Digital simulation of multioperational forest machine with a bundling device

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Abstract. In this article, an innovating multi-operational forest machine with a bundling device (MOFMB) is proposed. MOFMB is based on the tractor processor (TP) and it is planned for felling trees, delimbing-bucking operations and making bundles from logging residuals. Two technologies of the MOFMB operation are considered. The first technology provides for sequential operation of the MOFMB mechanisms without combining the operations of felling and processing trees. The second technology provides for parallel operation of the MOFMB mechanisms with a combination of felling and tree processing operations. As a result of simulation experiments, it was found that the tractor achieves the highest productivity in the case of parallel operation of its mechanisms with a combination of operations of felling and processing of trees. At this case, the utilization of the manipulator on the tree felling and the processor on the tree processing and logging residuals packaging will be maximum.

1. Introduction

Currently, various multi-operation machines are used in logging operations. For example, a harvester or a tractor processor (TP) is used (figure 1) [1]. This TP are equipped with a delimbing-bucking device that is aggregated with inexpensive general-purpose tractor. Depending on the technology and type of logging, TP can also be equipped with a manipulator with a felling head.

The main advantage of the TP is their low price compared to the harvester. Therefore, these machines are used in the case of low-volume logging, as well as in various types of care tree felling and sanitary felling. Also, TP can be effective in the case of different-age forests that are typical for southern Europe [2-3] and for harvesting thin trees [4].

Monitoring the operation of the TP showed that its disadvantage is the need to stop the operation of the machine for the time of removing the logging residuals that are formed before the delimbing-bucking device in the process of obtaining assortments. This reduces the productivity of the TP.

Logging residuals generated after delimiting and bucking trees into assortments are an additional wood raw material that remains on the cutting area, clutters it and increases its fire hazard [5].

These logging residues can be considered as raw materials for the production of biofuels, for example, fuel chips [2, 4, 6-13].

2. Methods and Materials

To ensure the continuous operation of the TP and increase its productivity, as well as to avoid cluttering the cutting area and to reduce its fire hazard, we have proposed an innovative multi-
operational forest machine with a bundling device (MOFMB) for the production of assortments and bundles from logging residues [6]. This MOFMB received a patent of the Russian Federation.

**Figure 1.** Tractor processor HYPRO755 with felling head [1].

MOFMB (figure 2) has a manipulator with a felling head 2 for felling growing trees 7 within the working zone 8 and delivering fallen trees 4 to the delimbing-bucking device 1, after which results of obtaining assortments 5. For the production of bundles from logging residues 6 (branches, twigs and tops), MOFB is equipped with a bundling device 3 for packaging residues 6.

**Figure 2.** Multi-operational forest machine with a delimbing-bucking device (MOFMB) and a manipulator with felling head: 1 — delimbing-bucking device; 2 — manipulator with felling head; 3 — bundling device; 4 — fallen trees; 5 — assortments; 6 — bundles; 7 — trees; 8 — working zone.

The bundling device for packaging logging residues (figure 2) consists of a receiving table for logging residuals with a movable base 9, with movable enclosing walls 10 and a strapping mechanism.
forming a bundle from residuals by compressing its, strapping its and taking the bundle outside the device.

The MOFB technology is shown in figure 3.

![Figure 3. MOFB technology: 1–MOFMB; 2–forwarder; 3–trees; 4–bundles; 5–assortments; 6–trail track; 7–loading area; 8–stockpile of assortments; 9–stockpile of bundles.](image-url)

MOFMB 1 moves along the trail track 6 and stops in front of growing trees 3. Then, within the working zone, MOFMB cuts all the trees, and places them on a delimming-bucking device. The delimming-bucking device clears the tree from branches and divides the tree trunk into assortments 5, and drops these assortments on the ground. Logging residues after delimming-bucking operations get to the bundling device for its packaging. Then, the logging residues are compressed and strapped to form the bundle 4, which is dumped on the ground.

Thus, MOFB allows you to eliminate processor shutdown due to the accumulation of logging residues in front of it and improve its productivity. In addition, it is not allowed to clutter the cutting area with logging residues.

Assortments 5 and bundles 4 are collected by the forwarder 2 and taken to the loading area 7, where they are placed in stockpiles, respectively, assortment stockpile 8 and bundle stockpile 9.

The work of the MOFB and the forwarder can be separated. Therefore, it is enough to study the MOFB operation to assess the effectiveness of the entire technology.

The efficiency of the MOFB was estimated in comparison with the operation of the TP. The research was carried out on mathematical models using computer simulation methods [5, 14-17].
2.1. Calculations
We will consider the working operations of the MOFB and TP as performing separate operations. This approach allows you to identify the impact of the productivity of individual operations on the overall productivity of the machines, and also simplifies the development of mathematical models as the TP and MOFMB.

In models, the cycle times of all operations are assumed to be random variables distributed according to the exponential law.

Tree felling operation
The hourly productivity of the TP and MOFB on tree felling operations was determined by the following formula:

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

(1)

where, \( q \) – tree volume, m\(^3\); \( T_{sum,f} \) – cycle time of felling tree operations, s.

2.1.1. Delimbing-bucking tree into assortments. The hourly productivity of the TP and MOFB on delimbing-bucking tree operations was determined by the following formula:

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

(2)

where, \( n_a \) – share of assortments output; \( T_{sum,a} \) – the total cycle time of delimbing-bucking operations, s.

2.1.2. Packaging logging residues into bundles. The hourly productivity of the TP and MOFB on packaging logging residues into bundles was determined by the following formula:

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

(3)

where, \( n_r \) – share of logging residuals output; \( T_{sum,r} \) – the total cycle time of bundling operations, s.

