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08.00.16 Raqamli iqtisodiyot va xalqaro raqamli integratsiya
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APPLYING LINEAR PROGRAMMING TO ANALYZE THE STATE OF COMMODITY AND RAW MATERIAL RESOURCES IN INDUSTRIAL ENTERPRISES

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Abstract: The tools of economic analysis of enterprise activity are associated with the processing of large volumes of information that are dynamic in nature and require an integrated system for monitoring the state of production. One of the key objects of economic analysis is the condition and evaluation of commodity and raw material resources of industrial enterprises. Efficient management of these resources is crucial, as inventories are continuously moving and significantly influence the use of working capital. Rational optimization of inventory levels contributes to improving capital turnover and overall production efficiency. This article explores the application of linear programming methods in economic analysis as an effective tool for enhancing the objectivity and reliability of economic assessments.

Key words: production, inventory, linear programming, simplex method.

Annotatsiya: Korxona faoliyatini iqtisodiy tahlil qilish vositalari dinamik xususiyatga ega bo‘lgan katta hajmdagi axborotni qayta ishlash bilan bog‘liq bo‘lib, ishlab chiqarish holatini muntazam monitoring qilishni taqozo etadi. Iqtisodiy tahlilning muhim ob’ektlaridan biri ishlab chiqarish korxonalarida tovar va xomashyo resurslarining holati hamda ulardan foydalanish samaradorligini baholash hisoblanadi. Mazkur resurslarning oqilona boshqarilishi aylanma mablag‘lar aylanishini jadallashtirish va ishlab chiqarish samaradorligini oshirishga xizmat qiladi. Ushbu maqolada iqtisodiy tahlilda chiziqli dasturlash masalalaridan foydalanish imkoniyatlari tahlil qilinib, ularning iqtisodiy baholashlarning ob’ektivligi va ishonchliligini oshirishdagi ahamiyati yoritib berilgan.

Kalit so‘zlar: ishlab chiqarish, zaxiralar, chiziqli dasturlash, simpleks usuli.

Аннотация: Инструменты экономического анализа деятельности предприятия связаны с обработкой значительных объемов информации, носящей динамичный характер и требующей комплексного мониторинга состояния производства. Одним из ключевых объектов экономического анализа является состояние и оценка товарно-сырьевых ресурсов производственного предприятия. Рациональное управление запасами способствует повышению оборачиваемости оборотного капитала и общей эффективности деятельности предприятия. В данной статье рассматриваются возможности применения методов линейного программирования в экономическом анализе как эффективного инструмента повышения объективности и надежности экономических оценок.

Ключевые слова: производство, запасы, линейное программирование, симплекс-метод.

INTRODUCTION

One of the key factors in achieving high performance and enhancing the overall efficiency of an enterprise is the effective management of the formation and utilization of material resource inventories. The primary purpose of maintaining material resource stocks is to balance varying intensities of material flows interacting with the production process, thereby ensuring its continuity and operational rhythm.

An essential component of commodity and material resource management is the systematic analysis of their structure, volume, and dynamics. The analysis of the state of commodity and raw material resources represents a comprehensive examination of the structure, dynamics, volume, quality, and efficiency of the use of material stocks at the enterprise or industry level. This analysis includes assessing the availability of required raw materials for production, identifying factors influencing the formation and consumption of resources, and determining effective approaches to their optimization. Such an analytical framework contributes to improving resource efficiency, strengthening production stability, and supporting sustainable enterprise development.

LITERATURE REVIEW

Material resources have been the subject of extensive research by numerous scholars. According to A. M. Gadzhinsky (2017) [1], material stocks are defined as products for industrial and technical purposes, consumer goods, and other items located at various stages of production and circulation, awaiting entry into the process of industrial or personal consumption.

T. B. Berdnikova (2020) [2] characterizes inventories as assets that meet specific criteria, including raw materials and supplies intended for use in the production process or service provision, goods intended for sale in the normal course of business, and assets currently involved in the production process.

A. P. Gradov (2012) [3] considers material resources to be one of the key components of an enterprise's production potential, encompassing raw materials, basic and auxiliary materials, semi-finished products, and finished goods. V. I. Belov (2015) [4] emphasizes the role of commodity and raw material potential as a determinant of enterprise sustainability, influencing production capacity, supply policy, and cost structure.

