REDUCING INDUSTRIAL IMPACT ON FOREST ECOSYSTEMS BY IMPROVING THE ORGANIZATION OF HARVESTING OPERATIONS

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Abstract: *Forest industry has a direct impact on natural environment, therefore, when setting technological requirements for forest machines an engineer should take into account the environmental implication of future operations. This problem is actual and still unsolved, mostly due to limited knowledge on quantitative estimation methods related to the evaluation of environmental impact. Hence, in this study we made a simulation of forest operations technology enhancement. The aim was to increase the harvesting system output up to the leading machine capacity level to decrease the harvesting time. Using the simulating analysis, this study implements the numerical estimation of impact caused by harvesting machines on the forest ecosystems. In particular, our results indicate that the absolute reduction of carbon oxide (CO) as percentage of machines' emission during the time was 8 to 21% depending on the yearly harvested volume.*

Key words: *forest ecosystems, impact, emissions, exhaust noxae, set of machines, harvesting system, operating modes.*

1. Introduction

Timber harvesting operations are carried out outdoor. Therefore, natural factors directly affect the workers and machines. In addition, operations are territorially dispersed so the equipment often moves from one site to other. In turn, sites are characterized by a variety of natural conditions which cause variabilities in machines' output. Harvesting operations are carried-out by the use of various harvesting systems (HS) that are further characterized by a different organization of machines and tools within each system.

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In the last decades, the problem of harvesting operations impact on the forest ecosystems in clear and selective cutting has become a key factor in the design and work organization of new machines. Ways of decreasing the negative effect of machines on the forests are detailed in the scientific literature [1], [2], [3], [4], [5], [6], [7].

The machines used in forest operations affect the natural environment directly. When designing new machines, their engineering should consider the environmental impact caused by their operation. This problem is still unsolved due to the absence of a technique able to quantitatively estimate the machinery impact [5].

Authors of the work [1] suggest the division of environmental impact into four groups: stem and root collar damages (bark stripping and breaking, limbing, crone fraying and breaking); root damages (visible and invisible breaks, bark stripping); mantle soil damage (soil compaction resulting in reduced capacity of feeding, rutting and erosion); pollution of forest ecosystem by fuel, oil and exhaust.

The factors characterizing the machinery impact on forest ecosystems are also supposed to be divided into four basic groups: natural and climatic, work organization, technological and structural.

The first group contains factors that are less controllable, being caused by the nature. The rest are caused by human activity.

Among the work organization factors are the choice of forest compartment, harvesting systems and the definition of optimal parameters for the machines' operation to ensure a maximal labor productivity and the extraction of timber in the allocated time. Apart from that, there are other factors that should be taken into account, such as personnel qualification, form and level of payment and the quality control in operations.

This paper describes a methodological concept to define the optimal parameters for the HS operation which to provide the maximal effectiveness of work, with minimal costs, minimal operation time, contributing this way to limitation of the HS negative impact decreasing.

2. Materials and Methods

2.1. Suggestions for Process Improvement

Analysis of the forest machinery performance shows that it is practically impossible to design that timber harvesting system, which can provide the same effectiveness in each harvesting operation. It is well known, that the workload disbalance causes non-productive periods of the most productive machines in the HS and therefore decrement of the total volume of harvested wood, down to the level of less productive operation. In turn, it causes the increment of the harvesting period and of the operation costs.

To increase the harvested wood volume up to the most productive (leading machine) machines' productivity level Q_{max} and to reduce the operational time and operating costs, we suggest to increase the number of machines and/or shift-working arrangements for one or more machines performing the operation i and for which $Q_i < Q_{max}$.

In theory, all harvesting operations may be seen as being connected together in a technical sense by buffer wood stocks. For

the operational planning and management of wood stocks, we have suggested the mathematical models and computer software, which allows planning the time of stock resupply, consumption and runout for different sets of machines in various operating conditions [9].

These models allow the calculation of the optimal operating modes for given HSs, providing the maximal amount of work together with minimal operation costs, by using additional equipment on slow operations. The organization of harvesting operations by controlling the number of machines and/or shift-working arrangements in slow operations and by considering the calculated level of buffer wood stocks, provides the maximal volume of harvested timber. This results in the reduction of harvesting period, together with reduction of operation costs and of the negative impact to forest ecosystems takes place.

