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Timber harvesting in the ukrainian carpathians: Ecological problems and methods to solve them

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ABSTRACT: The paper contains results of comparative investigations of crawler and wheeled skidders regarding their effect on soil surface, undergrowth and rut formation during mountain timber harvesting. It was shown that the extent of erosion resulting from damage to the soil surface depends on the steepness and length of slopes during both construction of skidding tracks and skidding by tractors. Considering the current condition of development of timber harvesting machinery, the use of crawler machines is the main method for transportation of cargos in regions with difficult access.

Keywords: crawler and wheeled skidders; damage to ground surface; rut formation; undergrowth damage

The Carpathians are an important part of the ecological, economic and recreational environment for people in the centre of Europe, shared by many nations and countries. It is one of a few regions that preserve relatively large areas of virgin forests with their unique fauna and flora. On their basis, a number of protected objects and territories were created. In May 2003, Ukraine signed The Convention on the Protection and Sustainable Development of the Carpathians, which defines the implementation of all-round policies directed towards the conservation and sustainable development of the region to improve the quality of life, strengthen local economies and communities and preserve natural values and cultural heritage.

One of the laws in force directed to more environment-friendly ways of forest utilization in Ukraine is the Ukrainian Act on "The moratorium on Performing Clear Cutting on Mountain Slopes in Spruce-Beech Forests of the Carpathian Region". This law was the first one on the state level to start using special approaches to the organization of mountain forestry, to introduce environmental forest technologies and to widen the network of protected territories and also to set a number of restrictions on the utilization of certain ways of timber cutting and certain systems of machinery.

To work out particular principles in detail and to better define the law, investigations started to determine the impacts of skidders on the forest environment and to work out environmental principles of timber harvesting.

Current condition of mountain timber harvesting

Mountain timber harvesting is a complex, multi-step process that determines economic as well as ecological productivity of forestry. The key part of this process is skidding that includes a number of factors affecting the soil surface of cutting areas either directly or indirectly. Investigations started by Ukrainian scientists unravelled these factors and determined the degree to which forest crawler and wheeled machinery influences the environment.

The main components of mountain timber harvesting are the construction and running of forest roads. If horses are used, this is horse portage, in the case of crawler and wheeled machinery, these are skidding tracks. They are an integral part of the organizational structure of primary transportation of

timber; thus, their optimal distribution determines the ecological efficiency of technology of exploitation of the cutting area.

It was stated (Byblyuk et al. 2002) that tractor skidding is the most harmful for the soil surface, especially during the construction of skidding tracks by a bulldozer. For example, in the mountains, if the area of skidding tracks is 8% of the total cutting area, the volume of soil damaged by erosion often amounts to 500 $m^3 \cdot ha^{-1}$. Erosion on skidding tracks may reach up to 70% of its total volume on the cutting area. The volume of soil erosion inflicted by forest machinery is a function of the steepness and length of a slope, degree of soil erosion vulnerability (which in general depends on the presence of small-size particles in soil); fraction of the area covered by vegetation; intensity, duration, extension and frequency of precipitation.

The intensity of natural renewal of the cutting area surface on mountain slopes and its consequent condition significantly differ from conditions on plains, thus, from ecological positions it is especially important to take measures to preserve the existing undergrowth during timber harvesting. The use of cableway skidding system ensures the preservation of viable undergrowth under forest floor and allows solving the problem of reforestation on steep slopes. The data obtained in the North Caucasus by Russian scientists (Pobedinskyy 1977) shows that in some cases it is possible to save 80–90% of existing undergrowth, which is 1.5–2 times more than during primary transportation of timber by skidders. Besides objective factors, a significant influence on the environment is caused by a human factor. The cases of violation of timber harvesting technology during cutting are not scarce. The location of undergrowth is not always taken into account; the regulated width of cutting, main and strip skidding tracks is not observed. This is caused by the absence of responsibility for violation of the ecological balance of forest ecosystems and damage inflicted to environment. In other countries, investigations on this problem have already been carried out for many years and economic stimuli to environmental forest utilization on steep slopes have been introduced.

