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Application of Linear Programming in the Textile Industry

Elena Karamazova Gelova [1], Mirjana Kocaleva Vitanova [1], Biljana Zlatanovska [1], Zoran Zlatev [1]

[1] *Faculty of Computer Science, Goce Delcev University, Krste Misirkov, 10A, 2000 Stip, North Macedonia*

Abstract **– The textile industry is one of the leading branches without which no country can function. Profits in the textile industry are important both for the founders of the company and for other employees and consumers. In this paper linear programming is applied in textile companies. Therefore, the main goal of the study is to apply linear programming for optimal use of resources in production t-shirts, blouses and dresses and attain maximum profit. The variables are three different types of clothes like men t-shirts, women blouses and children dresses produced in textile factory in Macedonia. The solution to the linear programming problem will be obtained by softwares LINDO, Excel and Mathematica and with Artificial Intelligence i.e., ChatGPT. At the end a comparison has been made for speed, usability, and simplicity of obtaining solutions using the mentioned software and ChatGPT.**

Keywords **– Textile factory, linear programming, production, optimum, profit.**

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Corresponding author: Biljana Zlatanovska,
Faculty of Computer Science, Goce Delcev University, Krste Misirkov, 10A, 2000 Stip, North Macedonia
Email: biljana.zlatanovska@ugd.edu.mk

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1. Introduction

Profit in any company and any industry is what matters most and is usually what a new business idea is based on. For the profit to be large, it is very important how much time will have to be spent producing a suitable product. In the textile industry it is very important how much a product will be in demand in the bazaar, as well as whether an employee will be able to complete everything related to its production in the company.

In this paper, the objective is to determine the optimal daily production levels for three products to maximize total profit. To achieve this, linear programming (LP) is applied to find the maximum value of a linear objective function. In the context, "programming" refers to the process of developing an optimal plan or decision strategy. More about linear programming is in line with [2], [13], [14], [15], [16].

The linear programming model is intended to support production and operations managers in making informed decisions regarding resource allocation. While managers may face limitations in terms of available resources, they are still expected to identify and implement optimal solutions. LP enables decision-makers to do so by identifying the most efficient allocation of scarce resources.

To efficiently and accurately solve the LP model, the LINDO software is used, chosen for its accessibility, ease of installation, and user-friendly interface. In addition to LINDO, Microsoft Excel and Mathematica are also used to solve the same model, to verify the results and compare outputs across different platforms. The solutions obtained from all three tools will be presented and analyzed.

A well-known technique for manually solving linear programming problems is the Simplex method. However, obtaining a solution manually using this method is significantly more time-consuming compared to using specialized software, as the Simplex algorithm involves numerous iterative steps.

Due to the laborious nature of manually solving such problems, it was decided to use artificial intelligence, specifically ChatGPT, to generate and solve a step-by-step process using the Simplex method. The output obtained through ChatGPT is also included and discussed in the paper.

Linear Programming (LP) has been widely applied to solve various scheduling and resource allocation problems. In [5], LP is used to address nurse scheduling challenges, and the study in [8] addressed the issue of determining the number of additional part-time nurses required to meet staffing needs during critical weeks. The objective was to ensure the minimum required number of nurses while minimizing hospital costs.

In [1], LP is utilized to allocate raw materials among competing products: big loaf, giant loaf, and small loaf in a bakery, with the objective of maximizing profit. Similarly, [3] developed an LP model to determine the optimal product mix for Golden Plastic Industry Limited. Their formulation helped identify the most profitable allocation of production resources within the company's operational layout. Authors in [17], [18], [20], [21] trying to optimize the production in the Textile industry with linear programming and authors in [12] use a linear programming approach to optimize animal feed rations by minimizing costs while meeting nutritional requirements.

In [4], the authors applied linear programming to personnel management, specifically to minimize the cost of staff training. The study offers practical recommendations to the management of Federal Polytechnic Ilaro, suggesting the optimal number of junior and senior staff to be selected for training programs in both academic and non-academic departments when such needs arise.

Application of linear programming to optimize the production process of Coca-Cola Company can be seen in [11]. In their model, the decision variables included products such as Coke, Fanta, Schweppes, Fanta Tonic, Krest Soda, etc. The constraints were based on key production factors such as drink concentration, sugar content, water volume, and carbon dioxide levels. The model was solved using the simplex algorithm. Following data analysis, the authors concluded that only two of the nine products significantly contributed to profit maximization. Based on this finding, they recommended that the company focus its production efforts on these two products to reduce costs and enhance profitability.

