ISSN 1313-2539

DESIGNING OF THE ROAD NETWORK IN WOOD OF THE SECOND GROUP

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Abstract

Road location is the "foundation" of any road. A road constructed in a poor location can fail and cause serious environmental damage, as well as add financial strain from continuous and costly maintenance problems. A road location must be accomplished on the ground, regardless of the procedures used for road construction control (whether direct location or survey) to assure a road can be properly constructed to meet management and environmental objectives. In either method, the goal is to get a road from one point to another in the most efficient manner, with the least amount of earth movement and the least amount of follow-up maintenance and environmental damage, given slope, topography, and ground stability, as well as the operating constraints of the vehicle, such as turning radius and grade.

The purpose of planning roads for timber exploitation is to try to achieve the combination of road cost and extraction cost (and sometimes road haulage cost as well) which gives the lowest overall cost of moving timber. There may, of course, be other purposes for roads through woodlands, such as general management, access for sporting and to property beyond the forest edge. Such needs may generally be accommodated within the road system designed for timber extraction.

Keywords: *forest roads, location, forest network, road density*

1. INTRODUCTION AND SCOPE RESEARCH

In Belarus, nearly 38 percent of the country is forested and hosts numerous beautiful and multifunctional natural resources.

Most forests - 9,4 million ha - and a volume amounting to almost 1433,9 million m^3 of standing trees, of which about 90 percent have a productive function, are located in the northern, north-eastern and south-eastern parts of the country, in remote areas with fairly high and steep lands. Because of the fact that these areas are far from rural or industrial centers and because road infrastructures are seriously lacking, access and penetration into forests is not easy and makes exploitation and silvicultural activities difficult [1].

We have actually altogether 14 852 km of roads network, with an average density of 2,2 m/ha, of which 65 percent constitutes high forests and the rest coppice. Around 10 862 km are macadam coated and allow annual circulation of transportation means, whereas the other part has a seasonal function, more especially from May to October.

As far as the technical situation is concerned, only 30 percent of the road network is in good condition, while the other part requires numerous and sometimes major management works.

The lack of a road network, the difficulty encountered when attempting to carry out silvicultural works or exploitation cuttings in old forests, explains the inadequate level of working methods and sometimes the use of a technology ecologically damaging and ill-adapted to the prevailing conditions of Belarusian forest lands.

The experience gained to-date by many countries and the results obtained have confirmed the importance and functions of an optimum density road network for forest management and scientific

ISSN 1313-2539

treatment, through the practice of intensive and nature-oriented silviculture. In addition, a good forest road network makes possible the utilization of modern exploitation and transportation methods [2].

As far as Belarusian forests are concerned, the studies carried out indicate primarily the urgency of setting up an adequate road infrastructure which will permit to harmonize ecological, technical, economic and social factors.

These studies draw attention to the following facts: 71 percent of forests have to be very well served and need a good road network; in high forests the road network has to increased to 4,3 m/ha; considering the actual state of our forests, manual unloading proved more effective on average distances (hand rolling) of 100-120 m; tractors on distances of 250-300 m; skylines on distances of 400-600 m.

The main trends and prospects still to be attained are: estimate of ecological data for each sector of the forest economy, where their environmental function occupies the first rank; the extension of the road network in the form of main roadways taking the exact shape of the valley and with short roads within plots; wood unloading according to simple or combined technological schemes, in the first place manual rolling downhill, tractors, skylines, etc.; a higher mechanization level in road works; optimum values and economic efficiency of road density and unloading distances; positive contribution of the road exploitation for tourism, leisure and restful activities, etc.

In short, these trends are among our most ambitious objectives in forestry and for their accomplishment funds, working means and technical assistance are sought from foreign organizations. In this manner, we would accomplish the extension of a properly designed and profitable road network capable of fulfilling its complex role with a special care for environment and nature.

2. THE PROBLEM OF BUILDING FOREST ROAD NETWORK

Belarus, a small country situated in the Europe, counts shading and forests among its most splendid and multifunctional natural resources.

