Ways of Conservation the Natural Environment and the Intensification of Logging Round Timber

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Abstract. The ways of working, schemes and parameters of machine systems for harvesting, round timber that provide for sustainable forest management by preserving the productivity of the forest environment, increasing productivity and reducing energy consumption are considered.

1. Introduction

The efficiency of timber harvesting is determined by the criteria of sustainable forest management, conservation of forest productivity, productivity, specific energy intensity and is provided by controlling the ways in which the machines operate in logging systems, their operation schemes, parametric picking and rational distribution of operations [1],[2]. Intensification in this context means improvement of the criteria by factors of management under certain conditions (natural and production conditions) of wood harvesting technology and regulatory restrictions in accordance with the rules of timber harvesting in the Russian Federation. The purpose of the work is to identify, structure and formalize the factors ensuring sustainable management of forests through the preservation of the natural environment, as well as to increase the efficiency of sets of machines "harvester-forwarder" kits in Russia. In connection with the above, the following problems are solved. The development and analysis of the ways of preparing the round timber ensuring synchronization of the machines in a set, preservation of the undergrowth, trees for growing and soil, improving productivity and reducing energy intensity, as well as industrial approbation of methods on the basis of experimental logging in the form of dynamic experiments. Management factors are justified in the form of: procurement methods, schemes, machine parameters in the set and distribution information-sorting operations between the machines in the set. A classification of sorting methods based on morphological analysis has been developed in the context of increasing the loading of the "harvester-forwarder" machine system. The methodological basis of the research was determined by a systematic approach that combines the theory of industrial active and passive, static and dynamical experiments, morphological analysis, probability theory and mathematical statistics, calculus of variations, and the theory of optimal control in application to objects of research. The operating factors providing achievement of a goal are considered in the article. Let us consider them in detail.

2. Management of logging methods

The creation of ways of harvesting wood with sets of machines "harvester forwarder" is based on placement and (or) combining technical functions (processing and relocating) in the space-time of
changing the state of the object of labor from the initial (forest site, standing tree) to the final (round timber, sawn timber, etc.). The theory of optimal placement (combination) of technical functions of logging is based on the calculus of variations, the theory of optimal control and is presented in [3], [4].

Figure 1. Technological scheme of harvesting round timber by the method according to the RF patent No. 2365093 (a is the roll of the tree standing in front of the machine, b is the roll of the tree standing behind the machine): 1 - harvester; 2 - fiber; 3 - standing trees; 4 - harvester manipulator; 5 - the fallen down tree; 6 - staddle; 7 - bundles of round timber; 8 - felling residues.

Let us consider practical applications of research results on the basis of this theory in the form of RF patents [5], [6]. Harvesting of round timber by this method is carried out as follows. Harvester 1 performs tree-felling 3 forward (Figure 1, a) or back (Figure 1, b) at an angle to the drawing 2, which provides a directed roll by a vertex to the fiber. In addition, when felling, the end part of the tree rises above the ground with the manipulator of the 4 harvester. After the swath, the raised part of the fallen tree 5 raised above the ground is transferred to the logway line in such a way as to provide a compact arrangement of the round timber in the packs 7 outside the growth counterparts 6. In the case that the transfer of the root part of the fallen tree along the direction to the logway line is not sufficient to observe the specified conditions, the moving of the harvester is carried out and the tree is dragged along the logway. Then, pruning and severing are performed. In this case, the branches and apexes 8 are located on the machine.

The survey results showed (see table 1 and figure 2) that the roll of the vertex on the fiber without landing of the butt of the tree, as well as the compact arrangement of the round timber, taking into account the location of the cutouts of the coniferous youngsters, while harvesting the round timber by this method, provides almost complete preservation coniferous growth in apiaries outside technological corridors. In addition, the roll on top of the fiber provides the concentration of all felling residues on the machine, which allows to reduce soil compaction and to eliminate its stagnant over moistening. Analysis of the results of the synchronization study and the energy intensity of the technological process of harvesting and processing of wood indicated by this method showed that the reduction in the fuel consumption of the harvester when operating by the new method is on average 0.048 kg / m3 in comparison with the traditional method [4],[7]. By the traditional method is meant a method with felling of trees and laying of burdens perpendicular to the dredge, dragging the top of the treated tree during trimming and bending over the parcel, area not occupied by technological corridors.