2.2. Estimation of Impact on Forest Ecosystems. Technique and the Calculation Sample

The HS taken into study included one LP-19 feller-buncher, two LT-154 skidders and one LP-33A tree length delimber. The skidding distance was of 300 meters and the stem volume was of 0.22-0.29 cubic meters. According to [10], the maximal and minimal labor productivities on logging operations are of 174 m^3 and 123 m^3 per day respectively. The difference between the greatest and lowest productivity levels (or in other words the potential for productivity rate increment) is 51 m^3 per day. Moreover, depending on the average stem volume, it may be of up to 95 m^3 per day (Table 1).

Changes in the working shifts and/or in the number of machines of the HS causes a decrement in the number of working days needed to carry on the harvesting operations (Table 2). Decrement in terms of number of days is defined as the difference between the number of working days under the conditions of maximal and minimal HS daily output in the felling block (Table 2).

$$D_{st} = D_{max} - D_{min} , \qquad (1)$$

where: D_{max}, D_{min} are number of days needed to complete the harvesting under the conditions of maximal and minimal LSM daily output respectively.

Table 1

Standard HS daily output and output increment depending on the average stem volume

| Average Stem Volume (q_{sv}) m^3 | HS output, m^3/day | | | | | HS output increment | |
| | Standard | | | Output | | | |
	LP-19 (1 machine)	LT-154 (2 machines)	LP-33A (1 machine)	P_{max}	P_{min}	m^3/day	%
0.22-0.29	165	174	123	174	123	51	41.5
0.30-0.39	195	200	144	200	144	56	38.9
0.40-0.49	225	218	163	225	163	62	38.0
0.50-0.75	265	234	190	265	190	75	39.5
0,76-1,10	310	248	223	310	223	87	39.0
≥ 1.1	355	264	260	355	260	95	36.5

Also, it is important to keep the buffer bunks at the level calculated for the conditions specific to the site and by taking into account the additional machines involved in the slowest operation. This allows to increase the daily HS output up to 40% (Table 1) or to decrease the harvesting period by 30% (Table 2).

Table 2

Decrease of harvesting period depending on the annual output and average stem volume

Annual output volume, th. m³	Decrease of harvesting period (days) depending on the average stem volume (m³)					
	$q_{sv}=$ 0.2-0.29	$q_{sv}=$ 0.3-0.39	$q_{sv}=$ 0.4-0.49	$q_{sv}=$ 0.5-0.75	$q_{sv} =$ 0.76-1.0	$q_{sv} >1,1$
12	28	23	21	18	16	12
14	34	27	24	21	18	14
16	38	31	27	24	20	16
18	43	35	30	27	23	18
20	48	39	34	30	25	21
22	53	43	37	33	28	23
24	57	47	40	35	30	25
26	62	51	44	39	33	27
28	67	54	48	41	36	29
30	72	58	51	45	38	30

To this end, the reduction of harvesting period causes a reduction of the forest machinery negative impact on forest ecosystems. This decrease can be achieved by controlling some factors. First, the exhaust of harmful substances (CO, HO, CH) into the atmosphere decreases. Secondly, the extra-time needed for repairing and maintenance of machines would be lower, with obvious positive effects in terms of environmental impact. This subject is insufficiently studied yet and its results are not used in practice. Therefore, our goal was to suggest an approach to calculate, quantify and implement the forest machinery negative impact and its reduction based on the HSs optimal operating modes. This allows reducing the negative effect of HSs the forest ecosystems in various labor conditions.

The core of the suggested technique is as follows. The volume of toxic emissions released into the atmosphere by forest machines exhaust can be defined using the formula:

$$V_{BD} = \sum qsji \cdot N_{eji} \cdot n_{ji} \cdot D_d \cdot T_{sh} \cdot k_{ji} , \quad (2)$$

where:
   q_{sji} is the specific ratio of toxic element s exhaust, mg/hr, by machine type j in operation i;
   N_{eji} – engine power of machine type j in operation i, kW;
   n_{ji} – number of machines of type j at operation i;
   D_{ji} – number of working days for machine of type j in operation i;
   k_{ji} – shift factor of machine type j in operation i;
   T_{sh} – shift duration, hours.

The reduction level of negative impact caused by HSs can be estimated by the formula:

$$V_{BD} = \sum q_{sji} \cdot N_{eji} \cdot n_{ji} \cdot D_d \cdot T_{sh} \cdot k_{ji} , \quad (3)$$

where: D_d is the number of days by which the harvesting operations decreased at felling site.

