DOI: 10.17323/2587-814X.2024.4.98.111

Management of pricing policy of a timber enterprise considering the problems of formation of raw material supply chains and determining production volumes

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Abstract

This paper considers a mathematical model that allows managers of a timber enterprise to develop supply chains and manage the pricing policy of the organization. This model is a modification of the model developed earlier and differs from it by taking into account the technology of raw material cutting. The model takes into account the consumption rates of raw materials, purchases on the commodity exchange, transportation of products and pricing policy of the enterprise taking into account the demand. The purpose of the model is to maximize the value of operating profit of the enterprise. When searching for a solution, an optimization strategy is applied which includes two stages: application of linear optimization at the first stage and genetic algorithm at the second stage. As a result of testing the model at one of the timber processing enterprises in the Primorsky Territory, data were obtained, based on which recommendations are formulated for managers of the company regarding cooperation with loggers. This work represents an

* The article is published with the support of the HSE University Partnership Programme

important step in the development of supply chain management methodology in the timber industry, taking into account the technology of raw material cutting. Further research may include modification of the model using stochastic factors, improving decision-making methods and development of more accurate product demand functions. The work has practical significance for enterprises of the timber processing industry, since it can contribute to the improvement of their production processes and increase profits.

Keywords: supply chain, production volume, timber enterprises, optimality of decisions, mathematical model, commodity and raw materials exchange, share of the useful volume of raw materials, transit time, rational raw material transactions, increasing efficiency

Citation: Rogulin R.S. (2024) Management of pricing policy of a timber enterprise considering the problems of formation of raw material supply chains and determining production volumes. *Business Informatics*, vol. 18, no. 4, pp. 98–111. DOI: 10.17323/2587-814X.2024.4.98.111

Introduction

Timber enterprises, which play a significant role in the economy, face ever-increasing challenges and difficulties in organizing efficient supply chains of raw materials and the organization of production using cutting technologies. At timber enterprises, the issues of price policy optimization taking into account the formation of supply chains and determining production volumes are topical and critically important [1–10].

The timber industry is of strategic importance, supplying raw materials and products necessary for a variety of industries – from construction to paper and furniture production. However, under the conditions of changing market requirements, environmental constraints and intense global competition, timber companies have to constantly adapt and optimize their production and logistics processes [2, 11–15].

The importance of this topic is emphasized by its relevance in the modern world. A sharp increase in competition and external factors, such as climate change and legislation, put pressure on timber enterprises, forcing them to strive to increase production efficiency, reduce costs and improve product quality [3].

Analysis of existing studies [1–22] confirms the complexity of the problem of optimizing raw material supply chains and production volumes at timber enterprises. Effective management of these processes requires taking into account many variables, constraints and uncertainties related with production and logistics operations.

Relying on the above, it can be argued that the development of mathematical models and optimization methods for the formation of effective supply chains and production volumes using cutting technologies is becoming an integral part of the development strategy of timber enterprises.

The research presented in this article is relevant in the context of an ever-changing forest industry environment and rapidly evolving technologies that can improve production efficiency and reduce negative environmental impacts. These solutions can help timber companies to reduce costs, optimize production processes and improve product quality, as well as to meet new sustainability and environmental standards.

The current study, on the one hand, differs from its counterparts [1–20] in that it allows us to take into account the technology of cutting round wood entering production in conjunction with other important factors of forestry production. Particularly, these factors include the formation of raw material supply chains from the commodity and raw material exchange (since the enterprise does not have its own plots) and determining production volumes and pricing policy of the enterprise over the entire planning horizon. On the other hand, this paper complements the work [21] because it presents an optimization algorithm that allows us to speed up the process of finding an optimal solution.

The structure of the work provides justification of the topicality of the study, review of the literature, setting the goals and objectives of the study, development of a mathematical model and optimization algorithm, description of the results of approbation of the model on the data of the commodity and raw materials exchange and one of the timber enterprises of the Primorsky Territory, as well as the formulation of proposals for further development and modification of the model.

1. Literature review

The topic of optimizing the formation of raw material supply chains and production volumes using cutting technology at timber enterprises is a multifaceted field of research which is becoming increasingly relevant in the modern world. Timber industries operating in a changing economic and ecological environment face ongoing challenges in managing supply chains and optimizing production processes.

The main objectives of research in this area are to increase production efficiency [1–3], reduce production and logistics costs [4, 5], reduce waste [6, 7], and improve product quality [8, 9], taking into account the relationship between demand and prices. Over the last three years, only one paper [13] was published that would combine the main factors of production of the timber industry complex: the relationship between demand and prices for finished products, the production process, the formation of raw material supply chains and the construction of routes for transportation of finished products to customers. However, the second derivative of the demand function in this model at point 0 is not continuous, which indicates that there is an instantaneous rate of change in demand with an extremely small change in price. In addition, the real production of the timber industry is more often engaged not in the production of OSB boards, but in the cutting of lamellas and other workpieces from the incoming round wood for further production.

In recent decades, researchers have been actively working on the development of mathematical models [10] and optimization methods [11] to solve complex problems related to supply chain management and production management in timber enterprises. These models and methods are able to account for the many variables, constraints and uncertainties that are inherent in this industry.

One of the key aspects of the research is the integration of nesting technology into supply chain and production optimization [12]. Cutting technology allows producers to maximize the efficient use of forest raw materials and minimize waste, which is important from the point of view of production sustainability.