Forests are mainly situated in the central, northern and southeastern parts of the country, in hilly lands and present a rough configuration. At the same time, most particular is the fact that they stretch onto lands considered "remote", far from rural or industrial inhabited areas. The distance worsens even more the lack of road infrastructure, essential to forest accessibility and to entrance into these forests. Because they cover various functions, priority must be given to adequate installations also matching the requirements of silviculture [1].

Actually, a 14 852 km long road network has been implemented with the aim to serve forest natural resources in our country. Out of 14 852 km of roads (total length), 73 percent are macadamized roads and permit the transportation of wood all year round, whilst the other part fulfils seasonal functions, mainly during the period May-October. As far as the technical situation is concerned, about 3 989 km, or 27 percent, are in a good condition, whilst the other part requires a lot of management work.

Compared to the total forest area, the road density index is very low, only 2.15 m/ha and in the case of productive forests 4.3 m/ha. These are mean values for this specific country whereas many particular economies have a higher density, thus rendering possible the access to mature forest, the application of appropriate techniques and technologies in silvicultural work, and distant transport of main and secondary forest products in close and distant areas. Table 1 gives the actual state of the road network, at the national level together with a few of its most typical characteristics.

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Table 1 - Typical characteristics of the forest road network.

Total Length (km)	Total Area (1000ha)	Road Density (m/ha)	Whole-year road network				Technical state of the road network			
			Macadam		Without macadam		Good		Bad	
			%	km	%	km	%	km	%	km
14 852	6921,89	2,15	73	10 862	27	3990	27	3989	73	10 863

From the data given in the table, concurrently to the low road network density, the value of other pertinent indexes is not satisfactory and limits activities in many forests, such as the introduction of silvicultural works, or does not allow particular forests to be multifunctional.

The serious technical situation of 73 percent of the road estate, the fact that only 73 percent of the existing roads are in a unsatisfactory condition, which prevents the all-year-round circulation of transport means, are more important than the savings generated by 10 percent of the high forests with a 13.5 million m3 volume of standing trees, without a single linear metre of roads suitable for motor vehicles. All this requires appropriate and efficient care, attention and investments with regard to road infrastructures.

Together with the lack of a road network, the difficulty of practicing fellings in old forests has also imposed an inadequate level of mechanization in the technological process and sometimes the use of technologies prejudicial to the environment and not well adapted to our forest lands, which are predominant on very hilly areas.

It is known that the extension of the road network in forested areas dates back to the first decades of this century. Nevertheless, the existing results, gained from experience in many countries, have certified the importance and the role it plays as a basic constituent and a permanent element in the modern forest exploitation system and transportation process. In the meantime, it allows operations related to forest management and scientific processing of wood, as well as the practical operation of an intensive and naturalistic silvicultural programme [3].

Nowadays, the experience gained in many countries has demonstrated the validity of these methods. The positive results deriving from a good road infrastructure and the profitable solutions that follow show how important this extension is for the present forest economy.

The extension of a road network depends on several factors and their study looks into their ecological, technical and economic effects on nature

A particular attention is devoted to the extension of a road network in high forested areas. About 87 percent of our forests are situated on hilly or plain lands starting with a 67 percent and more gradient, forested with coniferous trees (particularly shrinkage fir-wood), which are the dominant species in our country.

This difficult basic factor, up to a certain point, had exerted its influence on road infrastructure limitation in the forests and, when carried out, has caused heavy expenses.

Considering the ecological aspect - although it is commonly said that "road is a necessary damage, but the lesser" opinions about the extension of the road network in forests are situated at different levels but with a result which proves positive, rational and effective [4].

The construction of road infrastructures has positive effects on silvicultural works, as well as on exploitation, fellings, in view of agricultural activities, land reform or soil protection against erosion,

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avalanche control, etc. As far as the ecological aspect is concerned, negative aspects exist nonetheless regarding the protection of landscape or forest biotypes especially in the case of our forests.

A road network subject to extension works with a high density, where motor circulation prevails, always brings about negative and immediate effects on the forest environment.

On the contrary, a concrete extension of the road network, where data resulting from an ecological observation of each forest management aspect are well taken into account, allow such a forest, such a road, to fulfil each their environmental role and functions.

