Digital simulation of forest multioperation machine operation

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Abstract. In this article, an innovating multi-operational forest machine (MOFM) is proposed. MOFM is based on the tractor processor (TP) and it is planned for bucking trees and making bundles from waste wood. The article presents the results of digital simulation experiments with MOFM compared with TP. The article gives the results of modelling of forests with a reserve of 150 m³/ha and with an average volume of tree trunk volume 0.40 m³. In the article, the length of the winch rope is assumed from 10 to 30 m. Experiments were performed for different technology options. When working in parallel operations of the MOFM and winch, productivity increases with increasing skidding distance. Productivity increases until the skidding cycle time is less than the MOFM cycle time. After that, MOFM productivity decreases. For our case, the optimal skidding distance is close to 25 m. The length of the queue of trees to MOFM is increased as the skidding distance increases. The queue length stops growing when the skidding distance is 25-30 m. Digital simulation models were realized as computer programs. These models allow you to choose rational MOFM parameters for different forest characteristics.

1. Introduction

Logging includes the operation of felling trees with their subsequent operations of the delimbing-bucking them into assortments.

On these technological operations today various machines are used. For example, tractor processors (TP) are used (figure 1) [1]. Such TP are equipped with delimbing-bucking devices, which are aggregated with inexpensive general-purpose tractors. Depending on the technology and type of logging, the TP can be additionally equipped with a winch, a manipulator with a grip and a cutting mechanism.

The main advantage of TP is their relatively low price compared to harvesters. Another advantage is the low qualification requirements to the operator. TP are especially effective on low-volume forest harvesting, on sanitary felling and various types of care felling.

The disadvantages of TP, as well as many other logging machines, includes the fact that they do not solve the problem of utilization of logging residues. The TP drops branches, twigs and tops directly in front of the delimbing-bucking device. After one or two processed trees, a heap of logging residues is formed, which makes it difficult to load next trees into the delimbing-bucking device. It takes time to clean up the logging residues, which reduces the productivity of the TP.

In this article, we propose an innovating multi-operational forest machine (MOFM) [2], which allows not only to perform delimbing-bucking operations, but also to pack logging residues into bundles for the needs of bioenergy [3-12].
For these purposes, we propose to additionally equip the TP with a packet-forming (bundling) device (figure 2). This device includes a receiving table with a pressing device. The bundling device is designed for pressing cut branches and peaks, and forming pressed packages from them - bundles.

According to the proposed technology, felled trees are skidded with a winch to the MOFM, and then are processed into assortments, and the logging residues are pressed into bundles (figure 3). In this article, we consider two technologies. First is a technological chain, in which all operations from skidding to getting assortments from tree, are performed sequentially only by one worker. In the second technology, the skidding and deliming-bucking operations are separated and carried out in parallel by two workers.

It was decided to investigate the efficiency of the proposed MOFM technologies on mathematical models by the method of simulation [13-17].

This article describes the mathematical models of the MOFM and TP technologies and the results of simulation experiments with them.

![Figure 1. Tractor processor HYPRO 300 [1]](image)

1.1. Purpose of the paper
The aim of the article is to propose and study the technologies of logging using TP and MOFM. TP technology produces only assortments. MOFM technology produces as assortments as bundles from logging residues.

2. Methods and Materials
The technological scheme based on the use of a portable winch and MOFM [2] is shown in figure 3 [2].

Hourly productivity of the TP and MOFM technologies was determined by the formula (1):

\[
C_{hr} = \frac{3600 \cdot q}{T_{sum}}, \text{ m}^3/\text{hour}
\]

where, \( q \) – tree volume, m\(^3\); \( T_{sum} \) – the total cycle time of the TP or MOFM work operations, s.

The total cycle time of the TP or MOFM work operations was defined by the formula:

\[
T_{sum} = T_{sum_{winch}} + T_{sum_{d-b}} + T_{sum_{lr}}, s
\]

where, \( T_{sum_{winch}} \) – total time of tree skidding winch operations, s; \( T_{sum_{d-b}} \) – total time of tree deliming-bucking operations, s; \( T_{sum_{lr}} \) – total time of packaging logging residues into a bundle (only for MOFM technology), s.
Figure 2. Multi-operational forest machine with a bundling device (MOFM) and a winch: 1 — deliming-bucking device; 2 — manipulator; 3 — bundling device; 4 — winch; 5 — choker; 6 — tree; 7 — assortments; 8 — bundles.

Figure 3. Technological scheme based on the use of a winch and MOFM: 1 — MOFM; 2 — forwarder; 3 — felled tree; 4 — wood chopping; 5 — assortments; 6 — bundles from logging residues; 7 — growing tree; 8 — pile of assortments; 9 — pile of bundles; 10 — trail track; 11 — forest road.

2.1. Tree winch skidding operations
Total time of tree skidding operations by a winch was defined by the formula (3):

\[ T_{\text{sum, winch}} = t_{11} + t_{12} + t_{13} + t_{14}, \text{s} \]  

(3)

where, \( t_{11} \) — time to travel winch rope towards the tree, s; \( t_{12} \) — tree winch skidding time, s; \( t_{13} \) — time to choke a tree, s; \( t_{14} \) — time to unchoke a tree, s.
Time to travel winch rope towards the tree \((t_1)\) and tree winch skidding time \((t_2)\) depends on the length of the winch rope:

\[
t_1 + t_2 = \frac{l_r}{v_1} + \frac{l_r}{v_2}, \text{ s}
\] (4)

where, \(l_r\) – length of the winch rope, m; \(v_1\) – velocity to travel winch rope towards the tree, m/s; \(v_2\) - tree winch skidding velocity, m/s;

2.2. Tree delimbing-bucking operations

Total time of productivity of tree delimbing-bucking operation \(T_{\text{sum, d-b}}\) depends on technology.

