Software System for Sawmill Operation Planning

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Abstract

The paper describes research and development of software system for optimal planning of sawmill operation. This work is a part of long-term activity carried out by Petrozavodsk State University (PetrSU) in the field of scientific research, software development and customer projects for enterprises of pulp-and-paper and forestry industry of Russia. The system uses advanced mathematical models and optimization algorithms, developed by IT-park of PetrSU, to solve a series of planning tasks for any number of orders and any configuration of process equipment of a hardwood sawmill. The developed mathematical model takes into account all features, limitations and parameters of process equipment, as well as of raw material and production orders. The efficiency of solutions had been validated on real production data of several sawmills in Russia. The system has friendly and flexible user interface and can be easily modified to handle new customer-specific requirements.

Index Terms: Lumber production, Process automation, Mathematical methods, Optimization problems.

I. Introduction

Lumber industry is an important branch of the forestry industry. The aim of the sawing process consists in processing round wood into sawn lumber, as well as technological wood chips.

Typically, logs are transported to a mill by trucks, where they are graded for size and suitability for different uses. Various types of saws may be employed to cut the logs into rough lumber of different lengths, widths and thicknesses. The boards are then stacked and placed in drying chambers. Once dry, the boards are planed to final dimensions and to provide a smooth finish before being shipped [1].

The main raw material for a sawmill is timber of coniferous and deciduous breeds with diameter from 14 cm and more in topmost end. The logs are cut into sawn lumber according to a plan, developed in advance. The sawing pattern is a scheme of sawing of a separate log (or sorting group of logs with approximately same diameters) into sawn lumber of demanded sizes. The pattern shows the order and places of saw cuts, thickness, width and sometimes length of lumber. Also the sawing pattern sometimes refers to the group of saws in multi-saw machines set up according to the scheme of sawing [2].

After the calculation of sawing patterns for each sorting groups of logs, a monthly plan of cutting of all raw material is made. This plan contains quantity and size-qualitative structure of logs to be sawn and the lumber produced by applying each sawing pattern. Preparation of such plan is a highly responsible task, because one of the main targets is to produce required lumber from available raw materials with minimal waste.

When the monthly volume plan is ready, the more detailed production schedule is prepared. This schedule includes the sequence of sawing patterns, as well as the starting and ending times for loading drying chambers. Because the drying time is quite long (3 to 10 days), one of the targets is to minimize the unproductive idle time of the chambers.

The sawmill process creates a lot of waste material. Theoretically, useful output of edged boards ranges from 53 to 64%, but in practice it may be even less than that [2].

Various tasks related to planning of sawmill operation can be successfully solved with the use of specialized software based on mathematical modeling [3, 4, 5]. Such software allows to increase overall mill productivity, output of high-quality grades of lumber and better matching the production specification. It also improves the efficiency of calculating and correcting the operational plans [6]. Since a reasonably-sized sawmill processes tens of thousands of cubic meters of wood monthly, even a 1-2% increase in productivity or profitability is noticeable.

II. Development of sawmill optimal planning system

A. Problem statement

Typically a sawmill receives logs of various grades and diameters and sawn lumber is also divided according to sorts and sizes. The problem of sawing patterns calculation consists in specification of sizes and number of lumber to be cut from each log of given quality, length and diameter. As a rule, monthly plans cover more than 10 grade groups of logs and the number of produced sawn lumber grades exceeds 50 or even 100.

The solution to this problem must also take into account all features, limitations and parameters of process equipment, as well as of raw material and production orders.

The process equipment parameters to be taken into account include:

- The number and saw cut width for saws of 1st and 2nd row for each saw bench;
- Relation between maximal diameter of log, which can be cut on the saw bench, maximal height of the cut and maximal width of the sawing pattern;
- Productivity of each saw bench per shift depending of diameter and length of logs;
- Minimal width of the two-edged cant (separate for each log diameter), because smaller width leads to increased waste;
- Volume of logs of each kind available in a warehouse (or scheduled for delivery);
- Minimal (non-zero) production volume per each sawing pattern, because each re-tuning of saw bench leads to idle time;
- Minimal width of central part of the cant, minimal difference between width of cant and side part;
- Maximal width of side part, maximal number and width of side boards, maximal number of different types of sawn timber in the sawing pattern;
- Previously planned schedule of process equipment operation (saw benches, drying chambers, etc.);
- Many others, depending on the sawmill equipment parameters;
- The parameters of raw material and production orders to be taken into account include:
- Minimal and maximal production volumes for each type of sawn lumber;

