Fuzzy Linear Programming Approach in Balance Diet Planning for Eating Disorder and Disease-related Lifestyle

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Abstract: This paper addresses a balanced diet planning by using fuzzy linear programming approach. Recently, eating disorder and disease-related lifestyle have been assumed as a critical problem in the world. The cause of these problems has been considered to be westernization of eating habit, nutritional imbalance and depression. In this paper, balanced diet planning corresponding to each user takes a variety of foods for a few times per day. The planning will help users to obtain nutritional requirements for human body in daily routine and to prevent chronic disease such as diabetes and heart attack.

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Keywords: Eating disorder, Disease-related Lifestyle, Fuzzy Linear Programming, chronic disease
1. Introduction

A healthy diet relationship with food and human body will leads to develop physical and mental. Although millions of people turn to diets and take the weight loss products in hopes of improving their health, the reality is that diets do not work. There are 90% of people, who diet will gain back the pounds, often ending up at a higher weight than where they started. In addition, people who diet frequently have a much higher risk of developing eating disorders [5].

Nowadays, eating disorder habits is serious problem in the entire life course. The number of the patients afflicted by lifestyle-related diseases has increased. Actually, around 80% of people older than thirties are infected by chronic diseases associated with adult lifestyle habits [10]. From that statistics, 63% of deaths attributable to chronic diseases are already occurring in developing countries and high-income countries [20].

The diversification of a lifestyle, the increase in a single-person household and meal, underweight, undernutrition, overweight will pose eating disorder problem. Furthermore, the increase in a lifestyle-related disease poses that problem as a result. Lifestyle-related disease is a chronic disease associated with a person or group of people habits such as atherosclerosis, heart disease, and stroke; obesity and type 2 diabetes [19]. Those diseases are closely tied to our daily habits that involving in the metabolic syndrome. Metabolic syndrome is a combination of medical disorders that increase the risk of developing cardiovascular disease and diabetes. It affects a large number of people, and prevalence increases with age.

There are many studies which are focused on balance diet and chronic disease such as diet planning for humans using mixed-integer linear programming [16], prevention of chronic disease by diet and lifestyle changes [18] and diet problem and nutrient requirements using Fuzzy Linear Programming Approach [12-13].

Walter et al. [18] discussed about prevention of chronic disease by diet and lifestyle changes. This study identifies the relationships between dietary and lifestyle factors and chronic diseases and recommended lifestyle changes and the potential supporting evidence to prevent chronic disease. Meanwhile, Sklan and Dariel [16] have done a research about human diet planning using mixed-integer linear programming. A computerized model is applied to planning diet at minimum cost while supplying all nutritional requirements; maintain nutrients relationships and preserving eating practices. Mamat et al. [12,13] concentrates on human diet problem
using fuzzy linear programming approach. This research aims to suggest people to have healthy food with the lowest cost as possible.

To prevent chronic disease, we assume that it is necessary to obtain well-balanced diet in our daily life. Thus, fuzzy linear programming approach will be applied to get better results.

2. Research Motivation

In recent years, fast food has become a major food choice among people around the world. When we talked about fast foods, it is normal to experience a mental picture of that burger, fries, sandwiches, ice cream, and soda. It is so delicious and different to other food like rice. Unfortunately, fast foods are high in fat, sugar and calories and low in fiber and nutrients. According the result of a study, eating frequent fast food meals will cause teens and young adults to gain more weight and face an increased risk of developing insulin resistance [14]. However, despite the fact that many researchers and media report about the unhealthy nature of fast foods, many people have increased in the interest in the nutritional value of fast food [8]. From their opinion, fast food has become a part of lifestyle and symbol of modern living.

In the developed world, nutritional imbalances are caused mainly by disorders that limit the body's intake or absorption of nutrients or to unhealthy eating, or self-imposed dietary restrictions [3]. These imbalances may be noticed when nutritional needs increase such as in growth spurts in childhood, teens or in pregnancy. It is particularly common macronutrients that provide energy, especially fat and other nutrients including calcium, iron, folate, vitamin D, much sodium, or salt. Depending on the nutrients in short or excess supply, imbalances create unpleasant side effects and conditions that could lead to serious disease such anemia.

