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A Linear Model of The Forest Transport Network And An Algorithm For Assessing The Influence of The Density of Points And The Length of Links In Developing Multi-Forested Areas

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Abstract **-** *The analytical model of a transport network is inadequate for real networks because, due to the limited number of variables, it cannot consider the diversity and complexity of the natural and industrial conditions in which they exist. Therefore, there is a need to develop a new model. Its goal is the complete accounting of parameters and presenting the timber-hauling network in a form adequate to real networks in terms of structure and configuration. Locating the transport network in the forest area is influenced by factors, such as terrain, soil and ground conditions, the configuration of the raw material base, the total stock of merchantable wood and its distribution over the area, the type of logging transport, the type of logging rolling-stock, the location of the branching off point, the road turnover, and the volumes of summer and winter haulage. Under such variable conditions, it is required to find an oriented graph of the tree type with a base at the point of the lower warehouse that satisfies the minimum amount of road transport costs. Consideration of all these variables should be reflected in the model. The estimation of the influence of the parameters is based on their consideration in known models. The purpose of the work is to develop a linear model of the timber-hauling transport network and an algorithm for assessing the impact of the density of points and the length of connections to solve a set of problems arising in the development of richly wooded areas.*

Keywords - *logging road, design, transport network, linear model, estimation algorithm.*

I. INTRODUCTION

The terrain, as well as ground and soil conditions, affect the cost of the roadbed, pavement, and artificial structures. Therefore, the input of this data into the linear model of the timber-hauling transport network is necessary. Raw material bases have, as a rule, irregular geometric shapes that affect the placement of the network.

The distribution of the stock over the area is a variable value. There are plots without a reserve. The characteristics of the logging rolling-stock influence the transportation component of the traffic cost, which is included in the model explicitly.

Thus, the model should consider the influence of terrain, ground, and soil conditions, the configuration of the raw material base, the stock of wood in the planning quarters, and the type of rolling stock.

II. METHODS

The linear model of the timber-hauling transport network is based on the transport problem. In the classical transport problem, transportation is carried out from points of production only to points of consumption. Forest transportation to the point of consumption occurs through intermediate points. Therefore, the linear model uses a transport problem with transportation through intermediate points [1], [2].

In the network nodes, the material balance equation must be observed, which is expressed in the fact that for each point, import plus production should be equal to export plus consumption.

$$\sum_{i\neq j} x_{ij} + q_{ij} = \sum_{k\neq j} x_{jk} + в_j \qquad (1)$$

For nodes corresponding to forest reserve centers in planning quarters $в_j = 0$, and the material balance equation takes the form:

$$\sum_{i\neq j} x_{ij} + q_{ij} = \sum_{k\neq j} x_{jk} \qquad (2)$$

For the node corresponding to the point of the lower warehouse q_j =0, $\sum x_{jk} = 0$ *A* nd the equation of the material balance will take the form:

$$\sum_{i\neq j} x_{ij} = в_j \qquad (3)$$

The problem of constructing an optimal transport network can be formulated as follows: there are several points 1, 2, 3 ...i...n on the plane with coordinates x_i, y_i. Each point concentrates the stock (production) of wood q_i (or consumption at the point of the lower warehouse). It is necessary to determine the volume of transportation $x_{ij}$and connect the points of timber reserves with the lower warehouse, consuming wood, by the transport network in such a way that, while observing the equation of material balance

$$\sum_{i\neq j} x_{ij} + q_{ij} = \sum_{k\neq j} x_{jk} + в_j \qquad (4)$$

to minimize the amount of road transport costs.

$$Z=\sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}x_{ij} \quad (5)$$

Specific road transport cost c_{ij} It is a function of many variables, namely, the volume of traffic, the distance of transportation, terrain, ground and soil conditions, the cost of road construction and its maintenance, the cost of freight works, and the service life of the road section.

$$c_{ij} = f(x_{ij}, l_{ij}, z_{ij}, g_{ij}, k_{ij}, s_{ij}, \text{T}_{ij}, t_{ij}) \quad (6)$$

The value of c_{ij} is strongly influenced by the volume of transportation x_{ij} . Depending on the volume of transportation, road sections are divided into spurs, branches, and highways [3], [4].

