Modeling of operating modes of woodworking equipment

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Abstract. The effective use of the production capabilities of logging and woodworking equipment largely depends on the compliance of their design features and work organization parameters in specific production and technical conditions. This is achieved in the process of technological calculations with the determination of the optimal modes of their functioning. The paper proposes a methodology and results of modeling on analytical models when sawing logs. The proposed method consists in the fact that in order to maintain stocks at the calculated level, eliminate downtime of machines with the highest productivity in operations with a lower productivity, the duration of their operation is increased by the time calculated for specific conditions. As a result of the work, the analysis of methods and models of timber inventory management was carried out. The main features of woodworking production and its technological process are given. It has been established that the technological process is a production line of mixed aggregation with flexible connections.

1. Introduction
Logging and woodworking production is a multi-faceted ergatic (human-machine) complex system. In modern conditions, logging and woodworking enterprises, as a rule, work in one or two shifts. Technological process of logging and woodworking production process consists of a number of production operations that are performed in a strictly defined sequence. For example, in woodworking, marking is followed by cutting boards into blanks for parts, and then there is planning, pruning, making spikes, hollowing out nests, etc. According to the technological process, a raw material warehouse, a finished product warehouse, intermediate warehouses, or buffer warehouses, as they are called, are arranged. Such intermediate warehouses are arranged for holding parts after drying, after gluing and veneering, between the machine and assembly shops to store the parts after machining until they are needed for assembly. Such a technological process represents a production line of mixed aggregation with flexible links. Stocks provide flexible connection of the workflow. As a rule, the stock comes from one or more machines and parts or blanks are consumed from the stock by one or more machines.

At the same time, the presence of stocks, when one of the adjacent machines stops, allows not to interrupting the technological process, and the absence leads to failures in the functioning of the technological process. Rational control of the modes of operation of machines in the technological process involves the coordination (coordination) of intensities and modes of operations. For the organization of effective woodworking production, the problem of managing stocks of objects of labor
of all types, distributed along the production chain and undergoing a certain transformation into the final product during the production process, is extremely important [1]. This task is of particular relevance in special working conditions [2-3], including taking into account the high wear and tear of equipment [4].

Timber inventory management involves two approaches: process control and process control (dynamic control) [5]. From the point of view of the nature of timber stocks, it is necessary to distinguish between the tasks of managing active (interoperational), passive (reserve of all types) and combined stocks. Active reserves are characterized by the simultaneity of the processes of their creation, replenishment, consumption and production. The tasks of managing active stocks of timber are typical for individual links in the production chain or related technological operations [6]. Such problems can be solved by methods of queuing theory as multiphase systems and by methods of simulation based on mathematical models.

Passive stocks of timber differ in that the processes of their creation and consumption are spaced out in time: stocks are first created, and then, after a while, are used. The tasks of managing passive (reserve) stocks of timber can occur during sequential operational processing of timber in the presence of a significant time gap between operations. Such problems can be solved by both mathematical programming methods and conventional analytical methods of engineering calculations.

The tasks of managing the combined stocks of timber are the most typical and complex. It is precisely this kind of tasks that are characteristic of a full-fledged production process, therefore, a comprehensive solution to these problems is the essence of process management and process inventory management [7]. Such problems can be solved by analytical methods, methods of statistical, simulation and fuzzy modeling, expert methods, as well as by combining various methods [8-9].

The problem of inventory management is formulated as follows: based on the existing, existing, calculated or normatively specified level of timber stocks at the final operation, calculate the optimal levels of stocks for all previous operations [10-11].

This task can be solved by modeling the production process [12-13]. This ensures the achievement of the highest and most stable production rates of the entire optimized process as a whole.

At present, there are practically no works that would allow calculating the volumes of active interoperational stocks in the technological process of woodworking industries, which leads to non-fulfillment of the production plan of a given volume. Therefore, in order to achieve the maximum output volume and quality of products in the planned period of time, a method of managing active interoperable stocks is required, taking into account the specific production conditions of a woodworking enterprise.

2. Methodology
The design of any technological process for a given production volume requires the calculation of the number of technical means at each operation of the production line, as well as the scientific organization of labor, ensuring its effective functioning. Usually, the existing calculation methodology and production management make it possible to obtain a line productivity equal to the minimum productivity of technical means at one of the operations [14].

