OPTIMIZING THE LOGISTIC FLOW OF MANUFACTURING KN95 MASKS BY USING MATHEMATICAL CALCULATION METHODS

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ABSTRACT: In this research paper, the optimization of the manufacturing flow of the KN95 protective masks was performed using the Simplex linear mathematical calculation method. The introduction describes the research topic and the proposed objectives to be achieved, after which the current state of research is presented. The next step was to perform the calculations to optimize the logistics flow. The calculations were then compared with the results obtained using a website that performs the calculation using the Simplex method. By performing these mathematical calculations by the Simplex method, the aim of this work was to achieve the goal of maximizing turnover and to diversify the KN95 protective mask models manufactured by the logistics flow.

KEY WORDS: optimization, logistic flow, Simplex.

1. Introduction

The paper main goal is to optimize the logistic manufacturing flow of KN95 masks with the help of the Simplex linear mathematical calculation method. The logistic manufacturing flow of KN95 masks was chosen after a comparison made between 3 different logistic flows.

The Simplex algorithm is a numerical method for solving linear programming problems. The aim of this mathematical calculation method is to achieve the proposed objectives, namely: to diversify the types of KN95 protective masks manufactured by the logistics flow and to maximize turnover.

2. The current stage

2.1. General presentation

Below is a brief presentation of the current state of the logistical flow of manufacturing of KN95 masks.

This automatic protective mask formation line uses ultrasound to automatically make foldable masks. The production line performs several processes, such as: wire feed to the nose, loop welding, folding, forming and cutting, and collected waste. Only one worker is needed to operate this process. [1]

The flow includes the following equipment:

- ✓ Wire supply system;
- ✓ System for stamping the shape of the mask and gluing the layers;
- ✓ Clamping system for gluing the clamps;
- ✓ Folding and mask forming system;
- ✓ Surplus material cutting system;

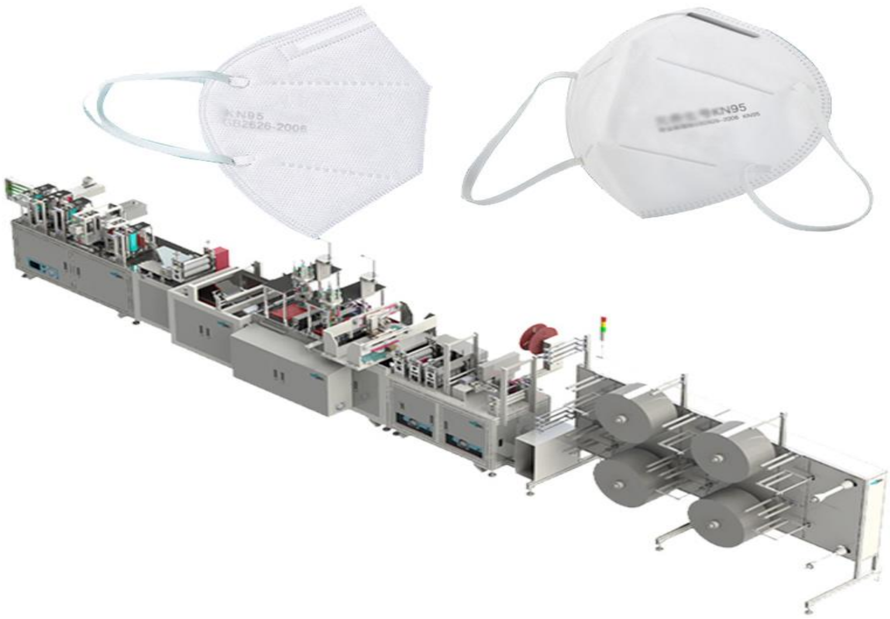


Fig. 2.1. KN95 protective mask manufacturing flow [1]

Flow specifications:

Table 2.1 Technical specifications [1]

Model number	KWKZN95
Equipment size	8539{L}x1318{M}x1985{H}MM
Voltage	200V 50/60 HZ
Capacity	30 – 50 pcs/min
Weight	1600 kg
Work table size	4965 {L}x670{M}x7985{H} MM
Air pressure	1 Pa
Power	8,5 KW
Automatic degree	Automatic
Frequency	50/60 Hz
Ear loop size	Width of 3 – 5 mm

2.2. Modelling, simulation and optimisation of the manufacturing flow

The modelling, simulation and optimisation of the manufacturing flow was made in Witness Horiozon (figure 2.2). After the preliminary simulation was achieved a productivity of 43149 masks in 24 hours.

