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@ ✉ Correspondence author
O. A. Styranivsky
styranivsky@ukr.net

M. G. Adamovsky, O. A. Styranivsky, M. M. Borys

Ukrainian National Forestry University, Lviv, Ukraine

SPATIAL MODELING OF TRANSPORT DEVELOPMENT OF FOREST AREA AND THEIR POTENTIAL ENVIRONMENTAL RISKS

Mykola Adamovsky,
PhD, Professor,
Email: adamovsky@ukr.net

Oleh Styranivsky,
PhD, Associate of Professor,
Email: styranivsky@ukr.net

Mykola Borys,
PhD, Associate of Professor,
Email: borysmm@ukr.net

Permanent attributes of timber harvesting are a number of potential environmental risks, each of which can cause significant damage to the environment. The intensive development of technology and the improvement of industrial production processes have led to a significant increase in technogenic impact both on increasing catastrophic natural disasters and on the global climate change formation. The adoption of the World Environmental Constitution by all the states would be an effective means of regulating and minimizing these negative processes. Timber harvesting is one of the most dangerous types of technogenic impact on the forest environment, as the forest stand, young growth, natural watercourses and soil are damaged during logging and transportation. However, the degree of the negative impact of timber harvesting can be reduced to an ecologically acceptable level, and technical indicators of the use of timber-hauling machinery can be brought to economically feasible values by properly assessing the intensity of the environmental risk of taking a decision on certain technical and technological issues and the implementation of environmental management of this process. The article presents some approaches to the creation of GIS spatial planning model of transport development of forest-exploitation area based on the cost estimation of timber skidding considering technogenic impact of forest machines. The development of the model of forest transportation planning is a complex task. In order to solve this task, the system under investigation should be divided into separate interconnected modules, each acting as its own model: the models for forest transportation planning, the database, formulation of the task, the results of modeling, an analysis of transport movement possibilities, an analysis of environmental damage, the assessment and improvement of the existing forest road network. Concerning the proposed model and methodology that is based on the analysis of potential environmental risks associated with the rutting and cost-assessment of timber skidding, we have obtained the model map of environmentally-acceptable types of timber-hauling machines for a real forest exploitation area, the Rozhanka forest district, the *Slavsk* State Forestry Enterprise in particular. The proposed model makes it possible to substantiate environmentally safe and economically feasible ways of skidding, estimate the ratio of transport development of a forest area using various terrestrial technical means (wheeled and crawler tractors or cable systems), as well as to outline the possible occurrence, intensity and spread of environmental hazards associated with timber harvesting.

Keywords: spatial modeling; timber-hauling development; forest-exploitation area; forest machine; environmental risks.

Introduction

The intensive development of technology and the improvement of industrial production processes have led to a significant increase in technogenic impact both on increasing the number of catastrophic natural disasters and on the global climate change formation (Braun, et al., 2000). The adoption of the World Environmental Constitution by all the states would be an effective means of regulating and minimizing these negative processes (Tunytsya, 2002). The idea of the WEC was formally presented on behalf of the President of Ukraine at the 63rd session of the General Assembly of the United Nations in September 2008.

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Formulation of research problem

The intensive development of technology and the improvement of industrial production technology have led to a significant increase in technogenic impact both on increasing the number of catastrophic natural disasters and on the global climate change formation (Braun, et al., 2000). The adoption of the World Environmental Constitution by all the states would be an effective means of regulating and minimizing these negative processes (Tunytsya, 2002). The idea of the WEC was formally presented on behalf of the President of Ukraine at the 63rd session of the General Assembly of the United Nations in September 2008.

Timber harvesting is one of the most dangerous types of technogenic impact on the forest environment, as forest stand, young growth, natural watercourses and soil are damaged during logging and transportation. However, the degree of the negative impact of forest harvesting can be reduced to an ecologically acceptable level, and technical indicators of the use of timber-hauling transport can be brought to economically feasible values by properly assessing the intensity of the environmental risk of taking a decision on certain technical and technological decisions and the implementation of environmental management of this process.

