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Applying a Mathematical Model for Linear Programming Using Numerical to Find the Optimal Solution for the Keto Diet

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ABSTRACT: The keto diet is considered one of the high-fat and low-carbohydrate systems with a moderate protein content, which has been proven to be important in treating some diseases such as epilepsy, as well as contributing to weight loss by burning fat. Therefore, in this this paper and by using the linear programming model, provided a novel mathematical methodology for obtaining the lowest cost that takes into account many objectives, the highest percentage of fat and the lowest amount of carbohydrates for men aged 19-50 years by using some important foods in the keto diet. Besides, the multi-objective system was solved by converting it to a single objective function by suggesting a weight for each function by diet specialists in a similar way to the interactive methods of multi-objective linear programming where the results were obtained through the simplex method to provide a high-fat, low-carbohydrate and the lowest cost.

Keywords: A Linear programming, keto diet problem, multi-objective, low-carbohydrate, high-fat, lowest cost.

Contents

1. Introduction

One of the most common and effective ways to achieve a healthy body is to follow a balanced diet accompanied by exercise [1] .There are many diets with multiple objectives in terms of following a diet that helps to lose weight [2] ,a system that stimulates muscle growth [3] , or some systems that help control many diseases such as heart disease [4] , diabetes [5] . The keto diet, which was introduced in the early twenties of the last century, is considered one of the effective alternatives to drugs used in the treatment of some diseases such as obesity or epilepsy, where this diet is represented by the amount of low carbohydrates as well as the percentage of high fats [6], where ketone bodies serve as an important source of energy instead of tissues, fats are converted by the liver into fatty acids and ketone bodies to provide the body with energy [7]. Controlled diabetic research examining whether low-carb diets assist control blood sugar levels have produced conflicting results for both type 1 and type 2 diabetes, despite claims of individual triumphs [8]. It's important to note that extreme calorie restriction has historically been linked to "starvation diabetes." For obvious reasons, human randomized dietary trials are very difficult. Because animals cannot choose to change their diet and are usually restricted to consuming bigger or less amounts of a predetermined macronutrient ratio, animal models offer more experimental control [9]. When blood glucose levels are tracked over several weeks, research on the ketogenic diet in rodents has thus far shown conflicting findings. Hence the role and the need to create models for healthy, balanced diets through which to meet the daily human need for food, it is a practical and theoretical approach to dealing with multi-objective decision-making problems [8,9]. To reduce eating disorders and meet nutritional needs,

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many researchers have proposed balanced diets to avoid chronic diseases such as hypertension, epilepsy, diabetes, and heart attacks. Linear programming plays a crucial role in solving optimization problems by using linear objective functions with a set of linear constraints that may arise in the case of equality or inequality, with the aim of satisfying these constraints by finding the best solutions [2,10]. With the goal of solving optimization and nonlinear system issues to their best potential, researchers have reviewed numerous studies in various scientific fields, including operations research, reliability, and optimization. However, in this paper [13,14], For men between the ages of 31 and 50, a novel ketogenic diet model is introduced. This model makes use of nine approved ketogenic diet meals, all of which contribute to meeting the individual's nutritional demands. In order to arrive at optimal solutions, the suggested model incorporates many objectives, including the lowest cost, lowest carbohydrate content, and highest fat content, in addition to several linear constraints to meet an individual's nutrient requirements [1,11]. The multi-objective system was solved by converting it into a single objective function, with nutritionists proposing a weight for each function, similar to the interactive approaches for multiple linear programming objectives. The results were obtained using the Big M method.

2. Methodology

Here is the diet problem's linear programming model:

$$Minimize \sum_{j=1}^{n} c_j x_j \tag{2.1}$$

Subject to the nutritional constraints,

$$\sum_{j=1}^{n} a_{ij} x_j \geq b_i, \quad \sum_{j=1}^{n} a_{ij} \leq d_i, \quad i = 1, 2, ...m, \quad x_j \geq 0 \tag{2.2}$$

where:

c_j = Food cost $j, j = 1, 2, \ldots, n$,

x_j = The diet's food unit count,

a_{ij} = amount of i^{th} nutrient in food type $j, i = 1, 2, \ldots, m$,

b_i = Daily intake of nutrients i,

d_i = Nutritional maximum daily consumption i,

m = the variety of nutrients,

n = the variety of foods.

3. Data Analysis

The proposed diet consists of nine foods whose dollar prices were collected from grocery stores, plus nine nutrients and daily needs for males aged 31 to 50. In Table 1, you can see the gram weight of the food, the nutrient density per unit of food, the cost of the food, and the daily nutritional needs of a person. The objective is to determine the x_j number that minimizes the diet's total cost while maximizing fat content and decreasing carbohydrate intake.

