Modeling the technological process of whelled harvester by applying Graph theory

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Abstract. The article presents typical schemes of the development of the harvest area and the technological operations performed by a middle-class feller-delimber-buncher (FDB) (Ponsse Ergo 8W) in the middle taiga of the Komi Republic under natural and production conditions of JSC Syktyvkar LPC. On the example of the most common in the logging practice plantation forest plantations modeled the technological process in terms of productivity of a typical multi-operational logging machine, the process of processing one tree by such a machine, taking into account the graph theory modeled and given graph of processing one tree, hourly productivity of FDB in such conditions, recommendations on the value of the planned indicator of hourly productivity of FDB in such conditions are given.

1 Introduction

In the Russian Federation wood industry complex, this stage of development of the production process is an important stage of the primary phase of logging, which uses modern multi-operational forest machines (feller-delimber-buncher and wheeled sorting-pickers), working mainly on Scandinavian sorting technology, each unit of which is under the control of the operator of logging machinery [1, 2, 3, 4, 5, 6].

At this stage of science and technology development it is worth noting the high level of development of foreign solutions for sorting (dominant) and whip technology [7, 8, 9, 10].

At the same time, there are domestic solutions in terms of software to increase the productivity of such equipment, especially feller-delimber-buncher machines (FDB) [11, 12, 13, 14, 15].

It is well known that a feller-delimber-buncher (FDB) performs the following technological processes: felling of trees, clearing of trees from limbs, buckling of logs into assortments, sorting of assortments [16]. The scheme of development of a typical harvesting area by a system of machines feller-delimber-buncher machine (FDB) and

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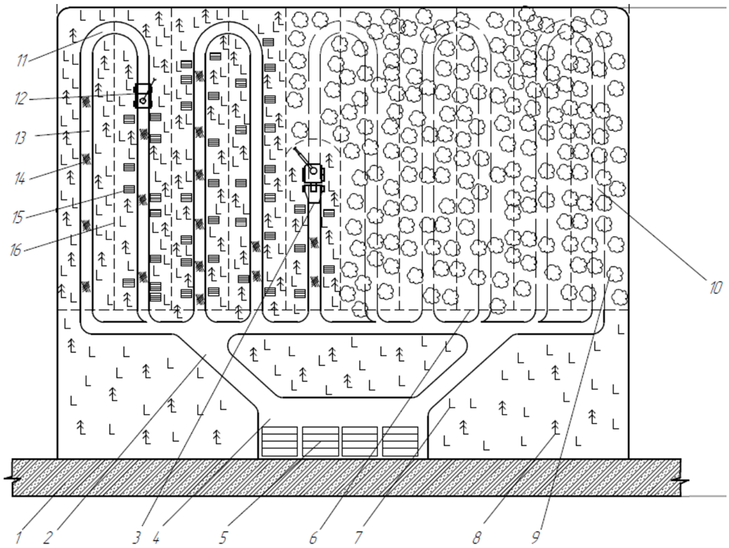
wheeled sorting pickers (SP) in the natural and production conditions of the JSC "Syktyvkar LPC" in the middle taiga of the Komi Republic is shown in Figure 1.