- Minimal and maximal length of lumber and cutting steps (e.g., with cutting step 0.3m, a 3.5m-long board should be cut to length of 3.3m and 0.2m of board go to waste, which reduces the high-grade production volume);
- Required moisture content after drying;
- Quality of lumber (A, B, C and other);
- Priority of an order (to ensure delivery performance);
- Requirements to positioning of lumber relative to log axis:
  - In cant part only, i.e., only from two-edged cant;
  - In side part only;
  - In central part only;
  - 2 Ex-Log, i.e., 2 boards in central part (without central board);
  - 2 Ex-Log not side board, i.e., 2 boards in central part with other boards in the two-edged cant;
  - 3 Ex-Log, 4 Ex-Log, 5 Ex-Log – similarly;
  - Not in the center;
  - 2,4,6 Ex-Log, i.e., in central part, without central board, but for large diameters (e.g., over 30cm) this constraint can be skipped;
  - Maximal share of lumber from side part (e.g., for Ex-Log it is not more than 20%).

B. Specifics of using methods of mathematical programming for solving the problem

The main unknown variables are volumes of logs to be cut according to each sawing pattern, which uniquely defines the order and places of cuts, as well as thickness, width and length of sawn lumber produced.

First of all, it should be noted that without constraint on minimal (non-zero) production volume per each sawing pattern the problem can be solved by linear programming methods. Some essential features of the problem should be noted:

1. Nonlinearity due to constraint on the minimal (non-zero) production volume per each sawing pattern. The following solution approach is proposed – to find exact solution without this constraint, remove sawing patterns, which do not satisfy this condition and solve the problem again using only sawing patterns, found at the previous step. With such approach, in some cases we may get only approximate solution [6, 7]. However, advantages of this approach are simplicity of implementation and practical applicability.
2. The complete set of feasible sawing patterns is not provided by a user due to exceedingly large number of those. Therefore, it is impossible to build the constraints matrix explicitly. In any case it would've been inefficient due to the large number of columns and complexity of the structure. Instead, the columns generation method is used. In this case, the new column to be added to the basis plan is found by solving an auxiliary optimization problem.
3. The solution of this auxiliary optimization problem involves solution of the problem of optimal cut of truncated cone to parallelepipeds with a considerable number of constraints. This problem is solved by using dynamic programming methods [8]. The solution time should not exceed few seconds, because solution of the main problem requires repeated (up to several hundreds times) solution of this auxiliary problem.

4. Taking into account the fact that the set of feasible values may be empty, auxiliary variables are calculated. They are equal to deviations from constraints (upper and lower bounds) for production volumes of each type sawn lumber and also for productivity of each saw bench.
5. There are several possible goal functions (e.g., maximum profit, maximum production volume, etc.) However, the main difference between them is only in goal function coefficients and effect on the solution algorithm is negligible.
6. The dual variables, obtained during solution of the main linear programming problem, are very important for revealing "bottlenecks" in production efficiency and structure of orders portfolio.
7. As such, the scheduling problem of loading drying chambers is NP-complete. Therefore, its solution requires the use of special algorithms.

III. Developed toolkit section

The software system for sawmill operation planning is implemented using a specialized versatile library developed in IT-park of PetrSU based on 25 years of experience in research and development of software systems for customers in various branches of industry [9]. The library includes a large number of closely integrated components and allows to unify and speed up the software development processes, to simplify the description of data models and to reduce the number of errors. In particular, it includes a module («the versatile solver») for solution of complicated optimization problems related to production planning. All components of the library are integrated into MS Visual Studio.NET environment and can therefore be freely and uniformly used together with standard methods and components of MS Visual Studio.

IT-park research and customer project experience shows that the constraints matrix in practical optimization problems typically has very large dimension and distinctive block structure. Due to the large number of blocks in such matrix, specification of their values and also of their position relative to each other, often leads to errors, which are very difficult to fix. Therefore, «the versatile solver» contains a special data structure («the matrix designer»), which increases the efficiency of storing and using the main constraints matrix by splitting it into sub-matrices.

Based on "the versatile solver", algorithms for effective solution of complicated cutting problems were implemented, including linear and nonlinear optimization problems, high-dimension problems, problems with combined criteria, etc. The algorithms utilize a wide range of linear, dynamic, convex and discrete programming methods and decomposition schemes, which allows to solve a wide range of optimization problems in the area of industrial production planning and scheduling.

The main method for solution of cutting optimization problems in the software system is the columns generation method [10, 11, 12]. Its major difference from other methods is that optimality of a solution is checked not by using the matrix of initial data, but by solving an auxiliary optimization problem. The standard columns generation method was improved to efficiently handle constraints that are typical for practical optimization problems – upper and lower bounds on production volumes, presence of several identical production units, proportional dependence between variables, etc.