Analysis of the literature allows us to identify several key areas of research. First, it is the development of mathematical models that enable optimization of supply chains and production volumes, taking into account various parameters and constraints [3, 8, 9]. Second, it is research in the field of inventory management and production processes optimization [1, 12, 13], including cutting technology [14–16]. Third, it is research into the impact of external factors such as climate change and environmental standards [17–19] on supply chain and production management in the timber industry [20, 21].

In addition, it is worth noting the significant advantages of applying information technology and modern data analysis methods in solving optimization problems. The implementation of digital solutions and analytical tools allows companies to more accurately forecast demand, optimize inventories and resources, and manage complex supply chains [22].

Despite significant advances, there remain unresolved challenges and problems in this area. Resistance to change on the part of employees and suppliers, as well as the changing global economic environment, present major obstacles. Moreover, there is a need to develop innovative approaches to supply chain and manufacturing management given the rapidly changing market conditions and requirements.

In view of the above, it can be stated that the problem that affects the determination of the price of finished products in conjunction with the tasks of determining production volumes, the formation of supply chains of raw materials and transportation of finished products to customers is important and topical.

The criterion for a more efficient model will be the number of iterations required for the algorithm to reach a solution that does not change significantly with increasing iterations. The closest work in the literature is the study [13]. The results of the model proposed by the author are mainly compared with the output of the model from [13].

2. Research goals and objectives

In [13], a model of the activities of enterprises in the timber industry is considered on which we rely in this study. The model presented in this paper takes into account three key production processes: supplies and volumes of raw material purchases from the domestic market of the region; production volumes, taking into account the demand for each type of product and available stocks of raw materials; as well as ways of delivery of finished products to customers. The production technology based on the cutting of incoming round wood in the warehouse is considered.

Usually, companies receive orders from customers in advance, which allows them to plan activities for long periods. This is important for optimizing production processes, material procurement and resource allocation. However, it should be noted that the demand for timber products is subject to seasonal fluctuations, such as increased demand for heating materials during the winter and demand for construction materials during the summer months. These seasonal changes create additional challenges for production planning and inventory management. However, with adaptive strategies and analysis of market trends, a company can effectively adapt to changing demand and successfully manage production processes [13].

The purpose of this study is to develop a mathematical model that allows for optimizing the production processes of the timber industry complex, including determining the volume of output using round wood cutting technology, purchasing raw materials on the domestic market, delivery of finished products to the buyer, as well as the formation of pricing policy of the enterprise at different planning periods. The main task is to assess the feasibility of interaction between the enterprise and the forest commodity exchange in order to optimize production processes and improve the efficiency of the company.

To achieve the goal of the work the following research objectives were put forward:

1) Design of a two-stage economic and mathematical model including:

a) determining a suboptimal vector of production volumes by days on a given planning horizon, raw material supply chains and transportation volumes of raw materials and finished products;

b) determining sale prices for finished products.

2) Formation of a consistent solution for the two stages of the mathematical model.

3) Development of software that allows us to solve the set tasks.

4) Analyzing the results of model testing.

3. Mathematical model

To ensure uninterrupted operation of the timber enterprise, timely supplies of raw materials are required. Each timber harvester (located in certain area of the region) notifies the company that it will prepare a given volume of raw materials by a predetermined date and put it up for sale. The buyer can buy a part of the lot and select the raw material required by characteristics from the stack.

After a sufficient volume of raw materials is delivered to the production warehouse, the enterprise has the task of determining the optimal set of production operations for cutting technology and setting prices for products, taking into account the current dynamics of market demand. It is important to note that the change in prices for products is limited by the value of μ per week, which requires careful planning and analysis of market trends. In addition, once the production plan has been developed, it is necessary to organize efficient logistics for delivering products to customers (taking into account their individual needs and preferences) through known transportation hubs. This process requires coordinated work between production, sales and logistics departments to ensure smooth order fulfillment and customer satisfaction [13].

Achieving this goal requires the development of a mathematical model that optimizes all the factors described above.

M – planning horizon under consideration (days);

k – type of product produced, $k = 1, ..., K$;

len_e – length of workpiece of type e (m);

$width$, $height$ – width and thickness of the workpieces, respectively (m);

$\mathbb{w}(m)$ – week number $\mathbb{w}(m)$ depending on day number m, where

$$\mathbb{W}(m) = \frac{m}{7}; \tag{1}$$

$\mathbb{W}(M) = \frac{M}{7}$ – – number of weeks depending on planning horizon M;

c_{imrl} – purchase price of 1 m^3 from the i-th application for raw materials of the l-th type in the r-th region on the m-th day (rubles, shipping costs are included);

$c_{\jmath}$ – total costs of transportation of finished goods to the buyer at the point $\jmath$ (rubles);

b_{et} – number of times a workpiece of type e is encountered in a cutting of type t (in the literature, the set $\{b_{et}\}$ is usually referred to as a cutting map);

V_{imrl} – volume of raw materials of type l in application i from region r on day m (m^3);

$\bar{u}$ – maximum warehouse capacity (m^3);

$\bar{O}$ – maximum number of cuttings per day (units);

v'_{imr} – volumes of raw materials of type l purchased in the previous period, about which it is known that they will arrive at the warehouse on day m (m^3);

p_{kml} – the selling price of goods of type k made from raw materials of type l on day m (rubles);