In the works of Yu. N. Kovalev (2018) [5], particular attention is paid to the importance of analyzing not only the quantitative but also the qualitative characteristics of material resources, which is essential for improving inventory management effectiveness. In this context, the availability and management of commodity stocks should be examined as an integral part of the overall commodity potential, as this potential determines the enterprise's capacity to ensure uninterrupted production, flexibility in resource allocation, and adaptability to changing market conditions.

L. M. Ivanova (2020) [6] defines the analysis of commodity and raw material potential as a comprehensive assessment of an enterprise's resources, including raw materials, materials, and finished products, aimed at evaluating their sufficiency, efficiency of utilization, and impact on production and economic performance indicators.

For industrial enterprises, the primary objects of this area of analysis include raw materials and basic materials, auxiliary materials, semi-finished products, finished goods in storage, goods in transit, as well as reserve and safety stocks used in production. Conducting such analysis enables the timely identification of potential imbalances in inventory levels, supports accurate forecasting of resource needs, facilitates economically justified procurement decisions, and contributes to the development of effective resource management strategies under dynamic market conditions.

RESEARCH METHODOLOGY

Linear programming (LP) is a mathematical modeling method used for the optimal allocation of limited resources in order to maximize economic benefits or minimize costs. This approach enables the formal description of economic processes through a linear objective function and a system of linear constraints that reflect resource availability, market demand, production capacity, and other relevant economic conditions.

In general form, a linear programming problem is defined by the following components.

Objective function

The objective function represents the economic indicator to be optimized, such as profit maximization or cost minimization:

where

x_j — decision variables representing production volumes or resource usage,

c_j — economic coefficients corresponding to each variable (for example, profit per unit of output or unit cost of resources).

Constraints

The constraints are expressed as a system of linear equations or inequalities that reflect limitations related to resources, demand, and production capacity:

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_i, i = 1,2,\dots,m \qquad (2)$$

where

a_{ij} — coefficients of resource consumption,

b_i — available amounts of the corresponding resources.

Non-negativity conditions

All decision variables must satisfy non-negativity conditions, as negative values are economically infeasible:

$$x_j \geq 0, j = 1,2,\ldots,n$$

To solve linear programming problems efficiently, various computational algorithms are applied. Among them, the simplex method is one of the most widely used approaches, allowing for systematic iteration through feasible solutions in order to identify the optimal result.

ANALYSIS AND RESULTS

The limited liability company “SAM ANTEP GILAM” is one of the leading enterprises specializing in the production of carpets and carpet coverings in the Samarkand region. In the production process, the enterprise uses a wide range of polymer fibers as raw materials, including polypropylene, polyester, viscose, and acrylic, which primarily form the pile layer of carpet products.

To manufacture the backing (base) of carpets, a shaft with a cotton or polyester foundation is applied, which is further interwoven with jute fiber to ensure structural strength. Latex is used to enhance product stability and to securely fix the pile layer. Such a diversified combination of raw materials enables the enterprise to produce carpets with varying technical and aesthetic characteristics.

Currently, the production capacity of the enterprise amounts to 13.5 million square meters per year, encompassing carpet products of different sizes, densities, and designs. The extensive assortment of raw materials involved in the production process necessitates an advanced and well-coordinated inventory management system. Under dynamic market conditions, including fluctuations in raw material prices and variations in demand for finished products, the importance of effective inventory control becomes particularly significant. Proper management of material stocks contributes to maintaining liquidity, improving turnover rates, and ensuring financial stability.

A preliminary analysis of commodity and raw material stocks focuses on assessing the storage duration of different types of raw materials in the warehouse. The primary sources of information for analyzing the state of the enterprise’s commodity and raw material resources are data obtained from the operational inventory monitoring system SAP (Systems, Applications, and Products in Data Processing) implemented at the enterprise.

To analyze the state of raw material stocks, particularly acrylic and polyester yarns, the structure of warehouse inventories was examined as of 01-02-2025 and 01-03-2025. The inventories were classified according to storage duration and grouped into three categories: stocks stored for up to 3 months, from 3 to 6 months, and for more than 6 months. This classification makes it possible to identify the distribution of material resources over time and provides a reliable basis for further optimization of inventory levels and resource allocation decisions (Figure 1).