In [6], the Nurse Scheduling Problem (NSP) was also solved using LP, focusing on optimizing the number of nurses needed each day throughout the week. Also, authors in [7] write about scheduling of the drivers in a transport corporation in a metropolitan city.

In that way [19] contains schedule of employees in the kindergartens and in a day care center for children. Aim of authors is to make an optimization model to deal with the large number of children and employees.

2. Main Results

In the beginning, the linear programming problem is defined and then the solution to that problem is obtained with the software LINDO, Excel and Mathematica, as well as ChatGPT.

2.1. Defining a Linear Programming Problem

Company X, a textile manufacturer, produces three types of garments: men's T-shirts, women's blouses, and children's dresses. The workforce hours, material requirements (in meters), colouring time (in hours), and profit per unit (in euros) for each product are provided in Table 1.

Table 1. Information for X textile company

Resource Limiters for Textile Company	Men's T-shirts	Women's Blouses	Children's Dresses	Total available
Profit per unit (euro)	4	3	5	
Workforce (in hours)	3	2	2	72
Material cotton (m)	2	1	3	60
Coloring (in hours)	1	2	2	48

From Table 1 the linear programming problem, that will determine the optimum production in a day for the three products men's t-shirts, women's blouses and children's dresses, is formulated. It will give maximum profit.

So, let x_1 is unit of men's t-shirts, x_2 units of women's blouses and x_3 children's dresses that should be produced. From the first row of Table 1 it can be observed that the profit per unit of men's T-shirts, women's blouses and children's dresses are 4,3 and 5 euros respectively. Furthermore, since the problem talks about profit maximization, the linear programming problem is maximization. Hence, the problem is to maximize the objective function:

$$F = 4x_1 + 3x_2 + 5x_3 \quad (1)$$

The constraints for each of the three resource limiters can be formulated from Table 1:

Workforce (in hours): 3 hours per unit of men's t-shirts with a tag x_1 plus 2 hours per unit of women's blouses with a tag x_2 plus 2 hours per unit of children's dresses with a tag x_3 amounts to at most 72 hours per day:

$$3x_1 + 2x_2 + 2x_3 \leq 72 \quad (2)$$

Material cotton (m): 2 m per unit of men's t-shirts with a tag x_1 plus 1 m per unit of women's blouses with a tag x_2 plus 3 m per unit of children's dresses with a tag x_3 amounts to at most 60 m per day:

$$2x_1 + 1x_2 + 3x_3 \leq 60 \quad (3)$$

Coloring (in hours): 1 hours per unit of men's t-shirts with a tag x_1 plus 2 hours per unit of women's blouses with a tag x_2 plus 2 hours per unit of children's dresses with a tag x_3 amounts to at most 48 hours per day:

$$1x_1 + 2x_2 + 2x_3 \leq 48 \quad (4)$$

Therefore, it can be observed

$$x_1 \geq 0, x_2 \geq 0, x_3 \geq 0 \quad (5)$$

From the above, the linear programming problem can be formulated as:

$$Maximize\ F = 4x_1 + 3x_2 + 5x_3 \quad (6)$$

Subject to:

$$\begin{aligned} 3x_1 + 2x_2 + 2x_3 &\leq 72 \\ 2x_1 + 1x_2 + 3x_3 &\leq 60 \\ 1x_1 + 2x_2 + 2x_3 &\leq 48 \\ x_1 \geq 0, x_2 \geq 0, x_3 &\geq 0 \end{aligned} \quad (7)$$

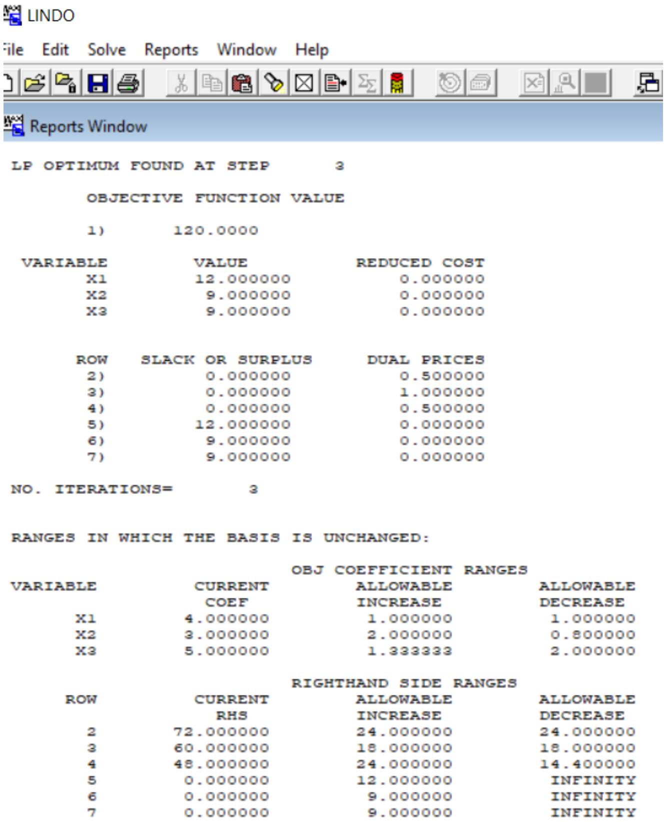
2.2. Solution to the Problem in a Lindo Software