The above method is the same as for the RF patent 2467559, which differs only in that it ensures the integrity of individual valuable trees in any tier and their group and trees of the second tier of economically valuable species for solid felling. To assess the effectiveness of methods in the framework of the Federal Target Program "Scientific and Scientific Pedagogical Staff of Innovative Russia" for 2009-2013 pilot-industrial logging was performed [7],[8] with a survey of the natural renewal of the forest under the canopy and after cutting.
**Table 1.** Conservation of staddle after logging by the traditional method and method according to the RF patent No. 2365093. (%) 

| Preservation rate (%) | After harvesting the wood, in a traditional way | After harvesting the wood by the method according to the RF patent No. 2365093 | The difference |
|-----------------------|-----------------------------------------------|---------------------------------------------------------------------------|---------------|
| Preservation of staddle | 43 | 67 | 24 |
| Preservation of coniferous staddle | 42 | 78 | 36 |
| Preservation of staddle outside the technological corridors | 54 | 82 | 28 |
| Preservation of coniferous staddle outside the technological corridors | 54 | 96 | 42 |
| Preservation of viable coniferous staddle | 37 | 79 | 42 |
| Preservation of doubtful coniferous staddle | 54 | 76 | 22 |
| Preservation of unviable coniferous staddle | 58 | 77 | 19 |
| Preservation of viable coniferous staddle outside of technological corridors | 47 | 96 | 49 |
| Preservation of dubious coniferous staddle outside the technological corridors | 76 | 98 | 22 |
| Preservation of unviable coniferous staddle outside the technological corridors | 71 | 96 | 25 |

*Source: OPTIMALLY FUNCTIONAL SYNCHRONIZED TRANS-PORT-PROCESSING SYSTEMS AND MANAGEMENT OF THEM 2011. Yakimovich S B Yakimovich K S Teterina M A Voldaev M N Shemyakin A V Efimov Yu V Minai A Ya Belov A I Stolyarov A M and Gruzdev V V. Report on research, Stage 2, No. 16.740.11.0518 dated May 16, 2011, (Ministry of Education and Science of the Russian Federation, Federal Target Program "Scientific and Scientific Pedagogical Staff of Innovative Russia" for 2009-2013, Activity No. 1.2.1. scientific research by scientific groups under the supervision of doctors of sciences). https://library.ru/item.asp?id=26665768

3. Schema management
One of the determining factors for preserving the productivity of the forest environment and the biological diversity of forest ecosystems during logging is the reduction in the area share of technological
corridors in the total area of the logging site. Scheme with a rectilinear auxiliary corridor (Figure 3), [9] allows to reduce the total length of the main technological corridors (logway) in the felling area, on which only the harvester works. The forwarder, which determines the bulk of damage to the soil, stands and the remaining left forest stand, works only on the main technology corridors. When the harvester develops an auxiliary corridor, as well as the main one, the whole cycle of operations is carried out: felling, pruning, bucking and bunching - however, the bundles of sorts are stacked at the maximum distance from the machine. This ensures the availability of packs formed by the harvester for the forwarder's manipulator moving along the main technological corridors while collecting round timber.

![Figure 3. Technological scheme of harvesting round timber with an auxiliary corridor: 1- Harvester route along main technological corridors and auxiliary corridor; 2 - the boundaries of the main technological corridor; 3 - borders of apiaries; 4 - bundles of round timber, formed during the development of the parcel, of the main technological corridor; 5 - bundles of round timber, formed during the development of the parcel, by means of an additional single pass of the harvester along the auxiliary corridor.](image)

The variant with two auxiliary corridors (Figure 4) [9], on which only the harvester also works, allows further reducing the overall length of the main technological corridors in the cutting area. Under this scheme, the main technological corridors are located at a distance of 4 to 5 effective outreach of the manipulator. In the auxiliary corridors, on which only a harvester works, the manipulator of this harvester sorts are stacked in packs in such a way that they are reachable for the forwarder's manipulator while moving along the main technological corridors.

