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Optimizing Human Diet Problem with Fuzzy Price Using Fuzzy Linear Programming Approach

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Abstract: There are two factors that influence diet problem which are rates of diabetes and other diet-related diseases are growing and fluctuation of the food price. This paper discusses human diet problem with fuzzy price. The approach used linear programming with fuzzy objective coefficient using linear membership function. The result showed that the uncertainty of food prices slightly affected the budget of human diet.

Key words: Fuzzy linear programming, human diet problem, membership function, price uncertainty, triangular fuzzy number

INTRODUCTION

The rise in overweight, obesity and malnutrition worldwide is a major public health challenge. Malnutrition is a major contributor to the total global disease burden. In a few developing countries, up to 20% of children under-five are overweight (WHO, 2009). Citizens in developed countries can afford to purchase food. Without considering the nutrients requirement, spending much money cause over nutrient that will harm to our body system. For example consuming high amount of fat, cholesterol and sugar exposes people to obesity, high cholesterol, or diabetic.

Raffensperger (2008) discussed that the least-cost of low-carbohydrate is more expensive than the least-cost of low-fat diet. The study also identified which nutrients had the greatest effect on cost for a low-carbohydrate and low-fat diet.

Meanwhile Cadenas *et al*. (2004) employed the fuzzy optimization to diet problems in Argentinean farms. It used a Decision Support Systems (DSS) named SACRA (a Spanish acronym for support system for the construction of cattle diets) that specially developed for the problem.

Htun *et al*. (2005) examined the effect of dietary protein quality on the black tiger shrimp and how food consumption and diet quality can affect the shrimp growth and survival. The used model can predict population of the shrimp under shrimp aquaculture conditions. It presented simple models for describing and predicting growth and feed requirement of black shrimp under shrimp aquaculture conditions.

Raffensperger (2008) has proposed the model of Minimize Cost Diet Problem (MCDP) as the following:

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

subject to $$\sum_{j=1}^{n} a_{ij} x_j \geq b_i \qquad (2)$$

$$\sum_{j=1}^{n} a_{ij} x_j \leq d_i,\ \ i = 1, 2, \ldots, m,\ x_j \geq 0 \qquad (3)$$

Where:

x_j : 100 g of food j eaten per day
a_{ij} : The amount of nutrient I in 100 g of food j
b_i : The required daily amount of nutrient i
c_j : The price of food j per 100
d_i : The maximum daily amount of nutrient i
m : The number of nutrients
n : The number of food

If c_j is noted as the amount of carbohydrate or fat nutrients, the diet problem might be called as low-carbohydrate diet problem or low-fat diet problem. Normally, budget for human diet depends on the food price. High price of foods do not guarantee sufficient nutrients. A survey on the food price had been done in Kuala Terengganu in January 2009. The obtained results showed that buying a large quantity of food was cheaper than buying in a small amount. The prices of food were also vary and keep changing between store A, B and C which situated at location A, B and C, respectively. Therefore, it can be considered that the prices of food were uncertain (fuzzy).

In order to determine the fluctuation of food prices, fuzzy theory approach was employed, where the prices of food were assumed as fuzzy numbers.

Human diet problem under food price uncertainty: For a triangular fuzzy number of a price, for example $\bar{a} = (a^-/a^0/a^+)$, a^- is the lowest, a^0 is the usual and a^+ is the

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highest price. Then, overcome this diet problem with uncertain price by using linear programming with fuzzy objective coefficients approach. The model of MCDP with fuzzy objective coefficients (MCDP-FOC) is:

Minimize $$\sum_{j=1}^{n} \bar{c}_j x_j \quad (4)$$

subject to $$\sum_{j=1}^{n} a_{ij} x_j \geq b_i \quad (5)$$

$$\sum_{j=1}^{n} a_{ij} x_j \leq d_i, \; i = 1, 2, ..., m, \; x_j \geq 0 \quad (6)$$

Where $\bar{c}_j$ is the uncertain price of food j per 100 g. The uncertain prices were assigned by triangular fuzzy numbers $\bar{c}_j = (c_j^- / c_j / c_j^+)$.