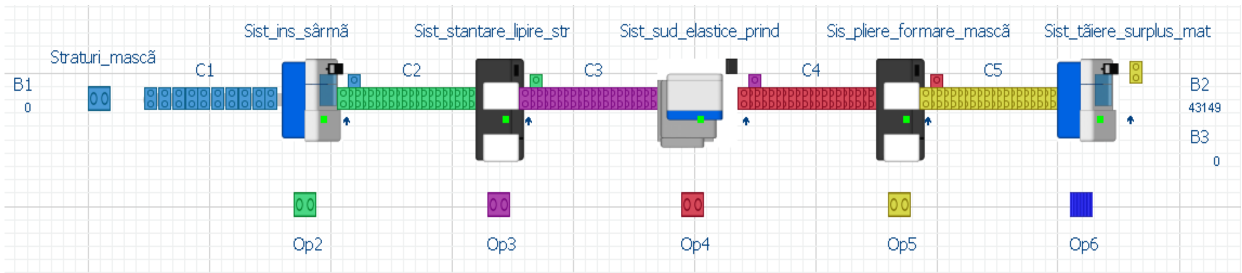


Fig. 2.2. The manufacturing flow before optimisation [2]

After the optimization was achieved a productivity of 71906 masks in 24 hours.

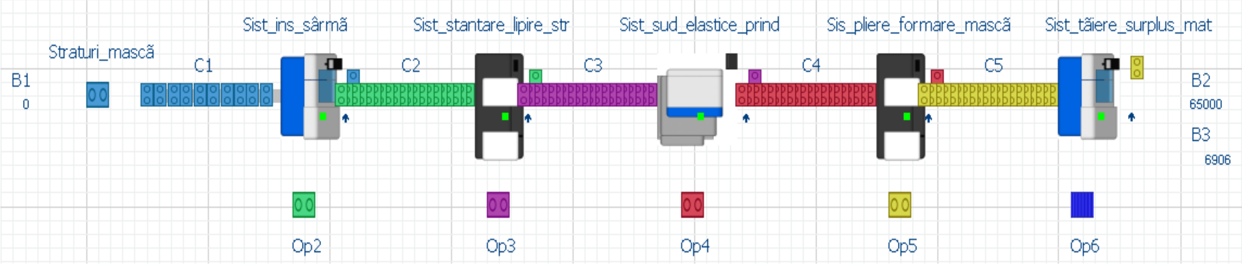
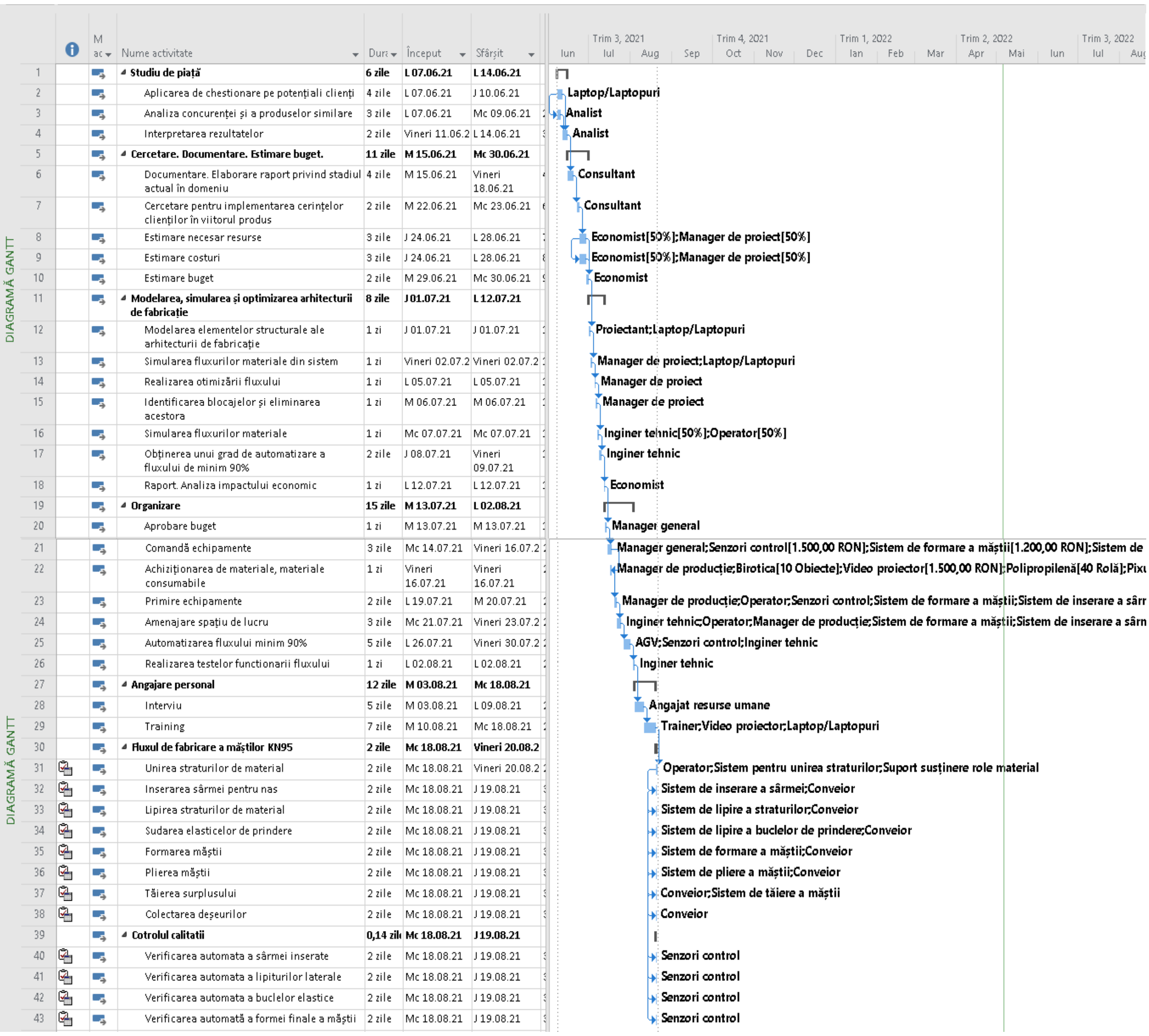


Fig. 2.3. Optimized manufacturing flow

2.3. Project management planning

In figure 2.4 are presented the project phases and activities including the folowing details: duration, start date, finish date, liks between activities etc.



