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A LINEAR PROGRAMMING MODEL FOR A DIET PROBLEM

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Abstract: *In this paper we solve a diet problem which has the goal to find an optimal combination of proposed foods on the condition that the daily nutritional requirements of a person are satisfied. First of all, we find the nutrient content of our proposed menu which a person generally consumes, throughout an entire day, 1 or 2 portions of some given foods (yogurt, cereals, rye bread , Feta cheese, coffee, chicken soup, baked salmon, boiled potatoes, lemon juice, dry wine, ice with milk and vanilla, spaghetti in tomato sauce with cheese, apple juice). Secondly, we search for quantities of all specified items of the same menu as the diet amount of calories is 2200 Kcal / a day, respectively 2500 Kcal / a day. Finally, we search for quantities of the same proposed menu, using linear programming techniques, as the diet contains minimum amount of calories. The mathematical model of the problem is formulated as a linear program where the objective function is the total amount of calories for the proposed menu, on the condition that the constraints regarding the amounts of protein, vitamins, minerals, fats, dietary fiber consumed throughout an entire day are satisfied. We solve this problem by using the Sover tool in MS Excel and we describe all the steps involved in solving the linear programming model in the context of the menu proposed by us.*

Key Words: *daily nutritional requirements, Solver in MS Excel, mathematical optimization*

Introduction

Linear programming (LP) is a technique for solving optimisation problems which involves the optimization of a linear objective function, subject to the linear equality or inequality constraints of decision variables. A mathematical optimization model consists of an objective function and a set of constraints in the form of a system of equations or inequalities. The process of variable selection requires multiple reiteration before a satisfactory objective function is developed. Linear programming deals with a class of optimization problems, where both the objective function to be optimized and all the constraints, are linear in terms of the decision variables. LP problems are usually solved by the Simplex method, originally developed by Dantzig in 1948, using methods from numerical linear algebra. Linear programming is being successfully applied to problems of design of diets, conservation of resources, economic growth prediction, transportation systems. The first computer-based menu planner, optimizing menu for nutritional adequacy and budgeted food cost was built in 1964 by Balintfy who applied linear programming Techniques [1]. Today there is a variety of software packages to solve optimization problems such as: LINDO, WinQSB, What'sBest for solving nonlinear and linear problems. Also, Microsoft Excel can provide a fast way to solve linear problems, using Solver. In our paper, we propose a computer-based method using the Solver tool from Microsoft Excel for planning an optimal menu with respect to the daily nutritional requirements of a person.

Materials and Methods

A linear programming problem can be defined as a problem of optimizing (*maximizing or minimizing) a linear function subject to linear constraints* [2] . A feasible vector which the objective function gets the value is called optimal. A feasible optimal problem is said to be unbounded if the objective function can assume arbitrarily large positive (resp. negative) values at feasible vectors; otherwise, it is said to be bounded. The value of a bounded feasible minimum (resp, maximum) problem is the minimum (resp. maximum) value of the objective function as the variables range over the constraint set. Any linear program consists of four parts: a set of decision variables, the parameters, the objective function, and a set of constraints. To solve a linear programming problem, we must find an objective function that minimizes, maximizes or achieves a specific goal (a feasibility problem), respectively, while variables satisfy the constraints of the model.

A classical diet problem [3] has to supply the required nutrients at minimum cost, for m different types of food, $F_1, \dots, F_m$, that supply varying quantities of the k nutrients, $n_1, \dots, n_k$, that are essential to good health.

In this paper we replaced the minimum cost of a given diet by a minimum amount of calories. We find the nutrient content of a proposed diet, on the condition that the daily nutritional requirements of a person (the amounts of protein, vitamins, minerals, fats and dietary fiber) are satisfied.

