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Application of R Programming in Solution and Sensitivity Analysis of Diet Problem of Indian Men

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Abstract: Diet problem is an application of Linear programming problem (LPP). Linear programming is a technique of Operations Research for determining an optimum schedule of interdependent activities in view of the available resources. The word programming means determining the plan of action from amongst several alternatives and the word linear refers to the fact that the relationships involved are linear. The various nutrients like carbohydrates, proteins, fats, vitamins and minerals in different food items like jawar, rice, milk, beetroot, banana, sesame seeds, etc. are helpful for maintenance, growth, reproduction and health of human beings. R is a widely used programming language and freely available software for statistical computing. This paper is the study of determining the optimum solution and analyzing its sensitivity for diet problem of sedentary and moderate working men in India. We solved this problem by using R programming. In this paper the various food items are taken as decision variables and constraints are designed corresponding to different nutrients. In the construction of constraints we have assumed that any intake of more than the minimum requirement of nutrients is not harmful to the human body. Here the objective is to find the optimum solution that is to find the quantity of food items that should be consumed to minimize the cost of diet which will fulfil the minimum requirement of nutrients for these two types of men.

Keywords: Nutrients, Diet, lpSolveAPI, lpSolve, Reduced cost, Shadow price

1. Introduction

Men need a wide range of nutrients to perform various functions in the body and to lead a healthy life. Since men derive all the nutrients they need through the diet they eat, their diet must be well balanced to provide all the vital nutrients in proper proportion [2]. Especially sedentary as well as moderate working men are in the high need of protein, fats, carbohydrates, vitamin A and C, iron, calcium and also dietary fibre to have a good nutritional status which will keep them free from diseases like anaemia, underweight, osteoporosis, etc. Hence their diet must have good accessibility to these nutrients through their regular diet which must be easily available to them. To find optimum nutritional benefits in low cost here we formulate the LPP (Diet Problem) in which we have to specify first, the four things which are,

1.1. Decision Variables

These are the variables for which we have to take the decision. We have taken 35 vegetarian food items as decision variables (as shown in table 2) which Indian men commonly use in their daily diet as a sustaining food. In this diet problem using LPP we have to find out how much grams of these food items are necessary for daily requirement of nutrients for men at minimum cost.

1.2. Objective Function:

The linear function which is to be optimized is called the objective function. In this problem, our main objective is to minimize the total cost of daily diet of men which will fulfil the minimum requirement of nutrients. Here we want the cost of food items purchased (as shown in table 2) to be as little as possible and at the same time, we also emphasised on the thing that these food items provide all the necessary nutrients required for the healthy life of men. Some food items can be common for different nutrients. It is beneficial for cost cutting of diet.

1.3. Constraints

Constraints mean restrictions i.e. food items should provide minimum nutritional requirements necessary for healthy life. There are many nutrients which are available in various food items, but for convenience, for sedentary and moderate working men we considered 8 nutrients which are commonly available in all types of food items and their minimum amounts which are required for sustaining a healthy life recommended by Indian Council of Medical Research (ICMR) are as shown in table 1[1].

Table 1: ICMR Recommended dietary allowances per day for Indians

Nutrients (gm/day)		Protein	Fats	Carbo- hydrates	Vitamin A	Vitamin C	Iron	Calcium	Dietary Fibre
Men (Body weight 60 Kg.)	Seden-tary work	60	20	100	0.0024	0.04	0.028	0.4	50
	Mode-rate work								

1.4. Non Negative Restrictions

All the decision variables are restricted to be non negative. Mathematically, the diet problem can be stated as follows,

$$MinZ = \sum_{j=1}^{n} c_j x_j \qquad \dots (1)$$

Subject to the constraints,

$$\sum_{j=1}^{n} a_{ij} x_j \geq b_i \qquad ; i = 1, 2, \dots, m \qquad \dots (2)$$

$$x_j \geq 0 \qquad ; j = 1,2, \dots, n \qquad \dots (3)$$

Where x_j's are the quantities of food items, c_j's are the costs of food items per 100 gm, a_{ij}'s are amounts of nutrients per 100 gm of food items and b_i's are daily minimum nutritional requirements.