Regarding the technical aspect, the extension of the road network in our forests showed demands concerning their management and scientific usage, particularly for productive forests presenting long-term installation projects.

As there is a majority of old forests, cuttings, which are considered indispensable to silvicultural activities, were used as a continuous and complementary wood provision source that averages 0,05 million m^3.

Considering the motorway a basic component of forest management works and a component of the modern transportation system in forested areas, and at the same time, technological solutions for two other phases of the complex exploitation process, the extension of a road network combined with the other available methods of unloading and transportation of felled trees, on storage or loading areas, near motorways (Figure 1).

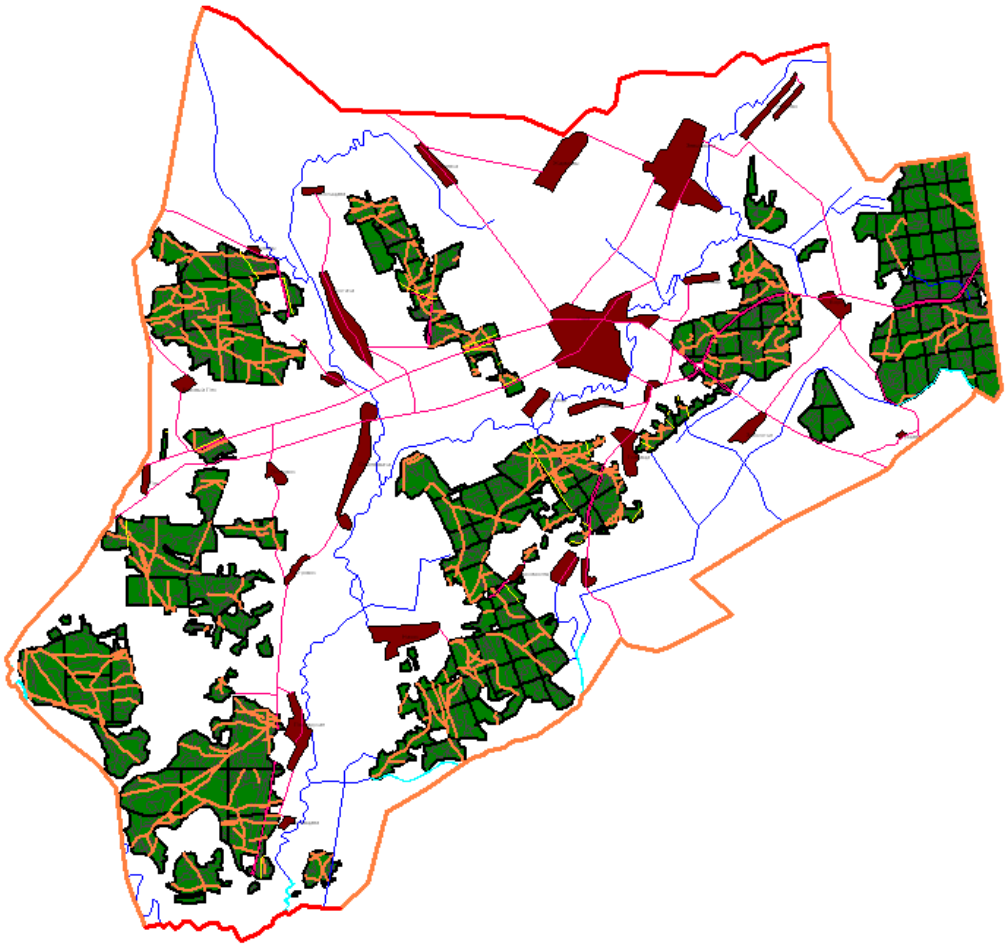


Figure 1. Forest road network

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Even though, in high forests, the road density is higher than somewhere else when compared to the average index value for the country, around 2,2 m/ha refers to the optimum average values that can be applied. Through the experience acquired by many European countries, it arises that the situation is not as expected and that it would have been desirable to emphasize intensive silvicultural practices.