If $x_{ij} \le Q_y$, then the variables take values peculiar to the spurs $T_{ijy}, t_{ijy}, S_{ijy}, K_{iy}(r_i g_i), K_{jy}(r_j g_j)$.

If $Q_y < x_{ij} \le Q_{\text{в}}$, then the values are applied for the branches $T_{ij\text{в}}, t_{ij\text{в}}, S_{ij\text{в}}, K_{i\text{в}}(r_i g_i), K_{j\text{в}}(r_j g_j)$.

If $x_{ij} > Q_{\text{в}}$then the variables take values characteristic of the highways $T_{ij\text{м}}, t_{ij\text{м}}, S_{ij\text{м}}, K_{i\text{м}}(r_i g_i), K_{j\text{м}}(r_j g_j)$.

C_{ij} can be expressed by the following formula:

$$\text{C}_{ij} = \eta_{ij} l_{ij}[s_{ij}t_{ij}(x_{ij}) + T_{ij}(x_{ij}) + K_{ij}(r_i g_i r_j g_j x_{ij}) \quad (7)$$

Expressing l_{ij} in terms of coordinates and indicating the dependence of the costs of maintaining roads and their construction on the volume of transportation, we can write

$$\text{C}_{ij} = \eta_{ij}(x_{ij})|\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}|.[\frac{s_{ij}t_{ij}}{x_{ij}} + T_{ij}(x_{ij}) + \frac{K_i(r_i g_i x_{ij}) + K_j(r_j g_j x_{ij})}{2x_{ij}}] \quad (8)$$

As can be seen from formula (8) C_{ij} and x_{ij} They are connected by a nonlinear dependence, and the transport network model turns out to be nonlinear. But because the methods of machine implementation of nonlinear programming problems are insufficiently developed, the nonlinear model is simplified and approximately solved by the method of linear programming [5]-[7].

The linear model reflects proportional dependencies. For a strictly linear model, the following condition must be met C_{ij}=Const.

Since C_{ij}depends on x_{ij}Non-linearly, the problem has to be solved in several stages. Initially, the quantities of C_{ij}They are given large values, i.e., corresponding to the characteristics of the spurs. Further, the values of C_{ij}They are calculated based on the volumes obtained at the previous stages. The values of C_{ij} Decrease from stage to stage. Thus, the step-by-step solution leads to the fact that the nonlinear function C_{ij}=f (x_{ij}) is approximated by a piecewise linear function at each stage.

The mathematical model of the network takes the following form:

Provided that

$$\sum_{i \ne j} x_{ij} + g_j = \sum_{k \ne j} x_{jk} + \text{в}_j \quad (9)$$

It is necessary to find

$$\min Z=\sum_{i=1}^{n}\sum_{j=1}^{n} \text{C}_{ij}\, x_{ij} \quad (10)$$

Under constraints, $x_{ij} \le Q_y, \text{то}\text{C}_{ijy}$,

If $Q_y < x_{ij} \le Q_{\text{в}}$, then$\text{C}_{ij\text{в}}$, $Q_{\text{в}} < x_{ij} \le Q_{\text{м}}$, then$\text{C}_{ij\text{м}}$.

The idea of using a linear model to study the optimum transport networks belongs to V.N. Livshits [8]-[10].

In relation to the logging transport networks, a linear model was proposed by G.A. Borisov [11], [12].

Employing constant and variable information entered for the meaningful solution of the linear model, the latter allows considering the features of the forest resource base of logging enterprises, such as terrain, ground and soil conditions, and consequently a variety of construction and transport costs, as well as the variable value of wood stocks in planning quarters, and the irregular shape of the forest resource base [13], [14].

Besides the problem of tracing a transport network in a forest area, the linear model allows solving problems of transport design, such as choosing the road branching off point, type of transport, and the pavement. Using a linear model, it is possible to solve a range of problems arising in the course of developing richly wooded areas.

