Healthy Diet Lists Considering Carbon Footprint and Calories

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Abstract. To maintain good health, people need to take suitable calories every day. The calories needed for persons depend on their personal features, such as gender, age, weight and levels of physical activity. In this paper, we develop a mathematical model to generate optimized diet lists according to individual conditions. To keep a sustainable environment, the carbon footprint related to diet is also considered in the model. Integer programming is employed to help users find solutions and compose suitable diet lists. As the number of candidate items and constraints become larger, the optimization problem discussed here becomes more complex. Given such understanding, a variety of experiments are performed to investigate the influences of some critical factors on the results. Experiments from this study show that the proposed approach can generate satisfying diet lists effectively.

Keywords: Diet list · Calories · Carbon footprint · Mathematical programming · Combinatorial optimization

1 Introduction

To keep a healthy body, people need to take suitable calories every day. The calories needed to take depend on an individual's body weight. Within a healthy, balanced diet, an average man needs around 2,500 kcal a day to maintain a healthy weight. For an average woman, that figure is around 2,000 kcal [1]. In addition to the weight, an ideal daily intake of calories varies depending on age and lifestyle [2]. For maintaining a healthy weight, one needs to balance the amount of calories obtained through food and drink with the amount of calories burnt through physical activity [2]. Therefore, the recommended daily calories for a person should consider levels of physical activity. The total number of calories a person needs can be found from some literature [3, 4].

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Though we know how many calories we should take with the consideration of all the above influencing factors, a real problem we have to seriously face is what food and drink we should take. In the past years, quite a lot of studies were concerned with this topic [5–15]. However, they seldom incorporate the carbon footprint in it. Furthermore, the food and dietary habits in different regions are dissimilar. The preferences to food and drink are different from region to region. Therefore, we should think over it to make practical diet lists. For reasons outlined above, papers related to optimization of diet lists that consider carbon footprints and/or regional differences still have high research value. To help people prepare appropriate food and drink, in this paper we develop an optimization model aiming at generating suitable diet lists with required calories conform to practical needs. A mathematical programming is employed to solve the optimization problem and help people find possible and feasible solutions. To investigate the influences of different parameters on the results, a variety of experiments were performed under different scenarios.

The remainder of this paper is organized as follows. The problem is introduced in Sect. 2. Subsequently, the proposed approach is presented in Sect. 3. Some experimental results and discussion are addressed in Sect. 4. Finally, concluding remarks are drawn in Sect. 5.

2 The Problem

Given some personal data such as gender, age, and the level of physical activity, the problem concerned here is to help people to find an optimized diet list which is composed of a variety of food and drink from a considerable amount of candidate ones with the objective that the sum of calories of all the selected items is equal to the required quantity for the person. Moreover, a number of constraints must be satisfied, which include "How many items can be selected for each category?" "How many items can be selected for diet lists?" "How many fruit and vegetable should we take every day?" and more.

To elaborate the problem and to facilitate the description, we define some variables as follows. Let $M = \{1, 2, \ldots, m\}$ be a set of categories of candidate items, where m is the total number of categories. For each category i, there are n_i candidate items, which are different in general. The total number of candidate items is designated as n_{tot}. The calories and the carbon footprint of item j in category i are represented by K_{ij} and C_{ij}, respectively. In addition, the required amount of calories for a person is denoted as $Kreq$; The emitted limit for the greenhouse gas is $(CO_2)_{\mathrm{lmt}}$; The decision variable is represented by x_{ij}.

Objective function:

The objective is to minimize the difference between the required amount of calories $Kreq$ for a person and the sum of calories of all the selected items, as illustrated in Eq. (1).

$$\text{Minimize} \quad Z = Kreq - \sum_{i=1}^{m} \sum_{j=1}^{n_i} K_{ij} x_{ij} \tag{1}$$

Subject to:

(1) Calorie constraint

$$\sum_{i=1}^{m}\sum_{j=1}^{n_i} K_{ij}x_{ij} \le Kreq \quad i = 1, \ldots, m;\ j = 1, \ldots, n_i \tag{2}$$

(2) Carbon footprint constraint

$$\sum_{i=1}^{m}\sum_{j=1}^{n_i} C_{ij}x_{ij} \le (CO_2)_{\text{lmt}} i = 1, \ldots, m; = 1, \ldots, n_i \tag{3}$$