4. Objective Function

The total formulation of the problem is:

$$Minz_1 = 1x_1 + 0.25x_2 + 1x_3 + 0.15x_4 + 1x_5 + 0.40x_6 + 0.20x_7 + 0.40x_8 + 0.15x_9$$

$$Min_c z_1 = 0x_1 + 0x_2 + 0x_3 + 0.78x_4 + 21.67x_5 + 8.53x_6 + 6.64x_7 + 9.61x_8 + 3.63x_9$$

Table 1: Nutrient requirement per day (males, 19-50 years old).

Nutritional Requirement										
nutrient	Food Items									daily requirement
	100gms of meat	100gms of chicken	100gms of tuna fish	egg 1	100gms of almonds	100gms of avocado	100gms broccoli	100gms berries	100gms of spinach	
Carbohydrate	0	0	0	0.78	21.67	8.53	6.64	9.61	3.63	
Fats	6.77	5.66	1.01	9.94	49.42	14.66	0.37	0.49	0.39	
Vitamin D	0	5	0	50	0	0	0	0	0	600 IU
Protein	19.35	28.29	22	12.57	21.22	2	2.82	1.39	2.86	56 mg
Fiber	0	0	0	0	12.2	6.7	2.6	5.3	2.2	33.6 mg
magnesium	24	24	34	12	268	29	21	20	79	400 mg
Potassium	315	246	407	134	705	485	316	162	558	4700 mg
Calcium	15	12	29	53	264	12	47	29	99	1000 mg
Sodium	82	95	37	140	1	7	33	1	79	1500 mg
Cost in $	1	0.25	1	0.15	1	0.40	0.20	0.40	0.15	minimization

$$Max_f z_3 = 6.77x_1 + 5.66x_2 + 1.01x_3 + 9.94x_4 + 49.42x_5 + 14.66x_6 + 0.37x_7 + 0.49x_8 + 0.39x_9$$

Subject to,

$0x_1 + 5x_2 + 0x_3 + 50x_4 + 0x_5 + 0x_6 + 0x_7 + 0x_8 + 0x_9 \geq 600;$

$0x_1 + 5x_2 + 0x_3 + 50x_4 + 0x_5 + 0x_6 + 0x_7 + 0x_8 + 0x_9 \leq 4000;$

$19.35x_1 + 28.22x_2 + 22x_3 + 12.57x_4 + 21.22x_5 + 2x_6 + 2.82x_7 + 1.39x_8 + 2.86x_9 \geq 56;$

$19.35x_1 + 28.22x_2 + 22x_3 + 12.57x_4 + 21.22x_5 + 2x_6 + 2.82x_7 + 1.39x_8 + 2.86x_9 \leq 172;$

$0x_1 + 0x_2 + 0x_3 + 0x_4 + 12.2x_5 + 6.7x_6 + 2.6x_7 + 5.3x_8 + 2.2x_9 \geq 33.6;$

$0x_1 + 0x_2 + 0x_3 + 0x_4 + 12.2x_5 + 6.7x_6 + 2.6x_7 + 5.3x_8 + 2.2x_9 \leq 70;$

$24x_1 + 24x_2 + 34x_3 + 12x_4 + 268x_5 + 29x_6 + 21x_7 + 20x_8 + 79x_9 \geq 400;$

$24x_1 + 24x_2 + 34x_3 + 12x_4 + 268x_5 + 29x_6 + 21x_7 + 20x_8 + 79x_9 \leq 1200;$

$315x_1 + 246x_2 + 407x_3 + 134x_4 + 705x_5 + 485x_6 + 316x_7 + 162x_8 + 558x_9 \geq 4700;$

$15x_1 + 12x_2 + 29x_3 + 53x_4 + 264x_5 + 12x_6 + 47x_7 + 29x_8 + 99x_9 \geq 1000;$

$15x_1 + 12x_2 + 29x_3 + 53x_4 + 264x_5 + 12x_6 + 47x_7 + 29x_8 + 99x_9 \leq 2500;$

$82x_1 + 95x_2 + 37x_3 + 140x_4 + 1x_5 + 7x_6 + 33x_7 + 1x_8 + 79x_9 \geq 1500;$

$82x_1 + 95x_2 + 37x_3 + 140x_4 + 1x_5 + 7x_6 + 33x_7 + 1x_8 + 79x_9 \leq 2300;$

$x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9 \geq 0$

Where:

$Minz_1 =$ suggest the most affordable option,

$Min_c z_2 =$ stands for the lowest carbohydrate content,

$Max_f z_3 =$ represents the largest amount of fat.

