

# Digital Simulation of Forest Machine for Clearance Urbanized Forest Park from Deadwood

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**Abstract:** This article discusses a forestry machine and a technological scheme for collecting and processing dead wood that lies on the ground into chips. The forest machine is designed to clear urbanized forest park from deadwood on the ground. The article presents the results of a digital simulation of the operation of a forest machine for clearance urbanized forest park from deadwood. Experiments with the digital model were carried out for the maximum productivity of the forest machine on range from 50 to 250 deadwood on ha. The productivity of the forest machine increases with the increase in the number of dead wood in the forest area. In experiments, this increase did not exceed 7.5%. To increase the productivity of the forest machine, it is recommended to increase the productivity of the chopping machine (milling cutter).

## 1 INTRODUCTION

In forests, dead wood is always present on the ground (hereinafter referred to as DW) (Figure 1). DW is the trunks of dead trees that have fallen and are lying on the ground (S.P. Karpachev and R.I. Diev, 2022). In urban forests and parks frequented by the population, DW must be collected and utilized. At the same time, damage to the surrounding growing trees and violation of the soil cover is not allowed (29.12.2007. The guidance documents).



Figure 1: DW in the forests of the Moscow region. (Photo by the author).


Existing technologies for clearing forests of DW are inefficient, costly and based on the use of manual labor. The use of heavy forestry equipment in urbanized forests and parks is difficult due to the limitations of their maneuver between growing trees.


In this article, we consider the technological scheme of collecting and processing DW for chips, which lies in the forest on the ground.

The proposed technology is aimed to solve the following tasks:

- cleaning of urbanized forests and parks from DW;
- exclusion of damage to living trees growing nearby;
- reduction of soil damage and the ability to work on weak soils;
- processing of DW into chips, which can be used for fertilizer or for bioenergy.

The purpose of the work is to propose a forest machine and to investigate the effectiveness of its work in urbanized forests and parks for cleaning from DW.

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## 2 CONCEPTUAL MODEL AND TECHNOLOGY

To implement the technology of cleaning urbanized forests and parks from DW, we have proposed the concept of a self-propelled small forest machine (hereinafter referred to as the FM) with a device for capturing and chipping the wood lying on the ground.

The conceptual model of the FM is presented in Figure 2.

When developing the conceptual model of the FM, we selected prototypes:

- Universal tractor processor (Karpachev, 2018), (Nazarenko, 2020);
- Tapio Stroke Harvesting Head (Tapio, 2023) (Figure 2).



Figure 3: Stroke Harvesting Head (TAPIO, 2023).

The conceptual model of the FM (Figure 3) includes an energy module I and a device II for capturing and chipping DW (hereinafter simply the device).

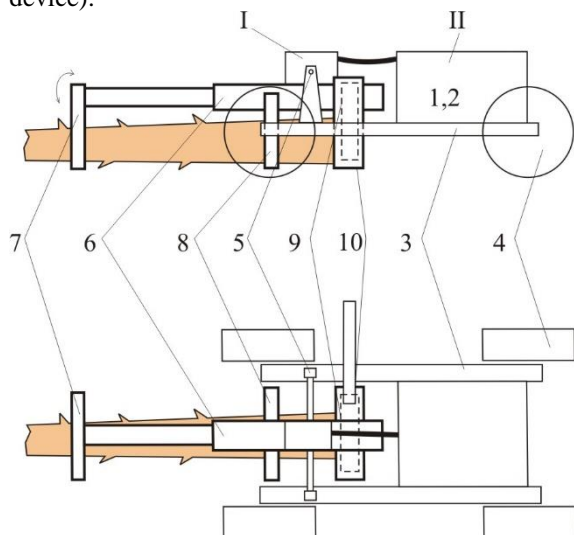


Figure 2: Conceptual model of the FM.

The energy module I includes an internal combustion engine 1 and a hydraulic station 2, which are placed on a frame 3 with drive wheels 4.

The device II is attached in the center of gravity by joint 5 to the frame 3 with the possibility of rotation in a vertical surface and consists of a stroke harvesting head (hydraulic cylinder) 6, a pulling gripper 7, a holding gripper 8, a chipping cutter 9 with a pneumatic pipe 10.

The stroke harvesting head 6 is a reciprocating hydraulic cylinder. A gripper 7 is attached to the hydraulic cylinder rod, and a gripper 8 is attached to the cylinder body.