I' – the number of orders that were purchased in the previous period (up to $m = 0$, and the date of their arrival at the warehouse is known in advance);

R – number of districts;

T_r – time consumption (in days) for delivery of any volume of raw materials from the region r by railroad;

$Q_{\jmath k \mathbb{w} l}$ – demand of $\jmath$-th retail company for product k from resource type l in week $\mathbb{w}$;

$\dot{Q}_{\jmath k \mathbb{w} l}$ – mathematical expectation of the volume of demand of the retailer $\jmath$ for products type k, produced from the resource of the type l, during the week $\mathbb{w}$;

$\mathcal{J}^*$ – number of retailers (final delivery points of manufactured products);

Bud_0 – initial budget;

$month(m)$ – month number depending on the day number;

$A_{ekl}^{month(m)}$ – amount of workpieces of type e, used to produce a unit of goods k from a resource of type l during the month $month(m)$ (units);

$Iter$ – number of independent iterations (units);

FC – fixed costs per day of operation (rubles);

$\mathbb{V}$ – slab volume (m^3);

$\tilde{L}$ – slab length (m);

x_{kml} – volume of production of goods of type k per day m made from raw materials of type l (pcs);

$\mathbb{z}_{\jmath k \mathbb{w} l}$ – volume of transportation of goods of type k made from raw materials of type l to point j during the week $\mathbb{w}(m)$ (units);

q_{tml} – number of cuttings of type t made from raw materials of type l per day m;

v_{imrl} — purchased volume of raw materials of type l from application i from region r on day m (m^3);

u_{ml} — volume of stock of raw materials of type l on day m in the warehouse (m^3);

$\tilde{u}_{eml}$ — volume of stock of workpieces of type e made from raw materials l by day m.

As an objective function, we will consider the value of the enterprise's operational profit on the planning horizon M (2):

The optimization problem has the following constraints:

$$\max_{p,x,v,\mathbb{z}} \sum_m \left(\sum_{k,l} p_{kml} x_{kml} - \sum_{i,l,r} c_{imrl} v_{imrl} - \sum_{\jmath,k,l} c_{\jmath} z_{\jmath k \mathbb{w}(m) l} \right). \quad (2)$$

$$\tilde{u}_{eml} = \tilde{u}_{e(m-1)l} + \sum_t b_{et} q_{tml} - \sum_k A_{ekl}^{month(m)} x_{kml},$$
$$e = 1:E, m = 1:M, l = 1:L, \quad (3)$$

$$\sum_{t,l} q_{tml} \le \bar{O}, m = 1:M, \quad (4)$$

$$\sum_{m=7(\mathbb{w}-1)+1}^{7\mathbb{w}} x_{kml} \le \sum_{\jmath} \mathbb{z}_{\jmath k \mathbb{w} l},$$
$$m = 1:M, k = 1:K, l = 1:L, \quad (5)$$

$$\mathbb{z}_{\jmath k \mathbb{w} l} \le Q_{\jmath k \mathbb{w} l}, \jmath = 1:\mathcal{J}^*, k = 1:K, \mathbb{w} = 1:\mathbb{W}, l = 1:L, \quad (6)$$

$$\sum_l \left(u_{ml} + \sum_e \tilde{u}_{eml} \cdot len_e \cdot height \cdot width \right) \le \bar{u}, m = 1:M, \quad (7)$$

$$x_{kml}, q_{tml}, \mathbb{z}_{\jmath k \mathbb{w} l} \in Z^+, \quad (8)$$

$$\tilde{u}_{eml}, u_{ml}, v_{imrl} \ge 0, \quad (9)$$

$$v_{imrl} \le V_{imrl}, i = 1:I, m = 1:M, r = 1:R, l = 1:L, \quad (10)$$

$$Bud_0 + \sum_{m=1}^{m^*} \left(\sum_{k,l} p_{kml} x_{kml} - \sum_{i,r,l} c_{imrl} v_{imrl} - \right.$$
$$\left. - \sum_{j,k,l} c_i \mathbb{z}_{\jmath k \mathbb{w}(m) l} - FC \right) \ge 0, m^* = 1:M, \quad (11)$$

$$u_{ml} = u_{(m-1)l} + \sum_{i,r} v_{i(m-T_r)rl} - \mathbb{V} \sum_t q_{tml}, \quad (12)$$

$$Q_{\jmath k \mathbb{w} l} = \left(\dot{Q}_{\jmath k \mathbb{w} l} \pm \varepsilon \right) \cdot e^{\left(\sum_{m=7(\mathbb{w}-1)+1}^{7\mathbb{w}} \frac{(p_{k(m+7)l} - p_{kml})}{7 \cdot p_{kml}} \right)}, \quad (13)$$

$$p_{k(m+1)l} = p_{kml} \cdot \left((1 + \varepsilon^{(1)} \right),$$
$$m = 1:M-1, \varepsilon^{(1)} = \left[-\varepsilon_1^{(1)}; \varepsilon_2^{(1)} \right], \quad (14)$$

$$A_{ekl}^{month(m)} = \max\left(0; \min\left(A_{ekl}^{month(m)}, A_{ekl}^{month(m)} + \varepsilon^{(2)}\right)\right), \varepsilon^{(2)} =$$
$$= \left[-\varepsilon_1^{(2)}; \varepsilon_2^{(2)} \right], \quad (15)$$

$$FC_\mu \in \left[\alpha^1, \beta^1 \right], \quad (16)$$

$$Z_{i\jmath k\mathbb{w}} \in \left[\alpha^2, \beta^2 \right], \quad (17)$$

$$c_{i\jmath\mathbb{w}} \in \left[\alpha^3, \beta^3 \right], \quad (18)$$

where ε, $\varepsilon^{(1)}$, $\varepsilon^{(2)}$ — uniformly distributed random variables of continuous type;