(3) Constraint of number of items in each category

$$(A_L)_i \le \sum_{j=1}^{n_i} x_{ij} \le (A_U)_i \quad i = 1, \ldots, m \tag{4}$$

(4) Constraint of the total number of selected items

$$N_L \le \sum_{i=1}^{m}\sum_{j=1}^{n_i} x_{ij} \le N_U \quad i = 1, \ldots, m; j = 1, \ldots, n_i \tag{5}$$

(5) Constraint of number of fruit plus vegetable

$$\sum_{i=1}^{m}\sum_{j=1}^{n_i} x_{ij} \ge V_{tot} \quad i = 1, \ldots, m;\ j = 1, \ldots, n_i \tag{6}$$

(6) Variable constraint

$$x_{ij} = \begin{cases} 1 \ \textit{if the item is selected}, \\ 0 \ \textit{otherwise} \end{cases} \tag{7}$$

where $(A_L)_i$ and $(A_U)_i$ are the lower and upper bounds of category i. To ensure that diet lists can include all categories, $(A_L)_i$ is generally set to be one. On the contrary, if a category is disliked by a person, its value can be set to be 0. For example, if a person is vegetarian, the lower and upper bounds of the category contain meat can be set to be 0 in Eq. (4). Likewise, if a candidate item is unacceptable by a person, x_{ij} can be set as 0. The sum of calories of all the selected items is not greater than the required amount of calories $Kreq$ for a person, as depicted in Eq. (2). Similarly, as illustrated in Eq. (3), the sum of emitted amount of CO_2 of all the selected items is not greater than the required amount of calories $(CO_2)_{\text{lmt}}$. Equation (5) requires that the total number of the selected items is between N_L and N_U. Equation (6) requires the number of fruit plus vegetable is not less than a number V_{tot}. The decision variable is x_{ij}, being either 0 or 1. If the i^{th} category of items and its j^{th} item is selected, $x_{ij} = 1$, as shown in Eq. (7).

3 The Proposed Approach

To obtain optimized diet lists, a decision mechanism is proposed, as shown in Fig. 1. The mechanism is composed of three stages.

At the first stage, the required data for generating diet lists are collected and/or calculated. Three main categories of data are needed: the managerial objective and user's needs, the required calories for a person, the amounts of calories and the carbon footprints of all the candidate items.

3.1 Objective and User's Needs

To stay healthy, basically, the daily calories intake should be equal to the required amount. Therefore, the objective is to minimize the difference between intake and requirement. Furthermore, some other constraints must be satisfied according to personal features, such as age, gender, and levels of activities, and more. The user's needs are collected first and accordingly suitable diet lists can be optimally generated.

3.2 The Required Calories

The required amount of calories for a person depends on gender, age, and the level of physical activity, as illustrated in Table 1 [4]. Once the gender, age, the activity level are known, the required amount can be obtained from the table. In general, an average male needs more calories than an average female with the same age. In addition, the 19–30 age group requires the most amount.

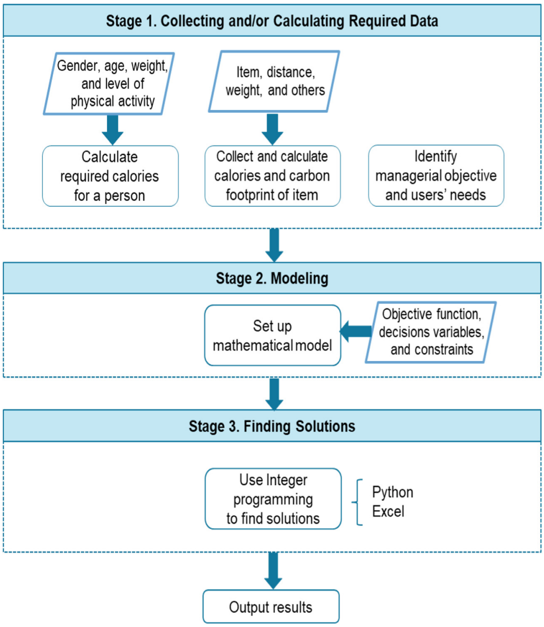

Fig. 1. The decision mechanism for the diet list optimization problem.

Table 1. Required amounts of calories for various gender and age groups at different levels of physical activity [4].