Analysis of recent research and publications

A number of works by both Ukrainian and foreign scientists is devoted to the modeling of the forest harvesting process considering environmental risks. In particular, there are many well-known models for analyzing the profile maneuverability of timber-hauling vehicles (Suvinen, 2004; Borys, 2010), their impact on the environment (Adams, Visser Rien & Prisley, 2003), the efficiency of the road (skidding) network (Yoshimura, 2005), cost estimation of technological operations (Dykstra, 2003), or scenario planning of timber harvesting (Lutni, 1998). The disadvantage of most of them is that they relate to the operation of only certain parts of the forestry resource such as forest machines or transport network. There is also a lack of a comprehensive approach to substantiation of environmentally acceptable and at the same time economically feasible harvesting technology. But the most important thing is that none of the known models has been adapted to the forest exploitation conditions of Ukraine.

Purpose of work is to develop a GIS model that can be used as a tool for strategic (long-term) and tactical (short and medium-term) solutions in spatial planning of timber harvesting.

Main results of the study

The development of the model of forest transportation planning is a complex task. In order to solve this task, the investigated system should be divided into separate interconnected modules, each acting as its own model (Fig. 1).

The structure of the model for timber transportation planning. Timber transportation, especially in mountainous terrain, is one of the most expensive and environmentally hazardous technological operations in the production process of timber harvesting. There are three known fundamentally different ways of timber transporting technologies of mountain logging (Styranivsky & Styranivsky, 2010). They are as follows: terrestrial (skidding trails), cable ways and aerial (aircraft).

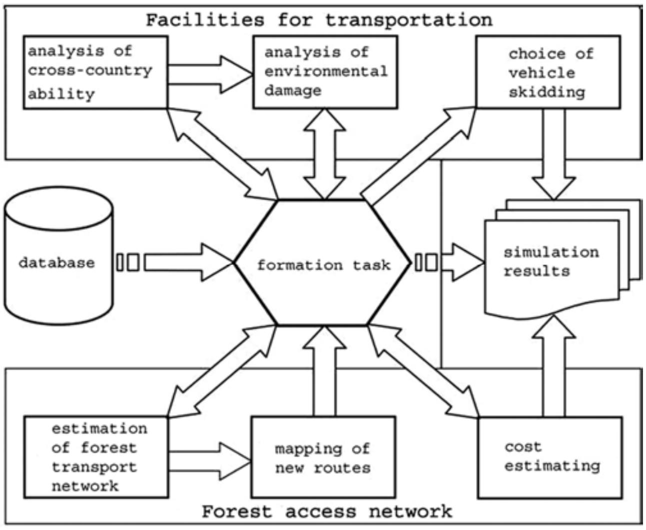

Figure 1. The conceptual model of timber transportation planning

A decision on the choice of a terrestrial type of forest machine can be taken only for a specific harvesting strategy, taking into account the maneuverability of the forest machine, the degree of its negative impact on the environment, the cost of road construction, operating costs, etc.

The main task of forest transportation planning is to decide on the possibility of using terrestrial, cable or air transportation technology for timber. We can solve this task by simulating alternative variants of transportation development of the forest area and finding an optimal concept provided that the quantitative indicators of environmental damage and the cost of timber harvesting are minimized (Bybluk, et al., 2000; Skoupy, 2000).

The Database includes digital models of items such as terrain, a forest roads network, soil conditions, as well as information on engineering structures, industrial facilities, tourist and recreational attractions, forest management data, main technical and operational parameters of forest machines, structural and technological limitations of their use, and also some options for timber harvesting strategies.

The interface of the "Formulation of the Task" module should include a set of pages where the user will be able to specify the types and parameters of existing forest vehicles, identify the forest-exploitation area, select a logging strategy and types of assessible environmental risks.

The results of modeling can be presented as a model map of environmentally acceptable and economically feasible types of forest vehicles for a given forest-exploitation area, or in the form of graphical or tabular information.

