Modeling of technology for cleaning up forest debris of wood natural mortality using the multi-operation machine

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Abstract. The technology of cleaning forests by collecting dead wood and fallen wood and their processing for firewood and woodchips is proposed and investigated. To mechanize this work, it is proposed to use a universal tractor processor patented by the author. The proposed machine is equipped with a splitter head instead of cutting accumulating head to process the trunk part of the tree for firewood. The article presents a conceptual model of such a multi-operation machine and an assessment of its efficiency. The studies were carried out on a mathematical model of the machine by simulation modeling methods. The variant of machine operation with an "infinite" stack of trees was considered. In the model, the time cycles of machine operations were taken as random numbers distributed according to the exponential law. Tree diameters were taken as random numbers obeying the beta-distribution law. Varied were the average cycle time of the splitter head to obtain firewood for one stroke (5-15-25 s) and the average tree diameter (14, 18, 22, 26, and 30 cm). The output value was the hourly capacity of the machine. The modeling showed that with independent operation of the splitter head and chipper, the capacity of the multi-operator machine increases when the cycle time of the splitter head decreases and the diameter of the tree increases. This dependence is nonlinear and is well described by a power function.

1 Introduction

The natural death of trees in forests is associated with the development of forest ecosystems and natural-anthropogenic factors, such as fires, wind-throw, snowfall, etc. The natural death of trees leads to the littering of the forest.

If the volume of wood fall and dead wood exceeds 20 m^3/ha, forest pathology surveys are conducted and sanitary measures for the removal of deadwood are specified [1]. This paper considers deadwood, wind-throw, snag trees that should be removed (further referred to as DW). The annual volume of DW is significant. For example, the DW volume in the Moscow region is estimated at 3 million m^3 [2].

Part of the DW is traditionally used by the local population for the production of firewood. However, the amount of removed DW from the forest must not exceed the

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maximum permissible value. For example, in spruce stands, the limiting value of DW extraction is 40% of the total volume [1].

Due to small volumes, machine technologies for collecting and processing DW are inefficient and therefore are based on the use of manual labor. Nowadays, the basic tool for DW processing is chainsaw. DW is cleaned from twigs and branches, sawed into short logs of 1-1.5 m length. Logs are manually stacked in billets for decomposition in the forest. The top part, twigs and branches are either burned, or shredded and scattered in the forest. The technology of shredding and leaving this part of the DW in the forest is the most preferable, because shredded wood fertilizes the soil.

In this paper we consider the technological scheme of mechanized cleaning up forest debris of wood natural mortality with the processing of DW for firewood and woodchips. Woodchips remain in the forest, and firewood can be sold to the public.

A universal tractor processor (UTP) [3] patented by the author is used for mechanized cleaning of forest from deadwood. UTP has a shearing accumulating head and a chipper. We propose to change the cutting accumulating head of the machine with a mounted splitter head for processing the trunk part of the tree for firewood. Currently, such splitter heads are commercially available, for example, RaMeC Firewood processor [4] or Naarva S23 harvester and firewood processor splitting firewood [5] (Fig. 1).

A conceptual model of a multi-operation machine (MM) equipped with a splitter head and a chipper is shown in Fig. 2.

Fig. 1. Naarva S23 harvester and firewood processor splitting firewood (Source: http://i1.ytimg.com/vi/it4LgXBS8w4/maxresdefault.jpg)

This paper considers the removal of DW from forest using multi-operation machine. The technology using MM should make it possible to eliminate manual labor and minimize the impact on the environment.

2 Materials and methods

The conceptual model of MM developed in this article (Fig. 2) consists of a base tractor 1, which is equipped by winch with a rope 2, a manipulator 3 with a splitter head 4. MM is equipped with a chipping machine 11 with a feed table 9 and a pneumatic line 12.

Before starting work, MM is placed on the working area on the dragline. The working area of MM is a part of forest with DW, which is covered by the cargo cable of the winch.