Psychological factor such as depression is consistently associated with eating disorders and chronic diseases. Depression will affect people at any race, age, sex or economical standing. There are more than 19 million people that age 18 and above are considered to be clinically depressed, or 1 out of 5 people in general society [2]. Many people that have depression tend to overeating or inadequate food intake. In addition, they consume the snacks and food indulged in as escape routes to deal with emotional stress. This situation indirectly will lead people to get chronic disease such as diabetes, kidney failure, high blood pressure and heart attack.
3. Fuzzy Linear Programming Approach

Fuzzy Linear Programming Approach (FLP) is a method that will be used to solve our research problem. Raffensperger [15] has proposed Minimize Cost Diet Problem (MCDP) model as following below:

Minimize \[ \sum_{j=1}^{n} c_j x_j \]

Subject to \[ \sum_{j=1}^{n} a_{ij} x_j \geq b_i, \sum_{j=1}^{n} a_{ij} x_j \leq d_i, i = 1, 2, \ldots, m, x_j \geq 0 \] (3.1)

where:
- \( j \): food eaten per day
- \( c_j \): amount of carbohydrate or fat nutrient,
- \( x_j \): 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 \( i \),
- \( d_i \): the maximum daily amount of nutrient \( i \),
- \( m \): the number of nutrients and
- \( n \): the number of food.

In this paper, the amount of carbohydrate or fat nutrients is uncertain and it is assume as fuzzy numbers. Therefore, this fuzzy amount of nutrients is approached by linear programming with fuzzy objective coefficients. Formula 3.2 is the model of Minimum Cost Diet Problem (MCDP) with fuzzy objective coefficient (MCDP-FOC).

Minimize \[ \sum_{j=1}^{n} \tilde{c}_j x_j \]

subject to \[ \sum_{j=1}^{n} a_{ij} x_j \geq b_i, \sum_{j=1}^{n} a_{ij} x_j \leq d_i, i = 1, 2, \ldots, m, x_j \geq 0 \] (3.2)

where \( \tilde{c}_j \) is the uncertain amount of carbohydrate or fat nutrient of food \( j \) per 100 g. \( \tilde{c}_j = (c_j^- / c_j / c_j^+) \) are triangular fuzzy numbers that assign the uncertain carbohydrate or fat nutrient of foods.
Since the uncertain prices of MCDP-FOC in formula (3.2) are assigned by triangular fuzzy number $\tilde{c}_j = (c_j^- / c_j / c_j^+)$, the objective will become multi-objective Linear Programming.

4. Multi-Objective Approach

One of Fuzzy Linear Programming Approach is known as multi-objective. Multi-objective linear programming problems can be found in various fields such as work scheduling [9], capital budgeting [7], blending [1] and cutting stock [17]. This paper focus on maximizing balanced diet and nutritional requirements for human body. Definition 1 shows the membership function of triangular fuzzy number.

**Definition 1.** The membership function of triangular fuzzy number $\tilde{c}_j = (c_j^- / c_j / c_j^+)$ is:

$$
\mu_{c_j}(x) = \begin{cases} 
(x - c_j^-)/(c_j - c_j^-) & , c_j^- < x < c_j \\
(c_j^+ - x)/(c_j^+ - c_j) & , c_j \leq x < c_j^+ \\
0 & , x \geq c_j^+ \text{ or } x \leq c_j^- 
\end{cases} \quad (3.3)
$$

where $\mu_{c_j}(x)$ is the membership function for uncertain carbohydrate or fat nutrient of food $j$ per 100 g.