	Nume activitate	Durată	Început	Sfârșit
1	**Studiu de piață**	**6 zile**	**L 07.06.21**	**L 14.06.21**
2	Aplicarea de chestionare pe potențiali clienți	4 zile	L 07.06.21	J 10.06.21
3	Analiza concurenței și a produselor similare	3 zile	L 07.06.21	Mc 09.06.21
4	Interpretarea rezultatelor	2 zile	Vineri 11.06.2	L 14.06.21
5	**Cercetare. Documentare. Estimare buget.**	**11 zile**	**M 15.06.21**	**Mc 30.06.21**
6	Documentare. Elaborare raport privind stadiul actual în domeniu	4 zile	M 15.06.21	Vineri 18.06.21
7	Cercetare pentru implementarea cerințelor clienților în viitorul produs	2 zile	M 22.06.21	Mc 23.06.21
8	Estimare necesar resurse	3 zile	J 24.06.21	L 28.06.21
9	Estimare costuri	3 zile	J 24.06.21	L 28.06.21
10	Estimare buget	2 zile	M 29.06.21	Mc 30.06.21
11	**Modelarea, simularea și optimizarea arhitecturii de fabricație**	**8 zile**	**J 01.07.21**	**L 12.07.21**
12	Modelarea elementelor structurale ale arhitecturii de fabricație	1 zi	J 01.07.21	J 01.07.21
13	Simularea fluxurilor materiale din sistem	1 zi	Vineri 02.07.2	Vineri 02.07.2
14	Realizarea otimizării fluxului	1 zi	L 05.07.21	L 05.07.21
15	Identificarea blocajelor și eliminarea acestora	1 zi	M 06.07.21	M 06.07.21
16	Simularea fluxurilor materiale	1 zi	Mc 07.07.21	Mc 07.07.21
17	Obținerea unui grad de automatizare a fluxului de minim 90%	2 zile	J 08.07.21	Vineri 09.07.21
18	Raport. Analiza impactului economic	1 zi	L 12.07.21	L 12.07.21
19	**Organizare**	**15 zile**	**M 13.07.21**	**L 02.08.21**
20	Aprobare buget	1 zi	M 13.07.21	M 13.07.21
21	Comandă echipamente	3 zile	Mc 14.07.21	Vineri 16.07.2
22	Achiziționarea de materiale, materiale consumabile	1 zi	Vineri 16.07.21	Vineri 16.07.21
23	Primire echipamente	2 zile	L 19.07.21	M 20.07.21
24	Amenajare spațiu de lucru	3 zile	Mc 21.07.21	Vineri 23.07.2
25	Automatizarea fluxului minim 90%	5 zile	L 26.07.21	Vineri 30.07.2
26	Realizarea testelor functionarii fluxului	1 zi	L 02.08.21	L 02.08.21
27	**Angajare personal**	**12 zile**	**M 03.08.21**	**Mc 18.08.21**
28	Interviu	5 zile	M 03.08.21	L 09.08.21
29	Training	7 zile	M 10.08.21	Mc 18.08.21
30	**Fluxul de fabricare a măștilor KN95**	**2 zile**	**Mc 18.08.21**	**Vineri 20.08.2**
31	Unirea straturilor de material	2 zile	Mc 18.08.21	Vineri 20.08.2
32	Inserarea sârmei pentru nas	2 zile	Mc 18.08.21	J 19.08.21
33	Lipirea straturilor de material	2 zile	Mc 18.08.21	J 19.08.21
34	Sudarea elasticelor de prindere	2 zile	Mc 18.08.21	J 19.08.21
35	Formarea măștii	2 zile	Mc 18.08.21	J 19.08.21
36	Plierea măștii	2 zile	Mc 18.08.21	J 19.08.21
37	Tăierea surplusului	2 zile	Mc 18.08.21	J 19.08.21
38	Colectarea deșeurilor	2 zile	Mc 18.08.21	J 19.08.21
39	**Cotrolul calitatii**	**0,14 zil**	**Mc 18.08.21**	**J 19.08.21**
40	Verificarea automata a sârmei inserate	2 zile	Mc 18.08.21	J 19.08.21
41	Verificarea automata a lipiturilor laterale	2 zile	Mc 18.08.21	J 19.08.21
42	Verificarea automata a buclelor elastice	2 zile	Mc 18.08.21	J 19.08.21
43	Verificarea automată a formei finale a măștii	2 zile	Mc 18.08.21	J 19.08.21

Fig. 2.4. Stages and activities of project management planning

2.4. Automatic quality control for surgical masks using the Vision sensor

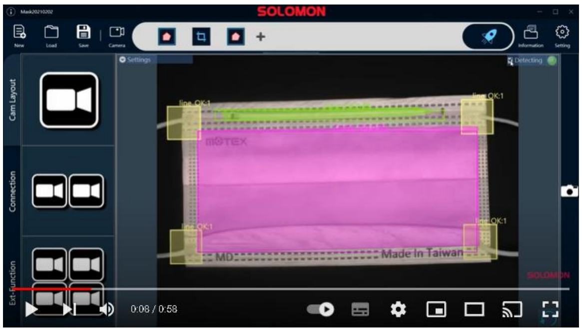


Fig. 2.5. Standard image [3]

In figure 2.5 an image with a standard mask is shown after which the inspections for the other masks will be performed.

