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LINEAR PROGRAMMING PROBLEMS: A PRACTICAL EXAMPLE AND OPTIMAL SOLUTION BASED ON THE SIMPLEX METHOD

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Abstract

This article examines the theoretical and methodological foundations of solving linear programming problems using the simplex method. In the study, a multi-product production process was selected as a practical example, and a mathematical model was developed based on four types of products, several resource constraints, production capacity, and market demand. The model was solved step by step using the simplex method, and an optimal production plan was determined. According to the calculation results, the optimal solution is , , , and the maximum value of the objective function is equal to unity. The results confirm the practical importance of the simplex method in rational allocation of production resources, profit maximization, and scientific substantiation of management decisions.$x_1 = 20x_2 = 15x_3 = 10x_4 = 25Z_{\max} = 2760$

Keywords: Linear programming, simplex method, optimization, mathematical model, objective function, resource constraints, basic solution, optimal solution

INTRODUCTION

The increasing complexity of production, logistics, transport, energy and service systems in the global economy has raised the issue of efficient use of resources to a strategic level. In particular, disruptions in supply chains, volatility in raw material and energy prices, uneven loading of production capacities and rapid changes in market demand require enterprises to make decisions based on mathematical models, rather than intuitive ones. According to the CSCMP State of Logistics report, US business logistics costs amounted to $ 2.3 trillion by the end of 2024, which was equal to 8.7 percent of national GDP; in 2025, the analysis showed that logistics costs increased to $ 2.58 trillion and remained at the level of 8.8 percent. These indicators indicate that the issues of optimization in production and distribution systems are not only theoretical, but also have direct practical and economic significance.

In such conditions, linear programming appears as one of the most important mathematical tools for allocating resources with limited resources, maximizing profits and minimizing costs. World experience shows that optimization methods have become an integral part of production planning, logistics, supply chain, budgeting and operational management today. According to the results of a survey of 440 commercial users in the Gurobi 2025 "State of Mathematical Optimization" report, 93% of respondents indicated that interest in optimization is increasing or at least stable in organizations, and 84% considered it a strategically important direction for the organization. The same report specifically mentions planning, logistics, supply chain planning and production planning as the most widely used areas of optimization. This confirms the relevance of the simplex method and linear programming in general for the real sector.

The growth of operations research and optimization as an international scientific school is also confirmed by the scale of the professional community. According to INFORMS, this organization unites more than 12,500 members worldwide and is one of the largest professional associations in the field of operations research, analytics and data science. The announcements for the organization's 2025 annual meeting indicate the participation of more than 6,000 specialists and researchers, and some materials indicate the participation of more than 6,500 specialists and researchers. These figures indicate that linear programming and optimization methods are in high demand today in the global scientific community, industry and management practice.

The simplex method occupies a special place in solving linear programming problems. Despite the fact that this method is classic, it has retained its importance even in modern optimization packages. For example, the official information of the open-source high-performance optimization system HiGHS indicates that it uses dual revised simplex solver, interior point solver, and mixed-integer programming solutions. This means that the simplex method is not only a theoretical learning algorithm, but also an important basis for modern computer optimization technologies. Therefore, setting a specific practical problem based on the simplex method, solving it step by step, and analyzing the optimal result economically fully meets today's scientific and practical needs.

The purpose of this article is to reveal the practical essence of linear programming problems based on the simplex method, to express in mathematical form a specific model for production planning, to determine its optimal solution through successive calculation steps, and to analyze the results obtained economically. In this regard, the article serves to highlight the role of linear programming in improving the efficiency of decision-making in enterprise activities, combining theoretical foundations with practical calculations.

LITERATURE ANALYSIS

Linear programming problems and methods for solving them have become one of the most important areas of economics, management, and applied mathematics since the second half of the 20th century. The theoretical foundations of this field are closely related to the work of LV Kantorovich and G. Dantzig, and in particular, the proposal of the simplex method by Dantzig made it possible to widely apply linear optimization in practice. In later periods, linear programming began to be widely used in production planning, transportation problems, resource allocation, financial modeling, and logistics systems.