For m different types of food, $F_1, \dots, F_m$, nutrients: $n_1, \dots, n_k$, let c_i be the amount of calories per unit of food F_i, let l_j be the minimum daily requirement of nutrient n_j ; let u_j be the maximum daily *allowance* of nutrient n_j; and let a_{ij} be units of nutrient n_j contained in one unit of food F_i Mathematically, the problem can be stated as follows: if x_i is the number of units of food F_i , then the objective function of this diet is:

$$f(x_1, x_2, \dots, x_m) = c_1 x_1 + c_2 x_2 + \dots + c_m x_m = X^T C \quad (1)$$

where we use the notation: $X = \begin{pmatrix} x_1 & x_2 & \dots & x_m \end{pmatrix}^T$ and $C = \begin{pmatrix} c_1 & c_2 & \dots & c_m \end{pmatrix}^T$

The amount of nutrient n_j contained in this menu is:

$$n_j = a_{1j} x_1 + a_{2j} x_2 + \dots + a_{mj} x_m = X^T \cdot A \quad (2)$$

for $j = 1, \dots, k$, where $A = \begin{pmatrix} a_{11} & \dots & a_{1k} \\ \dots & \dots & \dots \\ a_{m1} & \dots & a_{mk} \end{pmatrix}$ is the matrix of amount of nutrients from the menu.

We may consider the diet if the minimum and respectively the maximum daily requirements are met, as follows:

$$l_j \le a_{1j} x_1 + a_{2j} x_2 + \dots + a_{mj} x_m \le u_j \quad (3)$$

for $j = 1, \dots, k$, where l_j , u_j denote the lower and the upper daily requirements of nutrients. Because we can not have a negative amount of food , ee must have the constraints:

$$x_1 \ge 0, x_2 \ge 0, \dots, x_m \ge 0 \quad (4).$$

Our problem is to minimize the function (1) subject to the constraint (3) and (4) and the goal is to find and compare feasible solutions until no better solution can be found. Solutions are feasible if they satisfy all the problem constraints that are defined by dietary recommendations and guidelines [4].

For the first proposed quantities of the menu, we suppose that a person eat throughout an entire day the following dishes: yogurt made with whole milk, breakfast white cereals, bread of rye, Feta cheese, coffee – espresso, home made chicken soup, baked salmon, boiled potatoes, lemon juice, bread of rye (reduced calorie), dry wine, ice with milk and vanilla (in cone), spaghetti in tomato sauce with cheese, apple juice (bottled). We used a food database USDA national nutrient database for standard reference [4]. For the component of the proposed menu, values of nutrients are listed for: calories, protein, total fat, saturated, cholesterol, carbohydrate, total dietary fiber, some minerals (such as: calcium, iron, potassium and sodium) and vitamins (vitamin A, thiamin, riboflavin, niacin, ascorbic acid and vitamin C). The nutrients of this menu are specified in the Table 1, as follows:

Table 1

Nutrient content of proposed foods [4]

Amount of feeds	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}
Nutrients	Apple juice, bottled	Boiled pota-toes	Bread of rye, reduced calorie	Bread of rye, un-toasted	Breakfast cereals white	Cheese Feta	Chicken soup - home prepared	Coffee - espresso	Dry wine	Ice with milk and vanilla, in cone	Lemon juice	Salmon baked	Spaghetti in tomato sauce with cheese	Yogurt made with whole milk
Calories (kcal)	117	116	47	83	145	75	86	5	130	164	12	184	192	139
Protein (g)	0.01	2	2	3	3	4	6	0.1	0.1	4	0.01	23	6	8
Total fat (g)	0.1	0.1	1	1	0.4	6	3	0.2	0	6	0	9	2	7
Saturated fatty acids (g)	0	0	0.1	0.2	0.1	4.2	0.8	0.1	0	3.5	0	1.6	0.7	4.8
Choles-terol(mg)	0	0	0	0	0	25	7	0	0	28	0	74	8	29
Carbohy-drate (g)	29	27	9	15	31	1	8	1	4	24	4	0	39	11
Total dietary fiber (g)	0.2	2.4	2.8	1.9	0.5	0	0	0	0	0.1	0.2	0	7.8	0
Calcium (mg)	17	11	17	23	0	140	7	1	8	153	3	6	40	274
Iron mg)	0.9	0.4	0.7	0.9	1.5	0.2	0.5	0.1	0.2	0.2	0.001	0.5	2.8	0.1
Potasium (mg)	295	443	23	53	53	18	252	69	95	169	58	319	305	351
Sodium (mg)	7	7	93	211	0	316	343	8	9	92	0,001	56	963	105
Vitamin A(RE)μg	0	0	0	0,1	0	36	0	0	0	52	1	54	58	68
Thiamin (mg)	0.05	0.13	0.14	0.14	0.24	0.04	0.08	0.001	0.02	0.05	0.01	0.18	0.35	0.07
Riboflavin (mg)	0.04	0.03	0.11	0.11	0.15	0.24	0.2	0.11	0.02	0.26	0.001	0.15	0.28	0.32
Niacin (mg)	0.2	1.8	1.2	1.2	2	0.3	3.8	3.1	0.2	0.3	0.001	5.7	4.5	0.2
Ascorbic acid(mg)	2	10	0.001	0.001	0	0	0.001	0.001	0	1	22	0	10	1