Fig. 2.6. Defective mask (improperly glued elastic) [3]

In figure 2.6. a mask that does not have the elastic band attached to the bottom right is shown.

3. Using the Smplex method to maximize turnover by optimizing the logistics flow

Three models of KN95 face masks are on sale: KN95 face mask (three-layer), KN95 face mask (five-layer) without valve and a KN95 face mask (five-layer) with valve. Given that these masks are mainly for medical use, but also for other people who want to protect themselves against viruses and bacteria, it is expected to sell all the masks manufactured. The price of the face masks is: KN95 protection mask (with three layers) - 4 lei, KN95 protection mask (with five layers) without valve - 7 lei and KN95 protection mask (with five layers) with valve - 12 lei. The only problem is the supply sector, which is limited by four raw materials: cotton filter, polypropylene, elastic band and valves. To make a three-layer KN95 protective mask requires two layers of polypropylene, one layer of filter and two elastic bands, the KN95 five-layer protective mask without valve requires four layers of polypropylene, one layer of filter and two elastics and the KN95 five-layer valve mask requires four layers of polypropylene, a layer of filter, two elastic bands and a valve. Knowing that the stock of polypropylene is 250,000 units, that of cotton filter is 72,000 units, that of elastic clamps is 144,000 units and that of valves is 18,000 units, how many masks must be made of each type, so that turnover is maximized?

Answer:

Note x_1 – the number of KN95 three layers masks, x_2 – the number of KN95 (five layers) masks without a valve and cu x_3 – the number of KN95 (five layers) masks with a valve, and **z** – turnover.

To maximize the objective function:

$$z = 4x_1 + 7x_2 + 12x_3 \tag{1}$$

With restrictions:

$$2x_1 + 4x_2 + 4x_3 \leq 250000 \tag{2}$$
$$x_1 + x_2 + x_3 \leq 72000 \tag{3}$$
$$2x_1 + 2x_2 + 2x_3 \leq 144000 \tag{4}$$
$$x_3 \leq 18000 \tag{5}$$
$$x_1, x_2, x_3 \geq 0 \tag{6}$$

We convert the model to the standard shape:

$$2x_1 + 4x_2 + 4x_3 + y_1 = 250000 \tag{7}$$
$$x_1 + x_2 + x_3 + y_2 = 72000 \tag{8}$$
$$2x_1 + 2x_2 + 2x_3 + y_3 = 144000 \tag{9}$$
$$x_3 + y_4 = 18000 \tag{10}$$

Turn:

$$x_1 = x_2 = x_3 = 0 \tag{11}$$

And it turns out:

$$y_1 = 250000 \tag{12}$$
$$y_2 = 72000 \tag{13}$$
$$y_3 = 144000 \tag{14}$$
$$y_4 = 18000 \tag{15}$$

Now all the variables are positive:

$$x_1, x_2, x_3, y_1, y_2, y_3, y_4 \geq 0 \tag{16}$$

1 2 3

Table 3.1. Initial table

	4	**7**	**12**	0	0	0	0		
	x_1	**x_2**	**x_3**	**y_1**	**y_2**	**y_3**	**y_4**		
y_1	2	4	4	1	0	0	0	250000	0
y_2	1	1	1	0	1	0	0	72000	0
y_3	2	2	2	0	0	1	0	144000	0
y_4	0	0	1	0	0	0	1	18000	0
	-4	**-7**	**-12**	0	0	0	0	0	**z**

In the colum indicated by the number 1 arrow are the basic variables. The coefficients of the objective function are written on the highlighted lines, which are indicated by the arrow number 2. In the colum highlighted by the arrow number 3 are written the free terms of the restrictions.