One of the main reserves for increasing the efficiency of production processes is to improve the use of technical means on the basis of rational planning and management of their modes of operation, in particular, determining the volumes of operating stocks between each pair of operations and the time indicators of their creation, replenishment, consumption and production [15]. The definition of these data can be obtained as a result of computer modeling of a specific technological process (production line with flexible connections) according to previously developed mathematical models. The basis of the model developed by us is the organization of the production line, which provides a performance equal to or close to the maximum performance of technical means at one of the operations that make up this line.

The provision of this condition is possible by maneuvering the number and (or) shift of work (mobile technical means) or only shift of work (stationary technical means). On operations that have a lower productivity compared to the maximum (leading) one of the line operations, additional (mobile) technical means are connected for a certain time calculated for specific conditions or the number of
changes in the operation of technical means (stationary) increases. Maneuvering by the number (shift of work) of technical means is linked to the value of the interoperational stock of objects of labor, calculated for the same conditions.

A rational technology with an optimal composition of equipment is determined during the design process. As a rule, machines and equipment (technical means - TM) of production systems are combined into sets (lines). During the design process it is important to determine the expected performance of this kit (line)

During the operation of the vehicle, it is necessary to control and organize their work so as to obtain the maximum performance of both individual vehicles and the flow (line) as a whole. It should be borne in mind that vehicles are unreliable in operation, each has its own coefficient of technical readiness. The most disadvantageous situation for a pair of adjacent vehicles is when one of them fails after reaching a certain level of inventory. In such a situation, there may be a shortage of stocks of labor volumes (LV) or a shortage of areas for stocks.

A shortage of objects of labor will come when the previous (i-th) vehicle fails, and the volume of stocks is at a minimum. In this case, in order to provide the next (s-th) vehicle with work, it is necessary that a certain amount of LV be in stock during the idle time of the previous vehicle.

On the other hand, if the areas under LV stocks are limited, then provided that the stocks are at the level acceptable for this case, when the next vehicle stops, the previous one will have to stand idle due to the lack of space for storing its products. In this case, to provide the previous (i-th) vehicle with work, it is necessary to have a reserve of areas that ensure the storage of its products in stock during the downtime of the next (s-th) vehicle.

In both cases, it is necessary to know the duration of the vehicle downtime and the volume of LV stocks created during this time.

Previously obtained mathematical models [4, 9, 15] make it possible to determine the volumes of inter-operational reserves, but do not allow calculating the modes of their creation, replenishment, consumption and production, which makes the proposed models more versatile and effective.

3. Results
The possible duration of the vehicle downtime per unit of time can be determined by the formula (1):

$$ t_d = 1 - K_{vu}, $$

(1)

where $K_{vu}$ – vehicle utilization rate.

Then the possible duration of the vehicle downtime per shift will be

$$ T_d^{sd} = t_d \cdot T_{sd} = (1-K_{mu}) \cdot T_{sd}, $$

(2)

where $T_{sd}$ – shift duration, h.

In these cases, the stock of LV ensures (insures) the uninterrupted operation of one of the adjacent vehicles when the other is idle. Since these reserves insure the uninterrupted operation of the vehicle, we will agree to call them – insurance [9].

With this in mind, the in-shift insurance volume of OT stocks can be found by the formula:

$$ Z_c = T_d^{sd} \cdot \Pi_{imax} = \Pi_{imax} \cdot (1-K_{vu}) \cdot T_{sd}, $$

(3)

where $\Pi_{imax}$ – the highest (maximum) hourly productivity of one of the adjacent vehicles, m³/h.

This volume of OT is sufficient for the day the vehicle starts operating at the next operation (s-th vehicles), when the volume of replenishment of the i-th (previous) vehicles is greater than the volume of their production by the s-th vehicles ($Q_i > Q_s$). In cases where the volume of replenishment is less than the volume of production of reserves ($Q_i < Q_s$), it is necessary to create and maintain the volume of reserves at a certain level for specific conditions $Z_c$. The methodology for calculating the level of these volumes was given earlier [14], taking into account the fact that the average shift productivity for a certain period of calculations remained practically constant, and in order to learn the maximum
productivity of the line as a whole, it is necessary to increase it for a certain time at operations with lower productivity due to maneuvering in number, those connecting additional vehicles to work.

At woodworking enterprises, technical means are stationary, therefore, an increase in the productivity of vehicles in lagging operations is possible by increasing the shift in their work. Due to the fact that at present woodworking enterprises work, as a rule, in 1; 2 shifts, the daily output for each operation will be equal to:

\[ Q_s = \sum \Pi_{s,i} \cdot n_{j,i} \cdot K_{s,i}, \]  

(4)

where \( \Pi_{s,i} \), \( n_{j,i} \), and \( K_{s,i} \) — respectively, the average shift capacity, the number and shift ratio of the \( j \)-th vehicles at the \( i \)-th operation \((i = 1, 2, 3..., I; j = 1, 2, 3..., J)\).