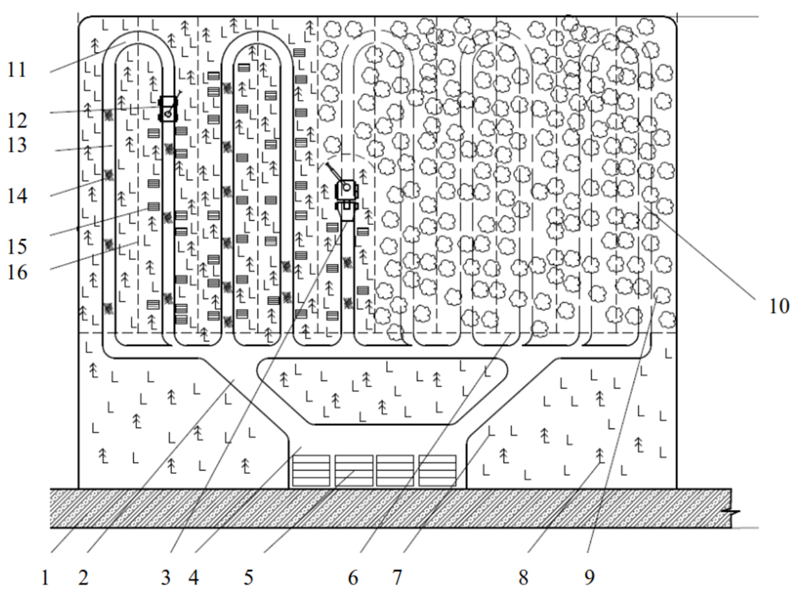


Fig. 1. Scheme of forest clearing development by FDB + SP machine system in the Middle taiga of the Komi Republic in the natural and production conditions of Syktyvkar LPC JSC with preservation of undergrowth and young trees.
1 - timber hauler; 2 - main drag; 3 - harvester; 4 - loading point; 5 - stack of assortments; 6 - boundary of the safety zone; 7 - stumps; 8 - preserved juveniles; 9 - plantings before felling; 10 - planned bee trail; 11 - reversal ring; 12 - forwarder; 13 - apiary skidding trail; 14 - logging residues; 15 - packs of assortments; 16 - pa-sec limit

2 Methods and materials

The FDB manufacturing process is modeled. Hourly production rate of FDB (P_h) is determined by the formula (1).

$$P_h = \frac{3600 * V_x}{T_c}, \qquad (1)$$

here V_x = average tree trunk, m^3;
T = cycle time of performed operations, s.

Hourly productivity of FDB is modeled on the example of plantation forest stands. The following typical taxation characteristics of forest stands in the Komi Republic are assumed. Average wood stock (M_{av}) in the Komi Republic is assumed to be 200 m^3 per ha. Average volume of a tree trunk (V_x) in the Komi Republic is assumed to be 0.3 m^3.

The number of trees (n) per 1 ha is assumed to be 666 trees ($n = M_{av} / V_x$ = 200 m^3/ 0.3 m^3 ~ 666.666 trees, i.e., 666 trees).

The scheme of a typical plantation harvesting area of 8.08 ha in the Middle Taiga of the Komi Republic is shown in Figure 2.

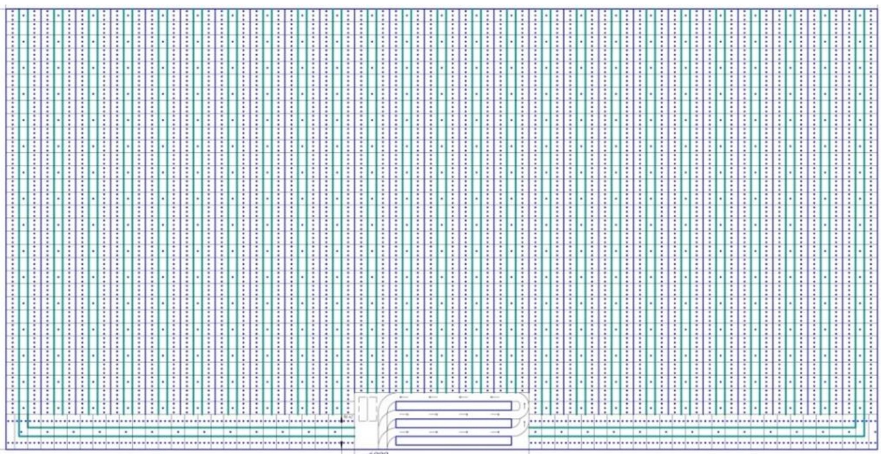


Fig. 2. Scheme of a typical plantation harvesting area in the Middle Taiga of the Komi Republic.

A typical plantation harvesting area in the Middle Taiga of the Komi Republic is divided into apiaries (b) with a width of 16 meters, a drag width of 4 meters, and a drag length of 202 meters. A fragment of an apiary is shown in Figure 3.

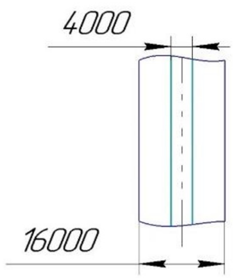


Fig. 3. Fragment of a typical plantation apiary in the Middle Taiga of the Komi Republic.