Equation (3.4) show the formula of multi-objective Linear Programming

$$
\text{Min } \sum_{j=1}^{n} c_j^- x_j , \text{ min } \sum_{j=1}^{n} c_j x_j \text{ and min } \sum_{j=1}^{n} c_j^+ x_j \quad (3.4)
$$

The objectives also can be written as

$$
\text{Max } z_1 = \sum_{j=1}^{n} (c_j - c_j^-)x_j , \text{ min } z_2 = \sum_{j=1}^{n} c_j x_j \text{ and min } z_3 = \sum_{j=1}^{n} (c_j^+ - c_j)x_j \quad (3.5)
$$

When there are constraints, the maximum and minimum value for each objective can be found. It is show as below.

$$
\begin{align*}
z_i^{\max} &= \text{max } z_i \\
z_i^{\min} &= \text{min } z_i, \quad i = 1, 2, 3 \\
\text{Subject to } & \sum_{j=1}^{n} a_{ij} x_j \geq b_i , \sum_{j=1}^{n} a_{ij} x_j \leq d_i , \quad \text{for } i = 1, 2, ..., m , \quad x_j \geq 0
\end{align*} \quad (3.6)
$$
Based on equation (3.6), the membership function of each objective is defined as:

\[
\mu_{c_1}(x) = \begin{cases} 
1 & , z_1 > z_{1\text{max}} \\
(z_1 - z_{1\text{min}})/(z_{1\text{max}} - z_{1\text{min}}), & z_{1\text{min}} < z_1 \leq z_{1\text{max}} \\
0 & , z_1 \leq z_{1\text{min}} 
\end{cases} \tag{3.7}
\]

\[
\mu_{c_2}(x) = \begin{cases} 
1 & , z_2 < z_{2\text{min}} \\
(z_{2\text{max}} - z_2)/(z_{2\text{max}} - z_{2\text{min}}), & z_{2\text{min}} \leq z_2 < z_{2\text{max}} \\
0 & , z_2 \geq z_{2\text{max}} 
\end{cases} \tag{3.8}
\]

\[
\mu_{c_3}(x) = \begin{cases} 
1 & , z_3 < z_{3\text{min}} \\
(z_{3\text{max}} - z_3)/(z_{3\text{max}} - z_{3\text{min}}), & z_{3\text{min}} \leq z_3 < z_{3\text{max}} \\
0 & , z_3 \geq z_{3\text{max}} 
\end{cases} \tag{3.9}
\]

Based on fuzzy decision making proposed by Bellman and Zadeh [4] and Fang et al. [6], let

\[
\beta = \min \left\{ \mu_{c_1}(x), \mu_{c_2}(x), \mu_{c_3}(x) \right\}
\]

From equation (3.7), (3.8), and (3.9), the model in problem 3.2 becomes the following optimization problem:

Maximize \( \beta \)

subject to

\[
\left( \sum_{j=1}^{n} (c_j^0 - c_j^-)x_j \right) + \beta(z_{1\text{max}} - z_{1\text{min}}) \leq z_1 \text{max} \tag{3.10}
\]

\[
\left( \sum_{j=1}^{n} c_j^0 x_j \right) - \beta(z_{2\text{max}} - z_{2\text{min}}) \geq z_2 \text{min}
\]

\[
\left( \sum_{j=1}^{n} (c_j^+ - c_j^0)x_j \right) - \beta(z_{3\text{max}} - z_{3\text{min}}) \leq z_3 \text{min}
\]

where \( x_j \geq 0, \ 0 \leq \beta \leq 1 \).
5. Data Analysis

The number of sample food that has been chosen is 40 types of sample and the sample number of nutrients is 27 types. The prices of foods (in RM) were collected from local grocery stores in March 2009, Terengganu, Malaysia. Nutrients requirements were for those of a 30 years-old-sedentary woman, taken from the Recommended Nutrient Intakes (RNI) of Malaysia [11]. The Acceptable Macronutrient Distribution Range (AMDR) for carbohydrate, fat and protein is 45% to 65%, 20% to 35% and 10% to 35% of calories, respectively. For 1982 kcal of energy, at 4kcal/g of calories correspond to a maximum of 322g of carbohydrate, 35% of calories correspond to maximum of 77.078 of fat. Table 1 shows the minimum maximum and actual nutrient requirements. Entering the price of food, nutrient requirements and amount of nutrients in food to the crisp and fuzzy model, the solutions as in table 1 can be obtained.