For the estimated period of the day of production lines (sets of vehicles) for logging operations, we took a month \([11, 14]\). The production conditions of logging operations are characterized by the fact that the areas occupied by inter-operational stocks of raw materials are not limited. In addition, stocks between adjacent operations do not remain in one place, but move as new areas are developed (tapes, plots, cutting areas).

In processing plants, the production deprivations of vehicles are located in the workshop premises. Each vehicle, as already noted, strictly corresponds to its place (with the exception of intra-plant transport). The areas occupied by stocks of labor volumes are strictly fixed and limited. Stocks are located in the form of stacks (stop), certain sizes, and hence the volume of labor. Therefore, when calculating the operating modes of machine tools and, in particular, the volumes of interoperable stocks, it is necessary to take these features into account. For each specific case, you should calculate the possible volume of blanks in the stack (stack):

\[ Q_p = L_p \cdot B_p \cdot H_p \cdot K_{fw}, \]  

(5)

Then the number of stacks (stop) for stacking the calculated volume of stock will be equal to

\[ n_p = \frac{Z_n}{Q_p} = \frac{Z_n}{L_p \cdot B_p \cdot H_p \cdot K_{fw}}, \]  

(6)

where \( L_p, B_p, H_p, K_{fw} \) — respectively, the length, width, height of the stack (foot), m, the coefficient of full wood of the stack (foot).

The required number of areas for stockpiling (excluding interstack space) can be determined from the dependence

\[ S_f = L_p \cdot B_p \cdot n_p, \]  

(7)

Substituting in place \( n_p \) we get its value.

\[ S_f = L_p \cdot B_p = \frac{Z_n}{L_p \cdot B_p \cdot H_p \cdot K_{fw}} = \frac{Z_n}{H_p \cdot K_{fw}}, \]  

(8)

If the required number of areas exceeds the available one \((S_f > S_g)\), then the permissible amount of labor in stock \( Z_n^{(p)} \) will be

\[ Z_n^{(p)} = S_a \cdot H_p \cdot K_{fd}, \]  

(9)

where \( S_a \) — available areas for stock placement (taking into account inter-staff distances and areas under the guarantee stock), m².

Analysis of the nature of replenishment and development of reserves and theoretical dependencies for determining the volumes of interoperable reserves showed that one of the main indicators affecting the size of the reserve is the duration of the settlement period (controlled period).

Expressing from the previously obtained dependencies \([14]\) the duration of the calculation period through the volumes of replenishment \( Q_i \) and production \( Q_s \) of the stock and the actual allowable volume of stock \( Z_n^{(p)} \), we get the equations for calculating the duration of the billing period.

1) for the occasion \((Q_i < Q_s)\):
\[
T^{(p)}_\rho = \frac{Z^{(p)}_\rho [Q^{(p)}_i - Q_s] (Q_s - Q_i) + Q_s \cdot Q_{s\alpha} - Z_c \cdot Q_s}{(Q^{(p)}_i - Q_s) \cdot (Q_s - Q_i) \cdot Q_i}
\] (10)

2) for the occasion \(Q_i > Q_s\):

\[
T^{(p)}_\rho = \frac{(Z^{(p)}_\rho - Z_c) \cdot Q_{s\alpha} \cdot Q_s + Z_c (Q_s - Q_i) \cdot (Q^{(p)}_i - Q)}{(Q^{(p)}_s - Q_s) \cdot (Q_s - Q_i) \cdot Q_s}
\] (11)

Taking into account the maximum output at a separate operation of the set, you can write:

1) for the occasion \(Q_i < Q_s\):

\[
T^{(p)}_\rho = \frac{Z^{(p)}_\rho [(Q^{(p)}_i - Q_{\text{max}}) \cdot (Q_{\text{max}} - Q_i) + Q_s \cdot Q_{s\alpha} - Z_c \cdot Q_s]}{(Q^{(p)}_i - Q_{\text{max}}) \cdot (Q_{\text{max}} - Q_i) \cdot Q_i}
\] (12)

