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Decision-making under conditions of partial uncertainty of baseline information when introducing high-speed traffic on existing lines

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ABSTRACT:*Decision-making in conditions of uncertainty is based on the fact that the probabilities of various variations of the development of events are unknown. In this case, the subject is guided, on the one hand, by his risk preference, and on the other hand, by the criterion of choosing from all alternatives according to the compiled "decision matrix". Decision-making under risk conditions is based on the fact that each situation of development of events canthe probability of its implementation should be set. This allows you to weigh each of the efficiency valuesand choose the situation with the lowest level of risk for implementation.*
Reconstructive measures to increase the speed of movement on the railway should be designed so that the safety and continuity of train traffic are ensured, the time of passengers on the way is reduced while ensuring the required size of transportation and the lowest construction and operating costs.The solution of the set tasks of designing the reconstruction of the railway is carried out on the basis of the methods of the theory of decision-making. The need to make decisions for which not completelythe conditions that determine them are taken into account, as well as their subsequent influence, which are found in all fieldsof technology, in particular when introducing high-speed traffic on railways.
The choice of technical parameters of reconstruction with an increase in the speed of movement in conditions of uncertainty of the initial information can be carried out according to the algorithm proposed in the article, the essence of which is to establish a set of design conditions and assign various options that are able to form a matrix of indicators of particular criteria. Decisions under uncertainty conditions can be made using various criteria: minimax criterion (MM-criterion, Wald criterion), Savage criterion (S-criterion, minimum risk criterion), Hermeyer criterion, criterion of products (P-criterion), etc. Each of the criteria eventually provides the decision-maker with a specific algorithm of actions.

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I. INTRODUCTION

When designing railways, due to the complexity and variety of construction and operational conditions of the object, in many cases it is necessary to consider a large number of options and choose the most rational one according to the accepted criterion with these limitations [1].The main reason for the of the problem of decision-making is the search for an option with an optimal criterion, in addition to which other factors should be taken into account in the decision-making process, which the theory allows to identify and evaluate decision-making [1].

Efficiency of optimization methods and the objectivity of the results obtained in solving project tasks depends on the correct formulation of the problem, its formalization and the choice of an appropriate search strategy. The unreliability of information when making design decisions on the reconstruction of a railway for high-speed traffic is caused by various factors that are subject to analysis taking into account the individual characteristics of each project. In this study, the decision is to choose one of the possible options for the reconstruction of the railway under high speeds. The need to reconstruct the railway with an increase in the running speed of trains is caused by a number of reasons. Passenger traffic displaces part of freight trains, which is especially noticeable in the conditions of increasing passenger train speeds. The main indicator here is the removal coefficient, the value of which depends on the speed of movement freight and passenger trains, train lengths and their non-identity, track development stations, estimated inter-train interval and a number of other factors. In this regard, it may be necessary to strengthen the power of the road – to increase its capacity and passing capacity. In high - speed traffic to ensure passenger comfort is subject to more stringent requirements for the line plan. The edges of small radii need to be flattened, the lengths of straight inserts and transition curves need to be increased to stabilize the movable joint at the ends of circular curves. In order to ensure the safety and continuity of train traffic, intersections with highways must be carried out at different levels. Replacement of switches, reconstruction of passenger platformsarerequired. In addition, SCB and communication devices should be modernized, strengthened the contact network and traction substations, aswell as environmental protection measures have been taken. Reconstructive measures to increase the speed of traffic on the railway should be designed so that safety and continuity are ensured train traffic, reduced fat transit time on the way while ensuring the required transportation times and the lowest construction and operating costs [2].

II. ADDRESSING THE SET OBJECTIVES

The solution of the set tasks of designing the reconstruction of the railway is carried out on the basis of the methods of the theory of decision-making [3]. Based on the information obtained as a result of the application of the mathematical apparatus, as well as the analysis of all the options that take into account the interaction of subsystems, as well as the interaction of the system with the environment and the superstructure, a decision is made. The method of choosing the technical parameters of reconstruction in the conditions of uncertainty of the initial information, according to this algorithm, is as follows. In block 1, the variants of the design conditions (RUp) – scenarios according to which the operation will be carried out should be defined roads. It is necessary to identify those factors of uncertainty that are most significant for this project case. In addition, it is necessary to determine the variant values of uncertainty factors. Possible combinations of these options determine various scenarios for the development of the conditions for the implementation of the project.The maximum number of options is

$$N = \prod_{\phi=1}^{\phi=\Phi} R_{\text{ф}},$$

where Φ is the number of uncertainty factors (1, ..., ф, ..., Φ); $R_{\text{ф}}$ – the number of variants of the values of each factor ф.

