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Hospital Patient's Menu Planning Using Linear Programming in Tegucigalpa, Honduras

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Abstract - Currently, the "Hospital Escuela Universitario in Tegucigalpa" faces budgetary constraints that compel it to offer a single menu for all hospital patients, regardless of their medical condition. In response to the situation, this research aimed to reduce food procurement costs while maintaining adequate nutrition by implementing a weekly menu at the hospital, utilizing operations research, specifically employing linear programming. The study was conducted with a quantitative approach, utilizing interviews and literature review as primary instruments. These instruments were crucial in understanding the hospital's current situation, and based on evidence gathered from various sources, it was decided to adopt the Mediterranean Diet as the standard for all patients. From this analysis, research variables, parameters, decision variables, and constraints were defined to formulate the mathematical model used in the study. Using the OpenSolver tool, three distinct mathematical models were generated. Each model helped identify errors and needs that required the addition of new constraints or the incorporation of additional nutritional recommendations. These decisions were supported by experts in linear programming and healthcare. It was determined that the final model is the most suitable for addressing the current needs of the hospital, as it aligns with the recommendations of the Mediterranean diet and daily nutritional requirements. The proposed menu cost is L. 389.03, deemed a viable solution since the included foods are currently available in the hospital's inventory. The mathematical model is considered flexible and adaptable, allowing for the inclusion of new constraints and data updates, thus paving the way for future projects such as the creation of customized menus for different medical conditions.

***Keywords*:** Linear programming, Hospital patients, weekly menu, Opensolver, nutritional recommendations, mediterranean diet.

1. Introduction

Menu planning in any hospital setting is a task that involves several aspects, such as nutritional needs, individual dietary restrictions, resources available in the hospital, and any budgetary limitations that may exist. The use of linear programming can optimize the menu development process, minimizing costs, and ensure a nutritionally balanced meal. By applying linear programming to the menu planning at the hospital, the aim is to accurately model dietary restrictions, cultural preferences, and hospital budget constraints, creating a mathematical model providing nutrition effective menus. This research not only aims to fulfill the nutritional requirements of a patient, but also to achieve a reduction in costs.

Currently, the hospital designs menus for patients in a cyclical manner, where each area of the hospital sends a daily list to determine the number of patients within the hospital. Due to budgetary limitations, the hospital provides the same menu for all patients, without considering specific pathologies and needs. Therefore, the proposal is to suggest a menu based on a Mediterranean diet. This decision is based in the fact that the Mediterranean diet is considered one of the most scientifically supported dietary models in terms of its benefits. The scientific community's interest has grown due to research of the diet's preventive and therapeutic role in various diseases such as cardiovascular, neurodegenerative, diabetes, and cancer, as indicated in [1].

Linear programming is a mathematical technique used to optimize the performance of a system subject to certain constraints. It focuses on maximizing or minimizing a linear function of multiple variables, known as the objective function, subject to a set of linear constraints [2]. Different researchers have conducted scientific articles related to the use of linear programming to reduce costs in menus while considering nutritional aspects. For example, in Argentina, a study [3] similar to the present article was conducted, where linear programming was used to plan a menu while minimizing costs, covering lunches, dinners, and snacks without neglecting the nutritional standards recommended by international organizations, achieving cost reductions of up to 25% [3].

Another related scientific article was one in Tegucigalpa, Honduras, the investigation uses linear programming to fulfill nutritional requirements considering only the foods from the country's basic basket. The objective was to create a combination of available foods from the basic basket to nutritionally satisfy a family's needs. Three models with different constraints were created, and the optimal solution selected 33% of the foods from the basic basket, while another model showed that for a family of four members, the basket is not viable [4]. Another example, in the country of Peru, a dietary plan for children was created using linear programming, as the Cajamarca region had the second-highest rate of malnutrition. Mathematical models were applied to determine the diets for children under 5 years old [5].

The present research consists of important sections. There is the methodology section where the scope, type of research, variables, and the population under investigation are explained. Also, a results section displaying all the variables, constraints, the objective function, and the explanation of the three different mathematical models with their respective outcomes. Furthermore, the conclusions of the scientific article are included, with insights from the research. Therefore, the project's main objective is to minimize the costs incurred in purchasing food for the weekly menus at the "Hospital Escuela Universitario in Tegucigalpa", considering nutritional requirements through an operations research model.

2. Methodology

2.1. Investigation Approach

A quantitative approach converts research questions into variables, which are subjected to a tool, measured, analyzed, and finally, the research is concluded [6]. Therefore, this research was carried out by adopting a quantitative perspective, as industrial engineering techniques were employed to achieve the research's objectives. Additionally, the scope of the research is analytical, as the purpose of the study is to understand the relationship between food costs, types of food, and the nutritional requirements of the hospital's general diet. Furthermore, these variables are selected because they can be objectively and quantifiably measured, which is one of the characteristics of correlational scope.