Daily Values have been established by the Food and Drug Administration, [4], as references to help consumers use information on food labels to plan a healthy overall diet. Food energy is reported as calories (as a unit of measure for the amount of energy furnished by protein, fat, and carbohydrate). The official unit of measurement for food energy is kilocalories (Kcal). The Daily Values are depending on what we eat: 2200 Kcal / a day or 2500 Kcal / a day.

Table 2

Recommended daily values for fat, sodium and cholesterol for a diet of:
2200 Kcal/ a day or 2500 Kcal / a day [4]

Nr. crt.	Nutrient	Recommended for	Quantity of calories	
			2200 Kcal	2500 Kcal
1	Total fat	Less than	73	80
2	Saturated fat	Less than	22	25
3	Cholesterol	Less than	300	300
4	Sodium	Less than	2400	2400

It is well known that 2,200 Kcal level is for moderately active women (of 20-60 years old), teenager girls, and sedentary men, whereas 2,500 calories is the target level for men (of 20-60 years old), teenager boys and active women. Many older adults, children and sedentary women need fewer than 2,200 calories a day and may want to select target levels based on 1,600 calories a day [4].

Table 3 contains nutritional requirements for a menu of: 2200 Kcal / a day or, respectively, 2500 Kcal / a day

Table 3

Nutrient contents of foods - daily values for: 2000 Kcal or 2500 Kcal [4]

Nr. crt.	Recommended values for	2200 Kcal	2500 Kcal
1	Protein (g)	50	63
2	Carbohydrate (g)	330	375
3	Total dietary fiber (g)	27	30
4	Calcium (mg)	1000	1000
5	Iron (mg)	10	15
6	Potasium (mg)	3500	3500
7	Vitamin A (mg RE*)	800	1000
8	Thiamin (mg)	1.1	1.2
9	Riboflavin (mg)	1.1	1.3
10	Niacin (mg)	14	16
11	Ascorbic acid (mg)	75	90

* Retinol Equivalents

The mathematical model of our proposed diet problem is formulated as a linear program, which has the objective function coresponding to the total amount of calories:

$f(x_1,\ldots,x_{14}) = 117\,x_1 + 116\,x_2 + 47\,x_3 + 83\,x_4 + 145\,x_5 + 75\,x_6 + 86\,x_7 + 5\,x_8 + 130\,x_9 + 164x_{10} + 12x_{11} + 184x_{12} + 192\,x_{13} + 139\,x_{14}$ (5)

At the daily-menu level, there are constraints that need to be satisfied:

Protein (g):

$50 \le 0{,}01.\,x_1 + 2.\,x_2 + 2.\,x_3 + 3.\,x_4 + 3.\,x_5 + 4.\,x_6 + 6.\,x_7 + 0{,}1.\,x_8 + 0{,}1.\,x_9 + 4.\,x_{10} + 0{,}01.\,x_{11} + 23.\,x_{12} + 6.\,x_{13} + 8\,x_{14} \le 65$ (6)

Total fat (g):

$0{,}1\,x_1 + 0{,}1\,x_2 + 1\,x_3 + 1\,x_4 + 0{,}4\,x_5 + 6\,x_6 + 3\,x_7 + 0{,}2\,x_8 + 0\,x_9 + 6\,x_{10} + 0\,x_{11} + 9\,x_{12} + 2\,x_{13} + 7\,x_{14} \le 80$ (7)