Our diet problem is to minimize the function (1) subject to the constraints (2) and non negative restrictions (3).

LPPs are usually solved by simplex method, originally developed by Dantzig in 1948. Here diet problem is of minimization and constraints are of greater than or equal to type. We solved it using a computer-based method i.e., R programming for planning an optimal menu with respect to the daily nutritional requirements of Indian sedentary and moderate working men [5].

Following the formulation of LPP and attainment of an optimum solution of it, it is often desired to study the effect of changes in the different parameters of the problem on the current optimum solution. If slight changes are made in the parameters or the structure of a given LPP after its optimum solution has been attained then the analysis of such post-optimal problems can thus be termed as post-optimality analysis or sensitivity analysis [4].

2. Formulation of Diet Problem

Table 2 provides us the input data for a LPP with 35 decision variables indicating the amount of various food items to be consumed and 8 constraints determining minimum nutritional requirement [3].

Table 2: Amount of various nutrients contained in different vegetarian food groups-items with costs

Sr. No.	Food Groups	Costs (in Rs.)*		Nutrients (gm / day)							
	(Food Items in 100 gm)			Protein	Fats	Carbohydrate	Vitamin A	Vitamin C	Iron	Calcium	Dietary Fibre
1	Cereals, Grains And Products										
	Wheat	x_1	3	8.2	1.6	77.2	0.000029	0	0.0049	0.037	1.7
	Jawar	x_2	4	10.4	1.9	72.6	0.000047	0	0.0041	0.025	1.6
	Bajra	x_3	4	11.6	5	67.5	0.000132	0	0.008	0.042	1.2
	Rice	x_4	6	7.5	1	76.7	0	0	0.0032	0.01	0.6
	Ragi	x_5	6	7.3	1.3	72	0.000042	0	0.0039	0.344	3.6
2	Pulses And Legumes										
	Red Gram Dal	x_6	10	22.3	1.7	57.6	0.000132	0	0.0027	0.073	1.5
	Green Gram Dal	x_7	11	24	1.3	56.7	0.000049	0	0.0044	0.124	4.1
	Bengal Gram Dal	x_8	8	7	1.4	14.1	0.000189	0.003	0.0238	0.34	2
	Moth Bean	x_9	9	23.6	1.1	56.5	0.000009	0.002	0.0095	0.202	4.5
3	Leafy Vegetables										
	Spinach	x_{10}	6	2	0.7	2.9	0.00558	0.028	0.00114	0.073	0.6
	Amaranthus	x_{11}	5	4	0.5	6.1	0.00552	0.099	0.00349	0.397	1
	Cabbage	x_{12}	5	1.8	0.1	4.6	0.000042	0.0366	0.0008	0.039	1
4	Roots And Tubers										
	Carrot	x_{13}	8	0.9	0.2	10.6	0.00189	0.003	0.00103	0.08	1.2
	Beetroot	x_{14}	8	1.7	0.1	8.8	0	0.01	0.00119	0.0183	0.9
	Onion	x_{15}	3	1.2	0.1	11.1	0	0	0.0006	0.0469	0.6
	Potato	x_{16}	3	1.6	0.1	22.6	0.001096	0.0114	0.00048	0.01	0.4
5	Condiments And Spices										
	Green Chillies	x_{17}	8	2.9	0.6	3	0.000175	0.111	0.0044	0.03	6.8
	Turmeric	x_{18}	20	6.3	5.1	69.4	0	0.0007	0.0678	0.15	2.6
6	Other Vegetables										
	Papaya Green	x_{19}	5	0.7	0.2	5.7	0.000666	0.057	0.0009	0.028	0.9
	Brinjal	x_{20}	4	1.4	0.3	4	0.000014	0.0022	0.00038	0.018	1.3
	Cauliflower	x_{21}	8	2.6	0.4	4	0	0.0482	0.00123	0.033	1.2
	Tomato	x_{22}	4	1.9	0.1	3.6	0.001496	0.016	0.0018	0.02	0.7
7	Fruits										
	Banana	x_{23}	3	1.2	0.3	27.2	0.000078	0.007	0.00036	0.017	0.4
	Pineapple	x_{24}	6	0.4	0.1	10.8	0.000003	0.0478	0.00242	0.02	0.5
	Mango ripe	x_{25}	12	0.6	0.4	16.9	0.001082	0.0364	0.0013	0.014	0.7
	Muskmelon	x_{26}	3	0.3	0.2	3.5	0	0.0367	0.0014	0.032	0.4
	Watermelon	x_{27}	2	0.2	0.2	3.3	0	0.0081	0.0079	0.011	0.2
8	Nuts And Oil Seeds										
	Sesame Seeds	x_{28}	16	18.3	43.3	25	0.00006	0	0.0093	1.45	2.9