All standing and hanging DW in the working area are cut down in advance, then all DW 7 are skidded with the help of winch 2 and stacked in the bundle 5 on the working platform at the dragline (Fig. 2).

Operations of skidding and stacking DW in bundles can be technologically separated by time from the operations of DW processing for firewood and woodchips. Therefore, to evaluate the effectiveness of MM during the operations of DW processing for firewood and woodchips, this paper considers the operation of MM with an "infinite" bundle of DWs.

MM operates as follows. DW 7 from the bundle 5 with the help of manipulator 3 is grabbed one by one with the splitter head 4. Further the firewood from the stem of the tree is processed into firewood 9, which is dumped into a soft mesh container 8.

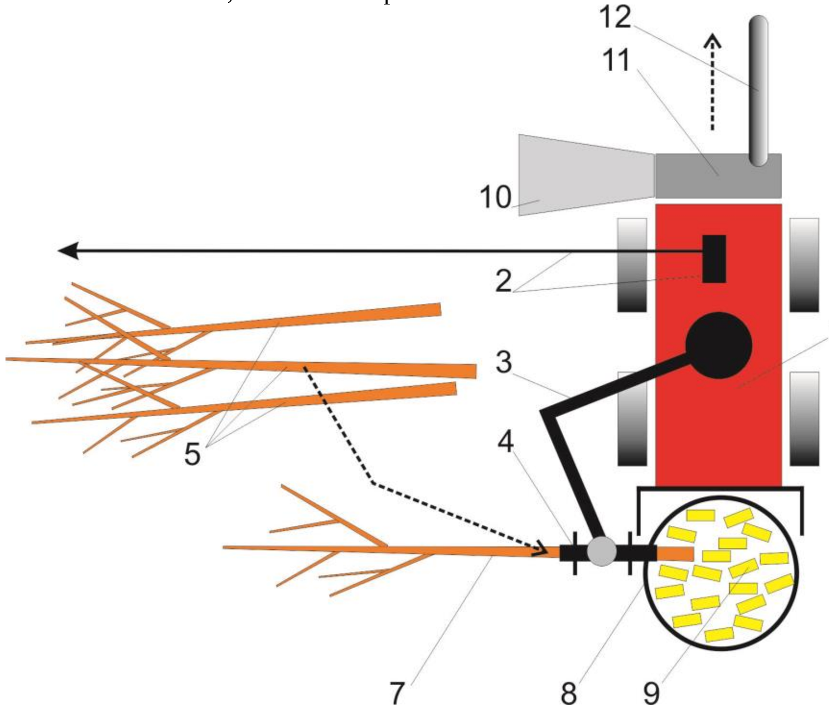

Fig. 2. MM operation during firewood production

The top part of DW (Fig. 3) with branches 13 in the splitter head 4 is carried by manipulator 3 and dumped on the feed table 10 of the chipper head 11. The conveyor of the feed table conveys the top 13 into the window of the chipper head 11. The chopped wood is discharged using the pneumatic conduit 12 to any place, for example, on the dragline in front of the tractor to strengthen the ground of the dragline 14.