Since the uncertain prices of MCDP-FOC are assigned by triangular fuzzy number $\bar{c}_j = (c_j^- / c_j / c_j^+)$, the objective function (4) will become multi-objective LP as below:

Minimize $$\sum_{j=1}^{n} c_j^- x_j \quad (7)$$

Minimize $$\sum_{j=1}^{n} c_j^0 x_j \quad (8)$$

and Minimize $$\sum_{j=1}^{n} c_j^+ x_j \quad (9)$$

The objective equations (7), (8) and (9) also can be written as:

Maximize $$z_1 = \sum_{j=1}^{n} (c_j^0 - c_j^-) x_j \quad (10)$$

Minimize $$z_2 = \sum_{j=1}^{n} c_j^0 x_j \quad (11)$$

Minimize $$z_3 = \sum_{j=1}^{n} (c_j^+ - c_j^0) x_j \quad (12)$$

Each objective will determine its maximum and minimum value that is subjected to the indicated constraints.

$$z_i^{max} = \text{Maximize } z_i \quad (13)$$

$$z_i^{min} = \text{Minimize } z_i, \; i = 1, 2, 3 \quad (14)$$

subject to $$\sum_{j=1}^{n} a_{ij} x_j \geq b_i \quad (15)$$

$$\sum_{j=1}^{n} a_{ij} x_j \leq d_i, \; i = 1, 2, ..., m, \; x_j \geq 0 \quad (16)$$

The membership functions of each equation (10), (11) and (12) are defined as:

$$\mu_{z1}(x) = \begin{cases} 1, & z_1 > z_1^{max} \\ \dfrac{(z_1 - z_1^{min})}{(z_1^{max} - z_1^{min})}, & z_1^{min} < z_1 \leq z_1^{max} \\ 0, & z_1 \leq z_1^{min} \end{cases} \quad (17)$$

$$\mu_{z2}(x) = \begin{cases} 1, & z_2 < z_2^{min} \\ \dfrac{(z_2^{max} - z_2)}{(z_2^{max} - z_2^{min})}, & z_2^{min} \leq z_2 < z_2^{max} \\ 0, & z_2 \geq z_2^{max} \end{cases} \quad (18)$$

$$\mu_{z3}(x) = \begin{cases} 1, & z_3 < z_3^{min} \\ \dfrac{(z_3^{max} - z_3)}{(z_3^{max} - z_3^{min})}, & z_3^{min} \leq z_3 < z_3^{max} \\ 0, & z_3 \geq z_3^{max} \end{cases} \quad (19)$$

Based on fuzzy decision making proposed by (Bellman and Zadeh, 1970), let

$$\beta = \min_x \{\mu_{z1}(x), \mu_{z2}(x), \mu_{z3}(x)\} \quad (20)$$

From the membership function (17), (18) and (19), then the model becomes the following crisp optimization problem.

Maximize $$\beta \quad (21)$$

subject to $$\left(\sum_{j=1}^{n} (c_j - c_j^-) x_j\right) + \beta(z_1^{max} - z_1^{min}) \leq z_1^{max} \quad (22)$$

$$\left(\sum_{j=1}^{n} c_j x_j\right) - \beta\left(z_2^{max} - z_2^{min}\right) \geq z_2^{min} \quad (23)$$

$$\left(\sum_{j=1}^{n} (c_j^+ - c_j) x_j\right) - \beta\left(z_3^{max} - z_3^{min}\right) \geq z_3^{min} \quad (24)$$

$x_j \geq 0$, $0 \leq \beta \leq 1$.

