Nutrient and Cost Optimization in Menu Planning at an Apex Tertiary Care Hospital Using Operational Research Techniques

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Abstract

Introduction: Menu planning involves meticulous customised designing of nutrients to fulfill the dietetic needs of patients with various clinical profiles admitted in the Hospital. The goal of the diet problem is to select a set of foods that will satisfy a set of daily nutritional requirement of patients at minimum cost. Various tools and techniques of applied simulation models in Operational Research are available to optimize the cost as well as quality of food.

Methodology: The study based on exploratory research design was conducted at Dietetics Department of an apex tertiary care hospital in India. It was based on an exploratory research design. The LPSolve programming language was used to analyse the data and generate the output. Integer Programming determined the most nutritious meals while considering the constraints of the RDA by ICMR. The Nutritive Value of Ingredients per 100 grams was obtained from the Nutritive Value of Indian Foods (2012) published by NIN, ICMR.

A model was formulated using the notations, N for the total number of dishes available, *ci* for the Cost of ith dish, where i = 1,2,3,……N, *xi* for the decision variable, LB for the Lower Bound of nutrition intake, UB for Upper Bound of nutrition intake, n for the Number of dishes required per day and T for the Total types of food, the following equations were used.

Objective Function: Minimize the total cost F, $F = \sum_{i=1}^{N} c_i x_i$

Constraint 1: Daily constraints $LB \leq \sum_{i=1}^{N} Nutrients(x_i) \leq UB_i$; where i=1, 2…….N

Constraint 2: $\sum_{i=1}^{T} Type\ of\ foods(x_i) = n_i$ where i= 1, 2, 3…….T

Results: It was found that the Indian recipes fail to provide the minimum RDA of Vitamin A and Vitamin B6 and therefore, the lower bound had to be reduced significantly for these Vitamins.

Conclusion: The application based on operational research techniques can be further developed to be deployed across different hospitals. This would help to not only to provide the RDA but also ensure that it is done at a lower cost.

Keywords: *Nutrient optimization, Cost Optimization, Menu Planning.*

Introduction

Menu planning involves meticulous customised designing of nutrients to fulfil the dietetic needs of patients with various clinical proiles admitted in the Hospital. The goal of the diet problem is to select a set of foods that will satisfy a set of daily nutritional requirement of patientsat minimum cost[1]. Various

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tools and techniques of applied simulation models in Operational Research are available to optimize the cost as well as quality of food.

In this study, the diet problem has been formulated as a linear program of Operations Research where the objective was to minimize cost and the constraints were to satisfy the specified nutritional requirements in the diet. The diet problem constraint typically regulate the number of calories and the amount of vitamins, minerals, fats, sodium, and cholesterol in the diet[1].

The process of decision making in the Menu Planning is complex. It involves multitude of factors that have to be taken into account while doing the menu planning exercise[2].

The diet problem was one of the first optimization problems studied in the 1930s and 1940s. Early researchers to study the problem was George Stigler, who made an educated guess of an optimal solution using a heuristic method[3].

Operations research is a discipline that deals with the application of advanced analytical method to help make better decisions[4]. It involves techniques from other mathematical sciences, such as mathematical modeling, statistical analysis, and mathematical optimization, operations research arrives at optimal or near-optimal solutions to complex decision-making problems[4].

Linear programming (LP) (also called linear optimization) is a method to achieve the best outcome (such as maximum profit or lowest cost) in a mathematical model whose requirements are represented by linear relationships. Linear programming is a special case of mathematical programming (mathematical optimization)[5].