2.2. Variables

2.2.1. Independent Variables

Within the independent variables identified in the project, the following stand out: available food, the seven days of the cyclical menu, mealtimes, and the maximum and minimum values of daily nutrients per person.

2.2.3. Dependent Variables

Within the dependent variables, the following are included: nutritional attributes: and food prices.

2.3. Techniques and Instruments

Within the Instruments utilized in the article, two were employed. The first was the interviews. A structured interview format was conducted to gather information regarding the hospital's menu planning, applying it to the Head of Nutrition of the hospital. These interviews were crucial in defining the variables and constraints of the mathematical model. It is a instrument widely employed in the field of operations research. For example, interviews were utilized in a project applying linear programming to gather crucial information about the expenses faced by a national production company in Peru with the aim of minimizing costs, as mentioned in [7]. The second instrument was literature review. The literature review was essential in establishing the recommendations of the Mediterranean diet within the model.

On the other hand, some tools were highlighted. Microsoft Excel was used to perform tasks related to data analysis and manipulation, as well as for table creation. Linear programming was the mathematical technique used to minimize the objective function, subject to a set of linear constraints, and finally, OpenSolver was used, being the only linear programming software or tool utilized in the research. OpenSolver is a widely used tool in linear programming problems. For example, in Honduras, a linear programming model was developed using the OpenSolver tool with the aim of scheduling the timetables for all grades in an educational center, considering teachers, subjects, available schedules, among other parameters [8].

3. Results and Analysis

3.1. Data Collection for Variable Definition through Interviews and Literature Review

The variables were defined through a nomenclature method determined by the researcher, where interviews were used to obtain the necessary information and thus determine the variables. Below is the nomenclature of the variables:

Table 1: Nomenclature

Description	Index
Available Food	For all *i* = (1, 2, 3, … 57) Set of foods *i* belonging to subset Ta, which represents the available food for each type: T1 (energy free) = {1} T2 (sugar free) = {2, 3} T3 (grains) = {4, …, 10} T4 (bread or tortillas) = {11, 12} T5 (fruits) = {13, …, 24} T6 (dairy) = {25, …, 31} T7 (legumes) = {32, 33} T8 (eggs) = {34, 35, 36} T9 (red meats) = {37, 38} T10 (fish) = {39} T11 (white meats) = {40, 41} T12 (vegetables) = {42, …, 56} T13 (potatoes) = {57}
Mealtime	For all *j* (1, 2, 3) where 1 represents breakfast, 2 lunch, and 3 dinner.
Menu days	For all *k*= (1,2,3,4,5,6,7) representing the 7 days of the cyclical menu.
Nutritional requirements	For all *l*= (1,2,3,4,5,6,7,8,9,10) representing the daily recommendations to be met

To determine the recommended portion sizes according to food groups and the recommended grams per portion, it is essential to refer to [9]. It is important to highlight that only the foods available within the hospital are considered, making this proposal an adaptation of the Mediterranean diet. As mentioned by[10], the implementation of the Mediterranean diet in hospitals is an innovative concept that eliminates the need for excessive spending on food. This diet provides a wide variety of micronutrients and macronutrients necessary for patients, below you can see the recommendations:

Table 2: Recommendations of the Mediterranean Diet

Type of food	Minimum	Maximum	Frequency	Recommended Grams per Serving
Sugar Free	0	2	Weekly	20
Grain	1	2	Daily	60
Bread or Tortillas	1	2	Daily	40
Fruits	1	2	Daily	120
Legumes	2	N / A	Weekly	60

Eggs	2	4	Weekly	50
Dairy	1	2	Daily	50
White Meat	2	3	Weekly	125
Red Meat	0	2	Weekly	100
Fish	2	N / A	Weekly	100
Vegetables	2	N / A	Daily	150
Potatoes	0	3	Weekly	150

Through the interview, the researcher was able to obtain a list of all the foods currently available at the hospital, along with their prices and amounts. For the sake of the research, all units were converted to grams, as the recommendations of the Mediterranean diet are based on the same measure unit. The prices of some foods are presented below:

Table 3: Prices of Foods According to the Recommended Serving

Food	**Price according to recommended grams per serving in Lempiras**	**Food**	**Price according to recommended grams per serving in Lempiras**
Jelly	3.20	Pineapple	2.10
Precooked rice	1.81	Semidry cheese	7.94
Corn tortillas	1.00	Red dried beans	2.58
Avocado	9.60	Fish fillet	22.05
Ripe plantain	6.00	Carrot	3.97