Diagram of the apiary with division into technological parking lots (length (a) 6 meters)) FDB (the area $S=a*b$ = 6*16 = 96 m^2) average of 6-7 trees per parking lot.

Thus, FDB can harvest timber from one apiary on 5-7 technological stands in the conditions of plantation forests in the Middle taiga of the Komi Republic.

3 Results and discussion

The process of processing 1 tree is modeled for a medium-class feller-buncher (FDB) Ponsse Ergo 8W in the middle taiga of the Komi Republic in the natural and production conditions of JSC "Syktyvkar LPC". Time for processing one tree FDB (T_c) is made up of the following:

$$T_c = t_1+t_2+ t_3+t_4\ t_5+t_6+ t_7+t_8+ t_9+t_{10}+ t_{11}+t_{12}+ t_{13}+t_{14}+ t_{15}+t_{16}\ t_{17}+t_{18}, \quad (2)$$

here

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1) t_1 – time for setting the harvester head (HH) on the tree trunk, s.

$$t_1 = \frac{l}{v} = \frac{5.5\ m}{0.4\ m/s} = 13.75\ sec;$$

2) t_2 – time of tree trunk gripping by the harvester head, s;

$$t_2 = \frac{l}{v} = \frac{0.4\ m}{0.2\ m/s} = 2\ sec;$$

3) t_3 – time for sawing a tree trunk, s;
4) t_4 – tree fall time, s;

$$t_4 = \frac{l}{v} = \frac{16\ m}{4\ m/s} = 4\ sec;$$

5) t_5 – time of moving the harvester head to the apiary fiber for chipping, s.

$$t_5 = \frac{l}{v} = \frac{4\ m}{0.4\ m/s} = 10\ sec;$$

6) t_6 – HH FDB timber butting time, s.
Figure 4 shows a schematic diagram of the barking of the tree as well as the top part of the tree.

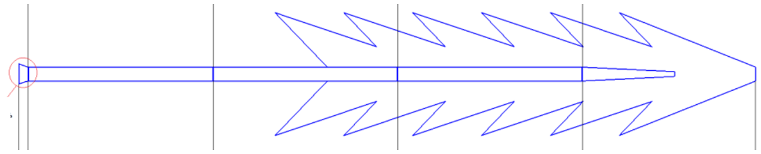


Fig. 4. Schematic of wood butting, as well as the top part of the tree.

7) t_7 – time of trunk moving to the apiary belt, s.
A diagram of the tree trunk at the apiary band is shown in the Figure 5.

$$t_7 = \frac{l}{v} = \frac{2\ m}{0.4\ m/s} = 5\ sec;$$

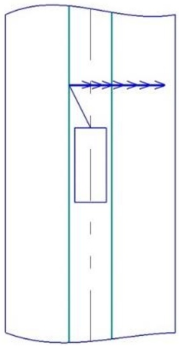


Fig. 5. Tree trunk at the apiary band.

8) t_8 – time for pulling a tree trunk through lopping blades for 4 meters, s.

$$t_8 = \frac{l}{v} = \frac{4\,m}{1\,m/s} = 4\,sec;$$

9) t_9 – time for sawing the trunk (1st saw log), s.
The layout of the 1st sawn timber is shown in Figure 6.

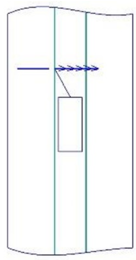
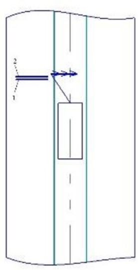


Fig. 6. Layout of the 1st saw log.

10) t_{10} – time for pulling a tree trunk through lopping blades for 4 meters, s;

$$t_{10} = \frac{l}{v} = \frac{4\,m}{1\,m/s} = 4\,sec$$

11) t_{11} – time for sawing the trunk (2nd saw log), s.
The layout of the two saw logs is shown in Figure 7.



1 - 1 saw log; 2 - 2 saw log.
Fig 7. Schematic diagram of two saw logs arrangement.