Analysis of movement possibilities. The ability of a forest machine to move off-road is determined by its maneuverability. It is one of the most important operational characteristic of a forest machine, which can be supporting and geometric. The supporting maneuverability is characterized by the strength of tractive resistance and the total traction force, which determine the ability of the machine to move in the certain road conditions. Geometric maneuverability is related to the geometric parameters of a forest machine and characterizes its ability to overcome various obstacles in the form of stumps, moans, debris, as well as the ability to maneuver among trees or pits, etc.

Most models for estimating the possibility of vehicles movement are based on the traction balance equation. As a result of the calculation, the value of the deviation, in which the process of motion reaches the boundary state, is determined based on the equality of the moving forces and tractive resistance forces.

The conclusion about the possibility of movement according to the indicators of geometric maneuverability is made on the basis of comparison of the clearance *k*, the base *B* and the width *W* of the forest machine and the parameters of the unevenness of the supporting surface (the height of the obstacle *h* and the distance between them *l*).

The process of modeling and evaluation of movement possibility of the forest machine in the given conditions of operation is described in detail in the paper (Styranivsky & Polovyj, 2008). The module "Analysis of movement possibilities" (Fig. 1) applies only to terrestrial forest machines.

Analysis of environmental damage. Geomechanical disruptions can cause the most dangerous damage to the environment as a result of mechanical timber harvesting. They can be classified into five main categories (Styranivsky, 2004) such as soil erosion, rutting, soil consolidation, slope land sliding processes, and surface damage as well.

The intensity of these damages depends to a great extent on the soil-hydrological (bearing capacity and soil surface moisture), topographical features of the terrain, the presence of surface decks (forest litter, grass cover, snow) and even the temperature of the atmospheric air. However, all these types of environmental damage indirectly depend on the ability of the soil surface to withstand external stresses from the forest engine drive without breaking or deforming, that is, counteracting the potential process of rutting formation

As the characteristic of the forest soil surface deformity, we recommend to take an equivalent E_{ekv} module of deformation and calculate the depth of the tracking rut for the multiple passage of a forest machine by using the following dependences (Borys, 2009; Styranivsky, 2014):

$$H_n = \frac{\omega \cdot p_{\max} \cdot b \cdot (1-\mu^2) \cdot (1+\chi \cdot \lg n)}{E_{ekv}}; \qquad (1)$$

$$E_{ekv} = \frac{E_g \cdot k_k}{1 - \frac{2}{\pi} \cdot \left(1 - \frac{1}{\left(\frac{E_d}{E_g \cdot k_k}\right)^{n-1}}\right) \cdot arctg\left(\frac{h_t}{D} \cdot \left(\frac{E_d}{E_g \cdot k_k}\right)^{n}\right)}, \qquad (2)$$

where p_{max} is the maximum pressure on the soil surface; E_g is the module of soil deformation; k_k is an empirical coefficient that characterizes the strengthening of the soil surface by surface decking; E_d and h_t are respectively, the deformation module and the thickness of the surface layer.

When analyzing and assessing the potential for rutting formation, it is necessary to take the size of the road clearance (the limit of the technical mobility of a forest machine) as the permissible limit in terms of economic expediency, and from the point of view of environmental safety - the depth of the damage, which corresponds to the possibility of restoring the forest environment to an environmentally sustainable state (Fig. 2).

Assessment and improvement of the existing forest road network. The level of technogenic impact on the forest environment and the cost of timber harvesting operations depend on the excellence and technical state of the forest transport network. On the one hand, a forest road, as an engineering structure, has certain ecological risks for the environment that need to be minimized in the course of its construction. On the other hand, timber transportation by forest roads with the help of forwarders will always have ecological and economic advantages compared with the skidding via timber transport routes that are primitively equipped.