To assess the effect of the density of the location of points on the configuration, structure, and total road transport costs, studies of the linear model of the transport network were carried out.

Four variants of the problem were considered: with one, two, three, and four points in a planning quarter 2 by 4 km in area, respectively, with a total number of points equal to 75, 152, 120, and 168 [15]-[17].

The formulation of the problem for all four variants was identical:

Find

$$\min Z=\sum_{i=1}^{n}\sum_{j=1}^{n} \text{C}_{ij}\, x_{ij} \quad (11)$$

under restrictions, if

$$x_{ij} \le Q_y, \text{то}\text{C}_{ijy} = \left(\frac{\text{К}_\text{у}}{x_{ij}} + \text{Т}_\text{у}\right) l_{ij}, \quad (12)$$

$$Q_y < x_{ij} \le Q_{\text{в}}, \text{то}\text{C}_{ij\text{в}} = \left(\frac{\text{К}_\text{в}}{x_{ij}} + \text{Т}_\text{в}\right) l_{ij}, \quad (13)$$

$$x_{ij} > Q_{\text{в}}, \text{то}\text{C}_{ij\text{м}} = \left(\frac{\text{К}_\text{м}}{x_{ij}} + \text{Т}_\text{м}\right) l_{ij}. \quad (14)$$

Numerical values obtained from the data of enterprises of the Komi Republic were taken as

$$\text{if } x_{ij} \le 280 \text{ thousand m}^3, \text{then}\text{C}_{ijy} = \left(\frac{2000}{x_{ij}} + 0.0685\right) l_{ij}, (15)$$

$$\text{if 280 thousand m}^3 < x_{ij} \le 2060 \text{ thousand m}^3, \text{then}\text{C}_{ij\text{в}} = \left(\frac{14767}{x_{ij}} + 0{,}0226\right) l_{ij}, (16)$$

$$\text{if } x_{ij} > 2060 \text{ thousand m}^3, \text{then}\text{C}_{ij\text{м}} = \left(\frac{28685}{x_{ij}} + 0.0158\right) l_{ij} (17)$$

All four variants of the problem were solved with a constant volume of transportation from the raw material base. Values of the objective function for each stage of the solution are given in the Table. Since there were planning quarters of various sizes in the raw material base, they were normalized, i.e., divided into smaller but approximately equal-sized quarters.

TABLE I
THE OBJECTIVE FUNCTION VALUES FOR EACH STAGE OF THE SOLUTION

T		Number of planning quarters (normalized)	Total timber reserve, thousand m^3	Stage number	Value of objective function, thousand rubles	Normalized values of the objective function
In the planning quarters	Total					
1	75	76	5,466	1	13,990	3,483
				2	5,295	
				3	4,418	
				4	4,408	
2	152	76	5,466	1	11,536	3,648
				2	4,898	
				3	4,770	
				4	4,712	
				5	4,730	
				6	4,692	
				7	4,656	
				8	4,620	
				9	4,645	
				10	4,613	
				11	4,604	
3	120	42	5,466	1	9,839	3,659
				2	3,848	
				3	3,687	
				4	3,641	
4	168	42	5,466	1	11,782	3,675
				2	3,944	
				3	3,913	
				4	3,903	

The number of normalized quarters in the first two variants is 76. In order not to increase the size of the matrix by increasing the number of points, the last two tasks were considered on a smaller area of the raw material base.

The number of normalized quarters in the base was reduced to 42, while the total stock remained unchanged. This was achieved by preserving the reserves of the reduced area at the entrance to the remaining area of the base.

Due to the change in the base area, the values of the objective functions for the first two variants are reduced to comparable conditions. The reduced values are obtained as the difference between the value of the objective function and the costs of construction and transport to the boundaries of the reduced zone [18], [19].

Using the table data, we get that the unit costs increase to 12% with an increase in the number of points.

The final solution of the transport network for each option was mapped on the raw material base and used to calculate technical and economic indexes of the network within the boundaries of the 42 planning quarters.

Due to the greater degree of detailing of the arrangement of tracks, the increase in the number of inventory centers in the quarter increases the total length of roads and total costs up to 11%.