Methods consisting in using manual or mechanical hauling for tree-length logs and mules for small-size logs have a large application in the international transportation fields. This technical solution said "in between" illustrates, with the help of internal transportation technological schemes, the repercussions of works carried out as far their efficiency is concerned.

At the same time, as it is impossible to build motor roads and, due to the limited number of mechanical equipment used to extract wood from our forests situated at a cross-country altitude, the only technically sound solution is the extension of the road network in the form of main roadways, positioned according to valleys and hollows with short access roads (Figure 1). The accumulation of fellings in their vicinity, especially down the slope is also very important. Wood hauling on long distances between wide spaces and motorways having mean values ranging from 100 to 120 m for manual hauling, 250 to 300 m for mechanical hauling (tractors) and 400 to 600 linear metres for skylines are the results of these solutions [5].

The road network under consideration with an optimum density of high technical characteristics and excellent structures, provided profitable returns for all types of works. They aim at easing man's access to sites, work technologies and extend their field of activities to environmental effects and repercussions on the protection of nature.

In spite of the results achieved during the construction of the road infrastructure, relatively high building costs, annual maintenance, recurrent repair costs have been experienced of average values twice as high as in some other European countries. Strongly marked slopes and abrupt shapes in forested areas, the regulations applying to silvicultural methods through selective cuttings (at two or three different stages of evolution) have to be considered separately.

The organization and positioning of road networks with a high coefficient together with what follows are a few of the results achieved so far:

- earthworks as part of the accomplishment of the main road network;
- numerous constructive works such as support walls, small bridges, piping, etc.;
- considerable annual maintenance works, especially during winter months;
- large amounts of recurrent repairs, often reaching 60 percent of the entire structure;
- structures made of paving blocks or gravel, to allow all-year-round circulation of motor vehicles;
- all this resulting in heavy expenses.

As far as the above-mentioned expenses are concerned, if we refer to Prof. N. P. Vyrko's point of view [6] concerning the classification of forests according to the functions fulfilled by motorways in about 70 percent of our forests, we can understand the delay in setting road infrastructures in these areas. Consequently, we retain that our forested zones are well served and we insist on the necessity to enlarge the road network to 2,6-4,3 m/ha.

The accomplishment of a satisfactory road network, which will allow intensive silvicultural activities, obviously belongs to the future. Nevertheless, a project financed by the Department of Forestry has been launched which anticipates the restoration of 13 900 km of the road network in forests.

The economic influence of wood extraction on factors such as the reciprocal indirect dependence between road density and hauling distances determinates the configuration of the road network extension. This operation in the case of specific data, situations or factors (forest, land, transportation facilities, technologies and working regulations, road classification, etc.) allows an estimation of

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optimum values for the two indexes (density of road network/hauling distance) which will permit the extraction of each unity (m^3) of wood with lower expenses.

Basing our argument on the above-mentioned laws and with the yielding capacity of forest road works in mind, during the last few years, studies have been carried out regarding the problems concerning access to the forests and extension of the road networks in our forest management. General information, not yet in final form, is given in Table 2.

Table 2 - Belarusian forest

Struc-ture	The basic breeds								Bu-shes	Total
	pine	spruce	oak	birch	alder black	aspen	Other	Total		
Surface, (10^6ha)	3474,6	676,02	240,91	1540,07	578,6	147,42	230,3	6888,34	33,41	6921,9
Volume, (10^6m^3)	695,2	149,54	37,79	233,83	92,95	26,07	30,45	1265,9	0,73	1266,62
Average stock, (m^3/ha)	200	221	157	152	161	177	132	-	22	-

In the course of the last few decades, experience has shown that, due to the low value of motorway density, wood had to be hauled on longer distances within plots. At the beginning, manual hauling on long distances, due to the lack of mechanization, was commonly done, whereas the gradual increase of technology relations between the extension of the road network and the hauling methods have become more efficient, leading to a 10-15 percent decrease of total costs for each unity of wood (m^3).

The increase of economic efficiency of the road network as a consequence of the cost of wood extraction affects the level of works carried out and their construction which, in our country, has been and is still very low.