Saturated fatty acids (g):

$0.\,x_1 + 0.\,x_2 + 0{,}1.\,x_3 + 0{,}2.\,x_4 + 0{,}1.\,x_5 + 4{,}2.\,x_6 + 0{,}8.\,x_7 + 0{,}1.\,x_8 + 0.\,x_9 + 3{,}5.\,x_{10} + 0.\,x_{11} + 1{,}6.\,x_{12} + 0{,}7.\,x_{13} + 4{,}8\,x_{14} \le 25$ (8)

Cholesterol(mg):

$0.\,x_1 + 0.\,x_2 + 0.\,x_3 + 0.\,x_4 + 0.\,x_5 + 25.\,x_6 + 7.\,x_7 + 0.\,x_8 + 0.\,x_9 + 28.\,x_{10} + 0.\,x_{11} + 74.\,x_{12} + 8.\,x_{13} + 29\,x_{14} \le 300$ (9)

Carbohydrate (g):

$300 \le 29.\,x_1 + 27.\,x_2 + 9.\,x_3 + 15.\,x_4 + 31.\,x_5 + 1.\,x_6 + 8.\,x_7 + 1.\,x_8 + 4.\,x_9 + 24.\,x_{10} + 4.\,x_{11} + 0.\,x_{12} + 39.\,x_{13} + 11\,x_{14} \le 375$ (10)

Total dietary fiber (g) :

$27 \le 0{,}2\,x_1 + 2{,}4\,x_2 + 2{,}8\,x_3 + 1{,}9\,x_4 + 0{,}5\,x_5 + 0.\,x_6 + 0.\,x_7 + 0.\,x_8 + 0.\,x_9 + 0{,}1.\,x_{10} + 0{,}2\,x_{11} + 0.\,x_{12} + 7{,}8.\,x_{13} + 0\,x_{14}$ (11)

Calcium (mg) :

$1000 \le 17.\,x_1 + 11.\,x_2 + 17.\,x_3 + 23.\,x_4 + 0.\,x_5 + 140.\,x_6 + 7.\,x_7 + 1.\,x_8 + 8.\,x_9 + 153.\,x_{10} + 3.\,x_{11} + 6.\,x_{12} + 40.\,x_{13} + 274\,x_{14} \le 1300$ (12)

Iron (mg) :

$10 \le 0{,}9x_1 + 0{,}4x_2 + 0{,}7\,x_3 + 0{,}9\,x_4 + 1{,}5\,x_5 + 0{,}2x_6 + 0{,}5x_7 + 0{,}1\,x_8 + 0{,}2x_9 + 0{,}2\,x_{10} + 0{,}001\,x_{11} + 0{,}5\,x_{12} + 2{,}8\,x_{13} + 0{,}1x_{14} \le 15$ (13)

Potasium (mg) :

$295x_1 + 443x_2 + 23x_3 + 53x_4 + 53x_5 + 18x_6 + 252x_7 + 69x_8 + 95x_9 + 169x_{10} + 58\,x_{11} + 319x_{12} + 305\,x_{13} + 351x_{14} = 3500$ (14)

Sodium (mg) :
$7x_1 + 7x_2 + 93x_3 + 211x_4 + 0.x_5 + 316x_6 + 343x_7 + 8x_8 + 9x_9 + 92x_{10} + 0{,}001.x_{11} + 56x_{12} + 963x_{13} + 105x_{14} \leq 2400$ (15)

Vitamin A (RE) µg:
$800 \leq 0.x_1 + 0.x_2 + 0.x_3 + 0{,}1.x_4 + 0.x_5 + 36.x_6 + 0.x_7 + 0.x_8 + 0.x_9 + 52.x_{10} + 1.x_{11} + 54.x_{12} + 58.x_{13} + 68x_{14}$ (16)

Thiamin (mg) :
$1.1 \leq 0{,}05x_1 + 0{,}13.x_2 + 0{,}14.x_3 + 0{,}14.x_4 + 0{,}24.x_5 + 0{,}04.x_6 + 0{,}08.x_7 + 0{,}001.x_8 + 0{,}02.x_9 + 0{,}05.x_{10} + 0{,}01.x_{11} + 0{,}18.x_{12} + 0{,}35.x_{13} + 0{,}07x_{14} \leq 1{,}4$ (17)