An increase in the number of stock centers leads to an increase in the length of lower category roads. The position of the highway changes slightly. Based on the analysis of the network structure and its configuration, we recommend assigning one reserve center within quarters of 2x4 km in size when designing the highway network and branches.

To assess the effect of the length of the connections, three types of tasks were considered: connections were established from the exit point with neighboring points, located within a radius of 3, 5, or 10 km. Connections were assigned depending on the set radius. For example, if the radius was 3 km, then connections were established with all points only within a radius of 3 km, while the rest connections were discarded.

The assignment of the minimum radius depended on the distance between the points. Its value was chosen such that the nearest point was connected to eight neighboring points.

Increasing the length of the connections almost does not change the value of the objective function. In qualitative terms, an increase in the length of the connections leads to a deterioration of the configuration and leads to the formation of nodes; the joining of connections occurs at very sharp angles.

III. CONCLUSION

One of the important issues of timber transportation is the correct determination of the qualitative composition of timber-hauling transport routes in raw material bases.

The exploited woodlands represent a cargo-generating area. Therefore, a gradual increase in the flow of timber cargo is characteristic of timber transportation roads. Considering this specificity of timber transportation, the optimal composition of the timber-hauling transport network should be qualitatively different as their load capacity increases, as well as their validity period.

The solution to the problem under consideration of establishing the qualitative composition of timber-hauling transport network can be obtained undertaking the several measures:

a) preserving the differentiation of the main types of transport routes using the stronger pavement on the roads of the first stage (on the spurs);

b) excluding from the network ground spurs and providing the transportation of timber along trunk lines directly to the logging road branches.

Each of the above-noted measures aimed at solving the problem of timber transportation under certain conditions may be appropriate, but all of them, in principle, should be tested in the work environment.

REFERENCES

[1] D.L.Drew, Traffic flow theory, and control, McGraw Hill, (1964).

[2] V.G.Kozlov, V.A.Gulevsky, A.V.Skrypnikov, V.S.Logoyda, and A.S. Menzhulova, Method of individual forecasting of technical state of logging machines, IOP Conference Series: Materials Science and Engineering, 327(4) (2018) 042–056. DOI: 10.1088/1757-899X/327/4/042056

[3] E.V. Chernyshova, Algoritmresheniyazadachi optimal'nogotrassirovaniyalesovoznoiavtomobil'noidorogi na neodnorodnoimestnosti [Solution algorithm of the problem of the optimum location of wood transportation road on composite terrain], Vestnik VGUIT, 79 2 (72) (2017) 113–120.

[4] V.V.Sil'yanov, and Yu.M. Sitnikov, Raschetskorosteidvizheniyapriproektirovaniiavtomobil'nykhdorog [Prediction of traffic velocities upon designing of motor roads], MADI, 72 (1974) 47–66.

[5] E.V. Chernyshova, Metodyformirovaniyatsifrovoimodelimestnostipritrassirovaniileso voznykhavtomobil'nykhdorog [Formation of digital model of terrain upon location of wood transportation roads],Sistemy. Metody. Tekhnologii, 3(35) (2017) 143–148.

[6] V.G.Kozlov, A.V.Skrypnikov, E.V.Chernyshova, E.V.Chirkov, S.A.Postavnichii, and R.V. Mogutnov, Teoreticheskieosnovyimetodymatematicheskogomodelirovaniyale sovoznykhavtomobil'nykhdorog [Theoretical foundations and methods of mathematical simulation of wood transportation roads],IVUZ Lesnoizhurnal, 6(366) (2018) 117–127.

[7] V.A.Gulevskii, A.V.Skrypnikov, V.G.Kozlov, D.V.Lomakin, and E.Yu. Mikova, Eksperimental'nayaotsenkastsepnykhkachestvirovnostipokrytiiprir azlichnykhsostoyaniyakhavtomobil'nykhdorogipogodnykhusloviy akh [Experimental estimation of coupling properties and coating flatness upon various states of motor roads and weather conditions], Vestnik Voronezhskogogo sudarst vennogo agrarnogo universiteta, 11 1(56) (2018) 112–118.