The positive effects which result from the increase of technology in wood extraction, together with a denser road network, will be higher if they lead to a major level of mechanization of construction works. In Albania, apart from a few tractors of bulldozer type, used to dig land and a few other means to transport materials, the technology indispensable to carry out specific tasks such as digging machines, superchargers, stone crushers, road rollers, transportation means, etc., is seriously lacking and it is highly recommended to consider the results obtained with such developed technology in some countries throughout the world.

The extension of the road infrastructure in mountain forested areas in Belarus is considered a solution that not only provides assistance in settling natural forest balance but, as these forests, typical of Belarus, are situated near rural centers, this assistance takes on double value, as it warrants social and economic development [6].

The solutions to this situation, i.e. connection between rural communities and motorways, easy motor circulation for the local population, delivery of farming products, exploitation of local mineral resources, etc., are all included in this context.

Access road by motor vehicles, especially the ones that go alongside and the ones that enter forests, apart from the important role they play in ensuring a proper service to the forest, allow and promote tourism, recreation and restful activities which go hand in hand with these developments.

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Numerous examples illustrate the complex role of forest roads in our country. They can be found in the following regions: Brest, Vitebsk, Gomel, Grodno, Minsk, Mogilev, etc.

3. MODEL OF SEARCH OF OPTIMUM PARAMETERS OF WOOD-TRANSPORT NETWORKS FOR ACCOMMODATION IN LARGE FOREST M_S

3.1 The purposes

Any wood-transport network (WTN) is created for achievement *of the basic purpose - maintenance transport development of large forests*. For such complex T - systems as the WTN the purposes which it is difficult to formulate, describe and plan ways of their achievement are peculiar some. Other difficulty consists in that, modern opportunities of the system analysis do not allow to express the purpose in a quantitative kind [7].

Therefore the purposes of creation the WTN we shall describe only at the qualitative level, the received results will be used for definition of the general directions on search of optimum parameters the WTN and a choice of optimum variants of its accommodation on a degree of preferability.

The purposes are formed under influence external and internal, in relation to the WTN, factors. Set of the purposes are united by one initial purpose which can be broken into set of more private, but also more simple and concretized purposes. Such splitting is connected with construction of *"a tree of the purposes"*. Thus the condition is provided: the purposes of the bottom levels should form a set, sufficient for achievement of the general purpose [8].

The formulation of the purposes - process exclusively creative and informal; it concerns to the theory of decision-making and in a strong degree depends both on intuition and art of the researcher, and from features most T - systems. In view of this we develop "a tree of the purposes" FG (fig. 3) for the decision of a problem of predesign synthesis the WTN.

<table>
<tr><td colspan="2">Maintenance of transport development of large forests and preservation of an environment</td></tr>
<tr><td rowspan="2">1.1. To choose optimum forest-transport process</td><td>1.1.1. To choose structure of process</td></tr>
<tr><td>1.1.2. To choose an optimum complex of machines</td></tr>
<tr><td rowspan="3">1.2. To place an optimum wood-transport network</td><td>1.2.1.1. To choose plans of development of cuttings area
1.2.1.1. To define stocks of a wood and operational conditions
1.2.1.2. To break economic sections into cuttings area</td></tr>
<tr><td>1.2.2. To choose the plan of development of large forests
1.2.2.1. To choose optimum structure the WTN
1.2.2.2. To choose an optimum configuration the WTN</td></tr>
<tr><td>1.2.3. To choose sequence of accommodation the WTN
1.2.3.4. To define volumes of freight traffics and volumes of passenger traffic</td></tr>
<tr><td rowspan="2">1.3. To provide preservation and reproduction of the forest environment</td><td>1.3.1. To execute the technological device of large forests
1.3.1.1. To break a large forest into economic sections</td></tr>
<tr><td>1.3.2. To choose ways of restoration of cuttings area</td></tr>
<tr><td colspan="2">1.4. To establish rational sequence of development of cuttings area</td></tr>
</table>

Figure 3. "A tree of the purposes"

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The most adequate display of a configuration and structure the WTN is the description of spatial connections of its components in the form of graph-tree G_s (X, L) where the set of tops X includes: sources X_i of formation of transport streams in size q_i, stations of an adjunction of network X_v and forks of ways X_s, and set of edges L - transport ways in length l_{ij}, connecting tops i and j [9].