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	Groundnuts	x_{29}	14	25.3	40.1	26.1	0.000037	0	0.0025	0.09	3.1
9	Milk And Milk Products										
	Paneer	x_{30}	32	13.4	23	7.9	0	0	0	0.48	0
	Milk(Buffalo)	x_{31}	6	4.3	6.5	5	0.000048	0.001	0.0002	0.21	0
	curd	x_{32}	8	3.1	4	3	0.000102	0	0.0002	0.149	0
10	Fats And Edible Oils										
	Sunflower Oil	x_{33}	14	19.8	52.1	17.9	0	0	0.005	0.28	1
	Ghee	x_{34}	60	0	100	0	0	0	0	0	0
11	Sugars										
	Sugar	x_{35}	4	0.1	0	99.4	0	0	0.000155	0.012	0

*The prices of food items are found from the grocery shop of Amravati (MS, India) in the month of April 2020 i.e. in the summer season. Here we have taken seasonal leafy vegetable-*spinach* and fruits- m*ango ripe, muskmelon and watermelon.*

3. Defining Diet Problem of Indian Men Using R Programming

The functions in figure 1 uses the simplex algorithm of George B. Dantzig (1947) and provides detailed results (e.g. dual prices, sensitivity analysis and stability analysis) [6].

In R programming solving the Linear Programming problem by the packages 'lpSolveAPI' and 'lpSolve' requires the installation of these packages, which are available on CRAN. These packages provide more detailed results (e.g. dual values, stability and sensitivity analysis) [7].

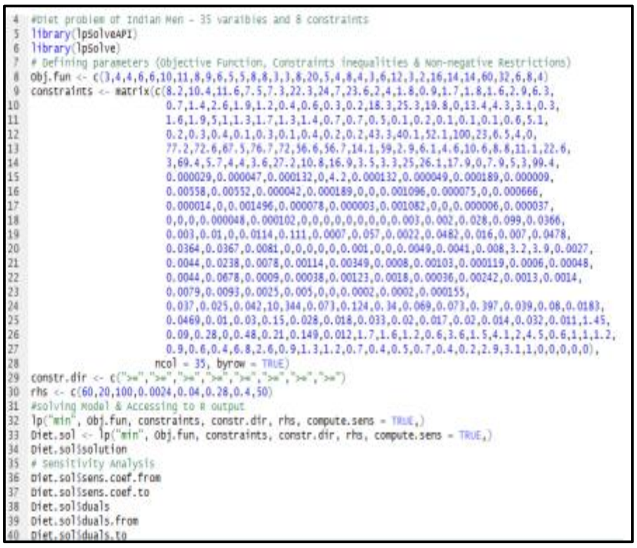

Figure 1: R script of Diet problem

4. Solution and Sensitivity Analysis of Diet Problem of Indian Men

Figure 2: R output of solution of Diet Problem

Here we get resultant optimum solution which gives the minimum cost (z) Rs. 65.70059 of food items satisfying minimum nutritional requirement (constraints) with values of basic variables as $x_1 = 4.39$, $x_5 = 0.059$, $x_{17} = 6.12$, $x_{29} = 0.23$, as shown in figure 2. Here x_1, x_5, x_{17}, x_{30} indicates quantities in 100 grams of wheat, ragi, green chillies and groundnuts.