12) t_{12} – time to turn the harvester head (HH), s.
13) t_{13} – time for pulling a tree trunk through lopping blades for 4 meters, s.

$$t_{13} = \frac{l}{v} = \frac{4\,m}{1\,m/s} = 4\,sec$$

14) t_{14} – time for sawing the rest of the trunk into balances, s.
15) t_{15} – time to move the top of the tree to the center of the apiary fiber, s;

$$t_{15} = \frac{l}{v} = \frac{2\,m}{0.4\,m/s} = 5\,sec$$

16) t_{16} – blade opening time, s;

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$$t_{16} = \frac{l}{v} = \frac{0.4\ m}{0.2\ m/s} = 2\ sec$$

17) t_{17} – time for falling of the tree top to the center of the apiary fiber, s;
18) t_{18} – time to move the harvester head (HH) to the starting position, s.
Cycle time of processing one FDB tree (T_c) is determined by the formula (2):

$$T_c = 13.75+2+4+4+10+4+5+4+4+4+3+2+4+3+5+2+2+4 = 79.75 \sim 80 \text{ sec}$$

Based on the components of the cycle time of processing one tree, the graph of processing one FDB tree is compiled and the following assumptions are made: $s1 = t_1$, $s2 = t_2$, $s3 = t_3$, $s4 = t_4$, $s5 = t_5$, $s6 = t_6$, $s7 = t_7$, $s8 = t_8$, $s9 = t_9$, $s10 = t_{10}$, $s11 = t_{11}$, $s12 = t_{12}$, $s13 = t_{13}$, $s14 = t_{14}$, $s15 = t_{15}$, $s16 = t_{16}$, $s17 = t_{17}$, $s18 = t_{18}$.

Real FDB performance (P_h) in plantation forest stands for feller-delimber-buncher (FDB) of medium class Ponsse Ergo 8W in the middle taiga of the Komi Republic in the natural and production conditions of JSC Syktyvkar LPC, taking into account the found values is determined by formula (1) and is equal to:

$$Ph = \frac{3600 * 0.3}{80} = 13.5\ m^3/h$$

The process of processing FDB trees per hour is further modeled. Time to process FDB trees per hour (T_c) consists of the following components:

$$T_c = t_{1\text{-}1} + t_{2\text{-}1} + t_{3\text{-}1} + t_{4\text{-}1} + t_{5\text{-}1} + t_{6\text{-}1} + t_{0\text{-}2} + t_{1\text{-}2} + t_{2\text{-}2} + t_{3\text{-}2} + t_{4\text{-}2} + t_{5\text{-}2} + t_{6\text{-}2} + t_{7\text{-}2} + t_{0\text{-}3} + t_{1\text{-}3} + t_{2\text{-}3} + t_{3\text{-}3} + t_{4\text{-}3} + t_{5\text{-}3} + t_{6\text{-}3} + t_{0\text{-}4} + t_{1\text{-}4} + t_{2\text{-}4} + t_{3\text{-}4} + t_{4\text{-}4} + t_{5\text{-}4} + t_{6\text{-}4} + t_{7\text{-}4} + t_{0\text{-}5} + t_{1\text{-}5} + t_{2\text{-}5} + t_{3\text{-}5} + t_{4\text{-}5} + t_{5\text{-}5} + t_{6\text{-}5} + t_{0\text{-}6} + t_{1\text{-}6} + t_{2\text{-}6} + t_{3\text{-}6} + t_{4\text{-}6} + t_{5\text{-}6} + t_{6\text{-}6} + t_{7\text{-}6} + t_{0\text{-}7} + t_{1\text{-}7} + t_{2\text{-}7} + t_{3\text{-}7} + t_{4\text{-}7} + t_{5\text{-}7} + t_{6\text{-}7} + t_{0\text{-}8} + t_{1\text{-}8} + t_{2\text{-}8},$$

where:
1. $t_{1\text{-}1}$ is time for felling and processing of the 1st tree at the 1st parking lot, s.
The arrangement of sorts after treatment of one FDB tree is shown in Figure 8.