The station of adjunction X_v refers to *as a root* which the fragments of a network named by *"branches"* graph G_s adjoin. Obviously, any two tops of a graph are connected by unique transport connection, and forks of network X_s for freight traffics are only transit points (fig. 4).

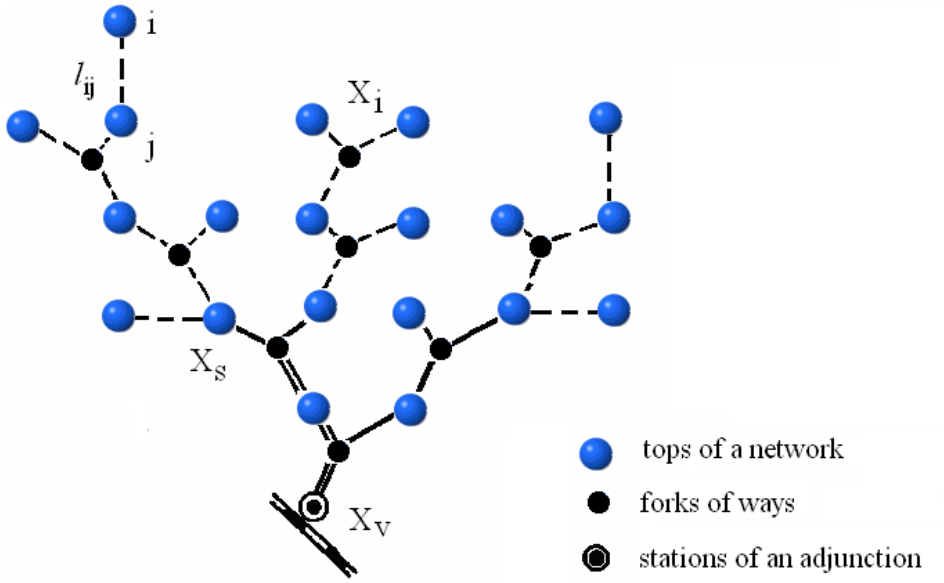


Figure 4. Graph of spatial connections G_s (X, L) the WTN

Change of a spatial arrangement of tops X_i and X_s at constant position of station of adjunction X_v conducts to change of a configuration of a network, and change of sizes of transport streams q_i, concentrated in points X_i, the WTN leads to change of throughputs q_{ij} transport connections l_{ij} and therefore, structures C_s, configurations K_s and density.

Basically the WTN is estimated by two is functional-structural properties: configuration K_s, as a parameter for an estimation of a spatial arrangement of wood-transport ways and trajectories of moving of transport streams of wood raw material and not forest loads, structure C_s presented by set of ways of various categories on all sites of a network and types of transport units.

Additional parameters for the WTN are: amount of the centers of formation of transport streams N_i of forks of ways N_s and stations of adjunction N_a in a large forest and specialization of a network.

For optimization of parameters the WTN we have started drawing up of mathematical models after performance of researches of the abstract networks representing various combinations of the treelike graph.

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3.2 Statement of a problem

Results of research of abstract models the WTN have allowed to draw the important conclusion: predesign synthesis optimum on a configuration and structure real the WTN will be connected with the decision of two mathematical problems:

1) Search of the shortest connecting network (SCN);
2) Search locally-optimum the WTN by addition of forks of ways and definition of their coordinates.

Let's carry out the formal description of a problem. Let in some limited area on a plane are set:

1) final set a load of forming tops $X_i \subset \{X_i, x, y, q_i\}$, including N_i the centers X_i stocks of wood, not forest loads and volumes of passenger traffic;

2) final set of root tops $X_v \subset \{X_v, x, y, Q_a\}$; containing N_a points of adjunction X_v of forest road.

Everyone X_i top of a network possesses the capacity equal to volume q_i of wood raw material concentrated to it; and capacity X_k tops - to volume q_k a transport stream. In X_v to top the station of an adjunction (a drain for a network), an accepting transport stream in volume Q_a equal to annual volume of manufacture of the bottom forest warehouse is located.