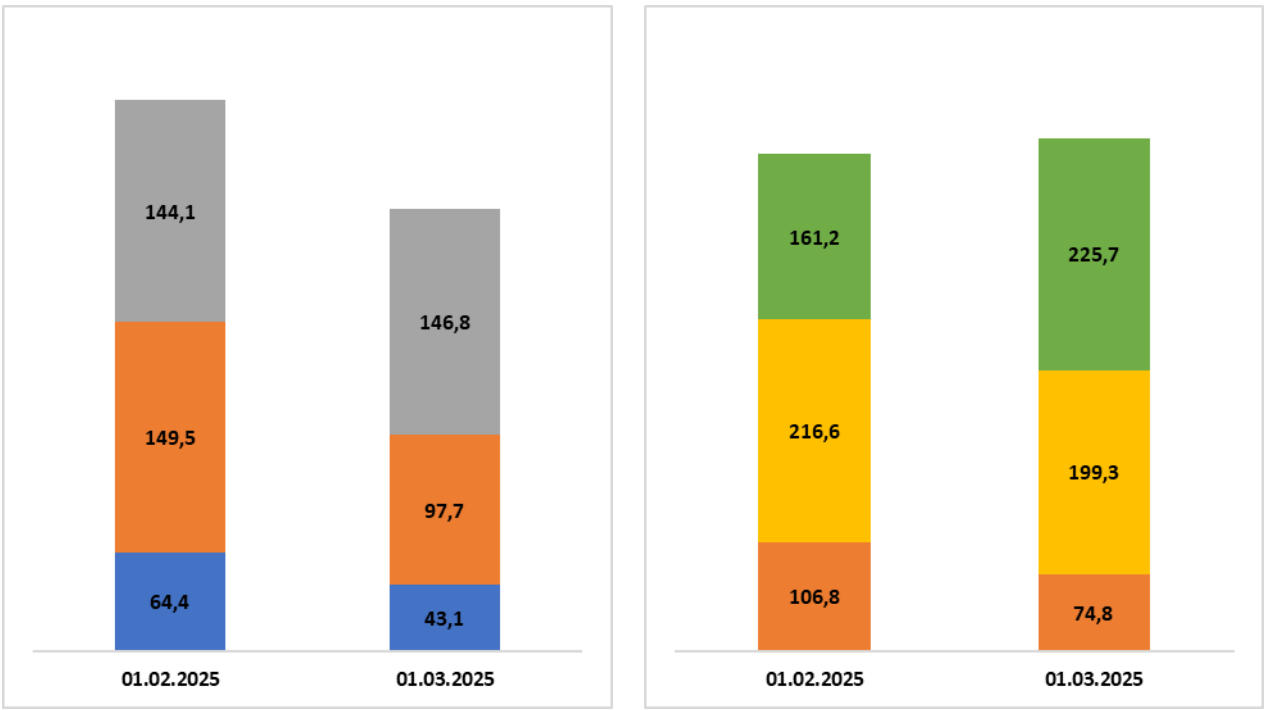

Figure 1. Diagram of changes in the balances of acrylic and polyester threads in the warehouse for the period 01-02-2025 and 01-03-2025 (t).

An analysis of warehouse balances as of 01-02-2025 and 01-03-2025 indicates that, for both types of raw materials, a significant share of inventories consists of batches stored for more than three months. In particular, long-term stocks account for approximately 85% of acrylic threads and 87% of polyester threads. This situation reflects structural features of carpet production, where threads of different colors and densities are interdependent within specific product collections. A shortage of any single component (for example, a particular color) reduces the effective usability of other available materials, thereby increasing the volume of slow-moving inventories in the warehouse.

In addition, a certain imbalance between production workshops and the purchasing department contributes to the accumulation of excess stocks, as procurement volumes may exceed actual production requirements. Addressing this imbalance through analytical tools enables more coordinated planning and supports rational inventory turnover.

For a more detailed analysis of commodity stocks, a linear programming (LP)–based optimization model was developed. The simplex method, which is widely applied in economic analysis, serves as an effective algorithm for solving LP problems related to the optimal allocation of limited resources. The primary objective of this method is to achieve either maximum profit or minimum costs while satisfying predefined economic constraints, such as raw material availability, production capacity, and market demand.

The simplex method operates through the successive improvement of feasible solutions by moving between the vertices of the admissible solution set, which ensures the identification of an optimal production plan. At present, this algorithm is implemented in many applied programming environments, including Python and R, which facilitates its practical use in enterprise-level analysis.

