Methodology for economic substantiation of assessment of the integrated use of organizational and technological solutions for land allocation for road and bridge construction

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Abstract. Background: Nowadays, the high dynamics of transport support for economic, military, socio-demographic and environmental security in a market economy require new approaches to the development of methods for allocating land for road and bridge construction. The problems of economic and military-economic justification for decisions in the field of integrated use of the country's unified transport system are especially acute. Methods: Studies have been carried out on the development of the concept of an integrated transport system of rational correlation of general transport infrastructure using general scientific methods - system analysis, logical and mathematical modeling, systems theory, as well as methods of operations research and economic and mathematical methods, economic-visual modeling, research methods of operations. Results: The necessity of reducing the problem of efficiency criteria and limitations to a system-target model based on the structure hierarchy of the transport system and the corresponding modeling of the reconstructed system of transport support goals is substantiated. The elemental base of land allocation for road and bridge construction at the construction site has been formed. The value of a land plot is determined using a specific example of calculating the value of a land plot for the construction of a 10-kilometer highway. Conclusion: The method of substantiating the economic efficiency of the calculation in the selection and justification of the optimal technology for land allocation for road and bridge construction is considered. Control tasks for calculating the value of a land plot for the construction of a highway are presented.

1 Introduction

The earth is the basis of the biosphere and is its main wealth. The soil cover of the earth determines all forms of flora and fauna. It serves as an accumulator and distributor of energy that has passed through plant photosynthesis, retaining the most important elements - carbon, nitrogen, phosphorus, potassium, calcium, sulfur, etc. The soil cover is involved in the formation of the hydrological regime of the land and significantly determines the balance of fresh water.

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The process of soil formation proceeds at a rate of 0.5–2 cm per century. With a natural vegetation cover, nature takes from 2 to 8.5 thousand years to form an arable layer with a thickness of 18-25 cm. Soil reserves on earth are about 2.4·10^{12} tons, and conditions for soil formation exist only on 22% of the earth's surface. The land balance of our planet is 14.9 billion hectares. Of these, 4.6 billion hectares (28%) are forests, 2.6 billion hectares (17%) are meadows and pastures, 1.4 billion hectares (10%) are cultivated land (arable land, gardens, etc.). The second half of the land is deserts, semi-deserts, glaciers, mountains, eternal snows, cities, villages, industrial enterprises, land communications, and so on. The earth is the source of human well-being. However, it is not bottomless and must be used with extreme care. For saving time and effective development of society, one has to pay with the withdrawal of land from agricultural production, i.e., reduction in national wealth. The negative impact of road and bridge construction on the environment begins with the allocation of land. The area occupied by roads and bridges is constantly increasing. In a number of European countries, the road network is 0.5 km/km². Therefore, the choice of the optimal option for building roads and bridges is especially important.

2 Methods

General scientific methods of system analysis, logical-mathematical modeling, systems theory, as well as methods of operations research and economic-mathematical methods, economic-visual modeling, research methods of operations were used. The recommended professional approach allows carrying out the construction of roads according to the approved design documentation agreed with the construction participants, which has passed the examination, and accepted by the customer - the developer of the facility [1-5].

An analysis of the economic aspects of the problem of choosing and substantiating the optimal technology for land allocation for road and bridge construction shows the insufficiency of work devoted to studying the problem (regarding individual private parties) of the efficiency of using an integrated road transport system. There is a need to create a modern scientific and methodological base for assessing organizational and technological solutions for land allocation for road and bridge construction at the level of model indicators of the road transport system. The methodological basis of the study is the analysis of the current system of the regulatory framework in the Russian Federation.

3 Results

Land allocation for road and bridge construction. In the general problem of environmental protection, the issue of the land preservation seems to be more relevant than the issues of atmospheric gas pollution or the reduction of traffic noise. Land allocation for the construction of highways is regulated by the norms of land allocation for highways [5-10].