Lindo is software for solving problems from linear programming, integer programming, nonlinear programming and stochastic programming. It is used to solve optimization problems in areas of business, industry, research, etc. Lindo is developed by Linus Schrage in 1981. LINDO API (Application Programming Interface) is a set of software libraries that can be called from different programming languages to create custom mathematical optimization applications, and the LINGO is a mathematical modeling language used as part of LINDO modeling system, offer powerful solvers for linear programs, based on methods that include primal and dual simplex for speed computations.

Steps for solving:

1. Start Lindo software and then enter the linear problem. For Maximize to be written Max and for "subject to" only "st".
2. To solve the model, can be use Ctrl + S on the keyboard.
3. Afterwards, it comes the question of whether the Sensitivity Analysis as a part of the report is preferred.
4. To see the output click Window and then Reports Window.

Using the Lindo software for this linear programming problem the following result is obtained:




```
LP OPTIMUM FOUND AT STEP      3

       OBJECTIVE FUNCTION VALUE

       1)      120.0000

  VARIABLE        VALUE          REDUCED COST
        X1        12.000000          0.000000
        X2         9.000000          0.000000
        X3         9.000000          0.000000

       ROW   SLACK OR SURPLUS     DUAL PRICES
        2)         0.000000          0.500000
        3)         0.000000          1.000000
        4)         0.000000          0.500000
        5)        12.000000          0.000000
        6)         9.000000          0.000000
        7)         9.000000          0.000000

NO. ITERATIONS=       3

RANGES IN WHICH THE BASIS IS UNCHANGED:

                           OBJ COEFFICIENT RANGES
VARIABLE         CURRENT        ALLOWABLE        ALLOWABLE
                   COEF          INCREASE         DECREASE
      X1        4.000000         1.000000         1.000000
      X2        3.000000         2.000000         0.800000
      X3        5.000000         1.333333         2.000000

                           RIGHTHAND SIDE RANGES
     ROW         CURRENT        ALLOWABLE        ALLOWABLE
                   RHS           INCREASE         DECREASE
       2       72.000000        24.000000        24.000000
       3       60.000000        18.000000        18.000000
       4       48.000000        24.000000        14.400000
       5        0.000000        12.000000         INFINITY
       6        0.000000         9.000000         INFINITY
       7        0.000000         9.000000         INFINITY
```

Figure 1. Result of linear programming problem received in Lindo

From Figure 1 can be seen that men's T-shirts, women's blouses and children's dresses should be produced. Their production quantities should be 12, 9 and 9 units respectively. This will produce a maximum profit of 120 euros.

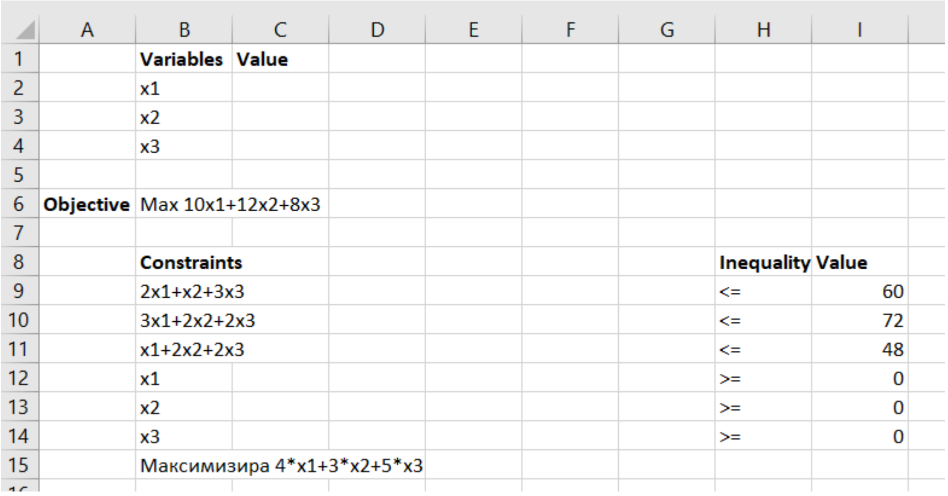
2.3. Solution to the Problem in Excel

To solve a problem with Excel, the Solver tool is required. If it is not already active, it must be enabled first.