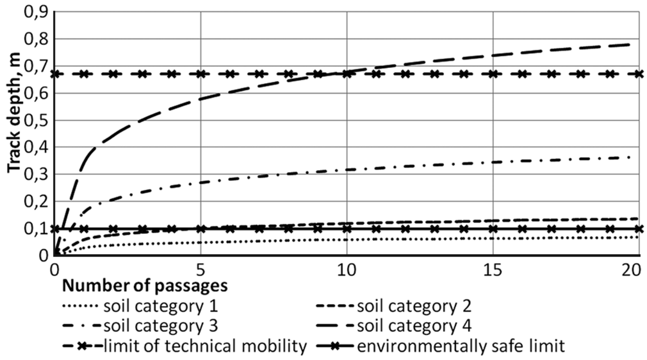

Figure 2. Dependence of the rut depth of the forwarder PONSSE ELK on the number of single trace passages in areas with different soil categories

In order to assess the existing forest road network, we have developed a special method (Styranivsky, 2005), which consists of a series of sequentially performed actions and operations aimed at identifying qualitative and quantitative indicators as well as defects of the existing infrastructure. As an assessment criterium, we have taken the indicator of the relative transport accessibility *D* (table), which is determined by the ratio of the accessible area to the total area of the forest-exploitation site. An example of assessment of transport accessibility to forest-exploitation area is shown in Fig. 3. In case of poor transport accessibility *D* < 65 %, you need to plan the expansion of the forest road network, using the procedure of automatic tracing of the forest road on a digital terrain model (Styranivsky, 2006).

Table. Assessment of Transport Assessibility to the Forest Exploitation Area

Indicators	Transport availability				
	poor	fair	average	good	excellent
Relative assessibility, %	< 55	≥ 55…65	≥ 65…75	≥ 75…85	≥ 85
Rating	1	2	3	4	5

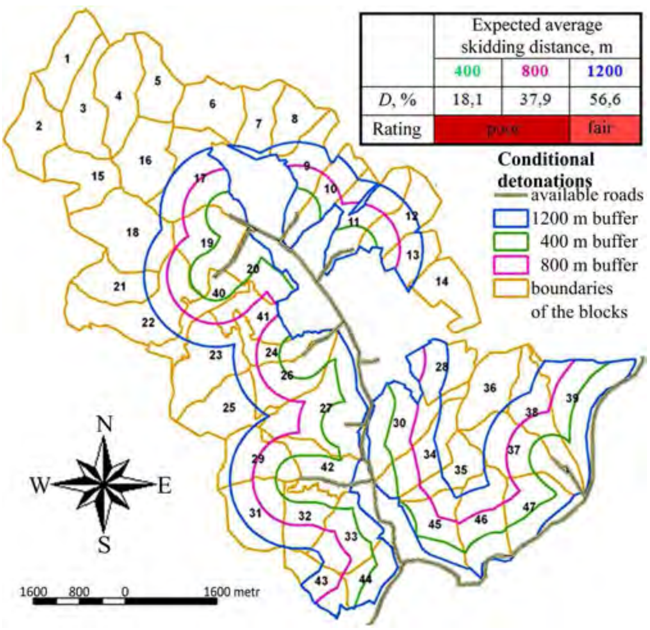

Figure 3. An example of the assessment of transport accessibility to forest-exploitation area

The main reason for the expediency of expanding the forest transport network is achieving certain economic benefits:

$$B_P \prec B_B \,, \tag{3}$$

where B_B and B_P are the cost of timber skidding, respectively, in the basic (existing) and the project (extended) forest road network.

When determining the total cost of timber skidding under the project variant of the B_P, along with the cost of timber skidding B we also take into account the cost of expanding the forest road network:

$$B_P = B + I \cdot (G_P - G_B) \cdot S + I_V \cdot l_V \,, , \tag{4}$$

where I is costs for construction and operation of 1 m of the forest road, UAH/m; G_P and G_B are density of the road network according to the project and basic variants, m/ha; S is the forest area, ha; I_V is capital costs for laying 1 m of skidroad, UAH/m; l_V is the length of skidroad, m.

Concerning the proposed model and methodology that is based on the analysis of potential environmental risks associated with the rutting formation and assessment of timber skidding, we have obtained the model map of environmentally acceptable types of timber-hauling machines (Fig. 4) for a real forest-exploitation area, the Rozhanka forest district, the Slavsk State Forestry Enterprise, in particular.