As an illustrative case, an optimization model was developed to determine the optimal rate of thread utilization for the company LLC “SAM ANTEP GILAM.”

First condition

At present, LLC “SAM ANTEP GILAM” produces 7,823 types of carpet collections of various sizes and designs that incorporate acrylic yarns. Using data extracted from the SAP system, planned raw material consumption per 1 sq.m. of carpet was determined. Based on this information and applying formula (2), the constraint conditions of the linear programming model were formulated as follows:

$$\sum_{j=1}^{n} a_{ij}\, x_j \le b_i\,, i = 1,2,\dots,m$$

where

a_{ij} — average consumption of raw materials (acrylic or polyester thread) per 1 sq.m. of carpet,

b_i — available quantity of the corresponding thread in the warehouse,

x_j — optimal volume of carpet production, expressed in square meters.

Second condition

Demand is one of the key determinants in linear programming models, as it defines the feasible range of production and sales volumes. To incorporate demand into the LP framework, boundaries for the optimal volume of carpet output were established in square meters:

$$x_j \in [D_a; D_b]$$

where

D_a and D_b represent the minimum and maximum expected demand levels for the analyzed period, respectively.

This formulation makes it possible to align production planning with market conditions while ensuring efficient utilization of raw material stocks and minimizing the accumulation of slow-moving inventories.

Third condition

To construct the objective function of the linear programming problem, the coefficient c_j was defined as a production stability indicator for the j-th carpet collection.

In this study, the production stability indicator characterizes the degree of variability of output volumes (carpet production) relative to their average level over time. It serves as a quantitative measure of production consistency and is defined as the inverse of the coefficient of variation:

$$SG = \frac{\mu}{\sigma} * 100\%$$

where

μ — the average monthly production volume,

σ — the standard deviation of production volume.

A higher value of this indicator reflects greater stability of production volumes over the observed period. The use of this ratio enables enterprises to assess production sustainability more accurately and to anticipate potential operational risks.

Based on this indicator, the objective function of the linear programming model was formulated to maximize overall production stability:

$$Z = \sum_{j=1}^{n} c_j x_j \rightarrow \max$$

Where x_j – the volume of optimal carpet output in square meters, and – is the output stability indicator. The idea of choosing an output stability indicator means that the linear programming algorithm distributes raw materials, focusing on collections in which the output stability coefficient is higher, and then distributes the remaining raw materials to less popular collections. c_j

In matrix form, our model looks like this:

$$M_{i*j} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1j-1} & a_{1j} & 1 & 0 & \cdots & 0 & 0 \\ a_{21} & a_{22} & & a_{2j-1} & a_{2j} & 0 & 1 & & 0 & 0 \\ \vdots & & \ddots & \vdots & & \vdots & & \ddots & \vdots & \\ a_{i-1,1} & a_{i-1,2} & & a_{i-1,j-1} & a_{i-1;j} & 0 & 0 & & 1 & 0 \\ a_{i1} & a_{i2} & \cdots & a_{i,j-1} & a_{ij} & 0 & 0 & \cdots & 0 & 1 \end{pmatrix}$$

where $M_{i\times j}$ is the matrix of raw material consumption coefficients, and each element a_{ij} represents the amount of the i-th type of raw material required to produce one square meter of the j-th type of carpet. The enterprise uses i types of raw materials to manufacture j types of carpet collections.

The constraint conditions of the model are expressed in vector form as:

$$\mathbf{b} = \begin{pmatrix} b_1 & b_2 & \cdots & b_i \end{pmatrix}^T$$

where $b_1, b_2, \ldots, b_i$ denote the available quantities of corresponding threads remaining in the warehouse. Similarly, the coefficients of the objective function are represented by the vector:

$$\mathbf{c} = \begin{pmatrix} c_1 & c_2 & \cdots & c_j \end{pmatrix}^T$$

where $c_1, c_2, \ldots, c_j$ are the production stability coefficients for each carpet collection.