The joint attachment in the center of gravity of the device II to the frame 3 allows it to be held horizontally to the ground surface while moving with the rod retracted. During operation, when the rod is extended due to the displacement of the center of gravity, the gripper 6 will independently descend to the ground to grab the trunk of the DW.

The MF reprocessed DW into chips as follows (Figure 4).

I. The FM approaches the trunk of the DW. The hydraulic cylinder rod is inside.

II. The rod of the hydraulic cylinder of the head 6 moves with the grip 7 to the trunk of the DW. The gripper 7 bends down to the DW and grips it.

III. The hydraulic cylinder rod retracts and delivers the DW to the chipping cutter 9. The cutter 9 grinds the delivered trunk into chips.

IV. After the rod is maximally retracted into the cylinder, the gripper 8 intercepts the trunk of the DW and grips it. The gripper 7 opens and relieves the trunk of the DW. After extending the rod, the gripper 7 captures the trunk of the DW. Then the gripper 8 releases the DW. After that, the cycle of crushing the trunk of DW into chips is repeated.

The technology of the FM for cleaning urbanized forests and parks from DW is accepted as follows (Figure 5).

At first, the forest area is divided into technological strips with a length of  $b$  and a width of  $a$ . The dimensions of the strip are determined based on the total size of the area, quantity (density) DW and the number (density) of growing trees.

The width of the strip ( $a$ ) can be preliminarily recommended to take equal to or a little greater than the average length of DW. In this case, the minimum time for maneuvering the FM is expected.

The FM 1 moves along the technological strip on which the DW 3 is located. The FM moves along route 2 from one DW to the next. FM 1 moves up to the DW 3, grip it and processed it into chips 4. Wood

chips are scattered on the ground. After processing the DW into chips, the FM moves within the strip to the next nearest DW. After processing one technological strip, the FM moves to the next strip, etc.

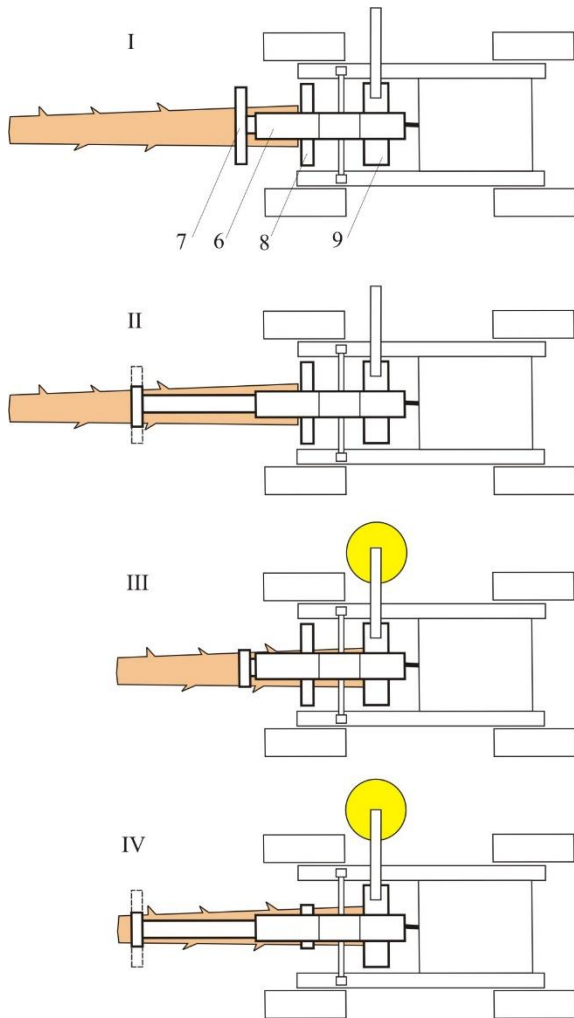


Figure 4: FM works with DW.

Thus, the proposed FM and the technology, allows you to solve the tasks, which were set in the article:

- mechanize the work on cleaning urbanized forests and parks from DW;
- minimize damage to nearby trees and reduce soil damage;
- to process DW into chips for fertilizer or for bioenergy.