Riboflavin (mg) :
$1.1 \leq 0{,}04.x_1 + 0{,}03.x_2 + 0{,}11.x_3 + 0{,}11.x_4 + 0{,}15.x_5 + 0{,}24.x_6 + 0{,}2.x_7 + 0{,}11.x_8 + 0{,}02.x_9 + 0{,}26.x_{10} + 0{,}001.x_{11} + 0{,}15.x_{12} + 0{,}28.x_{13} + 0{,}32x_{14} \leq 1{,}4$ (18)

Niacin (mg) :
$14 \leq 0{,}2x_1 + 1{,}8x_2 + 1{,}2x_3 + 1{,}2x_4 + 2.x_5 + 0{,}3x_6 + 3{,}8x_7 + 3{,}1x_8 + 0{,}2x_9 + 0{,}3x_{10} + 0{,}001x_{11} + 5{,}7x_{12} + 4{,}5x_{13} + 0{,}2x_{14} \leq 18$ (19)

Ascorbic acid (mg) :
$75 \leq 2.x_1 + 10.x_2 + 0{,}001.x_3 + 0{,}001.x_4 + 0.x_5 + 0.x_6 + 0{,}001.x_7 + 0{,}001.x_8 + 0.x_9 + x_{10} + 22.x_{11} + 0.x_{12} + 10.x_{13} + 1x_{14} \leq 90$ (20)

with $x_1 \geq 0, x_2 \geq 0, \ldots, x_{14} \geq 0$ (21)

where $x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{14}$ are amounts of foods given in the Table 1. The minimum and respectively the maximum daily requirements are given in Table 2 and Table 3 respectively.

To avoid the illogically diet (too much quantity of a type of food), or if we want to have a minimum quantity of a given food, we introduce some more inequalities regarding the maximum amount of some foods: $x_4 \geq 0{,}5$, $x_5 \leq 1$, $x_7 \geq 1$, $x_8 \geq 1$, $x_{10} \leq 2$, $x_{14} \leq 2$. Any specific nutritional requirements can be simply incorporated into the planning and a suitable solution will be computed [5]. The Microsoft Excel spreadsheet data for the problems is shown in Figures 1 for solving the linear programs for the proposed diet problem. The data include the ingredients, the nutrient contents of feed amount (to be solved for) and the ingredient restrictions diet as we can show in the Figure 1:

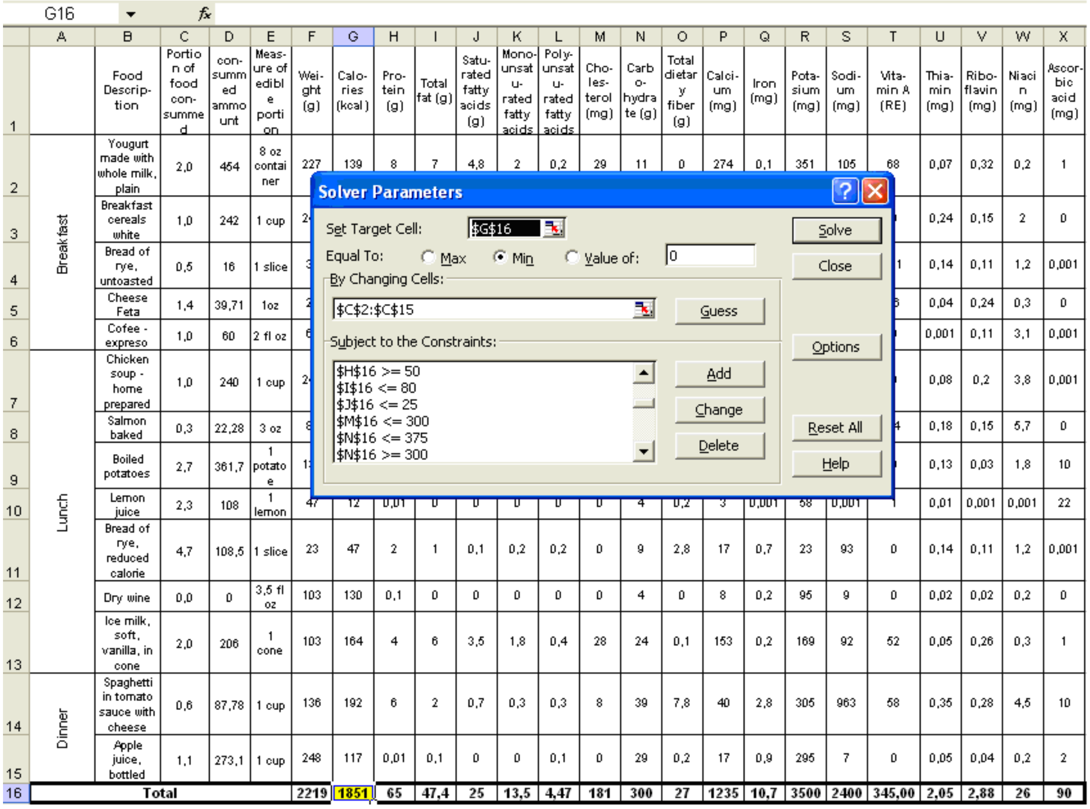

Figure 1. Inputs and results for the diet linear program solved by Solver in Microsoft Excel

Results and Discussion

The mathematical model of the problem is formulated as a linear program where the objective function coresponds to the total amount of calories. At the daily-menu level, there are constraints that need to be satisfied, regarding the amounts of protein, vitamins, minerals, fats, dietary fiber, etc. A linear program Excel workbook was developed using Solver tool.
First of all, we find the nutrient content of our proposed diet, on the condition that a person consumes throughout an entire day 1 or 2 portions of some given foods. In this situation we obtain a diet of 1687Kcal. Secondly, we search for the nutrient composition of the same diet such as the diet amount of calories is 2200 Kcal, respectively 2500 Kcal. To obtain these, we must put in the Solver parameters windows (figure 1) at "value of" the given amount of calories (2200 Kcal and 2500 Kcal, respectively). Thus, Solver tool can find the quantities of every given food so that the constraints are satisfied, on the condition that the total amount of calories is 2000 and respectively 2500 Kcal.
Finally, we search for the quantities of the proposed food, using linear programming techniques, so that the diet contains a minimum amount of calories. The results of determinations regarding numbers of units of portions and consumed amount (g) in these four situations are given in the Table 4 :

Table 4.
Units of portion of food consumed and consumed amount (g) obtained using Solver in MS Excel

Meals	Type of diet=	diet 1 of 1687Kcal		diet 2 of 2200 Kcal		diet 3 of 2500 Kcal		diet 4 of 1851 Kcal	
	Food description	**Units of portion of food consumed**	**Consumed amount (g)**	**Units of portion of food consumed**	**Consumed amount (g)**	**Units of portion of food consumed**	**Consumed amount (g)**	**Units of portion of food consumed**	**Consumed amount (g)**
Breakfast	Yougurt made with whole milk, plain	1.0	227	1.6	357.1	1.8	407.8	2.0	454.0
	Breakfast cereals white	1.0	242	1.8	445.5	2.2	528.9	1.0	242.0
	Bread of rye, untoasted	1.0	32	1.0	32.4	1.1	36.5	0.5	16.0
	Cheese Feta	1.0	28	0.7	20.6	0.7	20.8	1.4	39.7
	Cofee -expreso	1,0	60	1.0	60.7	1.0	61.2	1.0	60.0
Lunch	Chicken soup - home prepared	1.0	240	0.7	177.1	0.8	194.4	1.0	240.0
	Salmon baked	1.0	85	1.9	165.1	2.1	181.9	0.3	22.3
	Boiled potatoes	1.0	135	1.7	223.7	1.9	260.6	2.7	361.7
	Lemon juice	1.0	47	1.1	50.3	1.1	51.6	2.3	108.0
	Bread of rye, reduced calorie	1.0	23	1.1	24.5	1.1	26.4	4.7	108.5
	Dry wine	1.0	103	1.7	178.6	2.0	210.1	0.0	0.0
	Ice milk, soft, vanilla, in cone	1.0	103	1.7	179.9	2.0	209.8	2.0	206.0
Dinner	Spaghetti in tomato sauce with cheese	2.0	272	1.0	132.9	1.0	139.9	0.6	87.8
	Apple juice, bottled	1.0	248	1.7	412.4	1.9	480.8	1.1	273.1