Of course, it is not always possible to combine all levels of all factors. The article provides an example for one of the possible comparison options.

In block 2, possible variants of the complex of technical parameters and technical equipment for increasing the capacity of the reconstructed railway are assigned, determining its technical condition after reconstruction (TSi).

As a rule, the railways reconstructed for the high-speed movement of passenger trains belong to the mainline double-track lines with electric traction. Therefore, the set of power amplification options is limited. The measures to increase the throughput capacity should include the re-construction of permanent devices in an unsatisfactory state for the abolition of temporary speed limits, the modernization of SCB devices to reduce the travel and station intervals, etc. It is also possible to increase the mass of cargo vehicles by increasing the power of traction means or lengthening of the receiving and sending paths.

In block 3, an analysis of the development of transportation is performed. It is necessary to make traction calculations, determine the possible throughput capacity of the planned technical conditions and, comparing them with the required throughput capacity, identify their relationship. It is necessary to exclude the states of uncertainty [4] of some design conditions if they do not cope with the specified traffic sizes, or to provide for the possibility of additional measures to adapt the line to these external design conditions.

In block 4, calculations are carried out to determine the cost of the reconstruction of the railway, due to the need to increase the capacity of the line and reconstructive measures related to the implementation of high speeds of passenger trains. In the same block, it is necessary to determine the operating costs and the cost of the time passengers are on the way. In addition, it is necessary to determine the costs of acquiring rolling stock and establish the amount of return due to the sale of existing wagons and locomotives.

At the next stage (in block 5), the indicators of particular criteria for all assigned technical conditions in each of the calculated cases of external conditions accepted for consideration. Criteria like the rule is monetary. At the same time, both single-stage and multi-stage costs can be considered during the period of operation of the road adopted for comparison. When using multi-stage costs, when a step-by-step increase in line capacity is subject to analysis, it is necessary to optimize the scheme of development of the transfer at a fixed initial state. As a result , the following should be formed a matrix of particular criteria characterizing the assigned technical conditions in each of the variants of the design conditions (Tabl. 1). Based on Table 1, a risk matrix is formed (Tabl. 2) by condition

$$R_{in} = E_{pc} – \min E_{pc} ,$$

where E_{pc}- is an indicator of a particular criterion for the *i* design solution in the design conditions *n*; min E_{pc}–

is an indicator of the criterion for the most rational design solution in the design conditions *n*.

The risk matrix shows the additional costs for solution *i* compared to the most rational solution in the considered design conditions *n*.

In the remaining blocks, it is necessary to choose a method for evaluating the solution under uncertainty conditions, determine the general criterion for decision-making and establish the most rational design solution taking into account all possible conditions. The reliability of the choice of technical parameters in the railway line project largely depends on the correctly adopted method of comparison, as well as the criterion of the optimal solution. For example, consider an existing railway track on which the introduction of high-speed passenger train traffic is predicted. As a result of the analysis of possible options for the operation of the railway after reconstruction, two uncertainty factors were established for the high-speed movement of passenger trains: the size of the carriage and the value of the passenger-hour cost.

Tabl.1 **Matrix of indicators of private criteria for design solutions under different design conditions**

Solutions	Calculation conditions				
	1		*n*	…	*N*
1	*E*11		*E*1*n*	…	*E*1*N*
…	…		…	…	…
i	*Ei*1		*Ein*	…	*EiN*
…	…		…	…	…
I	*E II*1		*EIn*	…	*EIN*

Note. Ein is an indicator of a particular criterion.

Tabl.2. The risk matrix

Solutions	Calculation conditions				
	1	…	*n*	…	*N*
1	*r*11	…	*r*1*n*	…	*r*1*N*
…	…	…	…	…	…
i	*ri*1	…	*rin*	…	*riN*
…	…	…	…	…	…
I	*rI*1	…	*rIn*	…	*rIN*

Three variants of passenger traffic sizes havebeen adopted (n_{pasi} - the number of pairs of passengertrains,pairs of trains per day), as well as two variants of the passenger-hour cost ($e_{\text{pas-h}}$, conventional monetary units per train-hour):

n_{pas1} = 10 pcs.; n_{pas2} = 20 pcs.; n_{pas3} = 30 pcs.; $e_{\text{pas-h1}}$ = 3.3 nominal units (n. u.); $e_{\text{pas-h2}}$ = 6.6 nominal units.