The transport network plays an important role in the forest industry production of mountain regions where forest areas are scattered in vast territories and are characterized by complex relief, soil-hydrological features, low concentration of harvested timber per unit area, one-sidedness of freight traffic volume and other factors. Forest roads play an important role not only in forest utilization, renewal and preservation, but also in the general development of a region, its recreational potential, improving working conditions and well-being of the population. In European countries with developed forest industry, the construction of forest roads is subsidized as a part of the state transport network. Costs of the construction and maintenance of forest roads constitute there nearly one third of the total cost of harvested timber.

In the Carpathian region of Ukraine, the network of forest roads is not fully developed; its density is 4–7 times lower than in the countries of West and Central Europe. Forest areas with the density of roads more than 10 $m \cdot ha^{-1}$ constitute less than 2% of the total forest area. More than 40% of forest territories have the road density lower than 0.4 $m \cdot ha^{-1}$ (Fig. 1). This state of the transport network leads to wide utilization of primary trails of timber transportation in forest expanses, i.e. skidding tracks, which are basic passages established without using engineering structures and drainage and have rather large longitudinal inclines, which in most cases does not allow using them for the passage of wheeled machinery skidders and tractors with cable systems. The problem of selection of a type of

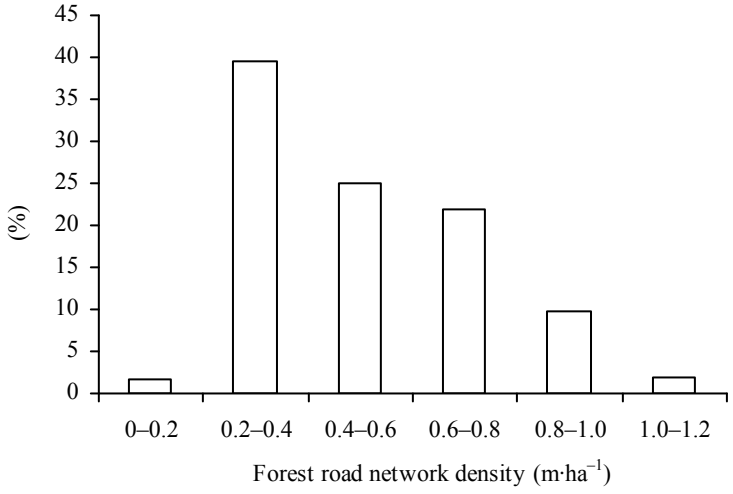


Fig. 1. Distribution of the forest areas of the Carpathian region by presence of roads

Table 1. Recommendations for utilization of wheeled and crawler forest machinery on surface with different inclines

Surface incline	Best results from the point of damage minimization		Recommendation for usage
	soil surface	rootage	
~ 0°	crawler harvester and wheeled or crawler forwarder	wheeled machinery	wheeled machinery
< 17°	crawler machinery	wheeled machinery	wheeled machinery
> 17°	crawler machinery	crawler machinery	crawler machinery

skidder, in particular, determination of advantages of wheeled vs. crawler driving unit is urgent not only for the mountain regions of Ukraine. Table 1 summarizes results of the comparative investigation (Matthies et al. 2003) of damage intensity to the soil surface and rootage by forest machinery with different types of driving units on mountain slopes of West Europe.

For all conditions of exploitation crawler machinery has clear advantages regarding the degree of damage to the soil surface. But on the other hand, wheeled machinery has an obvious advantage in minimizing the effect on rootage. For forests on plains and slopes of medium steepness there is no single recommendation.

However, the final decision on the choice of a skidder with either wheeled or crawler driving unit should be based on detailed analysis of physical-mechanical features of soil, predicted number of passages, specific pressure of forest machine on soil and weather conditions.

MATERIAL AND METHODS

The effect of wheeled and crawler skidders on forest environment was evaluated by investigating the damage to undergrowth and soil surface caused by timber skidding and also by investigating the processes of rut formation.

For the first type of investigation, research-industrial plots were chosen in the mountain zones of forest resources of five state enterprises. The plots were characterized by different natural-industrial conditions, which allowed getting real indices of the effect of different types of transport on the forest.

The investigation of undergrowth damage was performed on three transects located on a slope in different sites of the cutting area, i.e. in its lower, medium and upper part (far-off end of the cutting area) while 15–25 plots (depending on particular conditions, e.g. mosaics of renewal), 2 × 2 m each, were established on each transect.