Table 3.2. Iteration no. 1 – Stage 1

	4	**7**	**12**	0	0	0	0		
	x_1	**x_2**	**x_3**	**y_1**	**y_2**	**y_3**	**y_4**		
y_1	2	4	4	1	0	0	0	250000	0
y_2	1	1	1	0	1	0	0	72000	0
y_3	2	2	2	0	0	1	0	144000	0
y_4	0	0	1	0	0	0	1	18000	0
	-4	**-7**	**-12**	0	0	0	0	0	**z**

The initial solution is not optimal because there is at least one negative value. We choose from the three negative solutions the highest in absolute value (that is, 12). The yellow column is divided by the pivot (green column), namely: 250000: 4 = 62500, 72000: 1 = 72000, 144000: 2 = 72000 and 18000: 1 = 18000.

Of these terms, the smallest is chosen (that is, 18000: 1 = 18000). The row (purple) that contains the smallest element will be the pivot row.

Table 3.3. Iteration no.1 – Stage 2

	4	**7**	**12**	0	0	0	0		
	x_1	x_2	x_3	y_1	y_2	y_3	y_4		
y_1	2	4	4	1	0	0	0	250000	0
y_2	1	1	1	0	1	0	0	72000	0
y_3	2	2	2	0	0	1	0	144000	0
y_4	0	0	1	0	0	0	1	18000	0
	-4	**-7**	**-12**	0	0	0	0	0	**z**

The initial pivot lives (y_4)

Tabelul 3.4. Iterația nr.1 – Etapa 3

	4	7	12	0	0	0	0		
	x_1	x_2	x_3	y_1	y_2	y_3	y_4		
y_1	2	4	4	1	0	0	0	250000	0
y_2	1	1	1	0	1	0	0	72000	0
y_3	2	2	2	0	0	1	0	144000	0
x_3	0	0	1	0	0	0	1	18000	12
	-4	-7	-12	0	0	0	0	0	**z**

y_4 left the table and entered x_3. With the entry of x_3 instead of 0 in the objective function, the coefficient of x_3 will appear, ie 12.
Divide the line elements with purple at the pivot (ie divide the line elements with purple at 1).
In table 3.5. the results are shown after dividing the elements of the purple line by pivot 1.

Table 3.5. Iteration no. 1 – Stage 4

	4	7	12	0	0	0	0		
	x_1	x_2	x_3	y_1	y_2	y_3	y_4		
y_1	2	4	4	1	0	0	0	250000	0
y_2	1	1	1	0	1	0	0	72000	0
y_3	2	2	2	0	0	1	0	144000	0
x_3	0	0	1	0	0	0	1	18000	12
	-4	-7	-12	0	0	0	0	0	**z**

In the pivot column, ie the column of x_3, apart from the element 1 which is the pivot, the rest of the column is completed with zeros.
Only cells in columns that are not colored will be counted.

Table 3.6. Iteration no. 1 – Stage 5

	4	7	12	0	0	0	0		
	x_1	x_2	x_3	y_1	y_2	y_3	y_4		
y_1	2	4	0	1	0	0	-4	178000	0
y_2	1	1	0	0	1	0	-1	54000	0
y_3	2	2	0	0	0	1	-2	108000	0
x_3	0	0	1	0	0	0	1	18000	12
	-4	-7	0	0	0	0	12	216000	**z**

The calculations in equations (17), (18), (19) and (20) are the results of the arrows in Table 3.5. and are listed in Table 3.6. with each color corresponding to the arrow.
The same calculation method is used for the other cells. (the number 1 below the fraction being the pivot).