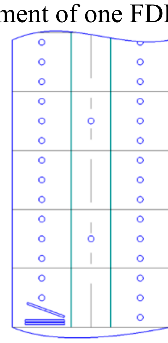

Fig. 8. Arrangement of assortments after FDB processing of one tree.

2. $t_{2\text{-}1}$ – time for felling and processing of the 2nd tree at the 1st parking lot, s;
3. $t_{3\text{-}1}$ – time for felling and processing of the 3rd tree at the 1st parking lot, s.
Arrangement of assortments after treatment of three FDB trees is shown in Figure 9;

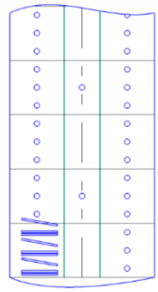

Fig. 9. Arrangement of assortments after FDB processing of three trees.

4. t_{4-1} – time for felling and processing of the 4th tree at the 1st parking lot, s;
5. t_{5-1} – time for felling and processing of the 5th tree at the 1st parking lot, s;
6. t_{6-1} – time for felling and processing of the 6th tree at the 1st parking lot, s.

Arrangement of assortments after treatment of six FDB trees is shown in Figure 10.

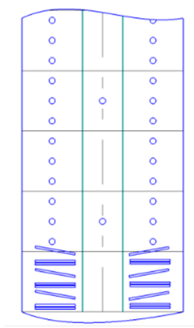

Fig. 10. Arrangement of assortments after FDB treatment of six trees.

7. t_{0-2} – time for FDB passage to the 2nd parking lot (6 meters), s;

$$t_{0-2} = \frac{l}{v} = \frac{6\ m}{0.5\ m/s} = 12\ sec$$

8. t_{1-2} – time for felling and processing of the 1st tree at the 2nd parking lot, s.

Arrangement of assortments after treatment of seven FDB trees is shown in Figure 11.

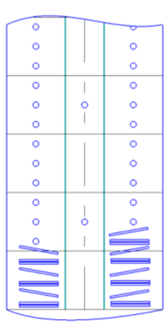

Fig. 11. Arrangement of assortments after harvester treatment of seven trees.

9. t_{2-2} – time for felling and processing of the 2nd tree at the 2nd parking lot, s.

The arrangement of assortments after treatment of eight FDB trees is shown in Figure 12.

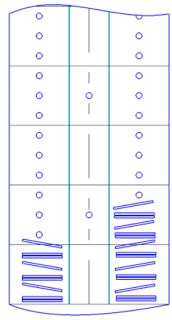

Fig. 12. Arrangement of assortments after harvester treatment of eight trees.

10. $t_{3\text{-}2}$ – time for felling and processing of the 3rd tree at the 2nd parking lot, s.
The location of assortments after processing of nine FDB trees is shown in Figure 13.

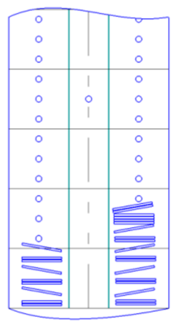

Fig. 13. Arrangement of assortments after FDB treatment of nine trees.

11. $t_{4\text{-}2}$ – time for felling and processing of the 4th tree at the 2nd parking lot, s;
12. $t_{5\text{-}2}$ – time for felling and processing of the 5th tree at the 2nd parking lot, s;
13. $t_{6\text{-}2}$ – time for felling and processing of the 6th tree at the 2nd parking lot, s;
14. $t_{7\text{-}2}$ – time for felling and processing of the 7th tree at the 2nd parking lot, s.

The locations of the assortments after processing the thirteen FDB trees are shown in Figure 14.

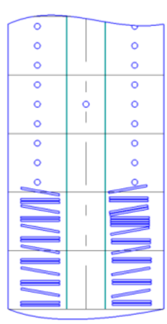

Fig. 14. Arrangement of assortments after FDB treatment of thirteen trees.