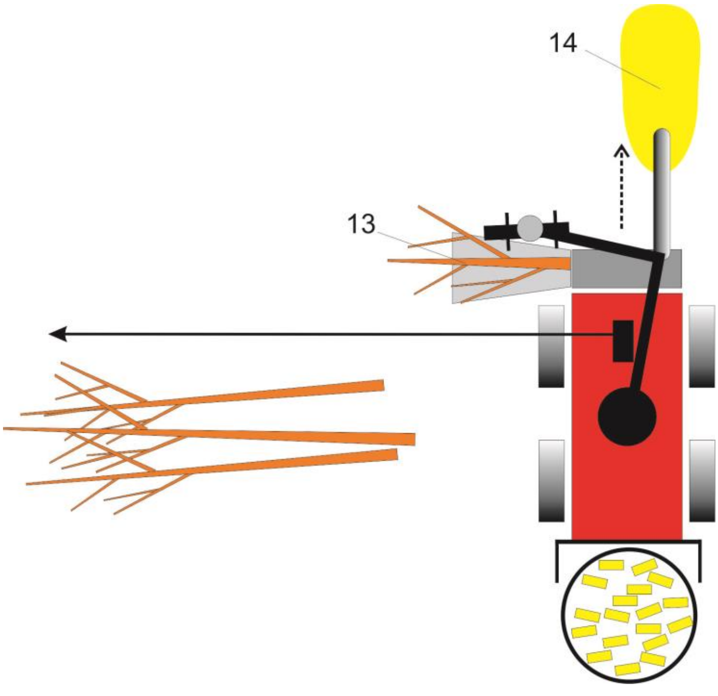

Fig. 3. MM operation during woodchips production

The effectiveness of MM operation was assessed using mathematical models by simulation methods [6-9, 11-20].

The MM operation was modeled as a mass service system. The splitter head and the chipper head are the service devices. DW is the service request. The hourly capacity of MM depends on how many DW requests go through all MM service devices:

Assume that MM processes for firewood *n* DWs from the bundle in an hour. Then the hourly output (Q_{hour}) of MM can be represented as the sum of DW volumes processed for firewood per hour (T_{hour}):

$$\frac{\forall \sum_{i=1}^{n} T_i}{3600} = T_{hour} \Rightarrow Q_{hour} = \sum_{i=1}^{n} q_{j\_fw} \quad (1)$$

where:

T_i is time of the *i*–th operation cycle of MM during processing of the *j*-th DW, s;

q_{j_fw} is the volume of firewood obtained from the *j*-th DW during the *i*-th cycle of MM operation, m^3;

n is the number of full cycles of MM operation per hour.

The cycle time for processing one DW was determined by the formula:

$$T = t_1 + t_2 + t_3 + t_4 \quad (2)$$

where:

t1 is time of bringing the manipulator to the stack, gripping the DW, and turning the manipulator to the container with firewood, s;

t2 is time for processing the trunk part of DW into firewood, s;

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t3 is time for turning the manipulator to the chipper and dumping the tops and branches onto the chipper's feed table , s;

t4 is time for processing the tops and branches into woodchips, s.

Note that the operations of firewood production from the trunk part of DW and the processing of the top with branches into woodchips are performed sequentially. However, after dumping the top on the feed table, the manipulator can immediately move the splitter head to pick up the next DW from the stack. The time required to chop the top and branches into woodchips is much shorter than the cycle time to process the trunk part of the DW into firewood:

$$(t_1 + t_2 + t_3) >> t_4 \qquad (3)$$

Considering inequality (3), time t4 was not taken into account in the total DW processing cycle (2).

The volume of firewood obtained from the trunk part of one DW was determined depending on the volume of DW. In the model, DW volume was calculated from the tree height, diameter at a height of 1.3 m, and the length of the trunk suitable for obtaining firewood.

DW diameter was determined as a random number distributed according to the beta-distribution law (Fig. 4).