$$\frac{2 \cdot 1 - 0 \cdot 4}{1} = 2 \tag{17}$$

$$\frac{4 \cdot 1 - 0 \cdot 4}{1} = 4 \tag{18}$$

$$\frac{0 \cdot 1 - 1 \cdot 4}{1} = -4 \tag{19}$$

$$\frac{250000 \cdot 1 - 18000 \cdot 4}{1} = 178000 \tag{20}$$

$$178000 \cdot 0 + 54000 \cdot 0 + 108000 \cdot 0 + 18000 \cdot 12 = 216000 \tag{21}$$

If there are only ≥0 numbers in the last line, the calculation stops. If not, the previous calculation steps are resumed until only positive results are obtained.

Table 3.7. Iteration no. 2 – Stage 1

	4	7	12	0	0	0	0		
	x_1	x_2	x_3	y_1	y_2	y_3	y_4		
y_1	2	4	0	1	0	0	-4	178000	0
y_2	1	1	0	0	1	0	-1	54000	0
y_3	2	2	0	0	0	1	-2	108000	0
x_3	0	0	1	0	0	0	1	18000	12
	-4	-7	0	0	0	0	12	216000	z

As there are still negative values, the procedure is continued. From the two negative values, choose the column with the highest absolute value, ie 7. Then divide the yellow column by the pivot column (green column) (178000: 4 = 44500, 54000: 1 = 54000, 108000: 2 = 54000 and 18000: 0 cannot be divided, the minimum positive is chosen).In this situation y_1 leaves the column (because it gives the positive minimum) and x_2 comes with the coefficient 7.

Table 3.8. Iteration no. 2 – Stage 2

	4	7	12	0	0	0	0		
	x_1	x_2	x_3	y_1	y_2	y_3	y_4		
x_2	0,5	1	0	0,25	0	0	-1	44500	7
y_2	0,5	0	0	-0,25	1	0	0	9500	0
y_3	1	0	0	-0,5	0	1	0	19000	0
x_3	0	0	1	0	0	0	1	18000	12
	-0,5	0	0	1,75	0	0	5	527500	z

The purple row is divided into pivots, ie 4, which is circled in Table 3.7. and enter the values in Table 3.8 .. Then make the calculations for the other cells in the columns that are not colored and also enter in Table 3.8. The calculations are performed as in Table 3.5. who has equations (17) → (21), only now the pivot is 4 instead of 1. As there is still a negative value, continue the procedure.

Table 3.9. Iteration no. 3 – Stage 1

	4	7	12	0	0	0	0		
	x_1	x_2	x_3	y_1	y_2	y_3	y_4		
x_2	0,5	1	0	0,25	0	0	-1	44500	7
y_2	0,5	0	0	-0,25	1	0	0	9500	0
y_3	1	0	0	-0,5	0	1	0	19000	0
x_3	0	0	1	0	0	0	1	18000	12
	-0,5	0	0	1,75	0	0	5	527500	z

Being the only negative value left, the column of x_1 will be taken. Divide the yellow column by the green pivot column (44500: 0.5 = 89000, 9500: 0.5 = 19000, 19000: 1 = 19000, 18000: 0 - cannot be divided). The minimum positive is chosen, in this situation having two equal results, we take the first minimum positive result from the column. Thus y_2 leaves the column and x_1 comes with the coefficient 4.

Table 3.10. Iteration no. 3 - Stage 2

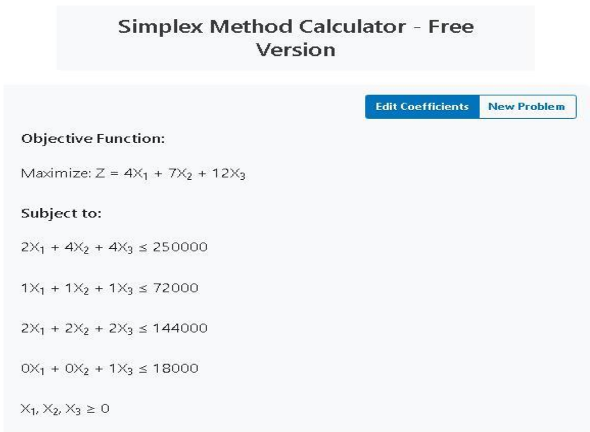
	4	7	12	0	0	0	0		
	x_1	x_2	x_3	y_1	y_2	y_3	y_4		
x_2	0	1	0	0,25	-1	0	-1	35000	7
x_1	1	0	0	-0,5	2	0	0	19000	4
y_3	0	0	0	0	-2	1	0	0	0
x_3	0	0	1	0	0	0	1	18000	12
	0	0	0	1,5	1	0	5	537000	z