$\mathbb{V}, Bud_0, \tilde{u}_{e0l}, u_{0l}, A_{ekl}^{month(0)}, p_{kml} = const;$

$\varepsilon^{(1)} \le \varepsilon \le \varepsilon^{(2)}; 0 < \varepsilon_1^1 < 1; 0 < \varepsilon_2^1 < 1; \varepsilon_1^2 > 0; \varepsilon_2^2 > 0;$

$\varepsilon^{(1)}, \varepsilon^{(2)}, \alpha^1, \alpha^2, \alpha^3, \beta^1, \beta^2, \beta^3 = const.$

Let us consider in more detail the constraints (3–18) of the optimization problem.

Constraint (3) gives an indication of what stock of workpieces should be kept in stock throughout the planning period to ensure continuous production.

Constraint (4) sets the maximum number of sheets available for cutting per day, which is important for optimizing material usage and production.

Constraint (5) controls both the amount of product production during each week and the amount of transportation, although with a target function of the form (2) it can be treated as an equality. This constraint has a direct impact on inventory management and logistics.

Constraint (6) ensures that the transportation volume to the end points does not exceed the demand volume at those points, which is important for efficient product delivery and customer satisfaction.

Constraint (7) describes the degree of warehouse occupancy.

Further, constraints (8–9) define the type of variables, and (10) limits the amount of raw materials purchased daily to the size of bids on the exchange. These constraints are the basis for procurement planning and inventory management.

Constraint (11) ensures that daily profits are non-negative, which is important for the financial stability of the firm.

Constraint (12) determines the availability of raw material stocks in the warehouse, which is necessary to ensure uninterrupted production.

Restriction (13) reflects the interdependence of demand and prices for raw materials (unlike the similar function used in [13], the second derivative of this function does not have a gap).

Constraint (14) defines the recurrent dependence of price on the day number, which helps to take into account the dynamics of price changes on the market.

Constraint (15) reflects the rates of consumption of billets for the production of each unit of output, which is a key factor for the efficient use of resources and optimization of production processes.

Finally, constraints (16–18) are necessary to "play out" the values of fixed costs, the maximum throughput of the transportation graph in delivering goods to buyers, and the values of costs of goods delivery.

The model (3–18) is a stochastic nonlinear mathematical programming problem. To solve this problem, it is planned to iteratively search for a suboptimal solution using two subproblems: optimization of the production plan, delivery of raw materials and finished products, and search for a suboptimal price vector for product sales. This approach will make it possible to effectively manage complex processes and minimize the cost of production of products and their delivery to customers:

1) Generate price vectors ($p^{(iter)} = \left\{p_{kml}^{(iter)}\right\}_{kml}$, $iter = 1:Iter$) and estimate (13) and p_{kml}. $Cnt = 0$, $iter_1 = 0$, generate values for (15–18). Move to step 2.
2) Solve task (3–13) with fixed parameters $p^{(iter)}$, $A_{ekl}^{month(m)}$, FC_μ, $Z_{i\jmath k\mathbb{w}}$, $c_{i\jmath\mathbb{w}}$ with the goal function (19) applying Chvatal-Gomory[1] algorithm. Let $iter_1 = iter_1 + 1$.

$$\left\{\max_{x,v,\mathbb{Z}} \sum_m \left(\sum_{k,l} p_{kml}^{(iter)} x_{kml} - \sum_{i,l,r} c_{imrl} v_{imrl} - \sum_{\jmath,k,l} c_{\jmath} z_{\jmath k\mathbb{w}(m)l} \right)\right\}_{iter}. \quad (19)$$

Estimate (20) and move to step 3.

$$\tilde{p}_{kml} = p_{kml}^{\arg\max\left(\pi\left(iter_1\right)\right)}. \quad (20)$$

3) If argmax($\pi(iter) = 1$, then $Cnt = Cnt + 1$, otherwise $Cnt = 0$. Move to step 4.
4) If $Cnt = g$, leave algorithm (end), otherwise move to step 5.
5) Generate price vectors (($p^1 = \{\tilde{p}_{kml}\}_{kml}$, $p^{(iter)} = \left\{p_{kml}^{(iter)}\right\}_{kml}$, $iter = 2:Iter$) (21–22).

$$\varepsilon^1 \in \left[-\left(\varepsilon_1^{(1)}\right)^{Cnt+1}, \left(\varepsilon_2^{(1)}\right)^{Cnt+1}\right]. \quad (21)$$

$$p_{kml}^{(iter)} = \min\left[\max\begin{pmatrix} \tilde{p}_{kml} \cdot \left(1-\varepsilon_1^{(1)}\right); \\ \tilde{p}_{kml} \cdot \left(1+\varepsilon^{(1)}\right) \end{pmatrix}; \tilde{p}_{kml} \cdot \left(1+\varepsilon_2^{(1)}\right)\right]. \quad (22)$$

6) Estimate (13–14). Move to step 2.