The main parameters characterizing the effect of timber harvesting technology on the young generation of forest are its quantitative and qualitative condition after timber cutting (Molotkov 1966; Parpan et al. 1988; Kudra 2005). The quantity of undergrowth on a cutting area was determined by counting it on experimental plots and relating it to the area of 1 ha. Qualitatively, undergrowth on a cutting area was divided into the following categories: undamaged, weakly or greatly damaged and destructed.

The effect of harvesting operations on the soil surface of cutting area was assessed complexly by investigation of the degree of damage to soil during harvesting operations and determination of plane and volumetric parameters of skidding tracks (Polyakov 1965; Oliynuk 1998). The degree of damage to soil was divided into the following categories:

Zero category: There is no damage, the soil surface is not disturbed. It includes areas which were not disturbed by harvesting operations and preserve the forest floor.

First category: The forest floor is loosened because of the fall of trees or moving their crowns. The soil is not damaged.

Second category: There are plots with forest floor removed by harvesting operations, but still preserving the humus horizon. The damage is mainly plain and local.

Third category: There are plots with linear damage in the form of primary skidding tracks (made by one trunk). It includes single and multiple passages of a tractor to the plots outside of the skidding tracks.

Fourth category: There is linear-plane damage in the form of secondary skidding tracks (damage made by several trunks) and horse and tractor skidding tracks. The third and the forth category of damage to soil is subdivided into three categories by their depth: under 5 cm, 6–10 cm and above 10 cm.

Fifth category: There are deposits, containing small fractions of soil, leaves and stones, which are created during skidding.

Field investigations of rut formation by the traffic of wheeled and crawler tractors on forest soils were

performed on specially selected plots in the forest. The main factors determining the effect of a driving unit on soil are density of soil in the rut and its depth, which depend on the number of passages in the same track. Investigations included measuring the depth of ruts, degree of damage to the bearing surface and soil sampling.

Before the beginning of investigations the radius of turns, lengths of linear plots, weight and geometrical parameters of a tractor were determined. Samples of the undamaged layer of soil were taken on each plot and at least four measuring points were established at the distance of 1 m from each other.

The following parameters were determined: soil moisture (by weight), physical density of soil, modulus of deformation, density by the difficulty of cultivation and depth of ruts. Based on the obtained data, plots of dependence of distribution of soil density in the rut from the number of passages were built.

RESULTS

Undergrowth damage

Investigations were performed during a snowless period on 56 experimental plots. For crawler tractors, the largest portion of cutting areas (41%) had slopes of 15–20° and for wheeled tractors the most common (34%) were plots with slopes of 10–15°.

The obtained results of investigations (Fig. 2) demonstrate that using crawler tractors for timber harvesting preserves on average 85.1% of undergrowth and using wheeled tractors preserves 84.4% of undergrowth. This percentage depends on many factors, including the season of harvesting, steepness of slope, position of skidding tracks etc., and varies between 50.0% and 99.5%. By the portion of undamaged undergrowth we mean the degree of its preservation on areas undisturbed by skidding tracks. But practically all undergrowth is destroyed on the skidding tracks because they are prepared before cutting. Thus, it can be considered that the portion of a plot occupied by skidding tracks is free of undergrowth and after timber harvesting it should be a subject for reforestation.

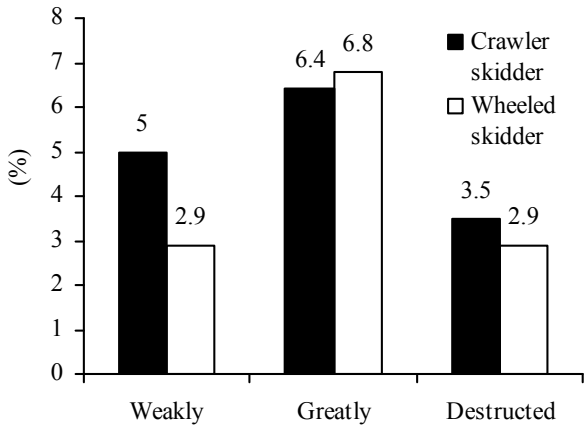


Fig. 2. Distribution of undergrowth damage by categories

There is no significant difference in the degree of damage caused by crawler and wheeled tractors because these forest machines perform identical operations during timber collection and skidding.

The intensity of undergrowth damage by skidders by categories is shown in Table 2. For both types of tractors the prevalent types of damage are peeling of trunks (46.2% and 57.1%) and weak or strong damage to rootage (19.1% and 23.1%) that is caused by the movement of trunks or tractors.