15. $t_{0\text{-}3}$ – time to move FDB to the 3rd parking lot (6 meters), s;

$$t_{0-3} = \frac{l}{v} = \frac{6\ m}{0.5\ m/s} = 12\ sec$$

16. $t_{1\text{-}3}$ – time for felling and processing of the 1st tree at the 3rd parking lot, s;
17. $t_{2\text{-}3}$ – time for felling and processing of the 2nd tree at the 3rd parking lot, s;
18. $t_{3\text{-}3}$ – time for felling and processing of the 3rd tree at the 3rd parking lot, s;
19. $t_{4\text{-}3}$ – time for felling and processing of the 4th tree at the 3rd parking lot, s;
20. $t_{5\text{-}3}$ – time for felling and processing of the 5th tree at the 3rd parking lot, s;
21. $t_{6\text{-}3}$ – time for felling and processing of the 6th tree at the 3rd parking lot, s;
22. $t_{0\text{-}4}$ – time for driving the harvester to the 4th parking lot (6 meters), s;

$$t_{0-4} = \frac{l}{v} = \frac{6\,m}{0.5\,m/s} = 12\,sec$$

23. $t_{1\text{-}4}$ – time for felling and processing of the 1st tree at the 4th parking lot, s;
24. $t_{2\text{-}4}$ – time for felling and processing of the 2nd tree at the 4th parking lot, s;
25. $t_{3\text{-}4}$ – time for felling and processing of the 3rd tree at the 4th parking lot, s;
26. $t_{4\text{-}4}$ – time for felling and processing of the 4th tree at the 4th parking lot, s;
27. $t_{5\text{-}4}$ – time for felling and processing of the 5th tree at the 4th parking lot, s;
28. $t_{6\text{-}4}$ – time for felling and processing of the 6th tree at the 4th parking lot, s;
29. $t_{7\text{-}4}$ – time for felling and processing of the 7th tree at the 4th parking lot, s;
30. $t_{0\text{-}5}$ – time for driving the harvester to the 5th parking lot (6 meters), s;

$$t_{0-5} = \frac{l}{v} = \frac{6\,m}{0.5\,m/s} = 12\,sec$$

31. $t_{1\text{-}5}$ – time for felling and processing of 1 tree at the 5th parking lot, s;
32. $t_{2\text{-}5}$ – time for felling and processing of the 2nd tree at the 5th parking lot, s;
33. $t_{3\text{-}5}$ – time for felling and processing of the 3rd tree at the 5th parking lot, s;
34. $t_{4\text{-}5}$ – time for felling and processing of the 4th tree at the 5th parking lot, s;
35. $t_{5\text{-}5}$ – time for felling and processing of the 5th tree at the 5th parking lot, s;
36. $t_{6\text{-}5}$ – time for felling and processing of the 6th tree at the 5th parking lot, s;
37. $t_{0\text{-}6}$ – time for driving the harvester to the 6th parking lot (6 meters), s;

$$t_{0-6} = \frac{l}{v} = \frac{6\,m}{0.5\,m/s} = 12\,sec$$

38. $t_{1\text{-}6}$ – time for felling and processing of the 1st tree at the 6th parking lot, s;
39. $t_{2\text{-}6}$ – time for felling and processing of the 2nd tree at the 6th parking lot, s;
40. $t_{3\text{-}6}$ – time for felling and processing of the 3rd tree at the 6th parking lot, s;
41. $t_{4\text{-}6}$ – time for felling and processing of the 4th tree at the 6th parking lot, s;
42. $t_{5\text{-}6}$ – time for felling and processing of the 5th tree at the 6th parking lot, s;
43. $t_{6\text{-}6}$ – time for felling and processing of the 6th tree at the 6th parking lot, s;
44. $t_{7\text{-}6}$ – time for felling and processing of the 7th tree at the 6th parking lot, s;
45. $t_{0\text{-}7}$ – time for driving the harvester to the 7th parking lot (6 meters), s;

$$t_{0-7} = \frac{l}{v} = \frac{6\,m}{0.5\,m/s} = 12\,sec$$

46. $t_{1\text{-}7}$ – time for felling and processing of the 1st tree at the 7th parking lot, s;
47. $t_{2\text{-}7}$ – time for felling and processing of the 2nd tree at the 7th parking lot, s;
48. $t_{3\text{-}7}$ – time for felling and processing of the 3rd tree at the 7th parking lot, s;
49. $t_{4\text{-}7}$ – time for felling and processing of the 4th tree at the 7th parking lot, s;