In the studies conducted by foreign scientists, the theoretical and practical aspects of linear programming have been thoroughly covered in various directions. In particular, D. Bertsimas and J. Tsitsiklis systematically explained the theoretical foundations of the simplex method, explaining the problems of linear optimization from a geometric, algebraic and algorithmic point of view. H. Taha, in the framework of operational research, connected the simplex method with economic and management decisions and showed practical mechanisms for its application in production, transportation and resource allocation. At the same time, the works of MS Bazaraa, JJ Jarvis and HD Sherali revealed the mathematical properties, algorithmic efficiency and limits of application of linear and integer programming methods in practical problems.

Literature analysis shows that the simplex method remains one of the most classic and widely used methods of linear programming. Its advantage is that it finds the optimal value of the objective function by sequentially moving along the support points of the domain of possible solutions. The logicality and clarity of this method for small and medium-sized problems are especially appreciated. Therefore, the simplex method is one of the main tools for teaching the ideas of optimization not only in scientific research, but also in the educational process.

In recent years, foreign research has been considering linear programming methods in an integrated manner with modern software tools. Optimization packages based on Gurobi, CPLEX, HiGHS, MATLAB, LINGO and Python allow for the automated application of simplex and its modifications. However, despite this, understanding the essence of the algorithm, especially showing the sequence of its execution through practical examples, remains scientifically and methodologically relevant. Because computer programs provide a ready-made result, it is necessary to know the step-by-step logic of the simplex method in order to analyze how the optimal solution is formed, which constraints are active, and how resources are distributed.

Based on the analyzed sources, it can be said that existing research on linear programming has developed mainly in three directions: the first is to improve the mathematical foundations of theoretical models and solution methods; the second is to increase the computational efficiency of algorithms; and the third is to apply them to real practical tasks in the fields of production, logistics, finance, and management. In this regard, the selection of a specific practical example based on the simplex method, its representation in the form of a mathematical model, and a step-by-step analysis of the optimal solution determine the scientific and practical direction of this article.

MATHEMATICAL FORMULATION OF A PRACTICAL EXAMPLE

The main task of production planning in an enterprise is to achieve maximum economic results through the rational use of available resources. In practice, enterprises often produce several products at the same time, and each product requires different amounts of raw materials, labor, equipment time, and energy resources. Therefore, it is important to determine the volume of production not intuitively, but based on a mathematical model.

In this study, a multi-product production process is considered based on a linear programming model. Suppose that a company produces four different products. Their production volumes are denoted by , , and , respectively.$x_1 x_2 x_3 x_4$

Here: x_1

— Production volume of product A;

$$x_2$$

— production volume of product B;

$$x_3$$

— C is the volume of product production;

$$x_4$$

— D is the volume of product production.

The profit that the enterprise receives from each unit of the product is different. 38 units of profit are received from product A, 35 units from product B, 35 units from product C, and 45 units from product

D. Therefore, the total profit of the enterprise is formed based on the volume of products and their unit profit indicators.

On this basis, the objective function is expressed as follows:

$$Z = 38x_1 + 35x_2 + 35x_3 + 45x_4 \rightarrow \max$$

Here, is the total profit of the enterprise. The main goal of the model is to determine the maximum value of the function given the available resources and production constraints.ZZ

The enterprise's activities are limited by several resource and organizational constraints. The first constraint is related to the raw material resource, which requires 2 units of raw materials to produce one unit of product A, 1 unit of product B, 3 units of product C, and 2 units of product D. The total amount of raw materials available in the enterprise cannot exceed 135 units. Therefore, the first constraint is written as follows:

$$2x_1 + x_2 + 3x_3 + 2x_4 \leq 135$$

The second constraint is related to labor resources. Product A requires 1 unit of labor, product B requires 3 units, product C requires 2 units, and product D requires 2 units. The total labor resources available in the enterprise are limited to 135 units:

$$x_1 + 3x_2 + 2x_3 + 2x_4 \leq 135$$

The third constraint represents the use of machine time or process capacity. Product A requires 3 units of machine time, product B requires 2 units, product C requires 1 unit, and product D requires 4 units of machine time. The available machine time is 200 units:

$$3x_1 + 2x_2 + x_3 + 4x_4 \leq 200$$

The fourth constraint is related to energy consumption. Each unit of products A, B, and C consumes 2 units of energy, and product D consumes 1 unit. The total energy resource available at the enterprise should not exceed 115 units:

$$2x_1 + 2x_2 + 2x_3 + x_4 \leq 115$$

The fifth constraint is the total production capacity [2-8]. The enterprise cannot produce more than 80 units of a product in total during a given period:

$$x_1 + x_2 + x_3 + x_4 \leq 80$$

The sixth constraint is related to the market demand for products B, C, and D. The total realization capacity for these products does not exceed 60 units:

$$x_2 + x_3 + x_4 \leq 60$$

The seventh constraint represents the maximum order size for product A. The order for product A cannot exceed 30 units:

$$x_1 \leq 30$$

In addition, production volumes cannot take on a negative value. Because, according to real economic meaning, the volume of product production must be zero or positive:

$$x_1, x_2, x_3, x_4 \geq 0$$

Thus, the mathematical model of the multi-product production problem will look like this:

$$Z = 38x_1 + 35x_2 + 35x_3 + 45x_4 \to \max$$
$$2x_1 + x_2 + 3x_3 + 2x_4 \leq 135$$
$$x_1 + 3x_2 + 2x_3 + 2x_4 \leq 135$$
$$3x_1 + 2x_2 + x_3 + 4x_4 \leq 200$$
$$2x_1 + 2x_2 + 2x_3 + x_4 \leq 115$$
$$x_1 + x_2 + x_3 + x_4 \leq 80$$
$$x_2 + x_3 + x_4 \leq 60$$
$$x_1 \leq 30$$
$$x_1, x_2, x_3, x_4 \geq 0$$

In this model, the objective function represents the total profit of the enterprise, and the constraints represent factors such as raw materials, labor, equipment time, energy, total production capacity, market demand, and order volume available in the production process. Therefore, the mathematical essence of the problem is to find the optimal plan that maximizes the enterprise's profit from the production volumes that satisfy all the constraints.

SOLUTION STEPS BASED ON THE SIMPLEX METHOD

To solve the above multi-product production problem using the simplex method, the model is first reduced to its standard form. To do this, the space variables are introduced for each inequality:

$$s_1, s_2, s_3, s_4, s_5, s_6, s_7 \geq 0$$

The objective function of the problem was as follows:

$$Z = 38x_1 + 35x_2 + 35x_3 + 45x_4 \to \max$$

The system of constraints is given as follows:

$$2x_1 + x_2 + 3x_3 + 2x_4 \leq 135$$
$$x_1 + 3x_2 + 2x_3 + 2x_4 \leq 135$$
$$3x_1 + 2x_2 + x_3 + 4x_4 \leq 200$$
$$2x_1 + 2x_2 + 2x_3 + x_4 \leq 115$$
$$x_1 + x_2 + x_3 + x_4 \leq 80$$
$$x_2 + x_3 + x_4 \leq 60$$
$$x_1 \leq 30$$

To apply the simplex method, these inequalities are reduced to the form of equations:

$$2x_1 + x_2 + 3x_3 + 2x_4 + s_1 = 135$$
$$x_1 + 3x_2 + 2x_3 + 2x_4 + s_2 = 135$$
$$3x_1 + 2x_2 + x_3 + 4x_4 + s_3 = 200$$
$$2x_1 + 2x_2 + 2x_3 + x_4 + s_4 = 115$$
$$x_1 + x_2 + x_3 + x_4 + s_5 = 80$$
$$x_2 + x_3 + x_4 + s_6 = 60$$

$$x_1 + s_7 = 30$$

The objective function for a simplex tableau is written as follows:

$$Z - 38x_1 - 35x_2 - 35x_3 - 45x_4 = 0$$

In the initial baseline solution, the main decision variables are assumed to be zero:

$$x_1 = x_2 = x_3 = x_4 = 0$$

In this case, the space variables take on the following values:

$$s_1 = 135, s_2 = 135, s_3 = 200, s_4 = 115, s_5 = 80, s_6 = 60, s_7 = 30$$

This situation means that production has not yet begun, and all resources are in full reserve.