Steps for solving:

1. Open a worksheet in Excel and enter the variables and inequalities of the system into the cells, along with appropriate comments to make solving the problem easier and more organized.
2. In cells from B2 to B4, input the variables x_1, x_2, x_3 .
3. In cells from B9 to B14, enter the right-hand sides of the inequalities in the system.
4. In cell B15, input the objective function.

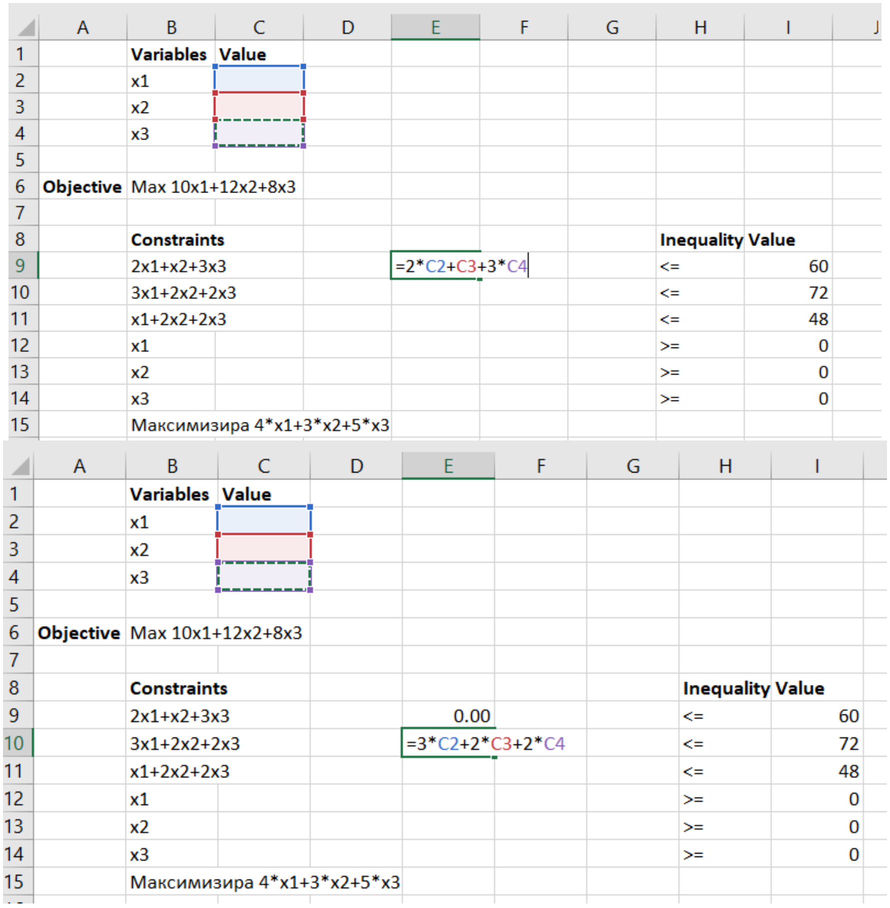
The first four steps are shown in Figure 2:



	A	B	C	D	E	F	G	H	I
1		**Variables**	**Value**						
2		x1							
3		x2							
4		x3							
5									
6	**Objective**	Max 10x1+12x2+8x3							
7									
8		**Constraints**						**Inequality**	**Value**
9		2x1+x2+3x3						<=	60
10		3x1+2x2+2x3						<=	72
11		x1+2x2+2x3						<=	48
12		x1						>=	0
13		x2						>=	0
14		x3						>=	0
15		Максимизира 4*x1+3*x2+5*x3							

Figure 2. Initial simplex table in Excel for the problem

5. In cells E9, E10, E11, E12, E13, E14, enter the formulas according to the right-hand sides of the inequalities in the system, (Figure 3).