The model (2–19) at played out values (13–19) belongs to the class of mixed-integer linear programming problems. We choose Matlab as the programming environment. At the first stage we use the method of branches and bounds to solve the problem (2–19)

[1] MathWorks. Documentation. Mixed-Integer Linear Programming Algorithms. https://it.mathworks.com/help/optim/ug/mixed-integer-linear-programming-algorithms.html

with the values (13–19) played out, and at the second stage (price change) the calculations are performed using the genetic algorithm. Note that the degree of closeness of the found price vector to the optimal one is achieved due to expression (22).

In practice, the program implementation in Matlab environment can be translated into any other programming language (for example, Python of any version) using, for example, programming language converters or neural networks (for example, ChatGPT, etc.).

4. Calibration

We will test the model using data from DNS-Les LLC2. At the end of each trading day, data on completed transactions is recorded. Based on these statistics, we will assess the feasibility of interaction between one of the large and at the same time young enterprises of the Primorsky Territory.

Based on the statistics of the enterprise, logging enterprises from five districts participated as sellers of raw materials in ensuring the uninterrupted operation of its operation: $r = 1{:}5$. On the planning horizon from Feb. 1, 2018 to Nov. 31, 2018, an array of the following data was received from the enterprise: prices (c_{imrl}), dates of the appearance of raw materials, volumes on these days, application prices (p_{kml}), number of applications for each type raw materials. In addition, the demand $\dot{Q}_{jkwl}$ in each week for each type of product is known based on the company's sales statistics [12].

All data that affects the input initial and constant values, the sheet cutting map and the standard costs of raw materials for the production of each unit of goods are presented in [12].

Assume that the price cannot change by more than ten percent every day. *Table 1* shows the limits of the values of random variables.

Table 1.

Stochastic values intervals

Parameters	$\varepsilon_1^{(1)}$	$\varepsilon_1^{(2)}$	$\varepsilon_2^{(1)}$	$\varepsilon_2^{(2)}$	$\varepsilon^{(1)}$	$\varepsilon^{(2)}$
Values	0.03	0.03	1	10	2	2

To find a solution, we will use the Matlab programming language, namely the *intlinprog* function[3]. The problem is of significant size, which makes it impossible to guarantee finding an optimal solution in a short time due to the algorithmic complexity (the number of calculations grows non-polynomially) of the branch and bound method, which is the default method for finding a solution in *intlinprog*. Therefore, we decided to limit the number of solution options to be explored to 107. If the algorithm fails due to the constraint despite finding a feasible solution, we consider it suboptimal rather than optimal. The results obtained are presented in *Figs. 1–5*.

Separately, we note that due to corporate ethics, the work does not indicate the actual recorded demand $\dot{Q}_{nkm}$. However, data regarding demand $ave\left(\sum_n Q_{nkm}\right)$ is presented in *Figs. 3, 4*.

5. Test results

Let us to look at *Figs. 1–5*. They reflect the main results of testing the model. In *Fig. 1* you can see how the profit value changed at each iteration $iter_1$. We introduce the notation $\pi_m(iter_1)$, which reflects the profit value by day m at iteration $iter_1$. The main change in the value of the objective function was observed in the first seven iterations, which is quite fast for a problem of this size. However, after the 2nd iteration, the value of the objective function changes slightly, which indicates that the new method solves problems of this kind more effectively compared to the algorithm in [13].

[2] Official website of the LLC DNS-Les Enterprise. Russia, Primorsky Krai, Spassk-Dalniy. http://dns-les.ru/

[3] Intlinprog. Documentation. MathWorks. https://www.mathworks.com/help/optim/ug/intlinprog.html

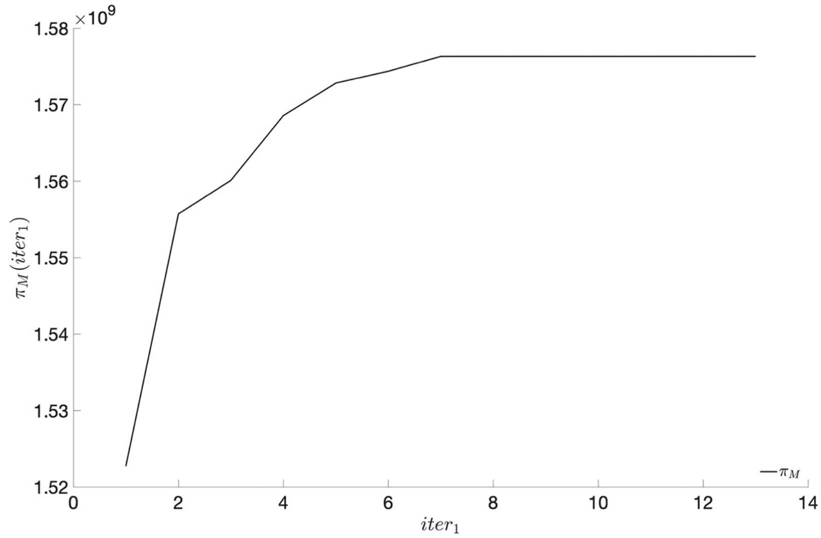

Fig. 1. Visualization of profit values depending on the iteration number.