Elementary simplex table

Basis	x_1	x_2	x_3	x_4	s_1	s_2	s_3	s_4	s_5	s_6	s_7	**RHS**
s_1	2	1	3	2	1	0	0	0	0	0	0	135
s_2	1	3	2	2	0	1	0	0	0	0	0	135
s_3	3	2	1	4	0	0	1	0	0	0	0	200
s_4	2	2	2	1	0	0	0	1	0	0	0	115
s_5	1	1	1	1	0	0	0	0	1	0	0	80
s_6	0	1	1	1	0	0	0	0	0	1	0	60
s_7	1	0	0	0	0	0	0	0	0	0	1	30
Z	-38	-35	-35	-45	0	0	0	0	0	0	0	0

In the simplex method, the column with the most negative coefficient in the row of the objective function is selected for the maximization problem. In the initial table, it is the most negative value, which belongs to the column. Therefore, it is included in the basis in the first iteration.$-45x_4x_4$
To determine the output variable, the values in the RHS column are divided by the positive elements in the column:x_4

$$\frac{135}{2} = 67.5, \frac{135}{2} = 67.5, \frac{200}{4} = 50, \frac{115}{1} = 115, \frac{80}{1} = 80, \frac{60}{1} = 60$$

Since the smallest positive ratio is equal to 50, it leaves the basis, and enters the basis.s_3x_4

Sequence of iterations

When pivot operations are performed sequentially in a simplex table, the basis changes as follows:

Iteration	Variable included in the basis	Variable leaving the basis	Objective function value
1	x_4	s_3	2250
2	x_3	s_6	2566.67
3	x_1	s_1	2582.22
4	x_2	s_2	2695.71
5	s_6	s_4	2760

From this sequence, it can be seen that the simplex method improves the value of the objective function at each iteration. In the initial state, the value of the objective function reaches .$Z = 0Z_{\max} = 2760$

Final simplex tableau

After the pivot operations are performed, the final simplex table looks like this:

Basis	x_1	x_2	x_3	x_4	s_1	s_2	s_3	s_4	s_5	s_6	s_7	RHS
x_1	1	0	0	0	-1/6	-1/2	1/6	2/3	0	0	0	20
x_2	0	1	0	0	-11/30	3/10	-1/30	4/15	0	0	0	15
x_3	0	0	1	0	13/30	1/10	-7/30	-2/15	0	0	0	10
x_4	0	0	0	1	1/5	1/5	1/5	-3/5	0	0	0	25
s_5	0	0	0	0	-1/10	-1/10	-1/10	-1/5	1	0	0	10
s_6	0	0	0	0	-4/15	-3/5	1/15	7/15	0	1	0	10
s_7	0	0	0	0	1/6	1/2	-1/6	-2/3	0	0	1	10
Z	0	0	0	0	5	4	6	3	0	0	0	2760

There are no negative elements left in the row of the final simplex tableau. This means that the optimal solution has been found using the simplex method.Z

From the table, the optimal values of the basic variables are determined as follows:

$$x_1 = 20, x_2 = 15, x_3 = 10, x_4 = 25$$

And the space variables are:

$$s_1 = 0, s_2 = 0, s_3 = 0, s_4 = 0$$
$$s_5 = 10, s_6 = 10, s_7 = 10$$

So, the first, second, third, and fourth resource constraints are fully utilized. The fifth, sixth, and seventh constraints have a reserve of 10 units.

The maximum value of the objective function is calculated as follows:

$$Z_{\max} = 38(20) + 35(15) + 35(10) + 45(25)$$
$$Z_{\max} = 760 + 525 + 350 + 1125$$

$$Z_{\max} = 2760$$

Therefore, to maximize profit, the firm should produce 20 units of product A, 15 units of product B, 10 units of product C, and 25 units of product D.