Table 2. Average numbers of damaged undergrowth – Type and magnitude of damage, thousands per 1 ha (%)

Crown damage	Fracture of top	Peeling of bark	Fracture of trunk	Roots damage
Skidding by crawler tractors				
0.2 (9.5)	0.1 (4.8)	1.2 (57.1)	0.2 (9.5)	0.4 (19.1)
Skidding by wheeled tractors				
0.2 (7.7)	0.3 (11.5)	1.2 (46.2)	0.3 (11.5)	0.6 (23.1)

Table 3. Average characteristics of skidding ways on research plots

Type of skidder	Length of skidding ways ($m \cdot ha^{-1}$)	Average width (m)	Area ($m^3 \cdot ha^{-1}$)	% of cutting area	Soil erosion volume on skidding ways ($m^3 \cdot ha^{-1}$)
Crawler tractors	108	5.0	522	5.2	220
Wheeled tractors	118	4.5	508	5.1	169

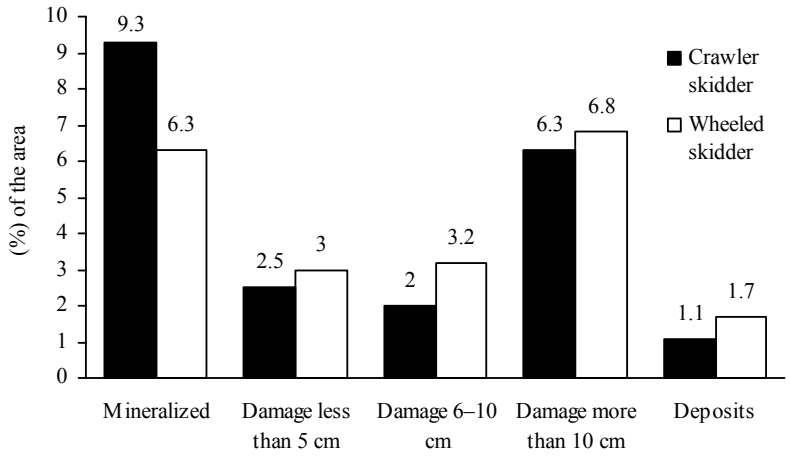


Fig. 3. Comparative data on the soil surface damage

Damage to soil surface

During the investigation of damage to the soil surface of mountain cutting area, the main features (extent, average width, area and volume of operational erosion) of skidding tracks used for the traffic of wheeled and crawler machinery were determined (Table 3). Their analysis suggests that the density of skidding track network and portion of the area they occupy in cutting areas developed by wheeled tractors is almost 10% larger than in cutting area developed by crawler tractors. This is explained by the existing limitations of slopes where wheeled tractors can be used and related necessity of laying a greater number of skidding tracks.

On average, on the investigated cutting areas, skidding tracks take up 5.2% of cutting area if crawler tractors are used, and 5.1% if wheeled tractors are used, which is basically the same number. The volumes of soil erosion caused by skidding tracks are 220 and 169 $m^3 \cdot ha^{-1}$, respectively.

In the case of tractor skidding, around 80% of the cutting area is left undamaged; the difference between wheeled and crawler tractors does not exceed 0.5%. The plots with mineralized surface, i.e. those where the forest floor is partly mixed with mineral particles of soil, constitute 9.3% of the total cutting area if crawler tractors are used, which is 1.5 times more than for wheeled tractors. But from the forestry point of view, mineralized plots play a positive role because they assist in the natural renewal of forests, especially in the case of unclear cutting. The average volume of soil erosion, taking into account skidding tracks and areas outside of skidding tracks is 264 $m^3 \cdot ha^{-1}$ if crawler tractors are used and 240 $m^3 \cdot ha^{-1}$ if wheeled tractors are used. The difference is in the range of 10%.

Comparative data on damage to the soil surface on a cutting area where wheeled and crawler tractors are used is shown in Fig. 3.