	A	B	C	D	E	F	G	H	I
1		**Variables**	**Value**						
2		x1							
3		x2							
4		x3							
5									
6	**Objective**	Max 10x1+12x2+8x3							
7									
8		**Constraints**						**Inequality**	**Value**
9		2x1+x2+3x3			=2*C2+C3+3*C4			<=	60
10		3x1+2x2+2x3						<=	72
11		x1+2x2+2x3						<=	48
12		x1						>=	0
13		x2						>=	0
14		x3						>=	0
15		Максимизира 4*x1+3*x2+5*x3							

	A	B	C	D	E	F	G	H	I
1		**Variables**	**Value**						
2		x1							
3		x2							
4		x3							
5									
6	**Objective**	Max 10x1+12x2+8x3							
7									
8		**Constraints**						**Inequality**	**Value**
9		2x1+x2+3x3			0.00			<=	60
10		3x1+2x2+2x3			=3*C2+2*C3+2*C4			<=	72
11		x1+2x2+2x3						<=	48
12		x1						>=	0
13		x2						>=	0
14		x3						>=	0
15		Максимизира 4*x1+3*x2+5*x3							

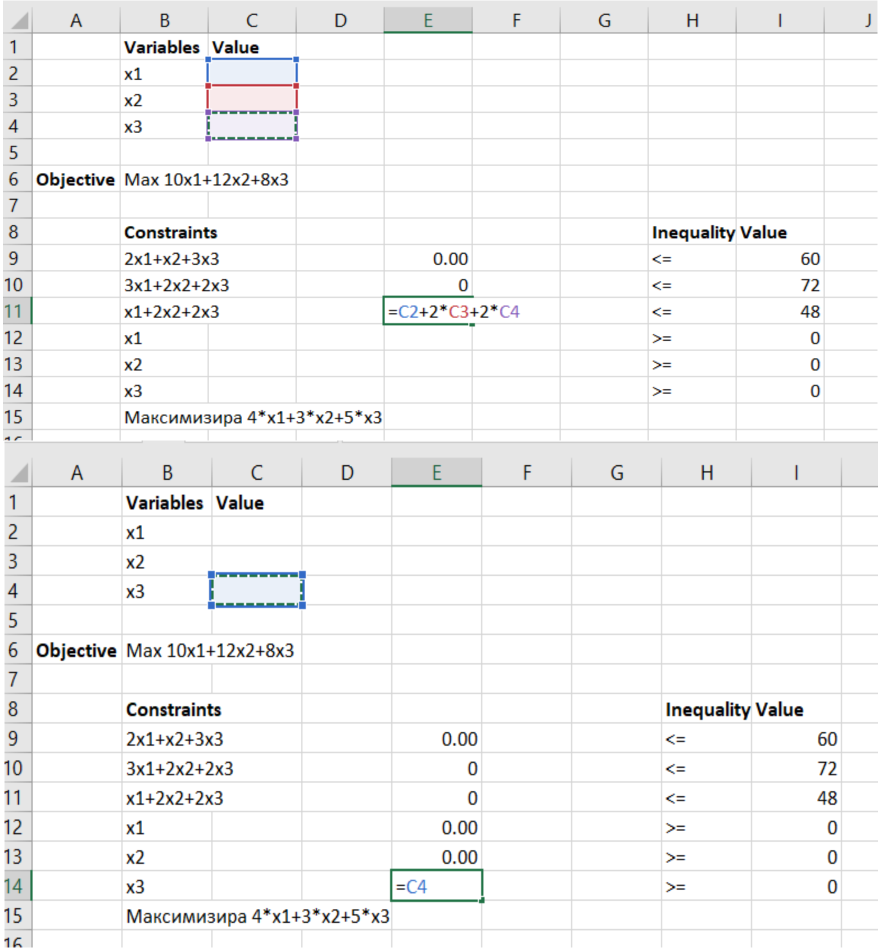


Figure 3. Inputting the formulas for the constraints

6. In cell E15, input the formula for the objective function, (Figure 4).

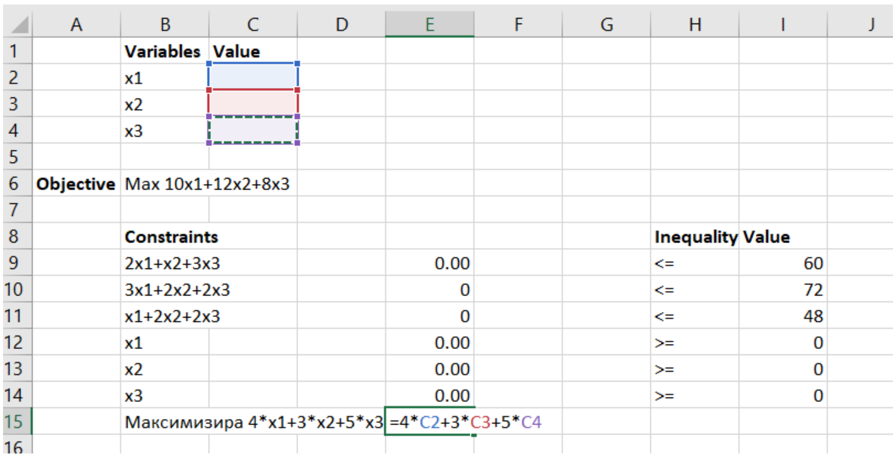


Figure 4. Inputting the formulas for the objective function

7. Select Solver in the Data part.