Numerical example: Based on the nutrient composition data of Malaysian food, there are 40 types number of

Table 1: Nutrient requirement per day (Female, 30 years old, sedentary, BMI 24.99 kg/m^2)

			Actual in crisp solution (MCDP)			Actual in fuzzy solution (MCDP-FOC)		
Nutrient	Minimum	Maximum	Low-Cost	Low-Carb	Low-Fat	Low-Cost	Low-Carb	Low-Fat
Energy (kcal/d)	1982.0	N.D	2223.00	1981.99	1981.90	2078.73	1981.99	1981.90
Sugar (g/d)	N.D	124.00	101.00	59.42	124.00	124.00	59.45	124.00
Carbohydrate (g/d)	130.0	322.00	322.00	154.59	301.11	235.12	154.59	301.11
Total fiber (g/d)	25.0	N.D	31.00	25.00	25.01	32.56	25.00	25.01
Fat (g/d)	N.D	77.078	77.00	77.00	31.55	77.00	77.00	31.55
Protein (g/d)	46.0	173.425	78.36	172.99	140.11	128.97	172.00	140.11
Vitamin A (IU)	2333.0	10000.00	10000.00	10000.02	10000.06	10000.02	10000.02	10000.12
Vitamin C (mg/d)	75.0	2000.00	566.00	730.66	694.67	815.52	730.87	694.67
Vitamin E (mg/d)	15.0	1000.00	15.00	15.00	15.00	15.00	15.00	15.00
Thiamin (mg/d)	1.1	N.D	1.14	1.10	1.10	1.10	1.10	1.10
Riboflavin (mg/d)	1.1	N.D	2.62	2.61	3.29	1.66	2.61	3.29
Niacin (mg/d)	14.0	35.00	15.16	34.83	25.50	26.11	34.83	25.50
Vitamin B_6 (mg/d)	1.3	100.00	2.16	1.83	1.96	1.87	1.83	1.96
Folate (µg/d)	400.0	1000.00	504.55	683.64	400.00	531.13	683.25	400.00
Vitamin B_{12} (µg/d)	2.4	N.D	N.D	15.84	15.04	15.64	15.83	15.04
Panto-thenic acid (mg/d)	5.0	N.D	8.21	9.28	5.80	6.71	9.27	5.80
Calcium (mg/d)	1000.0	2500.00	999.56	999.94	999.61	999.79	999.94	999.61
Copper (mg/d)	0.9	10.00	2.53	1.88	3.23	1.69	1.88	3.23
Iron (mg/d)	18.0	45.00	18.49	45.00	45.00	18.00	45.00	45.00
Magnesium (mg/d)	320.0	350.00	320.00	350.00	350.00	350.00	350.00	350.00
Manganese (mg/d)	1.8	11.00	3.23	1.58	1.38	1.19	1.58	1.38
Phosphorus (mg/d)	700.0	4000.00	1413.89	1770.47	1928.89	1401.66	1770.42	1928.89
Selenium (µg/d)	55.0	400.00	149.60	149.60	230.62	204.09	258.45	230.62
Zinc (mg/d)	8.0	40.00	8.00	12.37	9.05	8.00	12.36	9.05
Potassium (mg/d)	4700.0	N.D	4700.00	4700.00	4700.00	4700.00	4700.00	4700.00
Sodium (mg/d)	1500.0	2300.00	1500.01	1752.05	1500.00	1500.00	1751.83	1500.00

chosen foods, for example white rice, cabbage, apple, etc. The number of nutrients is 26 such as energy, sugar, carbohydrate, etc (Siong *et al.*, 1997). The prices of foods (in RM) were collected from local grocery stores in March 2009, Terengganu, Malaysia. Based on the Recommended Nutrient Intakes (RNI) of Malaysia (Kementerian Kesehatan Malaysia, 2009), the respondent for this research were for those of a 30 years - old - sedentary woman.

The Acceptable Macronutrient Distribution Range (AMDR) for carbohydrate is 45-65%, fat is 20-35% and protein is 10-35% of calories (Raffensperger, 2008). For 1982 kcal of energy, at 4 kcal/g, 65% of calories correspond to a maximum of 322 g of carbohydrate, 35% of calories correspond to a maximum of 173 g of protein. While for 1982 kcal of energy, at 9 kcal/g, 35% of calories correspond to a maximum of 77.078 of fat. Table 1 shows the minimum, maximum and actual nutrient requirements.

Conclusion: Table 2 shows the amount of foods in crisp and fuzzy solution. The main objectives of research that are to optimize the cost, carbohydrate and fat (low-cost, low-carbohydrate and low-fat) have been achieved. While Table 3 shows the value of the objective functions, comparison of the cost between crisp and fuzzy solutions, between low-carbohydrate and low fat.