Finding the optimum solution to a linear programming model is only the first step. After that we need to perform the sensitivity analysis of the optimum solution.

Sensitivity analysis is called "what-if-analysis" i.e. what happens to the solution if some parameters change.

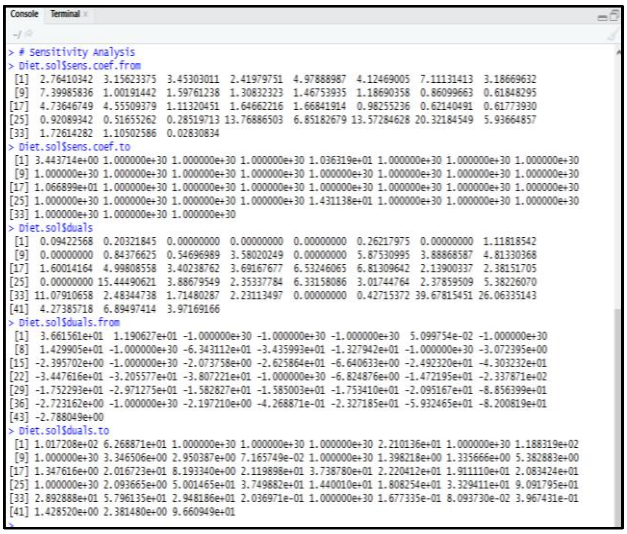

Figure 3: R output of sensitivity analysis of diet problem

The sensitivity report obtained from R programming is as shown in figure 3 which provides classical sensitivity analysis information for LPP (diet problem) including dual values and range information. The sensitivity coefficients (range) go from (2.7641, 4.9789, 4.7365, and 6.8518) to (3.443714e+00, 1.036319e+01, 1.066899e+01 and 1.431138e+01).The solution $x = 0$ is not feasible, Values of the simplex table those are actually zero might get small (positive or negative) numbers due to rounding errors, which might lead to artificial restrictions. Therefore, all values those are smaller than zero (default is 1e-30) are set to 0.The dual values for non basic variables are called reduced costs and for binding constraints are called shadow prices[6].

5. Results and Discussion

5.1. Interpreting Dual Values

Dual values are the most basic form of sensitivity analysis information. The dual value for a variable i.e. Reduced cost is nonzero only when the variable's value is equal to its upper or lower bound at the optimal solution. This variable is called a *nonbasic* variable, and its value was driven to the bound during the optimization process. The reduced costs tell us how much the objective function coefficients (costs per 100 gm) can be increased or decreased before the optimal solution changes.

The dual value for a constraint i.e., shadow price is nonzero only when the constraint is equal to its bound as shown in the figure 3. This is called a *binding* constraint, and its value was driven to the bound during the optimization process. These shadow prices tell us how much the optimal solution can be increased or decreased if we change the right hand side values (Minimum Requirement) with one unit.

The shadow/dual prices of the constraints are 0.09422568, 0.20321845, 0, 0, 0, 0.26217975, 0, 1.11818542, while for the decision variables are 0, 0.84376625, 0.54696989, 3.58020249, 0, 5.87530995, 3.88868587, 4.81330368, 1.60014164, 4.99808558, 3.40238762, 3.69167677, 6.53246065, 6.81309642, 2.13900337, 2.38151705, 0, 15.44490621, 3.88679549, 2.35337784, 6.33158086, 3.01744764, 2.37859509, 5.38226070, 11.07910658, 2.48344738, 1.71480287, 2.23113497, 0, 0.42715372, 39.67815451, 26.06335143, 4.27385718 6.89497414 and 3.97169166 respectively.

5.2. Interpreting Range Information

In this diet problem, the dual values are *constant* over a range of possible changes in the objective function coefficients and the constraint right hand sides.