When it comes to nutrients, it's important to refer to the dietary recommendations made by [11]. Nutrients are vital for the functioning of the human body; establishing ranges help prevent deficiencies or nutritional excesses that can lead to health problems. Furthermore, in the hospital setting, meeting nutritional ranges helps patients because adequate amounts can help accelerate recovery and prevent health complications [12]. It is worth mentioning that the nutritional characteristics of each food were determined in accordance with the findings of authors [13] and [14]. Below are the nutritional ranges:

Table 4: Daily Nutrients Recommendation

Nutrient	**Min**	**Max**
Energy (Kcal)	1900	2600
Protein (g)	60	70
Carbohydrates (g)	200	400
Fiber (g)	12	35
Lipids (g)	30	70
Calcium (mg)	400	2500
Phosphorus (mg)	300	700
Iron (mg)	4.5	12.6
Sodium (mg)	130	2000
Potasssium (mg)	470	N/A

After obtaining all the information through interviews and literature review, it is possible to determine the necessary known values and decision variable for solving the model:

Table 5: Parameters or Known Values

Ci	Cost of food portions for food item i.
Nil	Quantity of nutrients l for each portion of food item i.
Cmax$l$	Maximum quantity of nutrients l per day.
Cmin$l$	Minimum quantity of nutrients l per day.
Pmax$i$	Maximum portions of food types i in the model.
Pmin$i$	Minimum portions of food types i in the model.
Pdmax$i$	Maximum daily portions of food types i.
Pdmin$i$	Minimum daily portions of food types i.

Table 6: Decision Variable

Xijk	Variable indicating if the patient consumes one portion of food item i at mealtime j on day k of the weekly menu.

Subsequently, the objective function of the research was defined, which aims to minimize the costs of the hospital's weekly menu. The objective function is expressed as a sum, where it iterates over various indices, multiplying the decision variable Xijk by the coefficients Ci representing the costs of the foods per recommended grams. Z represents the objective function that is intended to be minimized, and the equation is shown below:

$$Min\ z = \sum_{i=1}^{57}\sum_{j=1}^{3}\sum_{k=1}^{7} Xijk\ \times Ci \tag{1}$$

3.2. Data Collection for Variable Definition Through Interviews and Literature Review

Like the process used to define the variables, the methodology of literature review has been employed to establish the constraints associated with the Mediterranean diet. Below, the equations representing these dietary constraints are presented, using the parameters of table 5:

$$\sum_{j=1}^{3}\sum_{k=1}^{7} Xijk\ \geq Pmini;\ \forall\ \ i \in Ta; where\ a = \{2, 6, 7, 9, 10, 11, 13\} \tag{2}$$

$$\sum_{j=1}^{3}\sum_{k=1}^{7} Xijk\ \leq Pmini;\ \forall\ \ i \in Ta; where\ a = \{2, 6, 7, 9, 10, 11, 13\} \tag{3}$$

$$\sum_{j=1}^{3}\sum_{k=1}^{7} Xijk\ \geq Pdmini;\ \forall\ \ i \in Ta; where\ a = \{1, 3, 4, 5\ ,8\ ,12\} \tag{4}$$

$$\sum_{j=1}^{3}\sum_{k=1}^{7} Xijk\ \leq Pdmaxi;\ \forall\ \ i \in Ta; where\ a = \{1, 3, 4, 5\ ,8\ ,12\} \tag{5}$$

$$\sum_{i=1}^{57}\sum_{j=1}^{3}\sum_{k=1}^{\mathbf{7}} Xijk * Nil\ \geq\ Cminl;\ \forall\, l = \{1, 2, 3, \dots, 10\} \tag{6}$$

$$\sum_{i=1}^{57}\sum_{j=1}^{3}\sum_{k=1}^{\mathbf{7}} Xijk * Nil\ \leq\ Cmaxl;\ \forall\, l = \{1, 2, 3, \dots, 10\} \tag{7}$$

$$Xijk = bin \tag{8}$$

3.3. Solution of the Mathematical Models
3.3.1. Solution of the First Model

After defining variables, parameters, indices, and constraints, a mathematical model was created in Excel using OpenSolver. However, the obtained solution did not meet the constraints due to restrictive conditions caused by constraint number 7, which sets maximum daily nutrient values. It was decided to address this issue by creating a second model.