Need for the Study: Advancement in the field of medicine has increased the chances of survival of patients with a variety of diseases that were considered incurable earlier. The prevalence of malnutrition has been estimated to be as high as 50% among acutely hospitalized adults, depending on the definition employed and the population assessed[6,7,8]. Malnutrition is consistently associated with adverse clinical outcomes, including increased morbidity, mortality, and length of hospital stay as well as reduced quality of life[9,10,11,12]. Various diseases commonly found in patients cause stress on the body and bring about changes in substrate metabolism, thus leading to the deficiency of various nutrients. The incidence of malnutrition is significant in critical, particularly in highrisk patients[13]. It is essential to identify malnourished patients and also patients at increased risk of malnutrition in order to devise a comprehensive nutrition care program. Nutrition societies across the world recommend nutrition screening tools to assess malnutrition in hospitalized patients, such as the Mini Nutritional Assessment (MNS) tool[14]. Chakravarty et alconcluded that almost two-fifth of admitted patients were malnourished in tertiary care hospital and there was an urgent need to develop a comprehensive nutritional care program. A study by Kowanko et al,concluded thatalthough nurses considered nutritional care to be important, many had difficulty in raising its priority above other nursing activities, as a result of time constraints and multitasking issues[15].So, there should be a system for nutritional assessment of all admitted patients and special individualized plan should be set. Reid and Allard-Gould reported that adequate nutritional screening and interventions have been demonstrated to be cost-effective resulting in fewer complications, faster recovery, shorter hospital stays and reduced hospital expenditures[16]. The value of nutrition therapy for the adult hospitalized patient is derived from the outcome benefits and the nutritional assessment should identify those patients at high nutritionalrisk, determined by both disease severity and nutritional status[17]. A NABH standard on Care of Patients (COP.19) talks about the nutritional therapy to be provided to patients consistentlyand collaboratively.[18] Taking into consideration the factors mentioned above this study was conceived

Methodology

The study based on exploratory research design was conducted at dietetics department of an apex tertiary care hospital in India. The LPSolve programming language was used to analyse the data and generate the output. Integer Programming determined the most nutritious meals while considering the constraints of the RDA by ICMR. The Nutritive Value of Ingredients per 100 grams was obtained from the Nutritive Value of Indian Foods (2012) published by NIN, ICMR.

The RDA for Indians as provided by ICMR[19] is given in Table 1 and Table 2 below.

Table 1: Recommended Dietary Allowances for Indians (Macronutrients and Minerals). Source: Dietary Guidelines for Indians– A Manual (2011), National Institute of Nutrition, ICMR

Group	Particulars	Body weight (kg)	Net Energy (kCal/d)	Protein (g/d)	Visible Fat (g/day)	Calcium (mg/d)	Iron (mg/d)
Man	Sedentary work	60	2320	60	25	600	17
	Moderate work		2730		30		
	Heavy work		3490		40		
Woman	Sedentary work	55	1900	55	20	600	21
	Moderate work		2230		25		
	Heavy work		2850		30		
	Pregnant woman		+350	+23	30	1200	35
	Lactation 0-6 months		+600	+19	30	1200	21
	Lactation 6-12 months		+520	+13	30		
Infants	0-6 months	5.4	92 Kcal/kg/d	1.16 g/kg/d	–	500	46 ìg/kg/day
	6-12 months	8.4	80 Kcal/kg/d	1.69 g/kg/d	19		5
Children	1-3 years	12.9	1060	16.7	27	600	9
	4-6 years	18	1350	20.1	25		13
	7-9 years	25.1	1690	29.5	30		16
Boys	10-12 years	34.3	2190	39.9	35	800	21
Girls	10-12 years	35	2010	40.4	35	800	27
Boys	13-15 years	47.6	2750	54.3	45	800	32
Girls	13-15 years	46.6	2330	51.9	40	800	27
Boys	16-17 years	55.4	3020	61.5	50	800	28
Girls	16-17 years	52.1	2440	55.5	35	800	26

Table 2: Recommended Dietary Allowances for Indians (Vitamins). Source: Dietary Guidelines for Indians – A Manual (2011), National Institute of Nutrition, ICMR[19]

