values of x_4 and x_1, the maximum value corresponds the interaction of the maximum value of x_2 and the minimum value of x_4.

By the force of influence on the coefficient of route execution possibility, the factors are arranged in the following order: experience of the driver, the length of the shoulder, the weight of the train, the profile of the area.

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