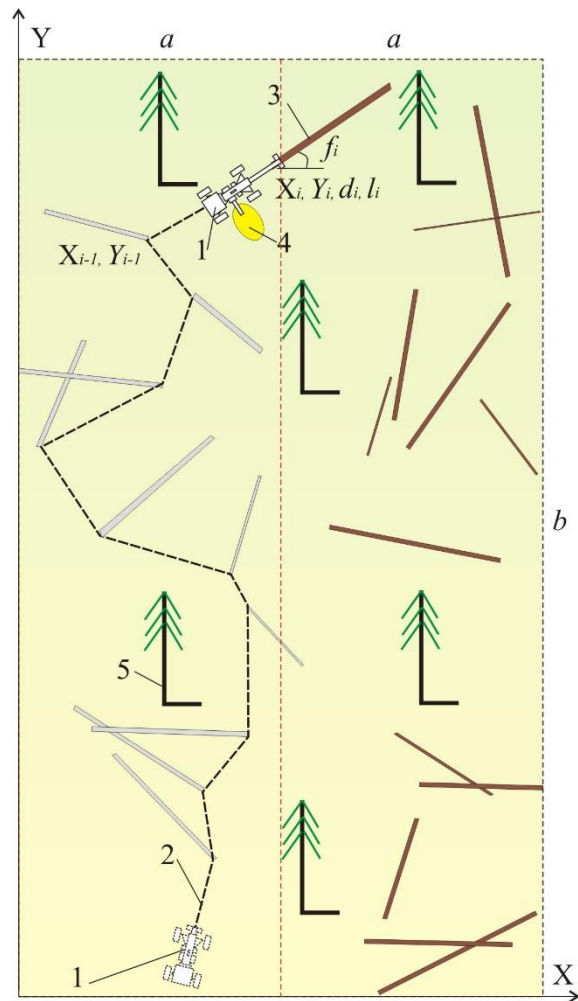


Figure 5: The technology of the FM's work on clearing the forest from DW.

### 3 MATERIALS AND METHODS

The criterion for the effectiveness of the technology of using the FM is the productivity of the machine for collecting and processing DW into chips for different amounts of them on the forest area.

The experiment planning matrix is given in Table 1.

Table 1: Experiment planning matrix.

Experiment number	Number of DW, pcs./ha
1	50
2	100
3	150
4	200
5	250

Each  $i$ -th DW generated in the model was assigned the following characteristics (Figure 5):

- coordinates of the trunk position  $X_i, Y_i$ ;
- diameter of the trunk  $d_i$ ;
- trunk length  $l_i$ .

The laws of distribution of  $X, Y$  coordinates of the position of the end of the DW trunk on the area were assigned according to a uniform law.

The laws of distribution of diameters and lengths of wood trunks were established by the authors experimentally on the basis of data collected on forest plots (Diev, 2018) (Figure 6).



Figure 6: Example of measuring the diameter of DW (Photo by the author).

The results of computing a sample of 325 trunks of DW are presented in the form of diagrams (Figure 7, Figure 8). Based on the results of sample processing, normal laws of distribution of diameters and lengths were accepted for DW.

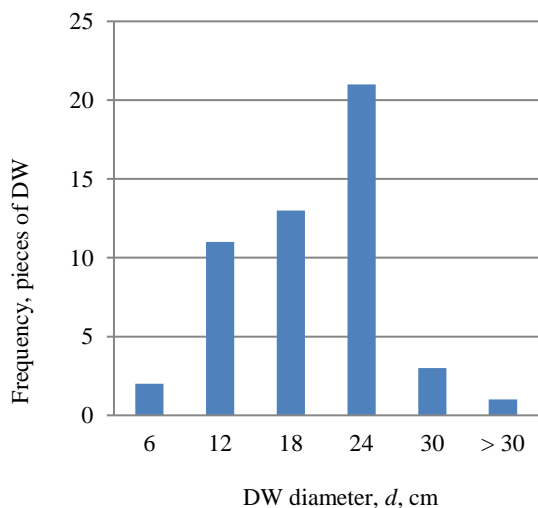


Figure 7: Histogram of DW diameter distribution.

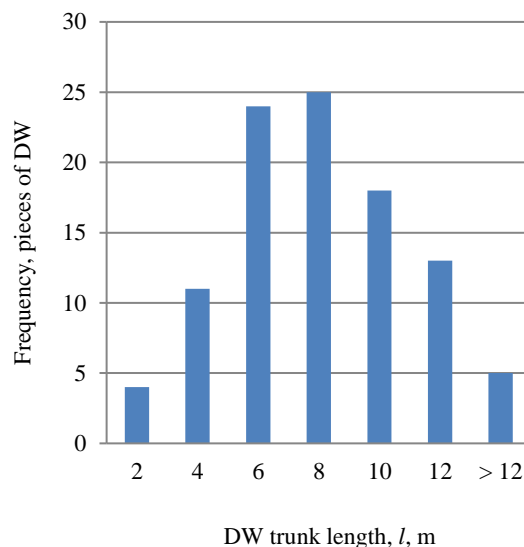


Figure 8: Histogram of DW length distribution.