Intensity of rut formation

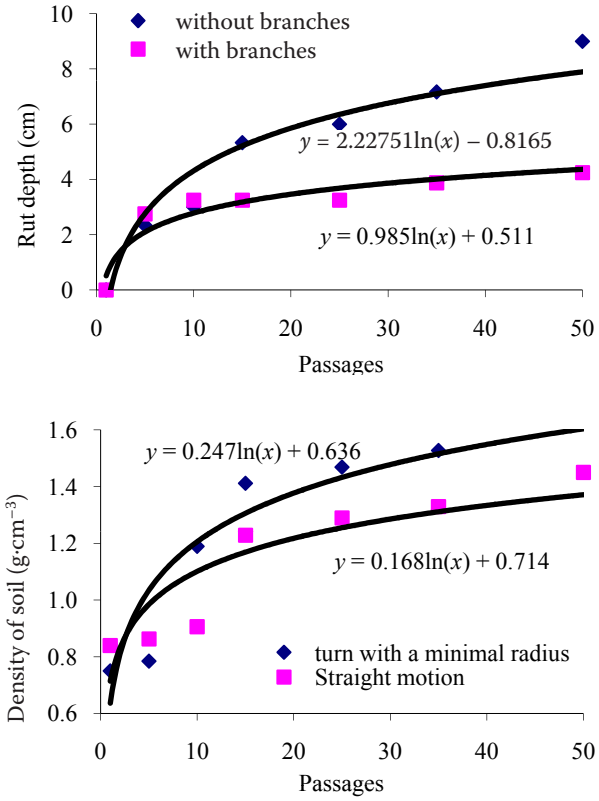
Features of plots used as the proving ground for the investigation of rut formation are shown in Table 4. Results of the investigation and photographs of individual stages of measuring are shown in Figs. 4–6.

Analysis of the obtained graphical dependences allowed drawing the following conclusions:

– The intensity of rut formation significantly depends on the bearing capacity of soil, which is

Table 4. Characteristics of test plots

Plot No.	Object of investigation; load	Description and transversal incline of the area	Primary parameters of soil	
			density ($g \cdot cm^{-3}$)	humidity (%)
1	LKT-81	covered by dense vegetation, 9°	0.65–0.99	70–81
2	TDT-55A		1.00–1.37	43–73
3	TT-4; 1 (t)	frozen soil with broken stone, compressed by branches, 0°	1.30–1.55	43–55
4	LKT-81; 0.7 (t)	covered with dense vegetation, well-ventilated, 7°	0.71–1.08	42–51
5	TDT-55A; 1.56 (t) TAF-657; 1.12 (t)	well-moistened and compressed with branches, 2°	1.18–1.49	32–61



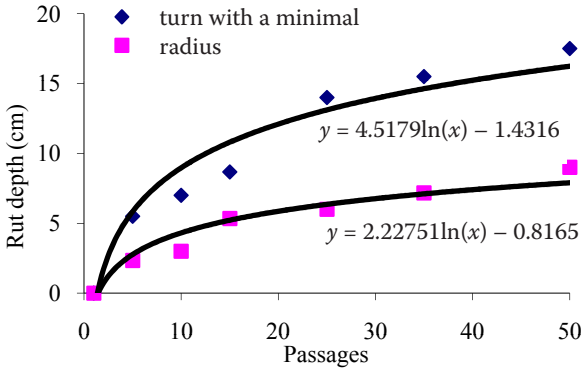
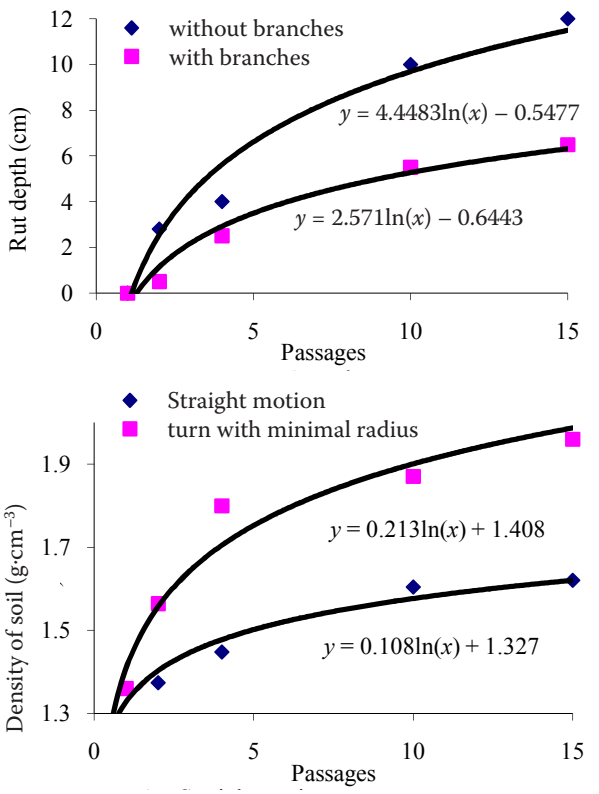


Fig. 4. Investigation of the interaction of wheeled skidder LKT-81 with bearing surface (plot 1)

determined by the geomorphologic structure of the Carpathians to a considerable extent.