CN 467 – 74 (M.: Stroyizdat, 1976 – P. 55 – 71). The width of the right of way and the size of land plots for roads for permanent and temporary use are set depending on the category of roads, the number of lanes, the height of embankments or the depth of excavations, and other conditions (Table 1). In general, when selecting, allocating and using land for roads, it is necessary to comply with regulations, primarily the “Basic Provisions for the Restoration of Lands Disturbed during the Development of Mineral Deposits, Geological Exploration, Construction and Other Works”.
Table 1. Average values of land allocation areas, in ha, for the construction of 1 km of the road (temporary and access road)

<table>
<thead>
<tr>
<th>Road category</th>
<th>Number of lanes</th>
<th>On agricultural land</th>
<th>On lands unsuitable for agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Permanent allocation (Fp)</td>
<td>Temporary allocation (Ft)</td>
<td>Permanent allocation (Fp)</td>
</tr>
<tr>
<td>I</td>
<td>8</td>
<td>6.3</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>5.5</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4.7</td>
<td>1.6</td>
</tr>
<tr>
<td>II</td>
<td>2</td>
<td>3.1</td>
<td>1.4</td>
</tr>
<tr>
<td>III</td>
<td>2</td>
<td>2.6</td>
<td>1.3</td>
</tr>
<tr>
<td>IV</td>
<td>2</td>
<td>2.4</td>
<td>1.3</td>
</tr>
<tr>
<td>V</td>
<td>1</td>
<td>2.1</td>
<td>1.2</td>
</tr>
</tbody>
</table>

When comparing options for building roads, the difference in the cost and productivity of the occupied land should be taken into account. And in cases where the planned roads continue in straight directions, costs to bring the land occupied by existing roads into a condition suitable for agricultural use should also be taken into account (SNiP 11-D 5.72, p.4). To solve the problem of determining the value of a land plot, an economic assessment of 1 hectare of allocated land is required, depending on its quality. Damage from land allocation is taken into account as a lost part of income, taking into account the time factor. These losses can be estimated by the value of gross output (W) obtained from 1 hectare of land. The amount transferred to the national income is equal to \( \alpha \cdot W \text{ rub/ha} \). This value expresses the annual value \( Z \) of hectare of agricultural land.

\[
Z = \alpha \cdot W \tag{1}
\]

Where \( \alpha \) – a complex variable coefficient that takes into account the type of agricultural products, material costs, wages, etc.

The value of gross output is determined by:

\[
W = G \cdot C \tag{2}
\]

\( G \) – the amount of gross output obtained from 1 ha, t/ha:
\( C \) – cost of 1 ton of products, rub/t.

Over time, the value of land changes, and in some year can be determined as follows:

\[
Z_i = Z_0 \left( 1 + K b_i \right) \tag{3}
\]

Where \( Z_0 \) – annual value of land in the year of land withdrawal for construction:
\( b_i \) – average annual increase in agricultural production for the future in\%;
\( K \) – coefficient taking into account the intensification of production; \( K = 1-1.4 \).

Since land allocation for road construction can be permanent or temporary, losses should be calculated for the relevant period. The total losses resulting from the withdrawal of 1 ha of land from agricultural production for \( n \) years are:

\[
\bar{Z} = Z_0 \sum_{i=1}^{n} \frac{1+K b_i}{(1+i_p)^i} \tag{4}
\]
Where $I_e$ – land use efficiency ratio.

The formula (2) is proposed to determine $I_e$.

$$I_e = \frac{\alpha \cdot Kb_i}{(1 - \beta)}.$$ (5)

Where:

$$\beta = \frac{y}{W}.$$ (6)

$y$ – net income, rub/ha.

The value of $I_e$ depends on the land quality, the rate of intensification of agricultural production, the level of material costs, and so on.

Table 2 presents indicative values of indicators characterizing the efficiency of agricultural land use.

<table>
<thead>
<tr>
<th>Land value</th>
<th>$\alpha$</th>
<th>$Kb_i$</th>
<th>$1 - \beta$</th>
<th>$I_e$</th>
<th>$\psi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valuable (irrigated)</td>
<td>0.6</td>
<td>0.06</td>
<td>0.70</td>
<td>0.05</td>
<td>44</td>
</tr>
<tr>
<td>Medium (systematically fertilized)</td>
<td>0.80</td>
<td>0.08</td>
<td>0.80</td>
<td>0.08</td>
<td>25</td>
</tr>
<tr>
<td>Low value</td>
<td>0.9</td>
<td>0.1</td>
<td>0.90</td>
<td>0.1</td>
<td>20</td>
</tr>
</tbody>
</table>

With constant allocation of land, i.e., at $n \to \infty$, the average value of 1 hectare of land will be

$$Z_p = Z_0 \psi$$ (7)

In case of temporary allocation of land ($n$ less than 3 years), the average value of 1 hectare of land is determined by the formula

$$Z_t = Z_0 \cdot n + \Delta$$ (8)

where $\Delta$ - cost of reclamation of 1 hectare of land, rub/ha.