8. Choose Max or Min.
9. Add the objective function and constraints according to Solver's instructions.
10. Steps 6, 7 and 8 are shown in Figure 5:

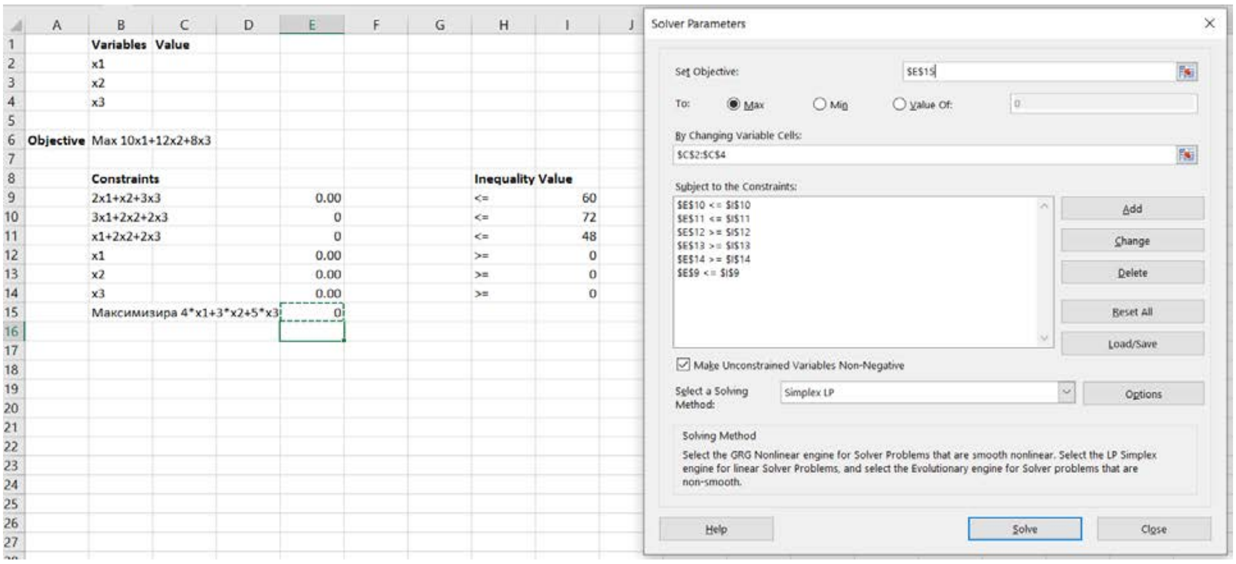


Figure 5. Inputting Solver's instructions

The look of the linear programming is presented in Excel, in Figure 6:

	A	B	C	D	E	F	G	H	I	J
1		**Variables**	**Value**							
2		x1	12.00							
3		x2	9.00							
4		x3	9.00							
5										
6	**Objective**	Max 10x1+12x2+8x3								
7										
8		**Constraints**						**Inequality**	**Value**	
9		2x1+x2+3x3			60.00			<=	60	
10		3x1+2x2+2x3			72			<=	72	
11		x1+2x2+2x3			48			<=	48	
12		x1			12.00			>=	0	
13		x2			9.00			>=	0	
14		x3			9.00			>=	0	
15		Максимизира 4*x1+3*x2+5*x3			120					
16										

Figure 6. Simplex table in Excel for the problem with the Solver

From Figure 6, the same solution is obtained as in the previous solution to the problem, i.e., 12, 9, 9 units respectively. The profit is maximized by producing 12 men's T-shirts, 9 women's blouses, and 9 children's dresses, and the maximum profit amount to 120 euros.