– The most intense compression of soil occurs during the first several passages (around 70% of the rut depth).

– The existence of a floor of branches significantly (2–3 times) decreases the depth of a rut and also decreases the intensity of soil compression by 10–20%. A larger decrease in the degree of damage is typical of the crawler driving unit.



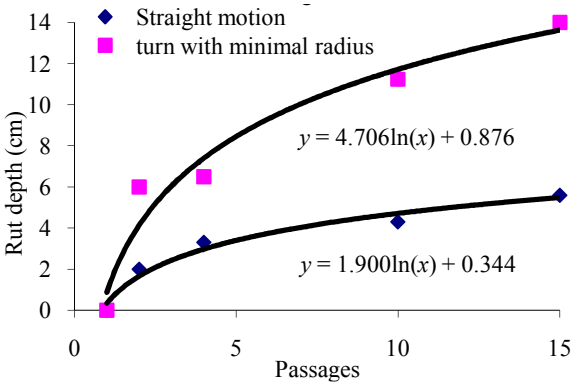


Fig. 5. Investigation of the interaction of crawler skidder TDT-55A with bearing surface (plot 2)

Fig. 6. Investigation of the interaction of wheeled TAF657 and crawler TT4 skidders with bearing surface (plot 5)

– At turns with minimal radius the depth of ruts increases 1.5–2 times for wheeled tractor and 2–3 times for crawler tractor as compared with linear movement.
– Soil compression by wheeled and crawler tractors during linear movement occurs practically by the same dependences.
– Greater damage to the soil surface with high bearing capacity is typical of crawler tractors while wheeled tractors cause greater damage to the surface with low bearing capacity.

CONCLUSIONS

The effect of technological processes and systems of machines used in mountain forests on the forest environment significantly depends on the way of primary transportation of timber and transportation network in forests.

The greatest damage to the forest environment (soil, undergrowth, forest) is inflicted during soil transportation of timber while using either crawler or wheeled tractors moving by elementary passages (skidding tracks). From this position, cut of length timber harvesting has clear advantage. It includes primary transportation of timber by forwarders and thus eliminates the possibility of damage to the soil surface by timber.

The highest volume of soil erosion (~70–80 %) is inflicted by shifting the soil while establishing skidding tracks which are the main cause of further erosion after the end of timber harvesting operations.

The volume of erosion resulting from damage to the soil surface during preliminary establishment of skidding tracks as well as skidding by tractors significantly depends on the steepness of a slope and its length (the degree of erosion is approximately proportional to double steepness of a slope in %).

The intensity of damage to the bearing surface depends on parameters of soil in the rut of skidding tracks, weather conditions during the works, number of passages and specifics of the construction of a skidder:

– With an increase in the number of passages the degree of soil damage grows logarithmically;
– Soil compression leads to a decrease in its humidity and softness and an increase in density thickness and shear strength;
– The damage to the bearing surface reversely depends on the degree of soil freezing;
– The presence of branch floor decreases the depth of ruts, especially on soils with undamaged structure (2–4 times);
– Crawler and wheeled tractors on loamy soils compress the bearing surface approximately to the same extent.

There are practically no differences in undergrowth damage inflicted by crawler or wheeled tractors because during timber collection and skidding the extraction by these machines performs practically the same operations.

At the current stage of development of timber harvesting machinery, the main method to solve problems of cargo transportation in regions difficult to access is the utilization of a system of machines using the crawler driving unit.

Technological processes of timber harvesting have to be based on the optimal combination of different types of special forest machinery, depending on specific natural-industrial conditions, with obligatory preliminary construction of forest roads and ensuring the optimal distances of primary transportation of timber.

One of the main methods to decrease the negative influence of primary timber transportation is the utilization of cable transport systems on steep slopes.

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