The cost of reclamation of 1 hectare of land, based on the experience of building roads, is 50-90 thousand rubles (at current prices). The value of a plot of land permanently allocated for the construction of m kilometers of a highway is

$$Z_{p,m} = m \cdot F_n \cdot Z_0 \cdot \psi$$ (9)

$F$ – area of permanently allocated land per 1 km of road construction, ha.

With temporary allocation, the value of a land plot during the construction of $m$ kilometers of road will be

$$Z_{t,m} = m \cdot F_t (Z_0 \cdot n + \Delta)$$ (10)

$F_t$ – area of temporarily allocated land per 1 km of road construction, ha.

If during the construction of the road both permanent and temporary allocation of land takes place, then the total value in rubles of the allocated land during the construction of $m$ kilometers of the road will be
If the annual value of 1 hectare of land in the year of withdrawal is $Z_0$, the number of lanes, the cross-slope of the road, and the cost of reclamation do not remain constant, we divide the road into sections where similar parameters are maintained. For each of the participants, the cost of allocated land is calculated, and then losses are determined as a result of the construction of the entire highway.

**4 Discussion**

These calculations (using the example of the presented calculation of the value of a land plot for the construction of a 10 km road) should be carried out at the stage of long-term planning for the development of road networks, when measures to protect the surrounding land through the rational use of land, water and forest resources can be most effectively taken into account [11-15].

Initial data:
- road category - 1st;
- number of traffic lanes - 4;
- cross slope of the road $i_{cr}$ - 1:20;
- land value - average (systematically fertilized);
- purpose of land - agricultural purpose;
- crop grown on the lands - wheat;
- the amount of gross output (yield) from 1 hectare of land - 25 q/ha = 2.5 t/ha;
- cost of 1 ton of wheat is 15,000 rub/ha.

**Calculation:**

1. We determine the cost of gross output obtained from 1 hectare of land:

$$W = G \cdot C.$$  

Where $G$ – amount of gross output, t/ha;  
$C$ - cost of 1 ton of products, rub/t;  
$W = 2.5 \cdot 15,000 = 37,500$ rub/ha;  
$W = 37,500$ rub/ha;

2. Annual value of 1 hectare of land in the year of its withdrawal for construction

$$Z_0 = \alpha \cdot W.$$  

According to Table 2, the complex variable coefficient, taking into account the type of agricultural products, for medium-sized lands is 0.8, i.e., $\square = 0.8$.  
$z_0 = 0.8 \cdot 37500 = 30,000$ rub/ha;  
$z_0 = 30,000$ rub/ha;

3. According to Table 1, we determine the areas of permanent (Fp) and temporary (Ft) land allocation in ha for the construction of a 1 km road on agricultural land, the cross-slope of the road is 1:20, the 1st category road with 4 lanes:

$Fp = 4.7$ ha;  
$Ft = 1.6$ ha.

4. We determine the average value of 1 hectare of land with permanent allocation of farmland.

$$Z_p = Z_0 \cdot \psi;$$  

According to Table 2, for medium lands (systematically fertilized), coefficient of permanent land allocation $\psi$ is 25.
Then \( Z_p = 30,000 \cdot 25 = 750,000 \) rub/ha;
\( Z_p = 750,000 \) rub/ha.

5. The value of a land plot permanently allocated for the construction of a 10 km road will be

\[ Z_{p,10} = 10 \cdot F_p \cdot Z_p = 10 \cdot 4.7 \cdot 750,000 = 35,250,000 \text{ rub}; \]
\[ Z_{p,10} = 35,250,000 \text{ rub}. \]

6. We determine the average value of 1 hectare of land during its temporary allocation:

\[ Z_t = Z_0 \cdot n + \Delta, \]
\( n \) - taken as 2.8 years, and \( \Delta \cdot 50,000 \) rub/ha;
\( Z_t = 30,000 \cdot 2.8 + 50,000 = 134,000 \text{ rub/ha}; \)
\( Z_t = 134,000 \text{ rub/ha}; \)

7. The value of a land plot temporarily allocated for the construction of a 10 km road will be

\[ Z_{t,10} = 10 \cdot F_t \cdot Z_t; \]
\( Z_{t,10} = 10 \cdot 1.6 \cdot 134,000 = 2,144,000 \text{ rub}; \)
\( Z_{t,10} = 2,144,000 \text{ rub}; \)

8. Total value (losses as a result of construction) of land allocated for permanent and temporary use during the construction of 10 km of the road

\( Z_{tot,10} = Z_{p,10} + Z_{t,10}; \)
\( Z_{tot,10} = 35,250,000 \text{ rub} + 2,144,000 \text{ rub} = 37,394,000 \text{ rub}; \)
\( Z_{tot,10} = 37,394,000 \text{ rub}. \)

The proposed methodology for economic substantiation for assessing the effectiveness of land allocation for road and bridge construction for the integrated use of transport in the interests of ensuring the economic, military and socio-demographic security of the state allows improving the elemental basis for planning and implementing measures to ensure continuous traffic on the transport and communications networks of the constituent entities of the Russian Federation and the country as a whole, reducing the economic, military and socio-demographic security of the state.