The software system for sawmill operation planning allows users to input initial data, calculate optimal production plan for given time period, as well as to generate various reports (tables and diagrams). These functions are accessible from the menu. Access to certain menu items can be restricted for certain users and user roles. For example, some users can be allowed only to enter data, but not to calculate plans, etc.

Initial data for planning is entered and stored in tables. There is a special tool box for adding, editing, deleting, sorting, copying and finding elements. Also visibility of fields can be configured. Total of 8 tables are implemented: raw materials (including statistical distribution per sorting groups), sorting groups (by diameter, including the minimum width of cant, which can be cut from it), saw benches, sawn lumber (including statistical distribution of output per each grade), nominal values for logs (the volume of logs of given length and diameter according to standards [13]), drying coefficients, lumber grades, groups of lumber lengths (for statistical distributions of output per each grade), shifts, schedule templates (for storing schedules of saw benches and drying chambers operation). New tables can be added, if needed.

The user interface for input of initial data and calculation of plans is given on Fig.1.

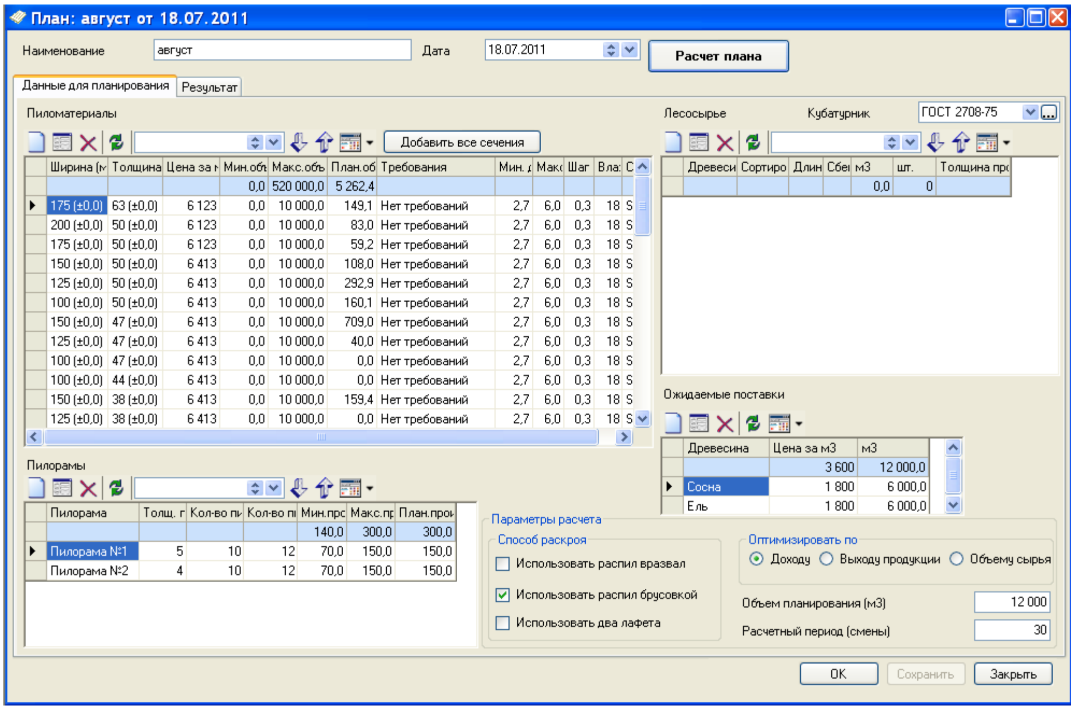

Fig. 1. The user form for creating/editing the plan, tab "Data for planning"

Parameters of all found sawing patterns, as well as the volume of logs to be sawn according to each pattern, are displayed after calculation. Each sawing pattern can also be presented graphically with indication of length of each board (Fig.2). Also for each type of sawn lumber the specified bounds and computed volume are displayed.

Calculated sawing plans (e.g., per month) can be stored in a database for later use.

The implemented reports include wood consumption, output and runtime of saw benches, output of sawn lumber, sawing patterns used, economic indicators of sawmill performance. New reports can be created according to customer demand.

IV. Implementation Result

The software system was tested on real operating data of several sawmills in Russia (OJS «Medvezhegorsky sawmill», OJS «Sokolsky DOK», CJS «Solomensky sawmill») over the time period of 12 months.