The purple row is divided into pivots, ie 0.5, which is circled in Table 3.9. and the values will be entered in Table 3.10. After which the calculations are made for the other cells in the columns that are not colored and are also entered in Table 3.10. The calculations are performed as in Table 3.5. which has equations (17) → (21), only now the pivot is 0.5 instead of 1.

Because there are no more negative values on the last row of table 3.10. the calculation stops and this solution is the optimal one. From the calculation it results that, in order to have the maximum turnover, ie z = 537,000 lei, x_1 = 19000 (pieces), x_2 = 35000 (pieces) and x_3 = 18000 (pieces).

The calculations previously performed by the Simplex method can also be done with the help of a website called "pmcalculators.com", which provides the calculation by the Simplex method.

Below will be presented images with the calculations resulting from this website, in order to compare and verify the correctness of the results obtained from the mathematical calculation.


Simplex Method Calculator - Free Version

Edit Coefficients | New Problem

Objective Function:

Maximize: $Z = 4X_1 + 7X_2 + 12X_3$

Subject to:

$2X_1 + 4X_2 + 4X_3 \le 250000$

$1X_1 + 1X_2 + 1X_3 \le 72000$

$2X_1 + 2X_2 + 2X_3 \le 144000$

$0X_1 + 0X_2 + 1X_3 \le 18000$

$X_1, X_2, X_3 \ge 0$

Fig. 3.1. Objective function and restrictions [4]

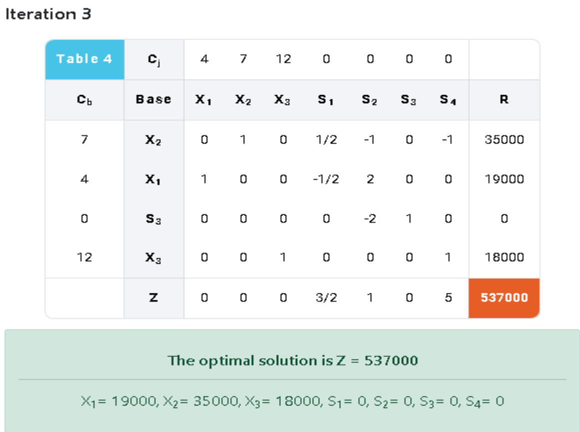

Iteration 3

Table 4	C_j	4	7	12	0	0	0	0	
C_b	Base	X_1	X_2	X_3	S_1	S_2	S_3	S_4	R
7	X_2	0	1	0	1/2	-1	0	-1	35000
4	X_1	1	0	0	-1/2	2	0	0	19000
0	S_3	0	0	0	0	-2	1	0	0
12	X_3	0	0	1	0	0	0	1	18000
	Z	0	0	0	3/2	1	0	5	537000

The optimal solution is Z = 537000

X_1= 19000, X_2= 35000, X_3= 18000, S_1= 0, S_2= 0, S_3= 0, S_4= 0

Fig 3.2. Iteration no. 3 [4]

4. Conclusions

The Simplex method has the advantage of being a versatile method, which can be used to solve any problem, the conditions of which are written in the form of a system of equations and inequalities.

In conclusion, with the help of the Simplex mathematical calculation method, it was possible to diversify the types of KN95 protective masks manufactured and to maximize the turnover at over 530,000 lei for 24 hours of work.

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