Studies of the efficiency of the FM were carried out by digital simulation methods on mathematical models for the conditions of Moscow region of Russia (Karpachev S.P., Bykovskiy M.A., Laptev A.V., 2021.), (Laptev A.V., Matrosov A.V., 2018), (Shirnin Yu. A., 2004), (Laptev A.V., 2013).

In the simulation experiments, the technological strip was assumed 30 m wide based on the results of exam of forest plots with DW (Diev, 2018). The length of strip  $b$  was determined by calculating from the condition of statistically significant results for a constant number of DW on the site equal to 10,000 pieces.

In experiments, the position of each  $i$ -th trunk on the forest area was determined by the coordinates of the position of the end of the trunk (Figure 5) as random numbers in meters according to a uniform distribution law at intervals  $X_i = (0, 30)$ ;  $Y_i = (0, b)$ .

The generated array of coordinates  $X_i, Y_i$  of the DW position on the area was sorted in ascending order of the  $Y$  coordinate ( $Y_{i+1} > Y_i$ ).

The diameter of the  $i$ -th trunk of the DW was set in centimeters as a random number distributed according to the normal law with an average value of 17.8 and a variance of 41.0.

The length of the  $i$ -th trunk was also assigned as a random number in meters distributed according to the normal law with an average value of 7.0 and a variance of 8.9.

The volume of the  $i$ -th DW ( $V_i$ ) was determined by calculation according to the formula of the cylinder.

The line of the FM movement was adopted by a polyline (Figure 5), consisting of straight segments between the DW.

The length of each  $(i+1)$ -th segment was determined by the formula:

$$L_{i+1} = \sqrt{(X_{i+1} - X_i)^2 + (Y_{i+1} - Y_i)^2}, \text{ m} \quad (1)$$

The time of the FM movement from the  $i$ -th DW to the  $(i+1)$ -th DW was determined by the formula:

$$t_{Li} = \frac{L_i}{v}, \text{ sec} \quad (2)$$

where:

$v$  is the speed of the FM, m/s.

The time of the DW processing cycle  $t_{FM}$  is determined by the trunk pulling cycle and chipping cycle. These operations are performed simultaneously. We analyzed both time cycles based on the timing of the TAPIO head and chipping machines. We have adopted a longer cycle. This was a chipping cycle. To account for additional operations to grip the trunk, the final time cycle  $t_{FM}$  has been increased by 20%.

The hourly productivity of the FM was determined by the formula:

$$P_{our} = 3600 \cdot \frac{\sum_{i=1}^n V_i}{\sum_{i=1}^n (t_{Li} + t_{FMi})}, \text{ m}^3 / \text{our} \quad (3)$$

where:

$n$  is the number of DW on the technological strip (Table 1).

## 4 RESULTS AND DISCUSSION

The results of simulation experiments were systematized and presented in Table 2.

Some research results are presented in the form of dependencies shown in graphs (Figure 9-10).

Graph on Figure. 9 represents the dependence of the hourly productivity of the FM depending on the number of DW per hectare.

This dependence is well described by a logarithmic curve ( $R^2 > 0.92$ ).

It follows from the graph that the productivity of the FM increases with the increase in the number of

DW per hectare. The greatest increase in productivity is observed when the number of DW increases from 50 to 100 pcs./ha. Productivity growth is about 4.8%. With a further increase in the number of DW from 100 to 250 pcs./ha, FM productivity growth is slowing down. Productivity growth in this interval does not exceed 0.9%.

Table 2: Results of simulation experiments.

Experiment number	Number of DT, pcs./ha	FM productivity, m <sup>3</sup> /hour	FM operating time cycle, sec	FM movement cycle, sec	Total FM cycle time, sec
1	50	8.48	56.6	22.4	79.0
2	100	8.89	56.6	18.8	75.3
3	150	9.01	56.6	17.8	74.4
4	200	9.06	56.6	17.4	74.0
5	250	9.09	56.6	17.2	73.7