Time needed to carry on harvesting operations is decreased due to reduction of the number of machines and their shift factor in slow operations. Therefore, during their operations, an additional amount of toxic agents will be exhausted into the atmosphere. Its volume can be calculated as follows:

$$V_{BS}^{(a)} = \sum q_{sji} \cdot N_{eji}^{(a)} \cdot n_{ji}^{(a)} \cdot D_d^{(a)} \cdot T_{sh} \cdot k_{ji}^{(a)} , \quad (4)$$

where:

$N_{eji}^{(a)}$ is the engine power of additional j-type machine in operation i;

$n_{ji}^{(a)}$ – number (as a rule $n_{ji}^{(a)}=1$) of additional j-type machines in operation i;

$D_{ji}^{(a)}$ – number of working days for j-type machine in operation i, which can be calculated using the technique [4];

$k_{ji}^{(a)}$ – shift factor (as a rule $k_{ji}^{(∂)} = 1$) of additional machine type j in operation i.

The number of working days D_{ij}^a for the additional j-type machines in operation i for all of the harvesting period can be defined as the product of the working time (t_{ij}) of these machines (calculated using the technique [9]) in each month and the number of months (n_m) of harvesting period:

$$D_{ji}^{(a)} = t_{ji} * n_m , \quad (5)$$

If the working time (t_{ji}) of additional machines in each month are not equal, we calculate the number of working days ($D_{ji}^{(a)}$) for additional machines as a sum of working time of each machine.

The number of months for harvesting can be defined as a quotient of the stand timber Q_V by the volume of harvested timber in each month $Q_m=Q_{max} *T_n$:

$$n_M = \frac{Q_V}{Q_M} , \quad (6)$$

where: T_n is the number of working days per month.

Therefore, the absolute reduction of the number of toxic agents - s exhaust can be calculated using formula:

$$V_{BS}^{(a)} = V_{BS} - V_{BS}^{(∂)}. \quad (7)$$

The results of calculations for toxic agents (ex. CO) exhaust, depending on enterprise annual output and average stem volume are presented in Figure 1. The specific ratio of CO exhaust reduction (as a percentage over the total exhaust volume) is shown in Figure 2.

The preserved from destruction forestland square depends on the number of days on which the site development period is decreased. It also depends on the LMS daily output and the average standing timber per hectare:

$$S_p = \frac{Q_{max} \cdot D_{st}}{g_{av}} \cdot K_{st} , \quad (8)$$

where:

g_{av} – average standing timber volume, m³/ha;

K_{st} – rate of saved utilization time.

The calculations of preserved from destruction forestland square depending on annual output and average stem volume are presented in Table 3.
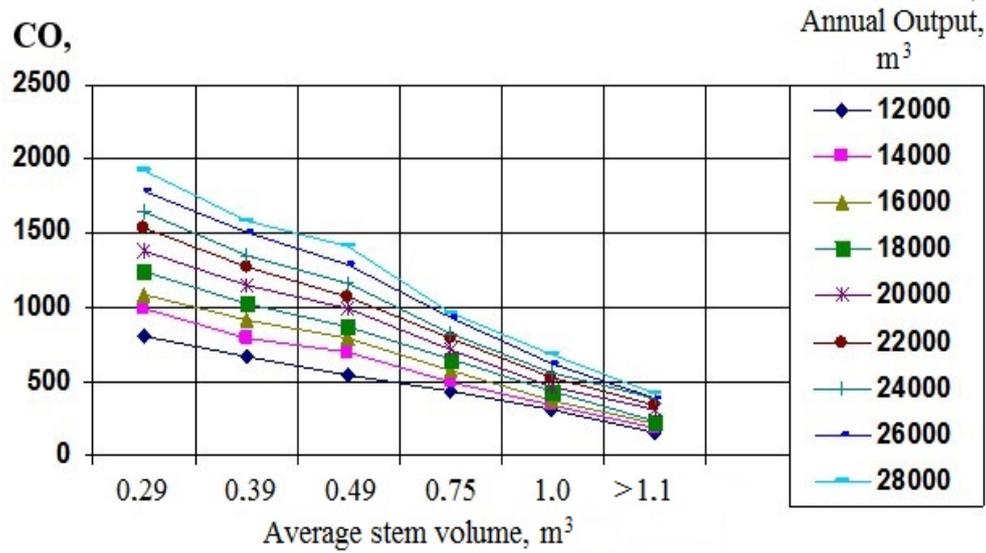
Fig. 1. *Absolute toxic agents (CO) exhaust reduction depending on enterprise annual output and the average stem volume values*
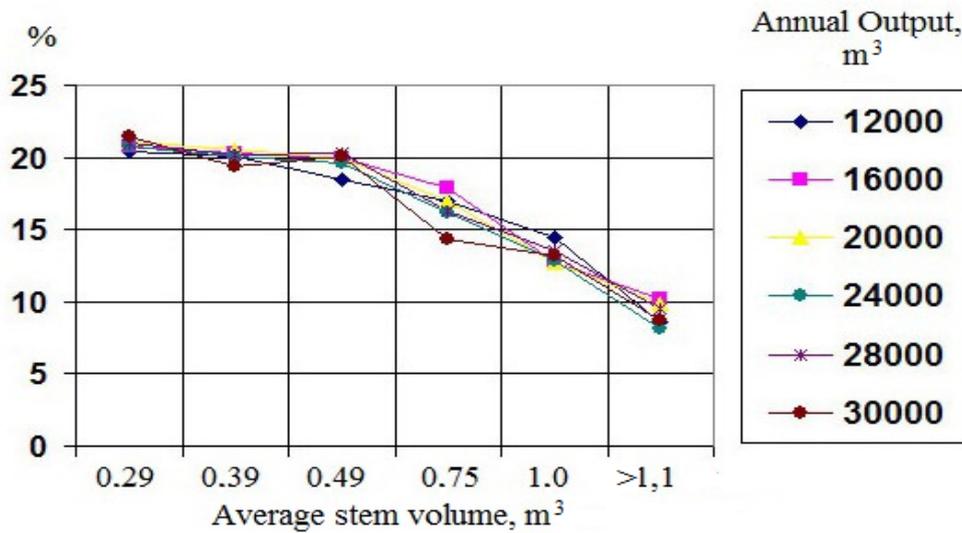
Fig. 2. *Specific ratio of toxic agents (CO) reduction, depending on enterprise annual output and average stem volume values*