50. $t_{5\text{-}7}$ – time for felling and processing of the 5th tree at the 7th parking lot, s;
51. $t_{6\text{-}7}$ – time for felling and processing of the 6th tree at the 7th parking lot, s;

FDB tree processing cycle time per hour (T_c) is determined by the formula (3) and, taking into account the obtained values, is as follows:

$$
\begin{aligned}
T_c \; = {} & 80+80+80+80+80+80+12+80+80+80+80+80+80+80+12 \\
& +80+80+80+80+80+80+12+80+80+80+80+80 \\
& +80+80+12+80+80+80+80+80+80+12+80+80 \\
& +80+80+80+80+80+12+80+80+80+80+80+80 \\
& = 3656\, sec
\end{aligned}
$$

The graph of FDB tree processing per hour taking into account the following assumptions: n1 = $t_{1\text{-}1}$;n2 = $t_{2\text{-}1}$; n3 = $t_{3\text{-}1}$; n4 = $t_{3\text{-}1}$; n5 = $t_{5\text{-}1}$; n6 = $t_{6\text{-}1}$; n7 = $t_{0\text{-}2}$;n8 = $t_{1\text{-}2}$; n9 = $t_{2\text{-}2}$;n10 = $t_{3\text{-}2}$; n11 = $t_{4\text{-}2}$;n12 = $t_{5\text{-}2}$; n13 = $t_{6\text{-}2}$;n14 = $t_{7\text{-}2}$; n15 = $t_{0\text{-}3}$;n16 = $t_{1\text{-}3}$; n17 = $t_{2\text{-}3}$;n18 = $t_{3\text{-}3}$; n19 = $t_{4\text{-}3}$;n20 = $t_{5\text{-}3}$; n21 = $t_{6\text{-}3}$;n22 = $t_{0\text{-}4}$; n23 = $t_{1\text{-}4}$;n24 = $t_{2\text{-}4}$; n25 = $t_{3\text{-}4}$;n26 = $t_{4\text{-}4}$; n27 = $t_{5\text{-}4}$;n28 = $t_{6\text{-}4}$; n29 = $t_{7\text{-}4}$;n30 = $t_{0\text{-}5}$; n31 = $t_{1\text{-}5}$;n32 = $t_{2\text{-}5}$; n33 = $t_{3\text{-}5}$;n34 = $t_{4\text{-}5}$; n35 = $t_{5\text{-}5}$;n36 = $t_{6\text{-}5}$; n37 = $t_{0\text{-}6}$;n38 = $t_{1\text{-}6}$; n39 = $t_{2\text{-}6}$;n40 = $t_{3\text{-}6}$; n41 = $t_{4\text{-}6}$;n42 = $t_{5\text{-}6}$; n43 = $t_{6\text{-}6}$;n44 = $t_{7\text{-}6}$; n45 = $t_{0\text{-}7}$;n46 = $t_{1\text{-}7}$; n47 = $t_{2\text{-}7}$;n48 = $t_{3\text{-}7}$; n49 = $t_{4\text{-}7}$;n50 = $t_{5\text{-}7}$; n51 = $t_{0\text{-}8}$.

Thus, the typical hourly productivity of FDB on the plantation forest area is determined by the formula (1) and is 13.5 m^3/h. This value can be recommended as a planned indicator for the FDB operator in the middle taiga of the Komi Republic in the natural production conditions of JSC "Syktyvkar LPC" when harvesting timber with a feller-delimber-buncher (FDB) of medium class (Ponsse Ergo 8W).

4 Conclusions

On the example of the most common in logging practice plantation forest stands in the middle taiga of the Komi Republic in the natural-production conditions of JSC "Syktyvkar LPC" the technological process is modeled in terms of productivity of a typical multi-operational harvesting machine: feller-delimber-buncher (FDB) of medium class (Ponsse Ergo 8W), the process of processing of one tree by such a machine, taking into account the graph theory the graph of processing of one tree is modeled and given, the hourly productivity (P_h) is given for FDB under these conditions (P_h = 13.5 m^3/h); the recommendations are given on the value of the planned FDB hourly production rate under such conditions.

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