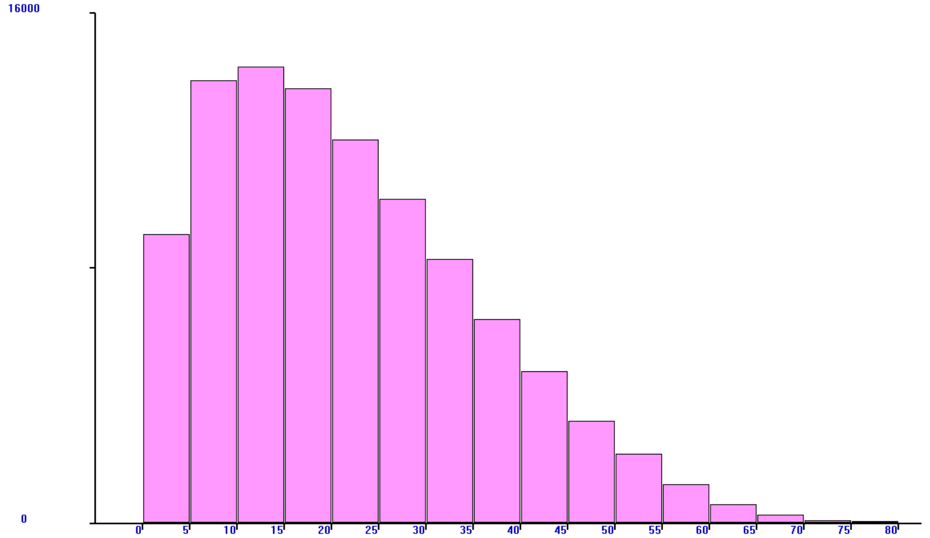

Fig. 4. Example of generating DW diameters with an average value of 22 cm

The DW height was set as a function of diameter using the formula [10]:

$$H = 1.462 \quad d^{0.8667} \quad , m^3 \qquad (4)$$

The length of DW trunk suitable for firewood production depends on many factors (percentage of rotting, time on the ground, etc.). We estimated this length as 50% of the tree height.

The time for bringing the manipulator to the stack, gripping the DW, turning the manipulator to the wood container (t_1), time for turning the manipulator to the chipper and dropping the top with branches to the feed table (t_3) were taken as random numbers distributed according to the exponential law.

The cycle time of the splitter head depends on the length of the DW trunk suitable for obtaining firewood. In the work, this time was defined as a random number distributed by the exponential law with the average value:

$$t_2 = \frac{H}{2 \cdot l} \cdot (t_{21} + t_{22}) \quad (5)$$

where:
l is the firewood length, m;
t_{21} is the average time per trunk cut, s;
t_{22} is the average time for thrusting and splitting of a short-cut wood, s.

This paper aims to reveal the influence of DW diameter and time of one cycle for producing firewood in one stroke (one cut and splitting of one short-cut wood) ($t_{21} + t_{22}$) on MM output. The diameter took the following values: 14, 18, 22, 26, 30 cm. The cycle time ($t_{21} + t_{22}$) took the following values: 5, 15, 25 s.

3 Results and discussion

Formulas (1-5) were used to develop a simulation model of the technological process of MM operation, and a plan of experiments was composed (Table 1).

Table 1 – Experiment planning matrix

No.	DW diameter	The cycle time ($t_{21} + t_{22}$)
1	14	5
2	18	5
3	22	5
4	26	5
5	30	5
1	14	15
2	18	15
3	22	15
4	26	15
5	30	15
1	14	25
2	18	25
3	22	25
4	26	25
5	30	25

Some experimental data are plotted in Figure 5.