5 Conclusion

What is the importance of soil cover for life on earth? What is the land balance of our planet? Why did the problem of environmental protection arise when land was allocated for road and bridge construction? What factors determine the width of the right of way and the size of land plots allocated for construction? How is the annual value of a hectare of farmland determined? How to determine the value of land over time?

In the theory of the efficiency of any system, one of the main problems is modeling the criteria for efficiency. With regard to the assessment of organizational and technological solutions for land allocation for road and bridge construction, it is recommended to use three concepts: performance indicators, performance criteria and limitations[16-20]. Such a gradation of indicators will provide the opportunity to:
to form, with the help of limitations, a lot of competitive options in the choice and justification of the optimal technology for land allocation for road and bridge construction;

choose the most effective of them using the criteria.

Performance indicators are recommended to be divided into three groups:

indicators reflecting the expected results (the pace and volume of road transport work; the timing of transportation; indicators of the sustainability of transport, the solution of social problems of the population);

estimated costs (cost of operation of road transport communications and vehicles; costs of material, technical and labor resources);

time to complete tasks.

Approximate tasks for calculating the value of a land plot for the construction of a highway are presented in Table 3.

### Table 3. Approximate tasks of calculating the value of a land plot

<table>
<thead>
<tr>
<th>Name of indicators</th>
<th>Options</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Initial data</td>
<td></td>
</tr>
<tr>
<td>Length of the road section under construction (m), km</td>
<td>5</td>
</tr>
<tr>
<td>Land availability</td>
<td>agricultural purposes</td>
</tr>
<tr>
<td>Road category</td>
<td>I</td>
</tr>
<tr>
<td>Number of lanes</td>
<td>6</td>
</tr>
<tr>
<td>Cross slope of the road ($i_c$)</td>
<td>1:10</td>
</tr>
<tr>
<td>Land value</td>
<td>valuable</td>
</tr>
<tr>
<td>Crops grown (produced) on lands</td>
<td>potatoes</td>
</tr>
<tr>
<td>Productivity of 1 hectare of land (G), t</td>
<td>4.5</td>
</tr>
<tr>
<td>Cost of 1 ton of agricultural</td>
<td>use market prices for agricultural products</td>
</tr>
<tr>
<td>Product, rub/t</td>
<td>Cost of reclamation of 1 hectare of land, thousand rubles/ha</td>
</tr>
<tr>
<td>----------------</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>98.0</td>
</tr>
</tbody>
</table>

| Number of years of temporary land acquisition n, years | 2.4 | 1.8 | 1.5 | 1.6 | 1.2 | 0.9 |

6 Designations

\( Z \) – annual value of a hectare of green land, rub./ha., \( Z_i \) – value of a hectare of land in the i-th year, rub./ha., \( Z_0 \) – annual value of land in the year of land allocation for construction, rub./ha., \( Z_p \) – average value of 1 hectare of land with constant allocation, rub./ha., \( Z_t \) – average value of 1 hectare of land in case of temporary allocation, rub./ha., \( Z_{p,m} \) – value of a land plot permanently allocated for the construction of m km of a road, rub., \( Z_{t,m} \) – value of a land plot temporarily allocated for the construction of m km of a road, rub., \( Z_{tot,m} \) – total value of land allocated for permanent and temporary use during the construction of m kilometers of road, rub., \( v_j \) – average annual increase in agricultural production for the future, \( % \), \( K \) – coefficient taking into account the intensification of production in the given area, \( I_e \) – land use efficiency ratio, \( Y \) – net income, rub./ha., \( \beta \) – ratio of net income to the value of gross output., \( \Psi \) – coefficient of permanent land allocation, \( n \) – number of years, \( m \) – length of the road section under construction in km., \( \Delta \) - cost of reclamation of 1 hectare of land, rub./ha., \( i_{cr} \) – cross slope of the road., \( F_p \) – area of permanently allocated land per 1 km of road construction., \( F_t \) – area of temporarily allocated land per 1 km of road construction.

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