The scheme of harvesting round timber with entrance on semi-parcel, and an auxiliary corridor (Figure 5) increases the distance between the main technological corridors to 5 effective outreachs of the manipulator R and provides a reduction in the area of the technological corridors by 3% compared with the traditional scheme. The technology of the harvester’s work is determined by the presence of a sinusoidal auxiliary corridor 2, through which only the harvester moves. The round timber harvested on the auxiliary corridor 2 are shifted by the harvester to the area of reach for the forwarder's manipulator to the main technological corridors 1 and entrance to the semi-parcel 6. Entrance to semi-parcel are performed as harvester during the harvesting of round timber, and the forwarder - during their collection. The results of the method described in [9], a comparative evaluation of some of the presented schemes on the criteria of the share of the area of technological corridors and productivity are given in table 2. Negative values in column 6 table 2 characterize the reduction of harvester’s productivity, which is caused by the need to shift the round timber to the availability zone of the forwarder's manipulator while the harvester is working in the auxiliary corridors. However, at the same time, the forwarder productivity is increased due to the increase in the round timber concentration in the access zone of the manipulator and the reduction of the collection time.

The foregoing determines the efficient work of the system of machines, in the sense of a system approach, as by means of synchronization and maximum loading of machines in the system by appropriate schemes and methods are ensured. The most effective method is with two auxiliary corridors (Figure 4), as it provides the most significant decrease in the area of technological corridors and the
highest concentration of round timber in the technological corridors, which does not exclude the possibility of effective use and other considerations methods.

**Figure 4.** Technological scheme of harvesting round timber with two auxiliary corridors: 1 - Harvester route along main technological corridors and auxiliary corridor; 2 - boundary of the dredge; 3 - borders of apiaries; 4 - bundles of round timber, formed during the development of the parcel, of the main technological corridor; 5 - bundles of round timber formed during the development of the parcel, by means of an additional single pass of the harvester along the auxiliary corridor.

**Figure 5.** Technological scheme of harvesting round timber with harvester and forwarder entrance to semi-parcel and auxiliary corridor: 1 - main technological corridors; 2 - auxiliary corridor; 3 - bundles of round timber, formed during the development of the parcel, through the main technological corridor; 4 - harvester; 5 - bundles of round timber, formed during the development of the parcel, by means of an additional single pass of the harvester along the auxiliary corridor; 6 - semi-parcel.

**Table 2.** The results of the comparative evaluation of technological schemes.

| Technological scheme | Effective outreach of the harvester's manipulator (m) | Share of technological corridors in the total area of the logging block (%) | Hourly productivity, harvester, m³/h | The difference between the shares of technological corridors in the total area of the logging block compared to the traditional scheme (%) | The difference in the hourly productivity of the harvester compared to the traditional scheme (%) |
|----------------------|-----------------------------------------------------|-------------------------------------------------|-----------------------------------|--------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| With entrance on semi-parcel and an auxiliary corridor (Figure 5). | R=10 | 22 | 21,14 | -3 | -12,91 |
| With the 1st auxiliary corridor (Figure 3) | R=8 | 25 | 34,0 | -6,25 | -0,1 |
| | R=10 | 20 | 28,61 | -5 | -5,44 |
| With 2 auxiliary corridors (Figure 4) | R=8 | 20,8 | 29,41 | -10,45 | -4,61 |
| | R=10 | 17 | 28,5 | -8 | -5,55 |

*Source: (Hertz, EF, Mekhrentsev, AV, Yakimovich, SB (2012)*
4. Management of system parameters

The preservation of the natural environment and the synchronization of machines in the systems for the preparation of round timber is provided by the management not only of technological schemes and methods of operation of machines, but also parameters (the forwarder's load capacity, the productivity of the harvester, etc.). This allows, in turn, to reduce the energy intensity of the systems, to exclude the presence of surplus reserves in adjacent operations of the technological process, to get rid of excess expenditures out of idle production equipment. An analysis of the results of solving synchronization problems for the "harvester-forwarder" system indicates that the management of such a factor as the forwarder's trip loading provides an average reduction of system downtime by 40%. In particular, for logging sites with a forest reserve of 200 m³/ha and an average distance of skidding of 500 m with traditional technology, the optimum trip loading of the forwarder is 27 m³. In addition, the recommended parameters based on the solution of the synchronization problems of the "harvester-forwarder" system ensure a reduction in fuel consumption by an average of 0.053 kg/min. [4].

The energy efficiency of the considered ways of round timber logging, except the conditions of synchronization, is also determined by the elimination of additional unproductive movements of machines and their working details, as well as the conservation of soil, staddle and young trees. In this regard, the least energy-efficient and environment-friendly method is the method with entrance to the semi-parcel (Figure 5), as during the entrance the fuel is also used to reverse the idling of the harvester and the environmental elements in the additional technological corridors are damaged.