Group	Particulars	Vit. A mg/d		Thiamin	Riboflavin	Niacin equivalent	Pyridoxin	Ascorbic acid	Dietary folate	Vit. B12	Magnesium	Zinc
		Retinol	b-carotene	mg/d	mg/d	mg/d	mg/d	mg/d	mg/d	mg/d	mg/d	mg/d
Man	Sedentary work	600	4800	1.2	1.4	16	2	40	200	1	340	12
	Moderate work			1.4	1.6	18						
	Heavy work			1.7	2.1	21						
Woman	Sedentary work	600	4800	1	1.1	12	2	40	200	1	310	10
	Moderate work			1.1	1.3	14						
	Heavy work			1.4	1.7	16						
	Pregnant woman	800	6400	0.2	0.3	2	2.5	60	500	1.2		12
	Lactation 0-6 months	950	7600	0.3	0.4	4	2.5	80	300	1.5		
	Lactation 6-12 months			0.2	0.3	3	2.5					
Infants	0-6 months	--	--	0.2	0.3	710 mg/kg	0.1	25	25	0.2	30	–
	6-12 months	350	2800	0.3	0.4	650 mg/kg	0.4				45	–
Children	1-3 years	400	3200	0.5	0.6	8	0.9	40	80		50	5
	4-6 years			0.7	0.8	11	0.9		100		70	7
	7-9 years	600	4800	0.8	1	13	1.6		120		100	8

Group	Particulars	Vit. A mg/d		Thiamin	Riboflavin	Niacin equivalent	Pyridoxin	Ascorbic acid	Dietary folate	Vit. B12	Magnesium	Zinc
		Retinol	b-carotene	mg/d	mg/d	mg/d	mg/d	mg/d	mg/d	mg/d	mg/d	mg/d
Boys	10-12 years	600	4800	1.1	1.3	15	1.6	40	140	0.2-1.0	120	9
Girls	10-12 years			1	1.2	13	1.6				160	9
Boys	13-15 years			1.4	1.6	16	2	40	150		165	11
Girls	13-15 years			1.2	1.4	14	2				210	11
Boys	16-17 years			1.5	1.8	17	2	40	200		195	12
Girls	16-17 years			1	1.2	14	2				235	12

Model Formulation: The objective of this study was to formulate a menu planning model that minimizes the cost and tries to achieve the maximum nutritional requirement based on the Indian RDA requirements.

Integer Programming was used to determine the most nutritious and palatable meals, while considering the constraints of the RDA, the cost of the menu items, the budget at hand as well as requirement of variety of food items. Various permutations and combinations to optimise the menu in terms of Calories required by patients as well as the efficiency in terms of Cost were put to test.

Notations Used:

N = Total number of dishes available

C_i = Cost of ith dish, where i = 1,2,3,……..N

x_i = decision variable

LB = Lower Bound of nutrition intake

UB = Upper Bound of nutrition intake

n = Number of dishes required per day

T = Total types of food

Objective Function:

Minimize the total cost F,

$$\mathbf{F} = \sum_{i=1}^{N} c_i x_i$$

Constraint 1:

Daily constraints

$$\mathbf{LB} \leq \sum_{i=1}^{N} Nutrients(x_i) \leq \mathbf{UB;}$$ where i = 1, 2, …….N

LB and UB are the vectors, give different value for each nutrient. This is to ensure that we meet the nutrients requirements. The details are shown in Table 3.

Constraint 2:

$$\sum_{i=1}^{T} Type\ of\ foods(x_i) = \mathbf{n;}$$ where i = 1, 2, 3…….T

This constraint makes sure that daily number of dishes/servings required must be fulfilled. The details are given in Table 4.

Data required:

1. **For Objective function:** Cost of each dish/serving in Rupees (C_i): Set to a random number as cost of the ingredients vary fortnightly as per rate list sourced at AIIMS
2. **For Constraint 1:**

Table 3: Data required for constraint 1

Nutrients	Lower Bound (LB)	Upper Bound (UB)	RDA
Energy (Kcal)	2050	2600	2320
Protein (g)	50	100	60
Fat (g)	20	100	25
Calcium (mg)	550	2000	600

Nutrients	Lower Bound (LB)	Upper Bound (UB)	RDA
Iron (mg)	14	30	17
b-carotene (mcg)	600	6000	4800
Thiamine (mg)	1	3	1.2
Riboflavin (mg)	0.5	2	1.4
Niacin (mg)	10	20	16
Pyridoxin (mg)	0	4	2
Ascorbic acid (mg)	30	200	40
Dietary folate (mcg)	150	250	200

3. For Constraint 2:

Table 4: Data required for Constraint 2

Type of food (T)	No. of requirement per day (n)
Breakfast	1
Dal-Vegetables	2
Roti	4
Rice	1
Dessert	1
Beverage	2

Results and Discussion

Outputs: After input of the required parametres, the output in form of an excel sheet was created based different permutations and combinations. The output had menu for the entire week and the nutrient information and cost per day (Table 5).