For MOFM technology:

\[
T_{\text{sum, d-b, MOFM}} = t_{21} + t_{22}, \text{ s}
\] (5)

where, \(t_{21}\) – time for placement a tree in the delimbing-bucking device, s; \(t_{22}\) – tree delimbing-bucking operation time, s;

For TP technology:

\[
T_{\text{sum, d-b, TP}} = t_{21} + t_{22} + t_{23}, \text{ s}
\] (6)

where, \(t_{23}\) – time for cleaning up the logging residues, s.

The time to place the tree in the delimbing-bucking device will depend on the skill of the operator, the location of the tree, etc. The average time to place the tree in the delimbing-bucking device and to clean up the logging residues was determined from practice.

2.3. Packaging logging residues into bundles

Total time of packaging logging residues into a bundle (only for MOFM technology):

\[
T_{\text{sum, lr}} = t_{31} + t_{32}, \text{ s}
\] (7)

where, \(t_{31}\) – time for packaging logging residues into a bundle, s; \(t_{32}\) – time for dropping a bundle down to the ground, s.

3. Results and Discussion

The article gives the results for forests with a reserve of 150 m\(^3\)/ha and with an average volume of tree trunk volume 0.40 m\(^3\).

The length of the winch rope is assumed from 10 to 30 m.

Experiments were performed for different technology options (table 1).

Some experimental results are presented as graphs in figure 4-7.

As can be seen from the graph in figure 4, according to the 2.1.0 technology (only assortments) MOFM productivity decreases with increasing skidding distance.

In the case of technology 2.2.0, MOFM productivity increases with increasing skidding distance. The increase in productivity is explained by the fact that the number of MOFM transitions from one working site to the next site is reduced. Productivity increases until the skidding cycle time is less than the MOFM cycle time. After that, MOFM productivity decreases. For our case, the optimal skidding distance is close to 25 m.

**Table 1. Technology options and description.**

| Processor | Technology option | Description of technology               | Product   |
|-----------|-------------------|----------------------------------------|-----------|
| TP        | 1.1               | Sequential operation of the TP and winch| Assortments|
| TP        | 1.2               | Parallel operation of the TP and winch  | Assortments|
MOFM 2.1.0  Sequential operation of the MOFM and winch  Assortments
MOFM 2.1.1  Sequential operation of the MOFM and winch  Assortments + bundles
MOFM 2.2.0  Parallel operation of the MOFM and winch  Assortments
MOFM 2.2.1  Parallel operation of the MOFM and winch  Assortments + bundles

The graph in figure 5 shows the total productivity of MOFM (assortments + bundles).

On the graph (figure 6) three curves are shown for technologies 1.2, 2.2.0, and 2.2.1. The graph shows that the production of assortments by the TP is more than by the MOFM. However, the total productivity of the MOFM (assortments + bundles) is greater that of the TP (only assortments) for our data.

If the time for tree winch skidding is less than the time for its processing (technology 1.2 and 2.2.1) a queue of trees is formed in front of the processors (MOFM or TP) (figure 7). The length of this queue increases as the distance of the tree winch skidding increases. However, because of the tree winch skidding time cycle increases as the skidding distance increases, the queue length tends to stabilize. The queue length stops growing when the tree winch skidding distance is 25-30 m for our data.

4. Conclusion
In this article, an MOFM is proposed. The MOFM base is the TP for delimbing-bucking trees. The MOFM is designed for delimbing-bucking trees and making bundles from logging residues.

Simulation experiments were conducted for forests with reserve of 150 m³/ha and with average volume of tree trunk volume 0.40 m³. The winch rope was taken from 10 to 30 m.

Experiments were performed for different technology options for MOFM and TP processors (table 1).

The graph on figure 6 shows that the production of assortments by the TP is more than by the MOFM. However, the total production of the MOFM (assortments + bundles) is greater that of the TP (only assortments) for our data.

When MOFM is working in parallel operations with the winch (technology 2.2.0), productivity increases with increasing tree winch skidding distance. Productivity increases until the skidding cycle time is less than the MOFM cycle time. After that, MOFM productivity decreases. The optimal tree winch skidding distance is close to 25 m for our data. The length of the queue of trees to MOFM is increased as the skidding distance increases. The queue length stops growing when the tree winch skidding distance is 25-30 m.

Digital simulation models were realized as computer programs. These models allow you to choose rational MOFM parameters for different forest characteristics.
Figure 4. The dependence of productivity of assortments (technology 2.1.0 and 2.2.0) on the distance of tree winch skidding.

Figure 5. The dependence of productivity of assortments + bundles (technology 2.1.1 and 2.2.1) on the distance of tree winch skidding.

Figure 6. The dependence of productivity of assortments (technology 1.2) and assortments + bundles (technology 2.1.1 and 2.2.1) on the distance of tree winch skidding.

Figure 7. The dependence of average length of the trees queue to TP (technology 1.2) and MOFM (technology 2.2.1) on the distance of tree winch skidding.
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