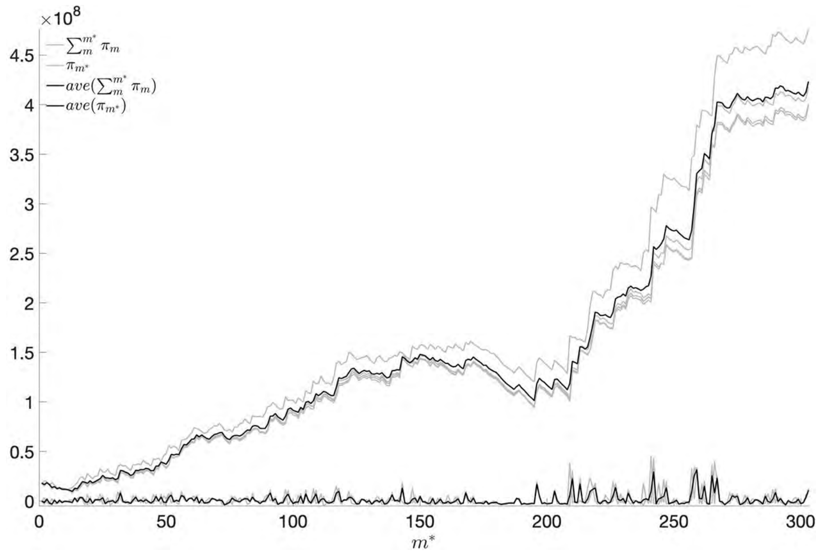

Fig. 2. Visualization of the testing process and the resulting solution.

Any solution requires a stability test. To do this, we will re-launch the developed model 4 times and find solutions. The results are presented in *Fig. 2.* Despite the rather large gap in the value of the objective function at the end of the planning horizon between solutions, the deviations in relative values are insignificant for all trajectories of values π_m for each decision.

Of particular interest is the observation that after the end of the summer period, closer to the winter period, the profit of the enterprise increases. This is due to the fact that production volumes increase in the winter and prices for raw materials fall.

An important factor is not only the prices of raw materials, but also the prices of final consumer goods

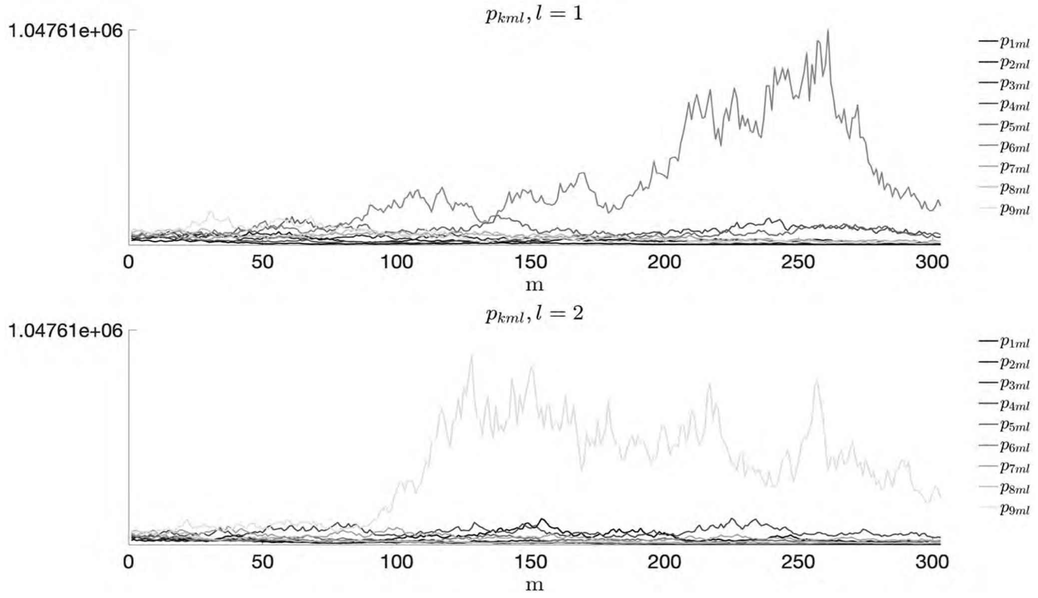

Fig. 3. Visualization of price behavior over the entire planning horizon.

that the enterprise produces. To do this, let's look at *Fig. 3.* It clearly shows that the "market" considers the most interesting product to be goods No. 6, made from raw materials of type $l = 1$, and No. 9, made from raw materials of type $l = 2$. This may be due to the cost of raw materials for the production of this product $A_{ekl}^{month(m)}$.

However, rising prices also imply a change in demand for goods. We introduce the notation Q^{0}_{jkwl}, which sets the trajectory of the changed volume of demand in accordance with the new calculated price values. *Figures 4, 5* show the behavior of demand for goods over the entire planning horizon on a weekly basis.

Of particular interest are the volumes of waste (cubic meters) that appear when cutting incoming raw materials. To do this, consider *Fig. 6.* Here, as with the behavior of the profit trajectory depending on the decision, you can observe a slight deviation from the average values for waste. Minor deviations in both cases with profit and waste means a high degree of predictability of the situation in the enterprise, which is an extremely important characteristic in the current turbulent times.

Let us consider the positive and negative aspects of the developed model and algorithm and propose options for their modification.