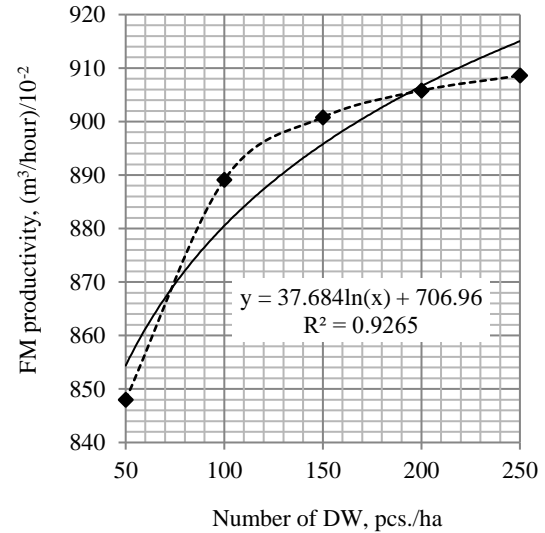


Figure 9: FM productivity.

The graph (Figure 10) shows the average values of the total cycle time of the FM with DW (Total FM cycle time, sec). The same graph shows the FM cycles to grip and deliver the trunk, and crush the DW into chips (FM operating time cycle, sec) and the cycles of the FM moving from  $DW_i$  to  $DW_{i+1}$  (FM movement cycle, sec).

It follows from the graph (Figure 10) that the total cycle time of the FM decreases with an increase in the number of the DW per hectare. According to the results of experiments, it was found that with an increase in the number of the DW from 50 to 250 pcs./ha, the decrease in the total cycle time was 5.3 seconds.

Note that the average cycle time for gripping and crushing the DW into chips does not depend on the number of the DW per hectare, which is to be expected. In the model, this time was 56.6 seconds.

In the model, the cycle time required to move the FM from one DW to the next DW turned out to be 60% less than the cycle time for gripping and crushing this DW into chips.

It follows from the graph (Figure 10) that the cycle time for moving the FM from one DW to the next DW decreases with an increase in the number of DW per hectare. As a result of experiments, it was found that with an increase in the number of DW from 50 to 250 pcs./ha the reduction in the total cycle time was 5.2 seconds. Such a decrease in this time cycle is caused by a reduction in the distance between DW with a decrease in the number of DW per hectare.

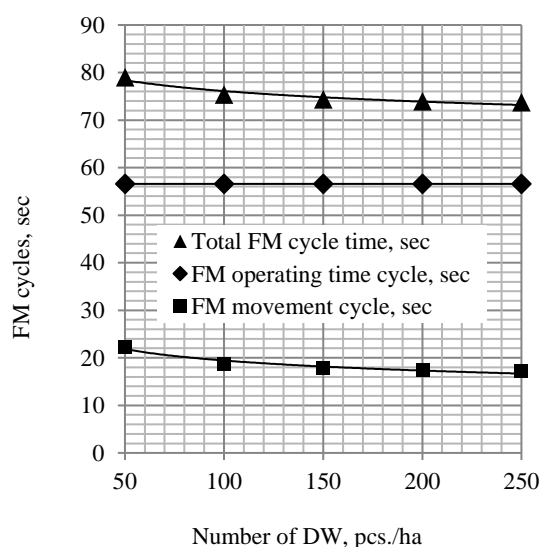


Figure 10: Working time cycles of the FM

## 5 CONCLUSIONS

The results of the simulation experiments carried out on the technology of the FM for clearing urbanized forest park from the DW allowed us to draw the following conclusions:

1. The productivity of the FM increases with an increase in the number of DW on the forest area (from 50 to 250 pcs./ha). According to the experimental data, the productivity growth turned out to be small. In experiments, this growth did not exceed 0.61 m<sup>3</sup>/hour or only 7.2%.

2. The increase in the productivity of the FM occurs as a result of a decrease in the distance

between the DW, which, in turn, is caused by an increase in the number of DW on the site (pcs./ha).

3. It has been experimentally established that an increase in the number of DW from 50 to 250 pcs./ha, led to a decrease in the cycle time for moving the FM by 23%. Under the same conditions, the reduction in the total cycle time of the FM was only 6.7%.

4. Analysis of the results of digital simulation experiments of the efficiency of the FM in urbanized forests and parks for clearing DW allows us to draw the following conclusions:

- To increase the productivity of the FM, it is necessary to strive to minimize the time cycle for gripping and crushing DW into chips. This can be done if, for example, a more productive chipping machine is used.

- The time cycle for the FM moving depends on the number of DW per hectare, that is, on natural conditions that we cannot change. Therefore, it is difficult to reduce this cycle for the FM.

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