2) for the occasion \(Q_i > Q_s\):

\[
T^{(p)}_\rho = \frac{(Z^{(p)}_\rho - Z_c) \cdot Q_{s\alpha} \cdot Q_s + Z_c (Q_{\text{max}} - Q_i) \cdot (Q^{(p)}_i - Q_{\text{max}})}{(Q^{(p)}_s - Q_{\text{max}}) \cdot (Q_{\text{max}} - Q_i) \cdot Q_{\text{max}}}
\] (13)

where \(Q_{\text{max}}\) – maximum average shift production at one of the set operation; \(Q_i, Q_s\) – average shift output at the \(i\)-th operation and the \(s\)-th operation; \(Q^{(p)}_i, Q^{(p)}_s\) – average shift production after changing the shift work on lagging operations; \(Q_{s\alpha}, Q_{s\alpha\text{max}}\) – the volume of the average shift output by which the average output at a lagging operation increased; \(i = 1,2,3..I; S = i+1\).

We calculate the operating modes of woodworking machines for two options [10]. The first option is for cutting raw materials on sleepers and a container board according to the scheme of figure 1a and the second one is for cutting low-grade raw materials into a container board according to the scheme of figure 1b.

**Figure 1.** Cutting scheme: a – sleeper raw materials; b – low-grade raw materials, mm.

For the first option, the productivity (number of logs per shift) of the sleeper cutting machine \(Ts\text{DT-}6-4\) with this sawing scheme will be:

\[
P_{\text{fue}} = \frac{8 \cdot 3600 \cdot \varphi_1 \cdot \varphi_3 \cdot V}{l_a \cdot n} = \frac{8 \cdot 3600 \cdot 0.7 \cdot 0.5 \cdot 1.3}{275 \cdot 5} = 963
\]

When sawing logs according to this scheme, two sleepers and two slabs are obtained from one log, therefore, 1906 sleepers and 1906 slabs are obtained per shift.

Productivity (number of slabs per shift) of rib machine CR-4

\[
P_{\text{fue}} = \frac{8 \cdot 3600 \cdot \varphi_1 \cdot \varphi_3 \cdot V}{l_a \cdot n} = \frac{8 \cdot 3600 \cdot 0.7 \cdot 0.5 \cdot 0.6}{275} = 2198
\]

The productivity (number of plates per shift) of the cutting machine \(Ts\text{D-8}\) at a speed of up to 1 m/s will be:
Comparing the productivity of the machines according to this sawing scheme, it is easy to see that the CR-4 machine will be the most productive - 2198 slabs (plates) per shift.

The technological reserve between the sleeper and ribbed machines is taken in the volume of the hourly productivity of the ribbed machine – 275 pieces. Between rib and dividing machines – 228 pieces.

The output of the sleeper cutting machine will increase due to an increase in the number of shifts of its work by 0.2 shifts $Q_{Di} = 381$ and will be $Q(D)i = 2287$ sleepers (slabs) per shift.

Then the volume of the guarantee stock between the sleeper and ribbed machines, provided $Qi < Qs$ defined by the formula (14):

$$
Z_g = \left[ T_{sd} \cdot \left( Q_{max} - Q_i \right) \cdot \left( Q^{(d)}_i - Q_{max} \right) + Z_c \cdot Q_{Ds} \right] \cdot Q_s
$$

$$
Z_g = \frac{[20 \cdot (2198-1906) \cdot (2287-2198) + 275 \cdot 381] \cdot 1906}{(2198-1906) \cdot (2287-2198) + 1906 \cdot 381} = 1584.
$$

The volume of production of the indexing machine will increase due to an increase in the number of shifts of its work by 0.3 shifts $Q_{Ds} = 2287$ and will be $Q^{(d)}_s = 2382$ change plates.

Then the volume of the guaranteed stock between the ribbing and dividing machines, provided $Q < Q_{Ds}$ defined by the formula (15):

$$
Z_g = \left( T_{sd} \cdot Q_{max} - Z_c \right) \cdot \left( Q_{max} - Q_s \right) \cdot \left( Q^{(d)}_s - Q_{max} \right) + Z_c \cdot Q_{max} \cdot Q_{DS}
$$

$$
Z_g = \frac{(19,2 \cdot 2198 - 228) \cdot (2198 - 1832) \cdot (2382 - 2198) + 228 \cdot 2198 \cdot 550}{2198 \cdot 550} = 2566.
$$

The possible area for placing the guarantee stock can be $3,5 \times 2,75 \text{ m}$. Then, with a permissible stack height of 1,5 m, it will accommodate about 300 blanks.