3.3.2. Solution of the Second Model

After identifying the incompatible condition between constraints, it was decided to prioritize the Mediterranean diet constraints over the nutritional ranges. Therefore, it was decided to be flexible and not consider the maximum ranges, but only the minimum ones. After obtaining the results from the model, it was possible to meet all the recommendations of the Mediterranean diet, as well as the minimum ranges of the nutritional attributes. The weekly menu value per patient is L. 319.83. The results of the mathematical model are presented below.

	Day1	Day2	Day3	Day4	Day5	Day6	Day7
Breakfast	Precooked rice	Precooked rice	Precooked rice	Corn tortillas	Precooked rice	Corn tortillas	Corn tortillas
	Corn tortillas	Corn tortillas	Corn tortillas	Pineapple	Corn Tortillas	Pineapple	Semidry Cheese
	Pineapple	Red dried beans	Red dried beans	Red dried beans	Red dried beans	Red dried beans	Red dried beans
	Red dried beans	Chicken	Green beans	Green beans		Green beans	
	Fish fillet					Scrambled eggs	
	Cabbage						
Lunch	Corn tortillas	Precooked rice	Corn tortillas	Precooked rice	Precooked rice	Precooked rice	Precooked rice
	Quesillo	Corn tortillas	Quesillo	Corn tortillas	Semidry Cheese	Corn tortillas	Corn tortillas
	Red dried beans	Red dried beans	Red dried beans	Quesillo	Red dried beans	Semidry cheese	Semidry Cheese
	Chicken	Green beans	Green beans	Red dried beans	Green beans	Red dried beans	Red dried beans
	Cabbage	Cabbage	Scrambled eggs	Green beans	cabbage	Green beans	Green beans
			Cabbage	Chicken		Cabbage	Cabbage
				Cabbage			
Dinner	Precooked rice	Pineapple	Precooked rice	Precooked rice	Corn Tortillas	Precooked rice	Precooked rice
	Red dried beans	Quesillo	Pineapple	Red dried beans	Pineapple	Red dried beans	Pineapple
	Fish fillet	Red dried beans	Red dried beans	Cabbage	Semidry Cheese	Green beans	Red dried beans
		Green beans	Green beans		Red dried beans	Cabbage	Green beans
		Cabbage	Scrambled eggs		Green beans		Cabbage
			Cabbage		cabbage		

Fig. 1: Weekly Menu - Second Model

Considering these results, it has been decided to propose a third mathematical model. The objective is to avoid excessive repetition of meals and ensure compliance with other constraints provided by advisors, such as avoiding certain foods at specific times and making changes to nutritional ranges. The changes to the nutritional ranges were evaluated based on an expert opinion, due to elevated values in the results of the second model, so it was decided to use the maximum range for protein, phosphorus, and iron from the research [3], as well as the minimum range for energy. The new constraints are presented below:

$$\sum_{i=37}^{41} \sum_{j=1}^{1} \sum_{k=1}^{7} Xijk = 0 \tag{9}$$

$$\sum_{i=34}^{36} \sum_{j=2}^{2} \sum_{k=1}^{7} Xijk = 0 \tag{10}$$

$$\sum_{i=31}^{25} \sum_{j=2}^{2} \sum_{k=1}^{7} Xijk = 0 \tag{11}$$

$$\sum_{i=32}^{33} Xijk \leq 1;\ \forall\, j = \{1, 2, 3\};\ \forall\, k = \{1, 2,3, \dots ,7\} \tag{12}$$

$$\sum_{j=1}^{3}\sum_{k=1}^{7} Xijk \leq 3;\ \forall\ i\ = \{42, 43, 44, \dots, 56\} \tag{13}$$

$$\sum_{j=1}^{3}\sum_{k=1}^{7} Xijk \leq 3;\ \forall\ i\ = \{13, 14, 15, \dots, 24\} \tag{14}$$