We describe all steps involved in solving the linear programming model in the context of our proposed diet problem, as follows: after setting-up the cell formulas in the spreadsheet, we can use the Solver dialogue box (as you can see in Figure 1). The target cell $G$16 (which contain the total amount of protein from the proposed diet) represents the objective of the linear program. We can adjust the changing cells $C$2:$C$15, which contains the portion of food consumed, to optimize the target cell. Constraints are restrictions that we placed on the changing cells and these are given in subject to constraints. In our model, all changing cells must be nonnegative because the amount produced of each product is nonnegative. After we input all the information in the dialogue boxes, we can press the Solve button to obtain the solution of our diet problem. Solver searches over all feasible solutions and finds the feasible solution that has the "best" target cell value, the smallest for minimum optimization. We find the quantities of food so that the diet has the **minimum** amount of calories which is 1851 Kcal / a day, on the condition that restrictions of the daily nutritional requirements of a person are satisfied.

From the figure 2 to the figure 10 we can observe the variation of the amounts of protein, vitamins, minerals, fats, dietary fiber, depending on the diet type, comparatively to the recommended values for 2200Kcal / a day or 2500 kcal / day, respectively

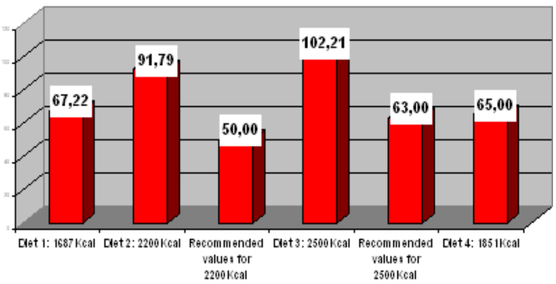

Figure 2. Variation of the quantity of protein (g) depending on the diet type

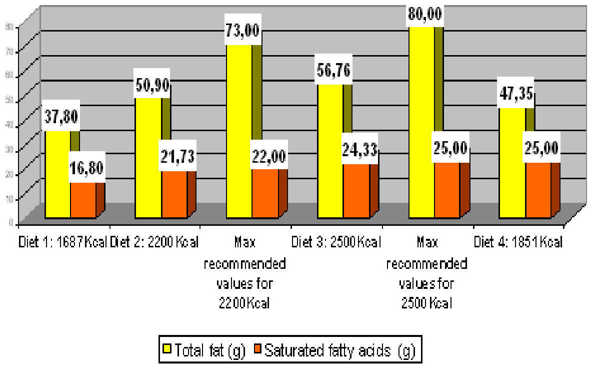

Figure 4. Variation of totally fat quantity (g) and saturated fatty acids (g), depending on the diet type

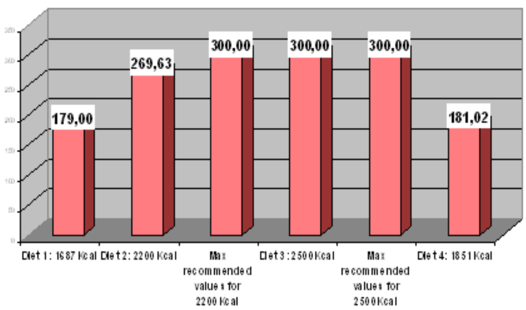

Figure 3. Variation of the quantity of cholesterol (mg) depending on the diet type

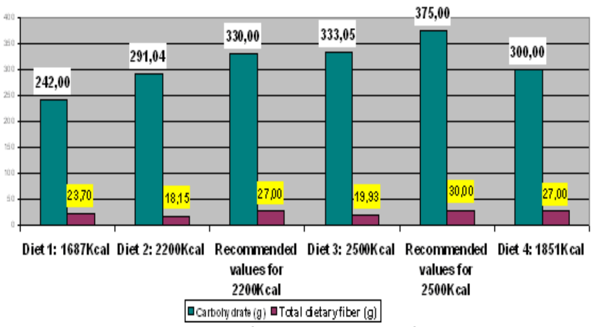

Figure 5. Variation of the quantity of carbohydrate (g) and, respectively, dietary fiber (g), depending on the diet type