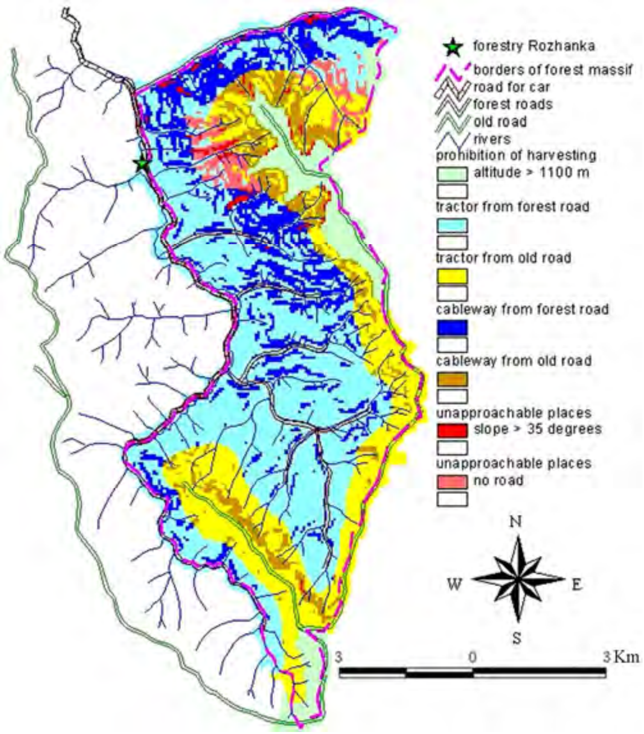

Figure 4. Model map of environmentally acceptable and economically feasible types of timber-hauling machines of the test forest-exploitation area

Conclusions

The proposed model enables substantiating environmentally safe and economically feasible ways of skidding, estimating the ratio of transport development of a forest area using various terrestrial technical means (wheeled and crawler tractors or cable systems), as well as outlining the possible occurrence, intensity and spread of environmental hazards associated with timber harvesting.

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М. Г. Адамовський, О. А. Стиранівський, М. М. Борис

Національний лісотехнічний університет України, м. Львів, Україна

ПРОСТОРОВЕ МОДЕЛЮВАННЯ ТРАНСПОРТНОГО ОСВОЄННЯ ЛІСОЕКСПЛУАТАЦІЙНОГО МАСИВУ З УРАХУВАННЯМ ПОТЕНЦІЙНИХ ЕКОЛОГІЧНИХ РИЗИКІВ

Незмінними атрибутами заготівлі деревини є низка потенційних екологічних ризиків, кожен з яких може призвести до істотних пошкоджень довкілля. Інтенсивний розвиток техніки та вдосконалення технологій матеріальних виробництв спричинили істотне зростання техногенного впливу як на збільшення катастрофічних стихійних явищ, так і на формування глобальних змін клімату. Дієвим засобом регулювання та мінімізації цих негативних процесів було б прийняття усіма державами світу Екологічної Конституції Землі. Лісозаготівельна діяльність є одним із екологічно найнебезпечніших видів техногенного впливу на лісове середовище, оскільки під час звалювання і транспортування деревини пошкоджуються деревостан, підріст, природні водотоки та ґрунт. Однак ступінь негативного впливу лісозаготівлі можна звести до екологічно прийнятного рівня, а технічні показники використання лісотранспортних засобів – до економічно доцільних значень шляхом належного оцінювання інтенсивності екологічного ризику прийняття певних технічних і технологічних рішень та здійснення екологічного управління цим процесом. У роботі наведено підходи до створення ГІС-моделі просторового планування транспортного освоєння лісоексплуатаційного масиву на основі вартісного оцінювання трелювання деревини та з урахуванням техногенного впливу лісових машин. Розроблення моделі лісотранспортного планування є комплексним завданням, для вирішення якого досліджувану систему доцільно розбити на окремі взаємопов'язані модулі, кожен із яких виступає власною моделлю: моделі для лісотранспортного планування, база даних, формування завдання, результати моделювання, аналіз можливості руху, аналіз пошкодження довкілля, оцінювання та вдосконалення наявної мережі лісових доріг. На підставі запропонованої моделі та методики, основаної на аналізі потенційних екологічних ризиків, пов'язаних з колієутворенням і вартісним оцінюванням трелювання деревини, отримано модельну карту екологічно прийнятних видів лісотранспортних засобів для реального лісоексплуатаційного масиву (Рожанське лісництво ДП "Славське лісове господарство"). Запропонована модель дає змогу обґрунтувати екологічно безпечні та економічно доцільні способи трелювання, оцінити співвідношення транспортного освоєння лісового масиву різними наземними технічними засобами (колісними і гусеничними трелювальними тракторами чи канатними системами), а також окреслити можливе виникнення, інтенсивність і поширення екологічної небезпеки, пов'язаної із заготівлею деревини.