For each decision variable, the report shows its coefficient in the objective function, and the amount by which this coefficient could be increased or decreased without changing the dual value (Allowable Increase and Allowable Decrease).

For each constraint, the report shows the constraint right hand side, and the amount by which the RHS could be increased or decreased without changing the dual value (Allowable Increase and Allowable Decrease).

Finally, the shadow/dual prices Lower limits (allowable decrease) of constraints are (3.661561e+01, 1.190627e+01, -1.000000e+30, -1.000000e+30, -1.000000e+30, 5.099754e-02, -1.000000e+30, 1.429905e+01), while forthe decision variables are (-1.000000e+30, -6.343112e+01, -3.435993e+01 ,-1.327942e+01, -1.000000e+30, -3.072395e+00, -2.395702e+00, -1.000000e+30, -2.073758e+00, -2.625864e+01, -6.640633e+00, -2.492320e+01, -4.303232e+01, -3.447616e+01, -3.205577e+01, -3.807221e+01, -1.000000e+30, -6.824876e+00, -1.472195e+01, -2.337871e+02, -1.752293e+01, -2.971275e+01, -1.582827e+01, -1.585003e+01, -1.753410e+01, -2.095167e+01, -8.856399e+01, -2.723162e+00, -1.000000e+30, -2.197210e+00, -4.268871e-01, -2.327185e+01, -5.932465e+01, -8.200819e+01 and -2.788049e+00), respectively shown in figure 3.

The shadow/dual prices upper limits (allowable increase) of the Constraints are(1.017208e+02, 6.268871e+01, 1.000000e+30, 1.000000e+30, 1.000000e+30, 2.210136e+01, 1.000000e+30, 1.188319e+02), while for the decision variables are (1.000000e+30, 3.346506e+00, 2.950387e+00, 7.165749e-02, 1.000000e+30, 1.398218e+00, 1.335666e+00, 5.382883e+00, 1.347616e+00, 2.016723e+01, 8.193340e+00, 2.119898e+01, 3.738780e+01, 2.220412e+01, 1.911110e+01, 2.083424e+01, 1.000000e+30, 2.093665e+00, 5.001465e+01, 3.749882e+01, 1.440010e+01, 1.808254e+01, 3.329411e+01, 9.091795e+01, 2.892888e+01, 5.796135e+01, 2.948186e+01, 2.036971e-01, 1.000000e+30, 1.677335e-01, 8.093730e-02, 3.967431e-01, 1.428520e+00, 2.381480e+00 and 9.660949e+01), respectively.

6. Conclusions

The optimum solution with food items wheat, ragi, green chillies and groundnuts from which the sedentary as well as moderate working men in India can have sufficient nutritional benefits necessary for sustaining the healthy life by spending **Rs. 65.70059** per day only. This diet may not be tasteful but there is no doubt about the optimality of the solution within the limitations we have formulated.

The costs of food items play a very important role in finding the optimum solution of diet problem. It should be noted that as costs always vary according to locations and seasons, the optimum solution changes.

The Sensitivity Report details how changes in the coefficients of the objective function affect the solution and how changes in the constants on the right hand side of the constraints affect the solution. For each variable, we can calculate the range of values that the coefficient can take on by subtracting the allowable decrease from the coefficient or adding the allowable increase to the coefficient. The second part of the Sensitivity Report examines how changes to the right hand side of any constraint affects the optimal solution. A change to the constant on the right hand side of a constraint changes the size of the feasible region. Increasing the right hand side of any constraint with positive coefficients shifts the border matching the constraint up. Decreasing the right hand side of any constraint with positive coefficients shifts the border matching the constraints down. The shadow price indicates how the objective function will change when the constant on the right hand side is changed [8].

The sensitivity analysis for a nonbinding constraint, like Carbohydrates Vitamin A, Vitamin C and calcium, is different. After we get the optimal solution, changes to the right hand side do not affect the costs as long as the right hand side is not decreased too much. This means that the shadow price is Rs. 0.

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