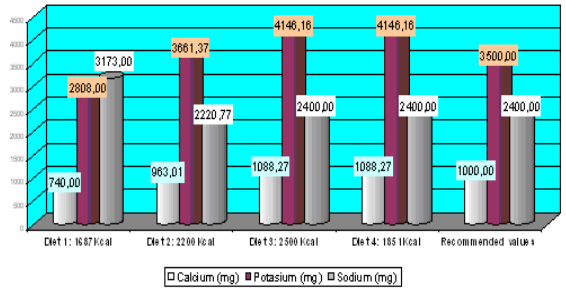

Figure 6. Variation of the quantity of calcium (mg) potasium (mg) and Sodium (mg)

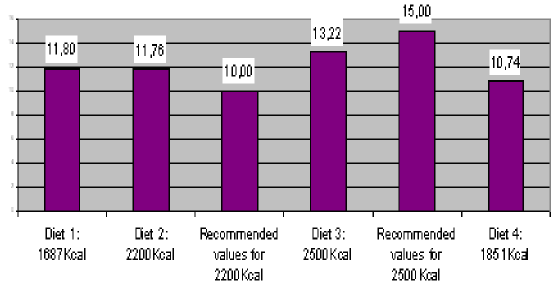

Figure 7. Variation of the quantity of Iron (mg), depending on the diet type

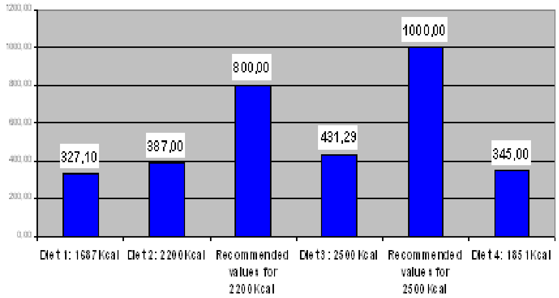

Figure 8. Variation of the quantity of Vitamin A (RE) (μg), depending on the diet type

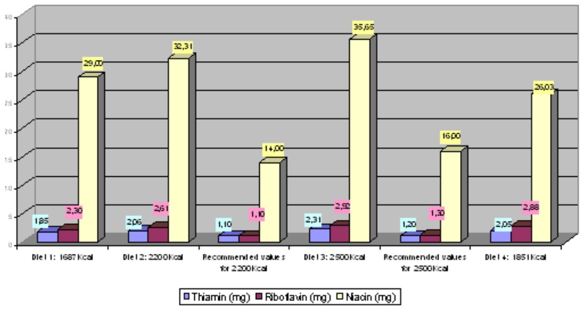

Figure 9. Variation of the amount of thiamin, riboflavin, niacin (mg), depending on the diet type

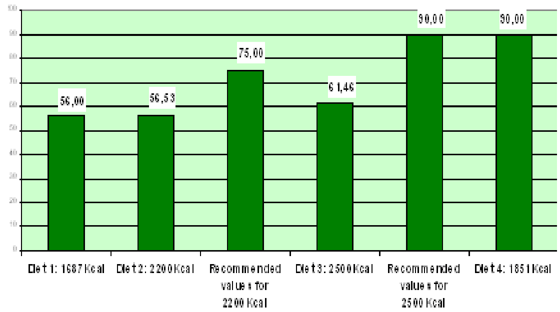

Figure 10. Variation of the amount of ascorbic acid (mg) depending on the diet type

Conclusion

A practical model of a linear programming applied to a dietary situation was constructed. The procedure described was adapted to a diet problem, where the variables are food items, the restrictions are nutritional requirements and the objective function is the amount of calories of the diet. Using Solver in Microsoft Excel we can provide a fast way to solve this diet problem and to observe if the daily nutritional requirements of a person are satisfied.

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