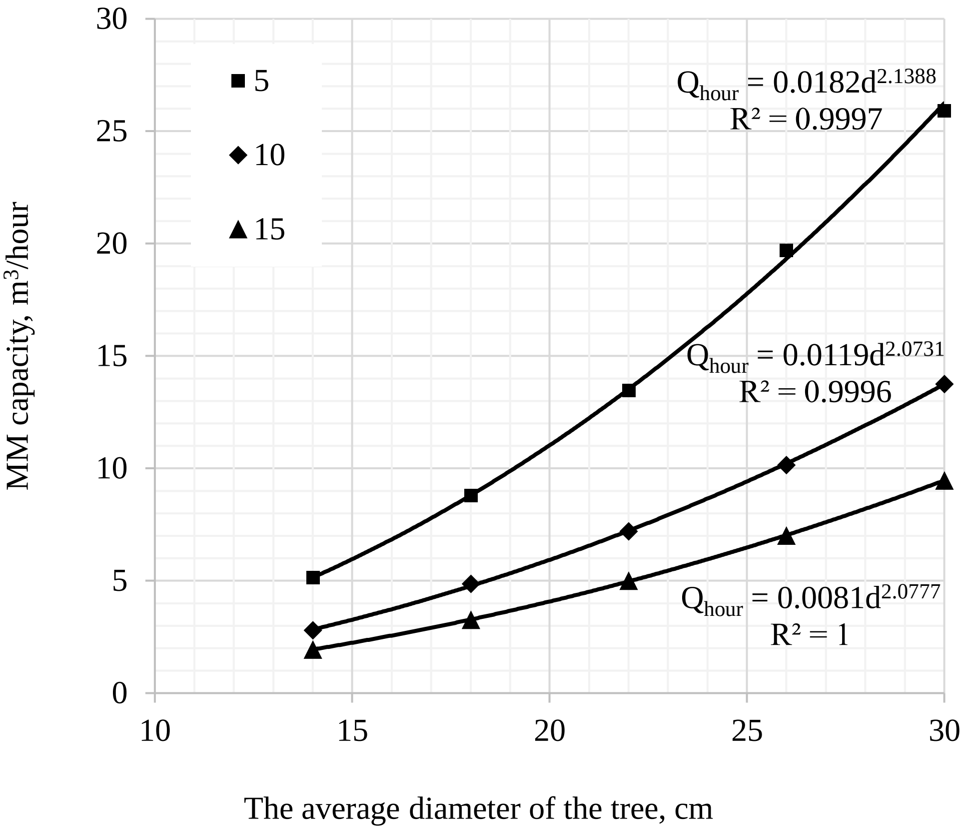

Fig. 5. Relationship between MM capacity and the average time of one cycle to get firewood in one stroke, s

Fig. 5 shows that in case of independent operation of the splitter head and chipper, MM capacity increases when the cycle time of the core-head decreases and the diameter of DW increases. It should be noted that this dependence is nonlinear and is well described by the power function $Q_{hour} = f(d^m)$. In this case, the MM capacity reaches the declared capacity of serial splitter heads for large DW diameters.

For example, for the RaMeC Firewood processor head [4], the declared capacity is 10 m^3/hour. This capacity is achieved with a cycle time of about 15 s and a DW diameter of 20-22 cm. In our model, the MM capacity for the cycle time of 15 s and the tree diameter of 20-22 cm was 6-7 m^3/hour. The decreased capacity is explained by the additional operation of turning the manipulator and dumping the top on the receiving table of the chipper.

Reduced capacity of MM in comparison with the serial RaMeC Firewood processor is compensated by the possibility to completely process DW, which is important in ecological forest cleaning from deadwood.

4 Conclusions

The results of simulation of operation of multi-operation machine allow us to draw the following conclusions:

1. The conceptual model of MM for cleaning forests from deadwood is proposed. MM makes it possible to process DW into firewood and to chop it into woodchips without using manual labor.
2. The option of MM operation using an "infinite" stack is considered.
3. MM capacity depends on DW diameter and cycle time of the splitter head. This dependence is nonlinear and is well described by the power function.
4. MM capacity of output of firewood (6-7 m^3/hour for a diameter of 20-22 cm) is slightly below that declared by the manufacturer of the splitter head (10 m^3/hour for a diameter of 20-22 cm). This is explained by the downtime of the splitter head during operations with top and branches.
5. During MM operation with DW of small diameters, the machine capacity sharply reduces. For example, when DW diameter decreases from 30 cm to 15 cm, the hourly capacity of firewood production decreases by 5 times.

In practice, if the task is to clear forests from deadwood as quickly as possible using MM, it is advisable to chop the whole DW, excluding the production of firewood. If the task is to remove debris together with firewood production, it may be recommended to chop only thin-sized (up to 14 cm) DW as a whole. The trunk part of the large (20-30 cm in diameter) DW can be processed into firewood.

In conclusion, it should be noted that the obtained results have limitations, since they were obtained for the case of an "infinite" DW stack and do not take into account the time for logging and skidding DW to the work site.

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