Here x, y - coordinates of tops of a network.

To receive representation about the difficulties arising at drawing up of mathematical model we shall note two features connected with predesign synthesis locally-optimum WTN.

The first feature - the sketch of a network represents R_s - a tier structural tree in the form of graph G_s with root tops X_v. The given graph are formed by introduction in SCN a new subset of forks of ways X_s $\{X_s, x, y\}$ with zero stocks of transport streams ($Q_s = 0$) in them. The concept the WTN in the form of (R_s) a tier tree is entered by us for the first time, meaning, that *r* tier of graph G_s edges l^{r}_{ij} having q_r a settlement turnover of goods make all.

The second feature. Simple connection of top X_i, X_j, transport connection l^{r}_{ij} does not allow to estimate cost of way C_{ij} since are unknown a category *r* and throughput q_{ij} ways.

The above described features do not allow to execute predesign synthesis the WTN known methods [9]. The following approach for the decision of a problem.

Therefore is supposed:

1 stage - to construct SCN with use of Prim's algorithm [10] in the form of graph G_p;

2 stage - at known configurations K_p, column G_p and costs of unit of length of ways C^{r}_{ij} (at $r = 1$) to conduct search minimal "Steiner's multitier tree " (SMT) by optimum accommodation of forks of ways X_s. It provides a finding the WTN with locally-optimum parameters and reception of the sketch in the form of graph G_s close to optimum $G_{s\ opt}$.

The mathematical description of network model M_s with N_i the centers of stocks of transport streams in size q_i, with N_a stations of an adjunction (with volumes of manufacture Q_a) and with N_s forks of transport ways is executed.

Criterion function - a minimum of expenses for transport development of large forests:

$$\min F(G_s) = \sum_{r}^{R} \sum_{i \neq j} C_{ij}^{r} \cdot l_{ij}^{r} \cdot q_{ij}^{r}$$

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4. RESULTS AND DISCUSSION

Models of optimization the WTN are developed on the basis of the executed parametrical description of systems cooperating among themselves "an environment - a wood-transport network - the environment of functioning". It has allowed for each model will make the list of considered factors, to execute the plan of transformation of the entrance information and interaction of factors in model, to prove criteria of an optimality and to define parameters for optimization.

Function of the purpose and mathematical model the WTN in the form of the graph including forks of ways are made and allowing to enter predesign search of their optimum configurations and structures. Are offered new mathematical model for the decision of problems of optimum accommodation of cuttings area in an economic section and model for definition of rational sequence of development of cuttings area in a section.

5. CONCLUSIONS

By results of modelling the WTN is obviously possible to conclude:

1. Results of research of developments a WTN arising at transport development of large forests, have allowed to develop hierarchical system of modelling the WTN in structure of:

- the basic models of optimizations located at hierarchical levels of decomposition the WTN (T-systems) both providing predesign synthesis and a substantiation of parameters: the WTN - for transport development of large forests; fragments the WTN - for accommodation in economic sections; temporary technological the WTN on cuttings area.

- the auxiliary models located at levels of a partition of structural structure the WTN and providing modelling of accommodation a section and cuttings area in large forests, optimization of structure of logging process and sequence of development of cuttings area, modelling of transport streams. Use of the given models allows to increase a degree of completeness of initial data for designing the WTN, than effective predesign synthesis of networks is provided.

2. At modelling the WTN new reserves of improvement of their configurations and structures - application of plans of connection of wood-transport ways with optimization of coordinates of forks of ways are revealed at existing classification of forest roads.

3. For the further increase of efficiency of search of optimum parameters the WTN complicating and excluding accommodation on them of wood-transport ways of sites of the forest and not forest grounds, situational model the technique of an estimation and modelling are developed for allocation of such sites on cards-plans of large forests and forest exploitation a section.

ACKNOWLEDGEMENTS

The Authors wish to thank Mr. Nikolay Pavl. Vyrko for his valuable help in the analytical work. Thanks are also due to Mr. Michail Naskovets for his assistance in interpreting the model, and for helping to create the forest roads network.

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