The optimal production plan is expressed as:

$$X^* = (20;\ 15;\ 10;\ 25)$$
$$Z_{\max} = 2760$$

This result shows that the simplex method can be used to determine the optimal production volume in a multi-product production process under the constraints of available resources, production capacity, and market demand. As a result, the enterprise achieves maximum economic efficiency by using resources rationally.

Optimal solution

As a result of calculations based on the simplex method, the following optimal solution was determined for the multi-product production model:

$$x_1 = 20, x_2 = 15, x_3 = 10, x_4 = 25$$

Here:

$$x_1 = 20$$

— Indicates that 20 units of product A need to be produced;

$$x_2 = 15$$

— Indicates that 15 units of product B need to be produced;

$$x_3 = 10$$

— C indicates that 10 units of product need to be produced;

$$x_4 = 25$$

— D indicates that 25 units of product need to be produced.

The maximum value of the objective function is calculated as follows:

$$Z = 38x_1 + 35x_2 + 35x_3 + 45x_4$$

We put the optimal values into the objective function:

$$Z_{\max} = 38(20) + 35(15) + 35(10) + 45(25)$$
$$Z_{\max} = 760 + 525 + 350 + 1125$$
$$Z_{\max} = 2760$$

Therefore, in order to achieve maximum profit with available resources, the enterprise should follow the following production plan:

Product type	**Optimal production volume**
Product A(x_1)	20 units
Product B(x_2)	15 units
Product C(x_3)	10 units
Product D(x_4)	25 units

Thus, the optimal production plan is expressed as follows:

$$X^* = (20;\ 15;\ 10;\ 25)$$

The maximum benefit is:

$$Z_{\max} = 2760$$

will be equal to unity.

This result shows that the enterprise should not focus only on producing the highest-profit product D. On the contrary, a balanced combination of products A, B, C, and D, taking into account all resource constraints, provides maximum profit.

RESULTS AND DISCUSSION

As part of the study, a multi-product production process was analyzed based on a linear programming model. The model assumed that the enterprise produces four different products, and for each product, unit profit, resource consumption, production capacity, and market demand constraints were taken into account. As a result of calculations based on the simplex method, the following optimal production plan was determined:

$$x_1 = 20, x_2 = 15, x_3 = 10, x_4 = 25$$

According to this result, in order to maximize profit, the company should produce 20 units of product A, 15 units of product B, 10 units of product C, and 25 units of product D.

The maximum value of the objective function was calculated as follows:

$$Z_{\max} = 38(20) + 35(15) + 35(10) + 45(25)$$
$$Z_{\max} = 760 + 525 + 350 + 1125 = 2760$$

Therefore, the total maximum profit of the enterprise under the optimal production plan is:

$$Z_{\max} = 2760$$

will be equal to unity.

To verify the correctness of the resulting optimal solution, we analyze it by subjecting it to all constraints.

The first constraint, namely on raw material resources:

$$2(20) + 15 + 3(10) + 2(25) = 40 + 15 + 30 + 50 = 135$$

This result indicates that the raw material resource has been fully utilized.

The second constraint, namely on labor resources:

$$20 + 3(15) + 2(10) + 2(25) = 20 + 45 + 20 + 50 = 135$$

This means that the labor resource is also fully occupied.

The third limitation, namely on hardware time:

$$3(20) + 2(15) + 10 + 4(25) = 60 + 30 + 10 + 100 = 200$$

This situation means that the equipment time constraint is also fully utilized in the optimal plan.

The fourth constraint, namely on energy resources:

$$2(20) + 2(15) + 2(10) + 25 = 40 + 30 + 20 + 25 = 115$$

This means that the energy resource has also been completely consumed.

The fifth constraint, namely on total production capacity:

$$20 + 15 + 10 + 25 = 70 \leq 80$$

Here is the production capacity:

$$80 - 70 = 10$$

One unit left in reserve.