The following can be attributed to the advantages of the proposals developed:

1. Increased speed of solution search compared to the scheme proposed in [13].

2. Taking into account the technology of round wood cutting.

3. Compared to [13], the second derivative of the demand function is continuous, which guarantees that there is no instantaneous acceleration of the demand value when crossing the point zero.

The negative sides include the following:

1. Despite the fact that the function (13) has continuous first and second derivatives, it has certain drawbacks. *Figures 4, 5*, which reflect the relationship between demand and prices, show that prices for the products that are of most interest to the market are rather overvalued and remain at this level for quite a long time. This is due to the fact that demand

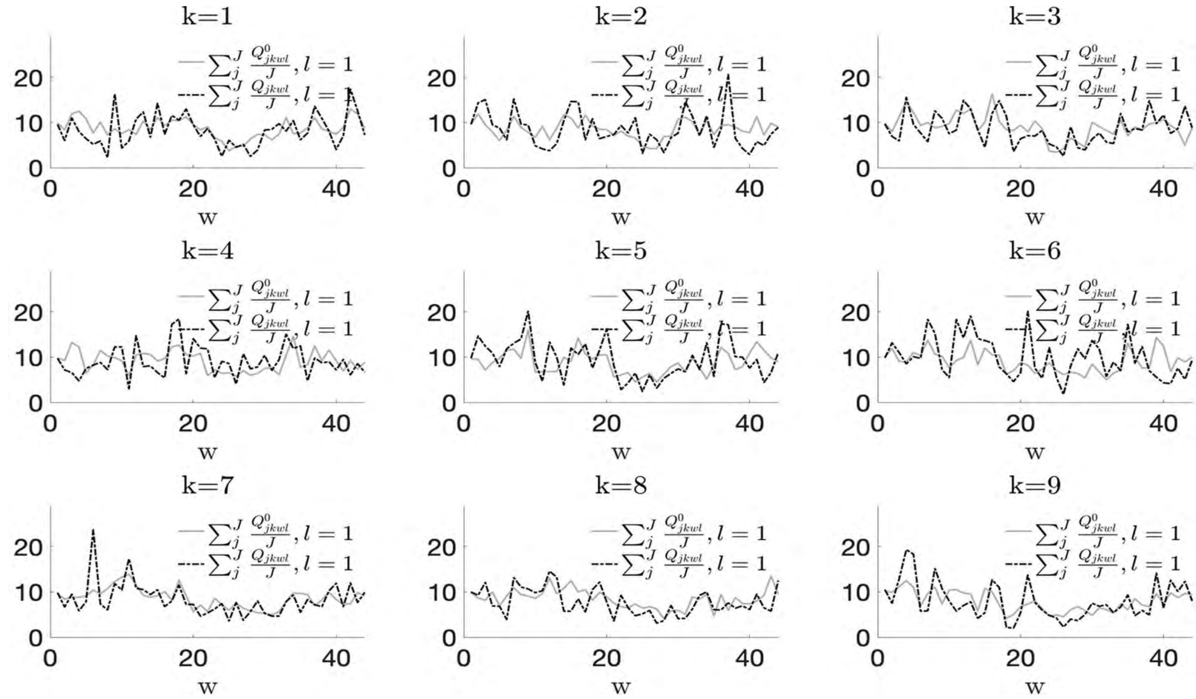

Fig. 4. Visualization of the volume of initial demand and the current volume of demand, which changed when searching for the price vector for $l = 1$.