In the model, TP performs the following operations sequentially:
1) tree felling;
2) delimbing-bucking tree into assortments;
3) cleaning logging residuals in front of the delimbing-bucking device with the help of a manipulator.

MOFMB performs the following operations:
1) tree felling;
2) delimbing-bucking tree into assortments;
3) packaging logging residues into bundles.

The model considered two options for the MOFMB.
1 – Operations of tree felling (manipulator with felling head), delimbing-bucking tree into assortments (delimbing-bucking device), packaging logging residues into bundles (bundling device) are performed sequentially without combining operations. The manipulator stops working after felling the tree and transferring the tree to the delimbing-bucking device. Tree felling with the manipulator begins only after the completion of the bundling operation.

2 – The tree felling operation is combined with the operations of the delimbing-bucking tree into assortments and bundling logging residuals. These operations are performed in parallel with the combination of these operations. The manipulator continues to work after transferring the tree to the delimbing-bucking device. The manipulator stops only for the time when the delimbing-bucking or bundling device processes a previously felled tree.
All technology options and its description are shown in table 1.
In the experiments, the average cycle time of the MOFMB bundling device was taken as a varying factor. The purpose of this article was to determine the effect of the bundling device cycle time on the productivity of the TP and MOFMB.

In the TP and MOFB models, the number of trees on the working zone in front of the machines was taken to be "infinite". Therefore, the time for moving processors was not taken into account.

| Processor | Technology option | Digital designation | Products               |
|-----------|-------------------|---------------------|------------------------|
| TP        | Sequential        | 1.1                 | Assortments            |
| MOFMB     | Sequential        | 2.1.0               | Assortments            |
| MOFMB     | Sequential        | 2.1.1               | Assortments + bundles  |
| MOFMB     | Parallel          | 2.2.0               | Assortments            |
| MOFMB     | Parallel          | 2.2.1               | Assortments + bundles  |

3. Results and Discussion

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

As you can see from the graph in figure 4, the productivity of the TP in the production of assortments is constant, since it does not depend on the time of bundling operations. The productivity of the MOFMB is higher than the productivity of the TP if the cycle time for cleaning the logging residuals in front of the TP is longer than the cycle time of the MOFMB for bundling of the logging residuals. For example, for an average tree trunk volume of 0.4 m$^3$ and a cycle time for cleaning the logging residuals of 30 seconds, the TP capacity will be 11 m$^3$/hour. The productivity of the MOFMB in sequential mode (2.1.0-table 1), for a bundling cycle time of 20 seconds, will be equal to 13.5 m$^3$/hour.

As the time for bundling of the logging residuals increases, the productivity of the MOFMB decreases. When the time of the bundling cycle for the MOFMB is longer than the cycle time for cleaning the logging residuals in front of the TP, the MOFMB's productivity will be less than the TP's productivity. For example, the productivity of the MOFMB in sequential mode (2.1.0-table 1), for a bundling cycle time of 50 seconds, will be equal to 9.4 m$^3$/hour, and the productivity of the TP will be equal to 11 m$^3$/hour.

In the case of combining of the manipulator operations on tree felling with the logging residuals bundling (2.2.0-table 1), the MOFMB productivity is significantly higher than that in sequential operation (2.1.0 - table 1). For example, for the bundling cycle time equal to 50 seconds, when the MOFMB is running sequentially, the productivity will be 9.4 m$^3$/hour, and when the MOFMB is running in the parallel option, the productivity will be 11.9 m$^3$/hour. This is due to the fact that combining operations reduces the total time for processing trees into assortments and bundles.
Figure 4. Dependence of TP and MOFMB productivity for different technology options (only assortments).

Figure 5. Dependence of TP and MOFMB productivity for different technology options (assortments + bundles).

The graph in figure 5 shows the overall productivity of the MOFMB, which includes assortments and bundles. The productivity of the MOFMB (2.2.1-table 1) is significantly higher than the productivity of the MOFMB (2.1.1-table 1). For example, for a bundling cycle time equal to 50 seconds, with sequential operation of the MOFMB, the total capacity will be 12.7 m³/hour. When running in parallel, the MOFMB will have a total capacity of 16.2 m³/hour, which is higher than the TP, which is 11 m³/hour.

The graphs in figure 6 and figure 7 show the dependence of the manipulator felling head utilization rate of the TP and MOFMB for different technology options on the bundling time. The utilization of the manipulator will be almost 100% for a parallel operation of the MOFMB with a combination of operations of felling and processing trees (2.2.0-table 1). If the MOFB works sequentially without combining the operations of felling and processing trees (2.1.0-table 1), the utilization of the manipulator may be lower than that of the TP. This occurs when the cycle time for clearing logging residuals in front of the TP is longer than the cycle time for bundling logging residuals of the MOFMB processor.

MOFMB will have the highest processor utilization (figure 7) when it is running in a parallel option with the combination of felling and tree processing operations (2.2.0 - table 1).

4. Conclusion
The article discusses the operation of an innovating multi-operational forest machine with a bundling device (MOFMB) based on a conventional tractor processor (TP). MOFMB performs of tree felling and delimming-bucking operations, and additionally logging residuals bundling operations.

Two technologies of the MOFMB are considered. The first technology provides for the sequential operation of the MOFMB without combining the operations of felling and processing trees. The second technology involves the combination of two operations.
The highest productivity of the MOFMB is achieved in the case of the parallel options with a combination of felling and processing trees operations. In this case, the utilization rate of the manipulator and processor will be maximum.

Figure 6. Dependence manipulator felling head utilization rate of the TP and MOFMB for different technology options.

Figure 7. Dependence processor utilization rate of the TP and MOFMB for different technology options.

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