Table 5: Nutrient and cost information for the planned diet

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Energy (Kcal)	2407.44	2285.36	2448.44	2298.46	2192.43	2054.65	2158.00
Protein (g)	71.96	67.88	50.08	71.59	57.70	69.55	50.69
Fat (g)	70.05	84.59	32.13	96.55	46.03	58.25	97.37
Calcium (mg)	1093.50	1858.90	583.25	822.44	613.16	1318.66	594.55
Iron (mg)	18.79	23.25	18.94	23.54	20.02	19.13	19.62
Carotene (mcg)	640.31	5781.88	641.03	1018.39	741.59	642.04	640.51
Thiamine (mg)	1.49	1.14	1.18	1.59	1.25	1.09	1.36
Riboflavin (mg)	1.16	0.50	0.67	0.61	0.79	0.62	0.76
Niacin (mg)	14.00	10.64	10.99	11.66	13.03	10.24	10.77
Total B6 (mg)	0.14	0	0	0	0.06	0.017	0
Vitamin C (mg)	67.08	90.59	78.57	68.8	56.49	35.82	31.61
Folic Acid (Total) (mcg)	176.12	188.73	152.20	150.04	153.86	157.01	196.05
Price (Rs.)	59.77	94.69	121.86	110.17	126.58	133.60	151.61

The table above shows the nutrient and cost information for the planned diet for a week. The energy requirements are being met on all the days of the week i.e, it falls between the acceptable range of 2050 Kcal to 2600 Kcal. There is a variation in provision of other nutrients over the period of week especially Carotene

availability varies widely from 640.30 mcg to 5781.88 mcg. The result must be read in the ontext of week as a unit for which the menu is planned. If we consider the week as a unit, then the nutrient requirements are generally met as required. In the instances of average length of stay ≤6/7 days, there is scope to counsel the patient to avail the nutrients in home diet. There were certain limitations, though, to meet all the nutritional needs as discussed later in this article.

Traditionally, in resource constrained healthcare institutions, the Dieticians plan the menu manually. The process of manual planning has no or less scope to involve all consummables vis-à-vis its nutrient values and the amount to be used in the end product to be served to the patient keeping the cost in mind.

A better alternative solution is the concept of Constraint Programming thacan be applied to the diet planning system effectively.[20]. Mathematical modeling using linear programming may be applied to problems related to optimized resource allocation in healthcare and could be a useful tool to support decision-making processes in healthcare. [21]

Comparaive research studies of such experimentation on optimizing the Nutrient & Cost of the diet in such a bigger healthcare institution are not found.

The prototype suggested in this study could be further improved. The optimization based on cost and budget can be done and the menu based on the daily budget defined by the user could generate output within the RDA limits. The Machine Learning can be used to provide relaxation to the limits of RDA to make generation of result much easier and faster. Further, Cloud Based Server can keep on updating the data based on the prevalent market price of commodity based on the geographical region and thus tailormade solutions can be derived.

Limitations of the Study:

1. It was found that the Indian recepies fail to provide the minimum RDA of Vitamin A and Vitamin B6 and therefore, the lower bound had to be reducued significantly (Table 3).
2. While ICMR RDA mentions requirements for Retinol, Vitamin B12, Magnesium and Zinc, the data for the ingredients was not available. On the other hand, Crude fiber and Phosphorous related data for the ingredients is there but the RDA requirement is not mentioned. Therefore, these nutrients were kept out of the ambit of the present study.

Conflict of Interest: Nil

Source (s) of Support: Nil

Ethical Clearance: The study was conducted as a dissertation for Master in Hospital Administration.

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