The results showed significant solution. The difference solution between normal diet problem using the model of Minimize Cost Diet Problem (MCDP) and diet problem with uncertain food price using the model of MCDP with fuzzy objective coefficient (MCDP-FOC) are listed as the following:

1. The actual nutrient for vitamin E, potassium and sodium are the same value in term of nutrient requirement per day, while the rest of other nutrients (13 types) are different
2. There are 11 kinds of food in the MCDP solution and 14 kinds of food in the MCDP-FOC
3. The difference of the cost is about RM5.45 per day. Total for a month roughly is about RM162.50.

It also shows that the most expensive diet is low-carbohydrate. Besides that, the difference cost between the low-fat diet and low-carbohydrate diet is not slightly different.

The minimizing cost diet problem with fuzzy price presented a minimum cost diet problem of human. By minimizing the cost, human still can fulfill their

Table 2: The amount of foods in crisp and fuzzy solution

	Crisp solution (MCDP)			Fuzzy solution (MCDP-FOC)		
Food	Low-cost (g)	Low-carb (g)	Low-fat (g)	Low-cost (g)	Low-carb (g)	Low-fat (g)
White rice	-	-	31.98111	-	-	31.98119
Cassava	160.2125	-	-	-	-	0.000140
Biscuits	-	-	-	-	-	-
Wheat flour	-	46.90016	4.292514	5.044585	46.83205	4.292440
Bread	40.13735	-	-	-	-	-
Long bean	-	-	-	-	-	-
Cabbage	-	-	-	-	-	-
Carrot	-	-	-	-	-	-
Cauliflower	-	288.5196	110.2078	-	287.6349	110.2069
Corn	20.37577	-	-	25.83213	-	-
Cucumber	-	-	-	-	-	-
Potatoes	259.1560	-	-	30.08751	-	-
Spinach	-	-	-	-	-	-
Tomatoes	-	-	-	-	-	0.014016
Apple	-	-	-	-	-	-
Banana	-	-	-	-	-	-
Grapes	-	-	-	-	-	-
Orange	-	-	-	447.2624	1.208071	-
Longans	-	-	299.8152	-	-	299.8147
Guava	52.32821	63.43107	2.8168	66.07815	63.44472	2.816794
Papaya	420.4254	712.6067	281.0652	536.3782	712.6943	281.0651
Mango	431.8890	18.29526	703.7620	298.0206	17.87551	703.7622
Melon	-	-	-	-	-	-
Water melon	-	-	-	-	-	-
Pineapple	-	-	-	-	-	-
Pears	-	-	-	-	-	-
Chicken	-	32.57432	-	-	32.79366	-
Sardine	79.6252	79.89287	79.78966	79.85905	79.89353	79.78966
Beef	-	173.4253	-	237.8010	172.9945	-
Eggs	240.6025	196.1295	-	-	195.9165	-
Anchovy	-	62.27634	-	-	62.20260	-
Shrimp	-	263.9200	287.7318	-	264.2263	287.7317
Fish	-	-	-	269.4664	-	-
Cuttlefish	-	-	133.5983	17.65028	-	133.5982
Cockle	-	155.5665	150.0448	45.44913	155.6040	150.0448
Sugars	-	-	-	-	-	-
Margarine	59.41616	57.53405	6.952326	93.78692	57.56826	6.952329
Cond-sweetened	128.0603	16.83365	114.7724	60.31383	16.86022	114.7724
Oils	-	-	-	-	-	-
Milo	-	-	-	9.917482	-	-

Table 3: The optimal solution for the cost/budget

	Low-cost (in RM)	Low-carb (in RM)	Low-fat (in RM)
Crisp	8.4893161390	15.1928602630	14.9099256260
Fuzzy	13.9356523002	15.1911181170	14.9099228570
Cost difference	5.4463361612	0.0017421460	0.00000276900

nutrient requirement every day. It used FLP with fuzzy objective coefficients as the model. Two approaches; probabilistic and linear membership function were used. The result showed that the exchange of foods price (the uncertainty of foods price) give some affects to the minimum cost diet problem.

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