Now by using weaknesses weighted- sums method (interactive method), a weight is assigned to each objective function, where the functions are combined to build one objective function, knowing that the sum of the weights is equal to one, and therefore the proposed improvement model will be converted to the following optimization formula:

$$Min\ z_4 = w_1 z_1 + w_2 z_2 - w_3 z_3, \tag{4.1}$$

such that

$$\sum_{i=1}^{3} w_i = 1, \quad 0 \leq w_i \leq 1, \tag{4.2}$$

with above constraints.

Where, w_i = the weight of objective function $z_i, i = 1, 2, 3$. By suggesting a weight for each function by diet specialists where $w_1 = 0.4, w_2 = 0.3, w_3 = 0.3$, so the mathematical model will be as follows:

$Minz_4 = 0.4(1x_1 + 0.25x_2 + 1x_3 + 0.15x_4 + 1x_5 + 0.40x_6 + 0.20x_7 + 0.40x_8 + 0.15x_9) + 0.3(0x_1 + 0x_2 + 0x_3 + 0.78x_4 + 21.67x_5 + 8.53x_6 + 6.64x_7 + 9.61x_8 + 3.63x_9) - 0.3(6.77x_1 + 5.66x_2 + 1.01x_3 + 9.94x_4 + 49.42x_5 + 14.66x_6 + 0.37x_7 + 0.49x_8 + 0.39x_9) = -1.631x_1 - 1.598x_2 + 0.097x_3 - 2.688x_4 - 7.925x_5 - 1.679x_6 + 1.961x_7 + 2.896x_8 + 1.032x_9$

Subject to,

$0x_1 + 5x_2 + 0x_3 + 50x_4 + 0x_5 + 0x_6 + 0x_7 + 0x_8 + 0x_9 \geq 600;$

$0x_1 + 5x_2 + 0x_3 + 50x_4 + 0x_5 + 0x_6 + 0x_7 + 0x_8 + 0x_9 \leq 4000;$

$19.35x_1 + 28.22x_2 + 22x_3 + 12.57x_4 + 21.22x_5 + 2x_6 + 2.82x_7 + 1.39x_8 + 2.86x_9 \geq 56;$

$19.35x_1 + 28.22x_2 + 22x_3 + 12.57x_4 + 21.22x_5 + 2x_6 + 2.82x_7 + 1.39x_8 + 2.86x_9 \leq 172;$

$0x_1 + 0x_2 + 0x_3 + 0x_4 + 12.2x_5 + 6.7x_6 + 2.6x_7 + 5.3x_8 + 2.2x_9 \geq 33.6;$

$0x_1 + 0x_2 + 0x_3 + 0x_4 + 12.2x_5 + 6.7x_6 + 2.6x_7 + 5.3x_8 + 2.2x_9 \leq 70;$

$24x_1 + 24x_2 + 34x_3 + 12x_4 + 268x_5 + 29x_6 + 21x_7 + 20x_8 + 79x_9 \geq 400;$

$24x_1 + 24x_2 + 34x_3 + 12x_4 + 268x_5 + 29x_6 + 21x_7 + 20x_8 + 79x_9 \leq 1200;$

$315x_1 + 246x_2 + 407x_3 + 134x_4 + 705x_5 + 485x_6 + 316x_7 + 162x_8 + 558x_9 \geq 4700;$

$15x_1 + 12x_2 + 29x_3 + 53x_4 + 264x_5 + 12x_6 + 47x_7 + 29x_8 + 99x_9 \geq 1000;$

$15x_1 + 12x_2 + 29x_3 + 53x_4 + 264x_5 + 12x_6 + 47x_7 + 29x_8 + 99x_9 \leq 2500;$

$82x_1 + 95x_2 + 37x_3 + 140x_4 + 1x_5 + 7x_6 + 33x_7 + 1x_8 + 79x_9 \geq 1500;$

$82x_1 + 95x_2 + 37x_3 + 140x_4 + 1x_5 + 7x_6 + 33x_7 + 1x_8 + 79x_9 \leq 2300;$

$x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9 \geq 0$

5. Results and Discussion

The model above contains 9 variables and 13 constraints, a solution to this problem was found by applying the Big M approach, where:
$Minz_4 = 40.076$,
$Minz_1 = 4.811$,
$Min_c z_2 = 74.82g$,
$Max_f z_3 = 214.82g$,
with balanced diet consisting of:

- 12 of eggs per day.
- 644 gms of avocado per day.
- 290 gms of spinach per day.

6. Conclusion

The goal of developing the mathematical model that was given was to lower the overall cost and obtain the least amount of carbohydrates and the highest percentage of healthy fat according to the diet problem presented in the form of the multi-objective linear programming model by using the samples of important foods in the keto diet that helping in losing the weight as well as treating seizures epilepsy and other diseases, knowing that it is possible to make some modifications in the model by replacing some foods and obtaining the desired goals.

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