Table 3

Forestlands preserved from destruction, depending on enterprise output and stem volume [min-max values]

q_{sv}, m^3	Forestland preserved from destruction, ha								
	12000	14000	16000	18000	20000	22000	24000	26000	28000
0.22-0.29	4.0-41	4,9-49	5.5-55	6.2-62	6.9-69	7.7-77	8.3-83	9.0-90	9.7-97
0.3-0.39	3.8-38	4,5-45	5.1-51	5.8-58	6.5-65	7.2-72	8.5-85	8.5-85	9.0-90
0.4-0.49	3.9-39	4,5-45	5.1-51	5.5-56	6.4-64	6.9-69	8.2-82	8.2-82	9.0-90
0.5-0.75	4.0-40	4,6-46	5.3-53	6.0-60	6.6-66	7.3-73	8.6-86	8.6-86	9.0-90
0.76-1.0	4.1-41	4,6-46	5.2-52	5.9-59	6.6-65	7.2-72	8.5-85	8.5-85	9.3-93
≥ 1,1	3.6-36	4,4-44	5.0-50	5.3-53	6.2-62	6.8-68	8.0-80	8.0-80	8.6-86

3. Results and Discussion

Figure 2 shows that CO exhaust decreases by 8-21% of the total amount. For the average stem volume between 0.22-0.29 m^3, this value was within the 20-21% limits and for $q_{sv} \geq 1.1$ m^3, the exhaust decreased at 8-10%. For equal values of the stem volume, the decrease of toxic agents' emission changes insignificantly. At the same time, increment of the average stem volume caused reduction of the toxic emissions more than twice.

The dependence shown in Figure 2 is linear. It emphasizes that the increment of enterprise productive capacity (or annual output) causes the increment of toxic emissions produced by machinery. On the contrary, the increment of average stem volume causes decrements in terms of emissions. These results from the fact that, in the former case, the number of days needed for harvesting was also increased, while in the latter case, it was decreased (Table 2).

Data given in Table 3 shows that even at minimal rates of time utilization the forestlands preserved from destructions reach considerable sizes (from 4 to 10 ha).

4. Conclusions

The described technique of HS work organization undergoes now the practical approbation at the logging companies of the Bryansk region of Russia. It already began to payoff. The application of optimal HS operating modes allows reducing the harvesting period. In turn, this enables a reduction of fuel consumption by 10-15% therefore reduction of toxic emissions by 5-10%. Obviously, the expansion of described method's practical area of application offers the opportunity to greatly reduce the level of HS technogenic impact on forest ecosystems.

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