Table 1. Nutrient requirement per day (Female, 30 years old, sedentary, BMI 24.99 kg/m²)

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Crisp</th>
<th>Multi-objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kcal/d)</td>
<td>1982</td>
<td>ND</td>
<td>2223.12</td>
<td>1991.31</td>
</tr>
<tr>
<td>sugar (g/d)</td>
<td>ND</td>
<td>124</td>
<td>100.75</td>
<td>124</td>
</tr>
<tr>
<td>Carbohydrate (g/d)</td>
<td>130</td>
<td>322</td>
<td>322</td>
<td>195.99</td>
</tr>
<tr>
<td>Total Fiber (g/d)</td>
<td>25</td>
<td>ND</td>
<td>30.54</td>
<td>30.97</td>
</tr>
<tr>
<td>Fat (g/d)</td>
<td>ND</td>
<td>77.078</td>
<td>77.0036</td>
<td>77.0005</td>
</tr>
<tr>
<td>Protein (g/d)</td>
<td>46</td>
<td>173.425</td>
<td>78.36</td>
<td>114.7</td>
</tr>
<tr>
<td>Vitamin A (IU)</td>
<td>2333</td>
<td>ND</td>
<td>10000.13</td>
<td>10000.02</td>
</tr>
<tr>
<td>Vitamin C (mg/d)</td>
<td>75</td>
<td>2000</td>
<td>565.68</td>
<td>811.39</td>
</tr>
<tr>
<td>Vitamin E (mg/d)</td>
<td>15</td>
<td>1000</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Thiamin (mg/d)</td>
<td>1.1</td>
<td>ND</td>
<td>1.1.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Riboflavin (mg/d)</td>
<td>1.1</td>
<td>ND</td>
<td>2.62</td>
<td>2.28</td>
</tr>
<tr>
<td>Niacin (mg/d)</td>
<td>14</td>
<td>35</td>
<td>15.16</td>
<td>26.74</td>
</tr>
<tr>
<td>Vitamin B6 (mg/d)</td>
<td>1.3</td>
<td>100</td>
<td>2.16</td>
<td>2.24</td>
</tr>
<tr>
<td>Folate (µg/d)</td>
<td>400</td>
<td>1000</td>
<td>504.55</td>
<td>604.83</td>
</tr>
<tr>
<td>Vitamin B12 (µg/d)</td>
<td>2.4</td>
<td>ND</td>
<td>10.84</td>
<td>17.66</td>
</tr>
<tr>
<td>Panto-thenic Acid(mg/d)</td>
<td>5</td>
<td>ND</td>
<td>8.21</td>
<td>9.67</td>
</tr>
<tr>
<td>Calcium(mg/d)</td>
<td>1000</td>
<td>2500</td>
<td>999.56</td>
<td>999.93</td>
</tr>
<tr>
<td>Copper (mg/d)</td>
<td>0.9</td>
<td>10</td>
<td>2.53</td>
<td>1.76</td>
</tr>
<tr>
<td>Iron (mg/d)</td>
<td>18</td>
<td>45</td>
<td>18.49</td>
<td>18</td>
</tr>
</tbody>
</table>
Magnesium (mg/d) | 320 | 350 | 320 | 350
Manganese (mg/d) | 1.8 | 11  | 3.23 | 1.02
Phosphorus (mg/d) | 700 | 4000| 1413.89 | 1713.06
Selenium (µg/d) | 55  | 400 | 149.6 | 263.06
Zinc (mg/d) | 8   | 40  | 8    | 8.08
Pottasium (mg/d) | 4700| ND  | 4700 | 4700
Sodium (mg/d) | 1500| 2300| 1500 | 1500

6. Conclusion

This paper has described fuzzy linear programming approach based on the variety of foods that consumed by users. The Fuzzy Linear Programming approach is used to calculate the amount of nutrient in food taken and it is considered to estimate nutritional requirements for human body in daily routine. Then, a balanced diet planning will be produced as a result. This planning will help users to prevent eating disorder and disease-related lifestyle such as anorexia nervosa, diabetes, heart attack and obesity.

References


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