After constructing the matrix form of the linear programming model, an optimization algorithm was developed and implemented in the R programming environment using the lpSolve package. This computational approach enabled the efficient determination of optimal production volumes under the specified constraints, thereby supporting informed managerial decision-making in raw material allocation and production planning.

```
1.  Install_packages (lpSolve)
2.  library(lpSolve)
3.  matrix25March = read_excel(«March 2025.xlsx», range = «X7:BN13650», sheet = «Sheet1», col_names = TRUE)
4.  matrix25March = as.matrix(matrix25March)
5.  matrix25March = 0.001*matrix25March
6.  diag_matrix= diag(13,643)
7.  diag_matrix = -1* diag_matrix
8.  mainmatrix = rbind(matrix25March, diag_matrix)
9.  digits = rep(«<=» , 13 719)
10. limit25March = read_excel(«March 2025.xlsx», range = «DA1:DA13720», sheet = «Sheet1», col_names = TRUE)
11. optimal25March = read_excel(«March2025.xlsx», range = «CW7:CW13650», sheet = «Sheet1», col_names =
    TRUE)
12. optimal25March = unlist(optimal25March)
13. limit25March = unlist(limit25March)
14. optimal_model1 = lp(«max», optimal25March, mainmatrix, digits, limit25March)
```

As part of the linear programming framework, the production plan was optimized by taking into account the current balances of acrylic and polyester threads available in the warehouse, as well as their liquidity status as of 01-03-2025.

Based on the analysis of available operational data, the optimization model generated results reflecting the potential for improving inventory utilization across individual types of raw materials. The analysis relied on actual data for each thread code, including their inventory coverage expressed in days of consumption (0–90 days, 91–180 days, and more than 180 days), as well as their liquidity levels, classified into the following ranges: 100–81%, 80–61%, 60–41%, 40–21%, and less than 20%.

According to the modeling results, more than 700 positions of acrylic and polyester threads were comprehensively analyzed. The linear programming model allocated raw materials into five groups based on the degree of optimal utilization, ranging from 100%–80% (highly efficient use) to 20%–0% (low liquidity). The aggregated results of this classification are presented in Table 1.

Table 1. Overall results by liquidity groups

Optimal use group	Acrylic thread	Polyester thread
100% – 81%	7.0%	12.7%
80% – 61%	3.0%	13.4%
60% – 41%	12.0%	9.1%
40% – 21%	27.0%	19.5%
20% – 0% (low-liquidity raw materials)	52.0%	45.2%

The results indicate that a substantial share of both acrylic and polyester threads belongs to groups with relatively low liquidity. At the same time, the application of the linear programming model makes it possible to clearly identify priority directions for inventory utilization and provides a quantitative basis for improving raw material turnover. Consequently, the proposed approach supports more informed production planning decisions and contributes to enhancing inventory management efficiency under dynamic market conditions.

CONCLUSIONS AND RECOMMENDATIONS

The application of an extreme linear programming–based optimization model to raw material management at LLC "SAM ANTEP GILAM" demonstrated the high effectiveness and significant practical potential of linear programming methods in solving production planning and inventory management problems. The results obtained from solving this local optimization problem allow the following scientifically grounded conclusions to be drawn.

First, only 7% of acrylic threads and 12.7% of polyester threads were classified into the most efficient utilization group with an optimality level of 100%–80%. This indicates that a relatively limited range of raw materials is currently used with maximum efficiency, highlighting opportunities for expanding the effective involvement of other inventory positions in the production process.

Second, a considerable share of raw materials falls into groups with moderate and low levels of optimal use. Specifically, 27% of acrylic threads and 19.5% of polyester threads belong to the 40%–21% utilization group, while more than half of the acrylic threads (52%) and nearly half of the polyester threads (45.2%) are

classified into the least efficient group with utilization below 20%. This distribution reflects structural imbalances between existing raw material reserves and actual production requirements, which can be addressed through more precise planning and coordination.

Third, acrylic threads with a long storage period exceeding 180 days account for more than 40% of total inventory balances, and a substantial portion of these materials is not involved in the current production plan. This finding underlines the need to revise procurement and inventory planning policies in order to align purchases more closely with production demand and to reduce the accumulation of slow-moving stocks.

Fourth, for polyester threads, the largest volume is concentrated in the 90–180 day storage category. At the same time, a significant share of these materials does not belong to the highly efficient utilization groups, which may indicate extended production cycles or a mismatch between available raw materials and current market demand. This situation creates a basis for reviewing the assortment structure and improving demand forecasting mechanisms.

Overall, the conducted analysis confirms that the linear programming model not only substantiates the necessity of optimizing raw material reserves, but also provides a clear and quantitative framework for identifying priority management actions. The proposed approach enables enterprises to maximize production volumes within existing resource constraints, enhance inventory turnover, and improve the overall efficiency of commodity and raw material resource management under current operating policies.

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