[8] A.V.Skrypnikov, S.V.Dorokhin, V.G.Kozlov, and E.V. Chernyshova, Mathematical model of statistical identification of car transport informational provision, Journal of Engineering and Applied Sciences, 12(2) (2017) 511–515.

[9] Ya.A.Kaluzhskii, I.V.Begma, V.M.Kislyakov, and V.V. Filippov, Primenenieteoriimassovogoobsluzhivaniya v proektirovaniiavtomobil'nykhdorog [Theory of queuing in the design of motor roads], Moscow: Transport, (1969).

[10] A.V.Skrypnikov, V.G.Kozlov, D.V.Lomakin, and E.Yu. Mikova, Otsenkavliyaniya na skorost' dvizheniya post oyanny khparametrov plana iprofilyaprirazlichnykhsostoyaniyakhpoverkhnostidorogi [Traffic velocity as a function of layout and profile upon various states of road surface],Forestry Bulletin, 21(6) (2017) 43–49. DOI: 10.18698/2542-1468-2017-6-43-49

[11] Ya.V. Khomyak, Proektirovanieseteiavtomobil'nykhdorog [Designing of motor road networks], Moscow: Transport, (1983).

[12] V.G. Kozlov, Methods, models, and design algorithms of wood transportation roads with consideration for the influence of climate and weather on traffic conditions,Ph.D. Thesis. Arkhangel'sk: SAFU, (2017).

[13] A.I.Zavrazhnov, A.N.Belyaev, V.A.Zelikov, P.V.Tikhomirov, and N.V. Mikheev, Designing mathematical models of geometric and technical parameters for modern road-building machines versus the main parameter of the system, In Proc. Int. Symp. «Engineering and Earth Sciences: Applied and Fundamental Research» Atlantis Highlights in Material Sciences and Technology, dedicated to the 85-th anniversary of H.I. Ibragimov ISEES (2019) 823–827.

[14] O. Berestnev, Y. Soliterman, and A. Goman, Development of scientific bases of forecasting and improving the reliability of mechanisms and machines – One of the Key Problems of Engineering Science, In Proc. Int. Symp. on History of Machines and Mechanisms, 325–332 (2000).

[15] V.N.Ivanov, V.N. Erokhov, Vliyanieparametrovavtomobil'nykhdorog na raskhodtopliva [The influence of motor road parameters on fuel consumption], Avtomobil'nyedorogi, 8 (2014) 10–13.

[16] A.K. Birulya, Ekspluatatsiyaavtomobil'nykhdorog[Motor road maintenance], Moscow:Transport, (1966).

[17] V.G.Kozlov, A.V.Skrypnikov, E.Yu.Mikova, R.V.Mogutnov, and Yu.A. Zelikova, Kompleksnyeeksperimental'nyeissledovaniyaizmeneniyaparametr ovikharakteristikdorozhnykhuslovii, transportnykhpotokovirezhimovdvizheniya pod vliyaniemklimataipogody [Comprehensive experimental studies of parameters and properties of road conditions, transport flows and traffic modes under the influence of climate and weather],LesotekhnicheskiiZhurnal, 8 (2018) 156–168,. DOI: 10.12737/article_5b240611858af4.37544962

[18] E.V.Kondrashova, and T.V. Skvortsova, Sovershenstvovanieorganizatsiidorozhnogodvizheniya v transportnykhsistemakhlesnogokompleksa [Improvement of traffic arrangement in transport systems of timber complex],Sistemyupravleniyaiinformatsionnyetekhnologii, 3.2 (33) (2008) 272–275.

[19] V.G.Kozlov, A.V.Skrypnikov, E.Yu.Mikova, R.V.Mogutnov, and E.V. Chirkov, Formirovaniemodeliproektirovaniyasistemy «dorozhnyeusloviya – transportnyepotoki» iputieerealizatsii[Design model of road conditions – transport flow system and its implementation],Lesoinzhenernoedelo, 8 1(29) (2018) 100–111,.DOI:10.12737/article_5ab0dfbe6ece23.91630316