Solving this problem in Excel requires knowledge of the Solver tool to arrive at a final solution. However, using this tool, the intermediate results cannot be known in the form of tables, which are obtained using the Simplex method.

2.4. Solution to the Problem in Mathematica

Furthermore, the problem with the Mathematica software will be solved. The solution in Mathematica is with the help of one command, Figure 7:

```
In[7]:= FindMaximum[
  {4 x + 3 y + 5 z, {3 x + 2 y + 2 z ≤ 72, 2 x + y + 3 z ≤ 60, x + 2 y + 2 z ≤ 48,
   x ≥ 0, y ≥ 0, z ≥ 0}}, {x, y, z}]

Out[7]= {120., {x → 12., y → 9., z → 9.}}
```

Figure 7. Solution in Mathematica

Figure 7 shows the same solution as before. The syntax of this command can be found on the website [10]. Remark: The problem can also be solved with a command as in paper [9], but the syntax of that command is more complex, and to find the profit, need an additional command. Such a linear programming problem can be solved with mathematical software Mathematica, using only one command.

However, the mathematical software Mathematica provides only a final solution to the problem, without displaying the intermediate results. In most cases, there is need for a detailed solution with displays the intermediate results in the solution process. In most cases, a detailed solution is required, showing all intermediate results throughout the problem-solving process. When a precise solution with step-by-step intermediate outcomes is needed, alternative computational tools may be utilized. Subsequently, the previously obtained result will be verified using ChatGPT to determine whether the same solution is achieved.

2.5. Solution to the Problem Using ChatGPT

The solution obtained from ChatGPT is documented through a series of images, which capture the step-by-step process provided by the model. These screenshots serve as visual evidence of the solution path and are included in the paper to support the comparison with the results from traditional mathematical software.

Steps for solving:

1. ChatGPT was given the problem as shown in Figure 8 and asked to solve it step by step using the Simplex method.

Problem Statement:

Maximize

$$F = 4x_1 + 3x_2 + 5x_3$$

Subject to:

$$\begin{aligned} 3x_1 + 2x_2 + 2x_3 &\leq 72 \quad \text{(Constraint 1)} \\ 2x_1 + 1x_2 + 3x_3 &\leq 60 \quad \text{(Constraint 2)} \\ 1x_1 + 2x_2 + 2x_3 &\leq 48 \quad \text{(Constraint 3)} \end{aligned}$$

Figure 8. ChatGPT problem statement

2. Transformation of the system and the objective function into standard form, as shown in Figure 9.

Introduce **slack variables** s_1, s_2, s_3 to turn inequalities into equalities.

$$\begin{aligned} 3x_1 + 2x_2 + 2x_3 + s_1 &= 72 \\ 2x_1 + 1x_2 + 3x_3 + s_2 &= 60 \\ 1x_1 + 2x_2 + 2x_3 + s_3 &= 48 \end{aligned}$$

Objective function in standard form:

$$Z = 4x_1 + 3x_2 + 5x_3 + 0s_1 + 0s_2 + 0s_3$$

Figure 9. Transformation into standard form

3. Compiling the first so-called initial Simplex table as shown in Figure 10.

▶ **Initial Tableau**

Basic Var	x_1	x_2	x_3	s_1	s_2	s_3	RHS
s_1	3	2	2	1	0	0	72
s_2	2	1	3	0	1	0	60
s_3	1	2	2	0	0	1	48
Z	-4	-3	-5	0	0	0	0

Figure 10. Initial Simplex table

4. The slack variable s_2 leaves, and the variable x_3 enters, (Figure 11).

We do the **minimum ratio test** to choose the **leaving variable**:

$$\frac{72}{2} = 36, \quad \frac{60}{3} = 20, \quad \frac{48}{2} = 24 \Rightarrow \text{Smallest is } 20 \Rightarrow s_2 \text{ leaves.}$$

Pivot element: 3 (row 2, column x_3)

Now we perform Gaussian elimination to make pivot column into a unit column.