Thus, N = 3 · 2 = 6 variants of calculation conditions are subject to analysis: $n_{pas1}e_{\text{pas-h 1}}$, $n_{pas1}e_{\text{pas-h2}}$, $n_{pas2}e_{\text{pas-h 1}}$, $n_{pas2}e_{\text{pas-h2}}$, $n_{pas3}e_{\text{pas-h 1}}$, $n_{pa3}e_{\text{pas-h2}}$.

At the same time, calculations of the criterion indicators in various design conditions are accepted for the following reconstruction options:

– extension of station railway tracks;

– construction of the III railway track;

– extension of station railway tracks in conjunction with of the III railway track.

After establishing a set of design conditions and assigning options for increasing the power of the line, we will form a matrix of indicators of the private criteria of the E_{in}.

As a criterion, the minimum sum of the reduced construction and operating costs and the cost of the time spent by passengers on the road for the estimated year of operation is taken.

The indicator of the efficiency criterion for the introduction of high-speed traffic includes the difference in operating costs caused by the reconstruction and replacement of rolling stock (±Ct).

The cost of the time spent by passengers on the road (C_{pas-h}) is determined taking into accountthe acceleration of traffic, n. u./year:

$$C_{pas-h} = 365\, p_{\text{pas}}\, m\, \alpha_{\text{stock}}\, (T' + T'')\, e_{pas-h},$$

where m – is the occupancy of the car, people; α_{stock}– is the reserve efficiency; T'+ T″ - is the time spent by passengers on the way in the directions "there" and "back", h.

The one-time costs included in the criterion indicator include capital investments for the reconstruction of the road (K_{rek}) and the purchase of rolling stock ($K_{p.s}$). The electric train was adopted, which has a tolerance of outstanding acceleration of a = 0.9 m/s^2.

The returnable cost is taken into account due to the release of used passenger cars and locomotives. The norm of the discont$E$ is taken to be equal to 0.1.

Of course, the comparison of options is accepted according to the criterion of the minimum of the above costs, which is not always equivalent according to operational and technological criteria. In such a situation, a multi-criteria cost comparison would be more logical. However, such an assumption makes it possible to further develop this research.

Based on these data, a risk matrix is obtained (Table. 3), showing the additional reduced costs (losses) in relation to the most rational solution in each of the calculation conditions. In each column of the matrix, the minimum value of min is found and the differences are calculated using the formula (2).

III. DECISION-MAKING METHODS

The calculation is made using mathematical methods that help the decision-maker to choose the best option.

Tabl.3. Matrix of indicators of private decision criteria under different design conditions

Design solutions	n_{pas1} = 10 pcs.; $e_{pas\text{-}h\ 1}$ = 3.3 nominal units	n_{pas1} = =10 pcs. $e_{pas\text{-}h\ 2}$ = 6.6 nominal units	n_{pas2} = 20 pcs. $e_{pas\text{-}h\ 1}$ = 3.3 nominal units	n_{pas2} = 20 pcs. $e_{pas\text{-}h\ 2}$ = 6.6 nominal units	n_{pas3} = 30 pcs$e_{pas\text{-}h\ 1}$ = 3.3 nominal units	n_{pas3} = 30 pcs$e_{pas\text{-}h\ 2}$ = 6.6 nominal units
extension of station railway tracks	0	0	4	0	0	4
construction of the III railway track;	1,3	16	6	1,3	16	6
extension of station railway tracks in conjunction with of the III railway track	0	28	10	0	28	10

Minimax criterion (MM-criterion, Wald criterion). This criterion uses an evaluation function corresponding to the position of extreme pessimism:

$$z_{MM} = \max_i e_{ir} = \max_i(\min_j e_{ij}), \qquad (3)$$

i.e. the set of optimal solutions E_0 is defined by the relation

$$E_0 = \left\{E_{io} \middle| E_{io} \in E \wedge e_{io} = \max_i(\min_j e_{ij})\right\}. \qquad (4)$$

The options chosen in this way are completely risk-free. However, this advantage comes at some cost. The use of MM criterion may be justified in the following situations:

- the possibility of occurrence of the states Fj not known;
- the solution is realised once or very very few times;
- It is necessary to exclude anyrisk must be eliminated.