Ключові слова: просторове моделювання; лісотранспортне освоєння; лісоексплуатаційний масив; лісова машина; екологічні ризики.

Н. Г. Адамовский, О. А. Стыранивский, Н. М. Борис

Национальный лесотехнический университет Украины, г. Львов, Украина

ПРОСТРАНСТВЕННОЕ МОДЕЛИРОВАНИЕ ТРАНСПОРТНОГО ОСВОЕНИЯ ЛЕСОЭКСПЛУАТАЦИОННОГО МАССИВА С УЧЕТОМ ПОТЕНЦИАЛЬНЫХ ЭКОЛОГИЧЕСКИХ РИСКОВ

Неизменными атрибутами заготовки древесины является ряд потенциальных экологических рисков, каждый из которых может привести к существенным повреждениям окружающей среды. Интенсивное развитие техники и совершенствование технологий материальных производств привело к существенному росту техногенного воздействия как на увеличение катастрофических стихийных явлений, так и на формирование глобальных изменений климата. Действенным средством регулирования и минимизации этих негативных процессов было бы принятие всеми государствами мира Экологической Конституции Земли. Лесозаготовительная деятельность является одним из экологически опасных видов техногенного воздействия на лесную среду, поскольку во время валки и транспортировки древесины повреждаются древостой, подрост, природные водотоки и почва. Однако степень негативного воздействия лесозаготовки можно свести к экологически приемлемому уровню, а технические показатели использования лесотранспортных средств – к экономически целесообразным значениям путем надлежащего оценивания интенсивности экологического риска принятия определенных технических и технологических решений и осуществления экологического управления этим процессом. В работе приведены подходы к созданию ГИС-модели пространственного планирования транспортного освоения лесоэксплуатационного массива на основе стоимостного оценивания трелевки древесины и с учетом техногенного воздействия лесных машин. Разработка модели лесотранспортного планирования является комплексной задачей, для решения которой исследуемую систему целесообразно разбить на отдельные взаимосвязанные модули, каждый из которых выступает собственной моделью: модели для лесотранспортного планирования, база данных, формирование задания, результаты моделирования, анализ возможности движения, анализ повреждения окружающей среды, оценка и совершенствование имеющейся сети лесных дорог. На основании предложенной модели и методики, основанной на анализе потенциальных экологических рисков, связанных с колееобразованием и стоимостной оценкой трелевки древесины, получена модельная карта экологически приемлемых видов лесотранспортных средств для реального лесоэксплуатационного массива (Рожанское лесничество ГП "Славское лесное хозяйство"). Предложенная модель позволяет обосновать экологически безопасные и экономически целесообразные способы трелевки, оценить соотношение транспортного освоения лесного массива различными наземными техническими средствами (колесными и гусеничными трелевочными тракторами или канатными системами), а также очертить возможное возникновение, интенсивность и распространение экологической опасности, связанной с заготовкой древесины.

Ключевые слова: пространственное моделирование; лесотранспортное освоение; лесоэксплуатационный массив; лесная машина; экологические риски.