Figure 11. Substituting x_3 for s_2

5. Compiling a Simplex table after replacing the slack variable s_2 with the initial variable x_3, (Figure 12).

Pivot 1 — x_3 enters, s_2 leaves

Basic Var	x_1	x_2	x_3	s_1	s_2	s_3	RHS
s_1	5/3	4/3	0	1	-2/3	0	32
x_3	2/3	1/3	1	0	1/3	0	20
s_3	-1/3	4/3	0	0	-2/3	1	8
Z	-2/3	-4/3	0	0	5/3	0	100

Figure 12. Simplex table after the first replacemen

6. The slack variable s_3 leaves, and the variable x_2 enters, (Figure 13).

- **Entering variable:** x_2 (most negative in Z row: -4/3)
- **Ratio test (RHS / x_2):**
  - Row 1: $32/\frac{4}{3} = 24$
  - Row 3: $8/\frac{4}{3} = 6$ ✅ minimum
  - Row 2: $20/\frac{1}{3} = 60$
- **Leaving variable:** s_3
- **Pivot element:** $4/3$

Figure 13. Substituting x_2 for s_3

7. Compiling a Simplex table after replacing the slack variable s_3 with the initial variable x_2, (Figure 14).

Pivot 2 — x_2 enters, s_3 leaves

Basic Var	x_1	x_2	x_3	s_1	s_2	s_3	RHS
s_1	2	0	0	1	0	-1	24
x_3	3/4	0	1	0	1/2	-1/4	18
x_2	-1/4	1	0	0	-1/2	3/4	6
Z	-1	0	0	0	1	1	108

Figure 14. Simplex table after the second replacement

8. The slack variable s_1 exits, and the variable x_1 enters, according to the procedure already shown above.

Compiling a Simplex table after replacing the slack variable s_1 with the initial variable x_1, (Figure 15).

Pivot 3 — x_1 enters, s_1 leaves

Basic Var	x_1	x_2	x_3	s_1	s_2	s_3	RHS
x_1	1	0	0	1/2	0	-1/2	12
x_3	0	0	1	-3/8	1/2	1/8	9
x_2	0	1	0	1/8	-1/2	5/8	9
Z	0	0	0	1/2	1	1/2	120

Figure 15. Simplex table after the third replacement

9. According to the last table, the final solution to the problem is obtained, (Figure 16).

Final Solution:

- $x_1 = 12$
- $x_2 = 9$
- $x_3 = 9$
- Maximum value of $F = 120$

Figure 16. Final solution for the problem

The same result is achieved as in the earlier solution, namely 12, 9, and 9 units. The profit reaches it is maximum when producing 12 men's T-shirts, 9 women's blouses, and 9 children's dresses, yielding a total profit of 120 euros.

From the above, ChatGPT offers a detailed and well-explained solution for solving problems with the Simplex method. However, to use this artificial intelligence tool, the user needs to explain the problem concisely, clearly, and give ChatGPT precise requirements for using the method, as well as which intermediate results are important for the context of the solution. Otherwise, ChatGPT provides incomplete, chaotic, and inaccurate intermediate results, which can significantly affect the accuracy of the final solution.

3. Conclusion

Based on the results, the optimal production quantities are 12 units of men's T-shirts, 9 units of women's blouses, and 9 units of children's dresses. This production plan yields a maximum profit of 120 euros. These results indicate that the X Textile Company should produce all three types of garments in the specified quantities to meet customer demand while maximizing profit.

In this study, ChatGPT is introduced to evaluate whether Artificial Intelligence provides solutions comparable in accuracy to established mathematical software. Additionally, comparing the speed, usability, and simplicity of obtaining solutions using LINDO, Excel, Mathematica, and ChatGPT when solving linear programming problems.

All the tools are used to obtain an exact solution to the given problem using linear programming. Depending on whether only the final solution or a detailed one is needed, the following conclusions are reached:

➢ If need only the final solution, then Lindo, Mathematica, and Excel are suitable for use.

➢ If there is a need for detailed solution with excellent comments and intermediate results, then it is best to use the artificial intelligence tool ChatGPT.

Depending on whether need a simpler procedure for obtaining the solution, the following conclusions have been drawn:

➢ For a simpler procedure for obtaining the solution, the Lindo and Mathematica tools are used.

➢ For a more complex procedure with a full range of instructions for obtaining the solution, the Solver tool as part of Excel is used;

➢ The ChatGPT tool does not have a complex procedure with instructions for obtaining the solution, but it requires the formulation of a well-thought-out and precise request.

From this paper can be seen that linear programming can be applied to find the maximum profit that a company can make when producing its products. The idea is good because there is a lot of software for solving linear programming problems that can be used to obtain solutions.

From the results, it can be observed that applying Artificial Intelligence to solve linear programming problems yields accurate, precise, and rapid solutions. Therefore, in addition to ChatGPT, other AI-based chatbots can also be employed for this purpose.

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