$$\sum_{i=37}^{41}\sum_{j=2}^{2}\sum_{k=1}^{7} Xijk \geq 1 \tag{15}$$

3.3.3. Solution of the Third Model

	Day1	Day2	Day3	Day4	Day5	Day6	Day7
Breakfast	Corn tortillas	Corn tortillas	Coffee	Coffee	Coffee	Precooked rice	Corn tortillas
	Pineapple	Pineapple	Precooked rice	Corn tortillas	Precooked rice	Banana	Avocado
	Scrambled eggs	Quesillo	Red dried beans	Banana	Corn Tortillas	Quesillo	Quesillo
	Cabbage	Red dried beans	Orange	Quesillo	Red dried beans	Scrambled eggs	Red dried beans
			Beet				
Lunch	Precooked Rice	Precooked rice	Jelly	Precooked rice	Precooked rice	Jelly	Precooked rice
	Beef steak	Corn tortillas	Precooked rice	Corn tortillas	Corn Tortillas	Corn tortillas	Corn tortillas
	Cabbage	Pineapple	Ripe Plantain	Chicken	Avocado	Avocado	Fish fillet
	Potatoes	Beef steak	Chicken	Potatoes	Chicken ham	Fish fillet	Onion
						Carrot	
Dinner	Precooked Rice	Precooked rice	Corn tortillas	Precooked rice	Banana	Precooked rice	Precooked rice
	Corn tortillas	Red dried beans	Quesillo	Ripe Plantain	Quesillo	Corn tortillas	Ripe plantain
	Orange	Cabbage	Sweet potato	Onion	Carrot	Red dried beans	Green Beans
	Quesillo	Carrot	Potatoes	Sweet Potatoes	Sweet Potatoes	Onion	Beet
	Red dried beans						

Fig. 3: Weekly Menu – Third Model

	Energy (kcal)	Prottein (g)	Lipids (g)	Carbohydrates (g)	Fiber (g)	Calcium (mg)	Phosphorus (mg)	Iron (mg)	Potassium (mg)	Sodium (mg)
Day1	1603.7	68.2	42.9	241.1	26.7	531.0	747.8	25.5	2305.2	426.3
Day2	1603.6	69.9	34.9	257.3	34.2	447.3	801.1	18.9	2533.2	375.5
Day3	1610.7	67.3	32.5	282.0	19.9	431.5	711.0	22.0	2686.6	495.2
Day4	1605.8	67.4	32.8	279.5	19.8	405.5	718.8	21.9	2643.4	388.7
Day5	1615.3	66.7	42.7	251.2	33.8	433.6	856.8	15.4	2954.7	1078.0
Day6	1622.5	68.9	42.7	248.6	30.2	418.3	956.8	16.4	2946.5	492.5
Day7	1606.4	69.5	34.9	275.8	28.2	400.4	988.8	18.3	3136.4	406.6

Fig. 4: Nutritional Values of the Weekly Menu - Third Model

The result provided by OpenSolver for the third model meets all the constraints established earlier, presenting a price of L. 389.03 per person weekly and L. 350,127 for 900 patients per week. Although it is the highest price among the evaluated models, it is the only one that meets the minimum and maximum ranges of nutritional attributes and meets all the recommendations of the Mediterranean Diet. It is important to note that OpenSolver did not produce an optimal result on this occasion. This is because a time limit was set due to the prolonged duration it took for the model to provide responses. However, a health expert pointed out that this model is the most suitable for meeting the established constraints, so its use is suggested.

3.4. Expert Triangulation Validation

Triangulation validation is a powerful tool or technique that facilitates the analysis of multiple approaches with the aim of validating data through various sources. In triangulation validation, it is important to analyze data from diverse sources, researchers, fieldwork, theory, and methodologies that are related to the object of study. [15]. During the research, a review of the proper functioning of the mathematical model was conducted with three advisors specialized in linear programming, ensuring the coherence of the results obtained. Additionally, consultation was made with an expert in the field of health, who confirmed that the results were consistent and appropriate in terms of health.

4. Conclusions

Interviews with key staff have allowed us to identify the current situation of the hospital and the fundamental variables that must be considered in the linear programming model for meal planning at the Teaching Hospital. The variable that exerts the greatest influence in the mathematical model is the availability of food or the index i. The influence of the index *i* lies in the fact that the values of this variable directly affect the menu prices, the number of nutrients the menu contains, and it is included in all model constraints.

After conducting the interviews, it was determined that there is a need to establish a general diet for all hospital patients. Therefore, following the use of literature review as a methodological tool, the decision was made to adopt the Mediterranean diet as the hospital's general diet. This choice entailed the need to consider the specific recommendations of this diet as constraints in the model. The restrictions on varieties of foods to be consumed daily or weekly became the key constraints to ensure compliance with the principles of the Mediterranean diet. After evaluating the models, it has been determined that model number three, with a cost of L. 389.03, is the one that best meets all the constraints of the model. Although this model may not be optimal, it is a feasible solution for the hospital, as all proposed foods are available within its inventories, and the menu follows the dietary pattern of an adapted Mediterranean diet, a diet supported by the scientific community for preventing and treating multiple diseases.

The research highlights the importance of hospitals having a balanced and nutritious menu to improve patients' health. Through interviews and literature review, a mathematical model was proposed using the OpenSolver tool. The model results were validated by experts in operations research and health, confirming its feasibility and suggesting its implementation within the hospital. The use of linear programming is valuable for optimizing problems in a variety of contexts, providing efficient and well-founded solutions that can improve decision-making and resource allocation.

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