The sixth constraint, namely, the market demand for products B, C, and D:

$$15 + 10 + 25 = 50 \leq 60$$

Also according to this restriction:

$$60 - 50 = 10$$

There is a unit reserve.

The seventh constraint, namely the maximum order quantity for product A:

$$20 \leq 30$$

Here:

$$30 - 20 = 10$$

It is determined whether there is a possibility of ordering an additional unit.

The results can be summarized in the following table:

Type of restriction	Estimated value	Available limit	Status
Raw material resource	135	135	Fully used
Labor resource	135	135	Fully used
Hardware time	200	200	Fully used
Energy resource	115	115	Fully used
Total production capacity	70	80	10 units spare
Demand for products B, C, and D	50	60	10 units spare
Order for product A	20	30	10 units spare

The table shows that in the optimal production plan, the first four constraints - raw materials, labor, equipment time and energy resources - are active constraints. All of these constraints have become equal, that is, there is no reserve in them. Therefore, these resources are the main limiting factors in increasing the profit of the enterprise.

In contrast, the total production capacity, market demand for products B, C, and D, and the maximum order limit for product A are all within a margin of 10 units. This means that neither production capacity nor market demand is the absolute limiting factor in the enterprise. The main problem is the limited availability of production resources, namely raw materials, labor, equipment, and energy.

From the point of view of the discussion, it can be said that in order to further increase the profit of the enterprise, it will not be enough to expand production capacity or increase the volume of orders. Because in the optimal plan there is a reserve in both production capacity and market demand constraints. To increase profit, it is first of all necessary to expand or increase the efficiency of using raw materials, labor, equipment time and energy resources.

The results obtained clearly demonstrate the practical importance of the simplex method. This method not only determines the maximum profit, but also determines which resources are active constraints, and which constraints have reserves. This allows for a scientific justification of management decisions in the production process.

Thus, the optimal solution determined based on the simplex method is summarized as follows:

$$X^* = (20;\ 15;\ 10;\ 25)$$
$$Z_{\max} = 2760$$

This result shows that an enterprise can achieve maximum profit by forming a balanced product mix under the conditions of available resources. Therefore, linear programming and the simplex method serve as important scientific and practical tools for production planning, resource allocation, and increasing economic efficiency.

CONCLUSION

This study examines the theoretical and practical aspects of solving linear programming problems using the simplex method. A multi-product production model was developed within the framework of the study, which took into account the constraints of four different products, raw materials, labor, equipment time, energy resources, total production capacity, and market demand. This allowed the production process to be analyzed not based on a simple approach, but through a mathematical optimization model.

The model was solved step by step using the simplex method and the optimal production plan was determined. According to the calculation results, it was determined that in order to achieve maximum profit, the enterprise should produce 20 units of product A, 15 units of product B, 10 units of product C, and 25 units of product D. This optimal plan is expressed as follows:

$$X^* = (20;\ 15;\ 10;\ 25)$$

In this case, the maximum value of the objective function is:

$$Z_{\max} = 2760$$

formed a unit.

The results showed that the optimal production plan fully utilizes raw materials, labor, equipment time, and energy resources. Therefore, these resources are the main limiting factors in the enterprise's activities. It was found that the total production capacity, market demand for products B, C, and D, and the maximum order limit for product A have a reserve of 10 units. This situation indicates that in order to increase the enterprise's profit, it is necessary to increase the efficiency of using raw materials, labor, equipment, and energy resources, not production capacity.

The results of the study confirm that the simplex method is not only a tool for finding the optimal numerical solution, but also an effective method for determining which production resources are active and which are inactive constraints. This allows for making scientifically based decisions in enterprise management on rational resource allocation, optimization of production structure, and achieving maximum profit.

Thus, linear programming and the simplex method are important scientific and practical tools for modeling multi-product production processes, efficient use of resources, and increasing economic efficiency. In the future, in order to further develop this model, it is possible to introduce integer conditions, minimum production requirements for products, uncertainty factors, or elements of multi-criteria optimization. This will ensure that the model is closer to real production systems.

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