Proceeding from this, the safety stock should be taken equal to 15 minutes and the calculation should be carried out for each week, then the volume of the guarantee stock in pieces between the sleeper and ribbed machines, provided that the technological stock is equal to 70 pieces of slabs for the first month, the work of creating stocks will be

$$
Z_g = \left[ 5 \cdot (2198 - 1906) \cdot (2287 - 2198) + 70 \cdot 381 \right] \cdot 1906
$$

$$
Z_g = \frac{(2198-1906) \cdot (2287-2198) + 1906 \cdot 381}{2198 \cdot 202} = 397.
$$

The volume of the guaranteed stock between the ribbing and dividing machines, provided that the technological stock is equal to 63 pieces of plates (15 min of the dividing machine operation), will be:

$$
Z_g = \frac{4.8 \cdot 2198 - 63 \cdot (2198 - 2016) \cdot (2218 - 2198) + 63 \cdot 2198 \cdot 202}{2198 \cdot 202} = 149.
$$

For the next months, respectively, between the sleeper and ribbed machines, the volume of the guaranteed stock will be

$$
Z_g = \frac{5 \cdot (2198 - 1906) \cdot (2287 - 2198) + 70 \cdot 381}{381} = 411.
$$

between rib and dividing machines:
Analysis of the results obtained shows that the volume of guaranteed stocks between the machines is located on the available areas.

If low-quality raw materials are supplied for processing and the sleeper cutter will process 953 logs, then there will be 2859 slabs and 2859 plates. Those, in this case will be the leading sleeper cutting machine. The difference in production volumes between the machines will be incompatible (the sleeper machine will make 2859 slabs and plates each and the ribbed and long-lasting machines will process 2189 slabs and 1832 plates, respectively). In this case, in order to reduce the discrepancy between the production volumes, it is necessary to increase the load factor of the rib and dividing machines. Then, with the load factor of the rib $\varphi_2=0.6$, the volume of production for raw materials will be 2626 slabs, and the dividing machine with $\varphi_2=0.7$-2264 plates, respectively.

To increase the output to the output of the leading machine, it will be necessary to increase the shift ratio of the rib machine by 0.1, then the volume of its output will be 3151 slabs, i.e. will increase by 263, and the shift ratio of the dividing machine must be increased by 0.15, then the volume of its output will be 2949, i.e. will increase by 385 plates.

$Z_g = \frac{5 \cdot (2198 - 2016) \cdot (2218 - 2198) + 63 \cdot 202}{202} = 153.$

The volume of the guarantee stock between the sleeper and ribbed machines will be

$$Z_g = \frac{(5 \cdot 2859 - 70) \cdot (2859 - 2626) \cdot (2889 - 2859) + 70 \cdot 2859 \cdot 263}{2259 \cdot 263} = 202.$$

The volume of the guarantee stock between the sleeper and dividing machines will be

$$Z_g = \frac{(5 \cdot 2859 - 63) \cdot (2859 - 25646) \cdot (2949 - 2859) + 63 \cdot 2859 \cdot 385}{2259 \cdot 385} = 484.$$

In this case, the results obtained show that the volume of guaranteed stocks is also located in the available areas.

4. Conclusion
The paper presents the main features of the woodworking industry and its technological process. It is established that the technological process is a production line of mixed aggregation with flexible connections. Stocks provide flexible connection of the workflow. A brief analysis of the methods and models of timber inventory management developed by scientists and industry researchers is carried out. The role and importance of timber stocks have been clarified.

In order to ensure the release of products of a given volume and quality in the planned period of time, a methodology and models for determining the operating modes of woodworking equipment in the technological process have been developed with the ability to take into account the specific production conditions of a woodworking enterprise and maximum output at the leading operation.

In the first variant of the calculation, due to an increase of 0.2 in the change of sleepers and dividing machines, the volume of production for raw materials will increase from 953 to 1143 logs, that is, it will increase by 20%.

In the second option, when processing low-quality raw materials due to an increase of 0.1 changes in the ribbing machine and 0.15 changes in the cutting machine, the volume of production for raw materials will be 953 logs, otherwise it would be 611 logs, i.e. the volume of production can increase by 55%.

The use of the obtained mathematical models (14) and (15) makes it possible to determine the volume of warranty stocks between each pair of operations, which, if they are maintained at the calculated level by increasing the shift of machine tools on lagging operations, will provide the volume of production of a set of machines equal to the volume of production of the leading machine.
The proposed method allows us to calculate the operating modes of sets of woodworking machines of various technological processes, which makes it possible in the future to widely apply it in the woodworking industry and the world forestry.

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