5. Managing the distribution of the sort operation between the harvester and the forwarder in the system

5.1. The value of the sorting operation and its distribution among machines in systems for preserving the natural environment and increasing productivity

One of the directions of the preservation of the natural environment and resource-saving in the procurement of round timber is the improvement of technology for sorting and packaging them. The problem of increasing the efficiency of sorting and packaging of wood by manipulating machines in the lower timber industrial warehouses was considered quite a long time ago [10],[11],[12],[13],[14]. However, the possibilities of preserving the natural environment and synchronizing machines in the round timber harvesting systems [4] based on the justification of the sorting technology were not considered. At the same time, for example, the management of the placement of sorting operations in the area of the parcel and the appropriate intensities of obtaining and transporting round timber will increase the safety of saddle by 20% the young trees almost completely and will provide synchronization with increasing the system’s load factor. In order to justify the most effective sorting technologies for round timber, it is necessary to carry out morphological analysis and develop a classification of the appropriate operations. The effect of increasing the system’s loading as a whole is due to the redistribution of round timber sorting from a more loaded machine to a less loaded one. To assess the effectiveness of this management factor, industrial experiments on leased forest sites of the PPPM group of companies (Perm Region) are planned. However, for the successful carrying out of experiments, it is necessary correctly identify the influencing factors and sorting characteristics and then classifying them.

5.2. Morphological analysis and classification development

Identified during the morphological analysis of sorting characteristics are presented in table 3.
### Table 3. Classification signs of sorting operations when harvesting round timber.

| Signs                              | Variants of signs                                                                 | Characteristics of the variants                                                                 |
|------------------------------------|-----------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| 1. Placement of the sorting operation | 1.1. In space (round timber orientation when sorting)                            | 1.1.1. In three-dimensional space                                                                |
|                                    | 1.2. In time (combination of functions) and in the place of sorting              | 1.2.1. In the process of felling                                                                |
|                                    | 1.3. Machine performing the operation                                            | 1.3.1. Harvester                                                                                |
| 2. Sorting type                    | 2.1. By featured                                                                  | 2.1.1. By size and quality groups                                                               |
|                                    | 2.2. By capture method                                                           | 2.2.1. Piece                                                                                   |
| 3. Method of laying or landing     | 3.1. Gravitational, self-attack of round timber under the influence of gravity    | 3.1.1. Without alignment (bunch, in a bunk)                                                     |
|                                    | 3.2. Forced laying                                                               | 3.2.1. Without alignment (bunch, in a bunk)                                                     |
| 4. Sorting devices                 | 4.1. Types of Forwarder Devices                                                  | 4.1.1. Grapple                                                                                 |
|                                    | 4.2. Types of harvester devices                                                  | 4.2.1. Harvesting head                                                                         |

When sorting with the harvester, the place and compactness of the placement of the round timber groups largely determine the preservation of the natural environment and the productivity of the forwarder. For example, when stacking groups of round timber on a belt, in order to shorten the time of collection of a pack by a fork-maker, it is necessary to ensure a sufficient number of round timber in the group and their location as close as possible to the drawing. Here we can distinguish a contradiction: the harvester puts the round timber according to their own priorities - the productivity of the harvester is higher - the forwarder is lower, and vice versa. The most compact arrangement of round timber provides less damage to the soil surface and staddle. The limiting method of placing the degree
of minimizing the impact on the natural environment is in the vertical position in the coordinates of standing trees.

Schemes with additional corridors for the harvester. With this sorting method, the round timber of the corresponding size-quality groups are shifted by the harvester to the borders of the apiaries, which are located on opposite sides of the longitudinal axis of the logway. In this regard, the productivity of the harvester is reduced, but the preservation of the natural environment is enhanced. The forwarder's performance is increased on the contrary due to the exclusion of the sort operation. Thus, this sorting method is a very effective means of synchronizing machines and preserving the natural environment.

Proceeding from the foregoing, the developed classification of sorting operations in the procurement of round timber ensures the allocation of techniques that preserve the natural environment. Managing the ways and placement of sorting operations is a means of synchronizing machines in the logging systems to improve the efficient operation of the “harvester – forwarder” system.

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