Savage criterion (S-criterion, minimum risk criterion). The estimate function of the Savage criterion is as follows

$$z_S = \min_i e_{ir} = \min_i(\max_j(\max_i e_{ij} - e_{ij})), \qquad (5)$$

and the set of optimal solutions is constructed as follows:

$$E_0 = \left\{ E_{io} \middle| E_{io} \in E \wedge e_{io} = \min_i e_{ir} \right\}. \qquad (6)$$

The value

$$a_{ij} = \max_i e_{ij} - e_{ij}$$

is seen as additional gain, if instead of variant $E_i$in state F_j one chooses another, optimal for this state.

Conditions for application of Savage's criterion:

- the possibility of the occurrence of states $F_j$is not known;
- the decision is realized only once or very few times;
- an insignificant risk is admitted.

In addition to classical criteria, for decision-making under uncertainty and risk the augmented minimax criterion, product criterion(P-criterion), composite BL(MM)-criterion, derived Hodge-Lehman criterion (HL-criterion), Hurwitz (HW-criterion) and Herrmeier criterion (G-criterion) [5].

Product criterion (P-criterion)is used in decision making under conditions of uncertainty. It is a more neutral criterion compared to the maxim and gambler's criterion. The product criterion produces a kind of "alignment" between between large and small alues of E_{ij}:

$$\min_i \prod_{j=1}^{N} Э_{ij}. \qquad (7)$$

The Hodge-Lehman criterion introduces factor of a certain subjectivity in decision making. The ecision is made under the conditions of risk. However, the decision maker, the LPR, has a certain distrust of theprobability distributions of environmental states. Therefore, the decision-maker introduces some "confidence factor" l to the probabilities of environmental states (j = 0) / (j = 1). In order not to take much risk, this coefficient is usually assumed to be 0.4. This coefficient is also called the level of optimism.

Ai is a measure of the effectiveness of a strategy according to is calculated using the formula

$$\min_i \left[\nu \sum_{j=1}^{n} p_j e_{i,j} + (1-\nu) \max_j e_{i,j} \right]. \qquad (8)$$

The Hurwitz criterion is that defines a measure of strategy effectiveness in which the decision lies somewhere between the points of view of extreme optimism (gambler's criterion) and extreme pessimism (maximin's criterion). To do this a coefficient l - the level of pessimism - is introduced. The choice of the level of pessimism is a subjective process. Most often it is selected as being equal to 0,6 or 0,5. After this, the indicator of strategy efficiency $A_i$according to theHurwitz criterion is calculated by the formula

$$\min_i \left[\lambda \max_j e_{i,j} + (1-\lambda) \min_j e_{i,j} \right]. \qquad (9)$$

Germain's criterion is used mainly for solving optimization problems of the value of losses or costs. The loss matrix given in the condition will contain negative elements (losses are expressed by negative values)

$$\min_i \max_i p_j e_{i,j}, \qquad (10)$$

where $p_j$are probabilities of external states F_j(j = 1, 2, ..., n).

Having calculated the risk matrix for each criterion, we have a summary table with value of losses for each of them(tabl. 4).

Tabl.4. Risk matrix according to different criteriaitions

Design solutions	**MM-criterion**	**S-criterion**	**P-criterion**	**Hodge-Lehman**	**Hurwitz**	**Germain's**
extension of station railway tracks	2,63	**0,04**	**0,04E+13**	**2,2**	1,73	**-0,7**

construction of the III railway track;	2,61	0,15	0,5E+13	2,23	1,76	-0,68
extension of station railway tracks in conjunction with of the III railway track	**2,59**	0,28	0,6E+13	2,25	1,79	-0,53

IV. CONCLUSION

Thus, the Savage, Hodge-Lehmann, Gurwitz, Germeier and product criteria recommend as an optimal solution for the reconstruction of a railway for high-speed of passenger trains to increase its capacity at the expense of extension of station railway tracks, which will increase the weight norm and reduce the required number of goods trains.

According to the Wald criterion, the best solution should be recommendextension of station railway tracks in conjunction with of the III railway track. This would increase possible line capacity and reduce the number of goods trains required.

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