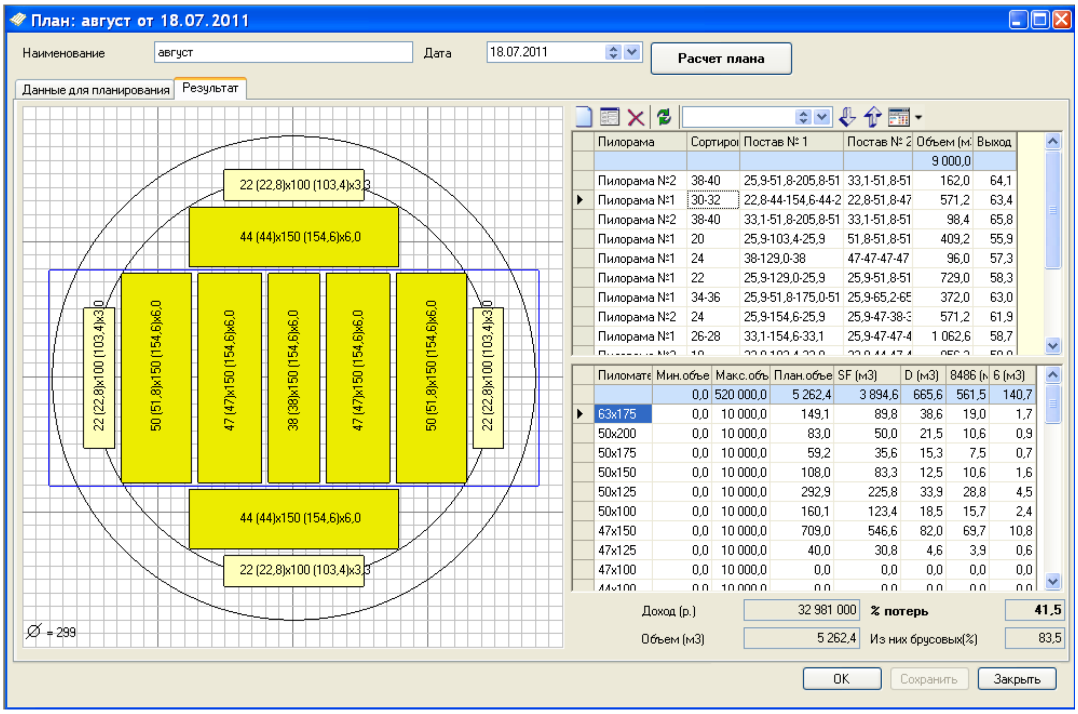

Fig. 2. The user form of creating/editing the plan, tab “Results of planning”

For each month the software system calculated optimal production plan, which was compared with production plan, prepared by the sawmill staff and actually used at the sawmill. In all cases the software system has found sets of sawing patterns, yielding the same volumes of sawn lumber of each type and grade, as specified by the sawmill staff. Technical feasibility of all sawing patterns and other parameters was confirmed by the mill staff. The average monthly saving on raw materials amounted to about 600 m^3 of wood or 3%, that is equivalent to a saving of about 300 thsd euro annually. The calculation time for the software system took only few minutes, while for the mill staff it usually took several hours.

Additionally, the software system was used to calculate the most profitable specifications of sawn lumber, which can be produced from available raw materials. The system has found production plans, which improved the monthly profit by about 1.5%. Again, technical feasibility of all sawing patterns and other parameters was confirmed by the mill staff.

In the end, the system was used to calculate the schedule of drying chambers operation for each monthly sawing plan in order to minimize their idle time (or, equivalently, to increase the output of end products). Average reduction of idle times was 1.3%. Technical feasibility of the schedules was confirmed by the mill staff.

V. Conclusion

The developed software system bases on the mathematical model which takes into account features, limitations and parameters of process equipment, as well as of raw material and production orders. The efficiency of solutions had been confirmed on real production data of several sawmills in Russia.

The system yields to the business the following benefits:

– Increased output of end products by 1-2%.

- Decrease wood consumption 1-3%.
- Very fast planning and replanning (just few seconds).
- Reduce time for order fulfillment.

The system has friendly and flexible user interface and can be easily modified to handle new customer-specific requirements.

Possible directions of further development of the system include modifications to the solution algorithm to take into account additional requirements, e.g., to the structure of annual rings of timber, to regularity of saw benches load and other customer-specific requirements. All basic components for that are already available in the versatile library developed in IT-park of PetrSU. This minimizes the expenses on adding new features and functions to the system for solving the aforementioned and other optimization problems, facing the enterprise and forestry industry as a whole.

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