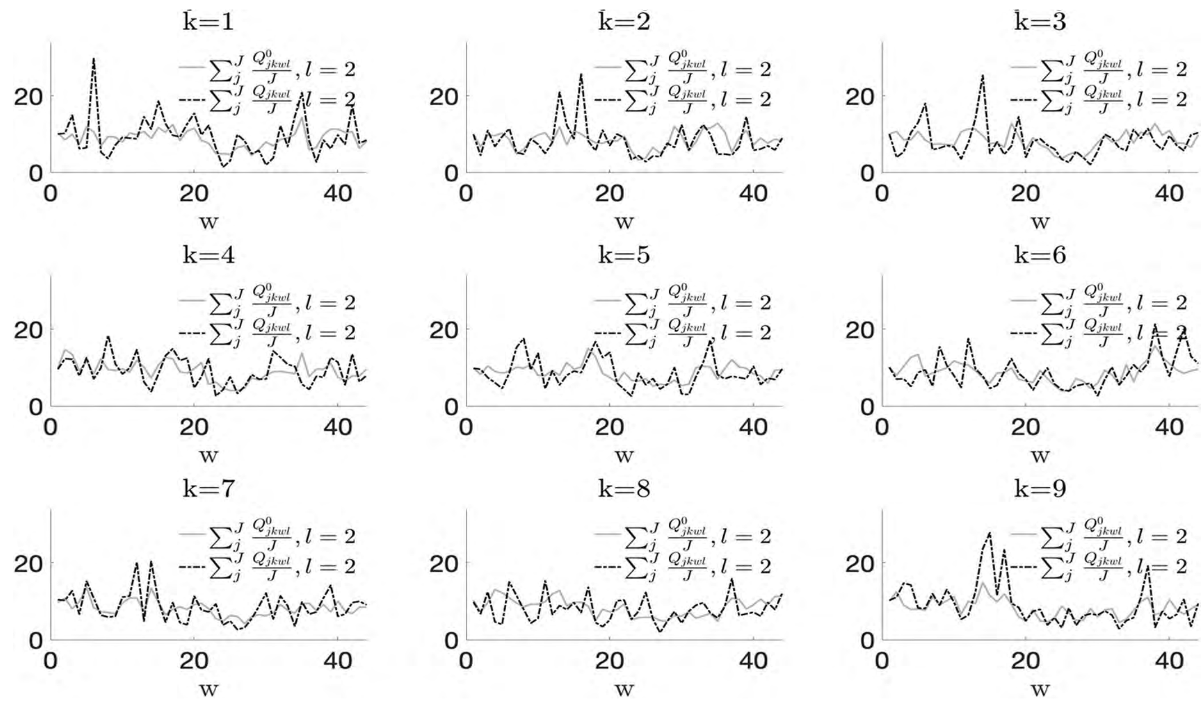

Fig. 5. Visualization of the volume of initial demand and the current volume of demand, which changed when searching for the price vector for $l = 2$.

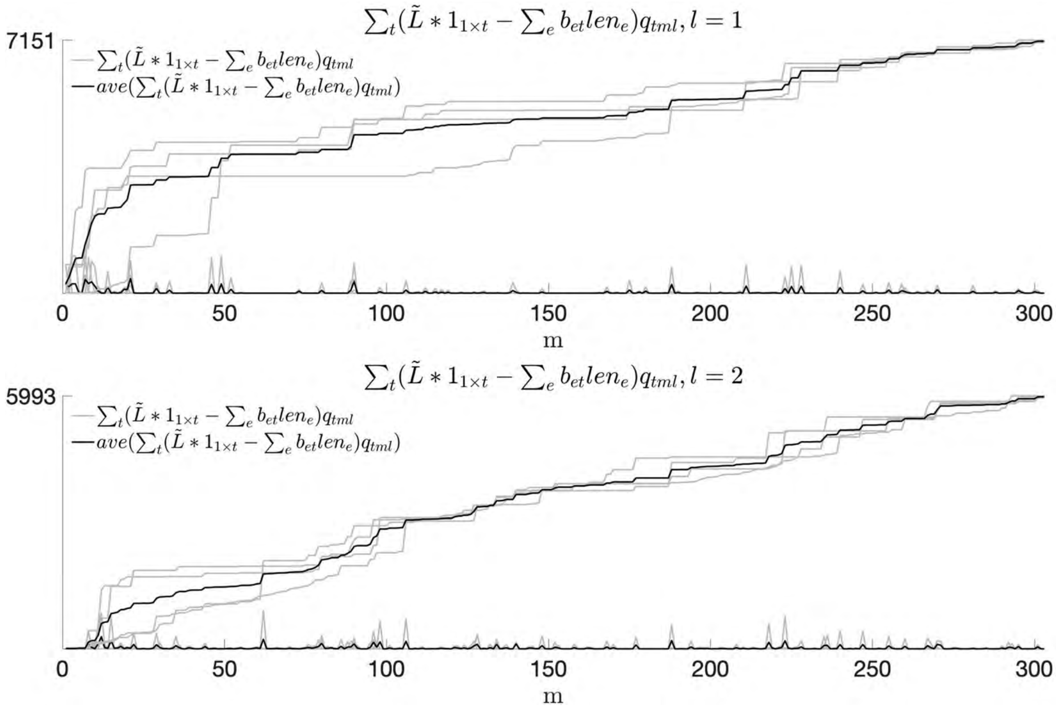

Fig. 6. Visualization of the volume of total waste of raw materials.

on the respective days decreased only during the period of price growth, after which its value kept in a small neighborhood of the initial value, since prices almost did not change. However, this is not possible in the real economy, as demand is also under pressure from high prices during subsequent planning periods. In order to take this aspect into account, it is necessary to modernize the demand-price relationship function.

2. The convergence of the algorithm has not been investigated.

3. Rapidly increasing dimensionality of the problem.

4. Price changes rarely occur every day.

5. To achieve diversification of raw material sources, the ability to purchase raw materials from the regional market should be added, as described in [13].

6. There is no consideration of the possibility of making borrowings.

Conclusion

The paper presents a mathematical model for solving the complex problem of suboptimal formation of the pricing policy of a timber industry enterprise, taking into account the process of developing stable supply chains from the commodity and raw material exchange and calculation of production volumes and transportation of finished products to consumers. This model is different in that it allows us to take into account the technology of cutting raw materials, which is important for this industry.

The central objective of the model is to maximize the operating profit of the enterprise, which is a complex mathematical problem. The model takes into account various aspects such as production rates of raw material consumption, procurement strategy at the commodity exchange, transportation volumes of finished products and pricing policy of the company. To solve such a complex problem, a two-stage optimization scheme including linear optimization and application of genetic algorithm has been developed.

The model was tested using real data from the timber processing complex of the Primorsky Territory. As the testing showed, the new optimization scheme allows us to find a solution faster than the previous version of the model based on the gradient descent method.

The results of the experiments made it possible to formulate valuable recommendations for the company's management staff in terms of interaction with loggers and improvement of production processes.

Further research may include modifying the model to account for probabilistic economic factors and improving solution search methods. It is also necessary to consider the possibilities of accelerating the search for a solution and to develop more accurate demand functions for the company's products. ■

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