Gender	Age(years)	Sedentary	Moderately Active	Active
Child	2–3	1,000	1,000–1,400	1,000–1,400
Female	4–8	1,200	1,400–1,600	1,400–1,800
	9–13	1,600	1,600–2,000	1,800–2,200
	14–18	1,800	2,000	2,400
	19–30	2,000	2,000–2,200	2,400
	31–50	1,800	2,000	2,200
	51 +	1,600	1,800	2,000–2,200
Male	4–8	1,400	1,400–1,600	1,600–2,000
	9–13	1,800	1,800–2,200	2,000–2,600
	14–18	2,200	2,400–2,800	2,800–3,200
	19–30	2,400	2,600–2,800	3,000
	31–50	2,200	2,400–2,600	2,800–3,000
	51 +	2,000	2,200–2,400	2,400–2,800

3.3 The Calories and the Carbon Footprint

The amount of calories of each item can be obtained from a lot of literature. In this paper, our calories data are mainly based on the literature [16]. As for the carbon footprint, some data of candidate items can be directly obtained from a few databases or literature [17–20], while a number of data need to evaluate by some calculators [21–23]. Though there are some calories data, the carbon footprint data are still lack for many foods or drinks, causing the number of data for experiments to be limited.

At the second stage, a mathematical model is set up. The practical problem is formulated based on the managerial objective and the needs of users, as expressed in Sect. 2.

At the third stage, integer programming is employed to solve the optimization problem. To facilitate the operation of integer programming, the minimizing problem is transformed into a maximizing problem first. Subtracting *Kreq* on the both sides of Eq. (1), we obtain

$$Z - Kreq = -\sum_{i=1}^{m}\sum_{j=1}^{n_i} K_{ij}x_{ij} \tag{8}$$

Since *Kreq* is intrinsically a constant once age, gender, and the level of activity are given, the problem of minimizing Z is equivalent to the problem of minimizing Z - *Kreq*. Therefore, we have.

Minimizing $Z \cong$ Minimizing (Z – *Kreq*)

$$\cong \text{Minimizing}\left(-\sum_{i=1}^{m}\sum_{j=1}^{n_i} K_{ij}x_{ij}\right)$$

$$\cong \text{Maximizing}\left(\sum_{i=1}^{m}\sum_{j=1}^{n_i} K_{ij}x_{ij}\right) \tag{9}$$

After transformation, we employ integer programming to solve the problem. The steps include:

(1) construct the objective function
(2) set the decision variables
(3) set the constraints
(4) input the required data for diet lists
(5) solve and find the solutions

In this paper, we use Python and Excel Solver to solve the integer programming problem. Excel Solver is easy to use. However, the standard Microsoft Excel Solver has a limit of 200 decision variables for both linear and nonlinear problems. For a larger size problem, we use Python to get solutions.

4 Results and Discussion

To investigate the influences of different factors on the results, a reference case was set up. The reference case was based on real personal needs. The calories data were mainly collected from a health-related website to conform to the localized needs [16]. There are seven categories of food and drink: staple food, meats and protein, soy and milk, vegetables, fruits, dessert, bread, and snacks, and beverages, as shown in Table 2. Each category is composed of different number of items ranging from 15 to 36. The lower and upper bounds of the total number of selected items N_L and N_U are set to be between 11 and 20, respectively. The required amount of calories is 2,200 kcal, based on a 20 years-old male person with a moderate activity level. The total number of candidate items is 147.

Table 3 shows part of the data of the candidate items. These data are aggregated into an Excel worksheet to facilitate the entry into the Python program.

Table 4 shows the results with different N_L and N_U values. From the table we may see that the results apparently depend on lower and upper bounds of the total number of selected items. If the total number is set to be too small, an infeasible solution will be given. To ensure that feasible solutions can be obtained, the total number of selected items should be set large enough. In addition, to be more friendly to the environment, one needs to changes the lower and upper bounds and makes a number of experiments to get solutions with lower CO_2 emission. As we can see, the lowest CO_2 emission occurs at $N_L = 16$ (or 17) and $N_U = 20$.

A typical diet list generated by the program is shown in Fig. 2. Given the desired constraints, the list is generally produced in a short time. The experiments were performed under different need scenarios and all the solutions are satisfying.

Given a lower value of $(CO_2)_{lmt}$, the results are different, indicating that the solutions depend on the allowed amount of emitted CO_2. Similarly, to obtain feasible solutions, the

Table 2. The categories and their item number at the reference case [16].

	Category	Number of items, n_i	Lower bound, A_L	Upper bound, A_U
1	Staple food	16	2	3
2	Meats and protein	25	1	3
3	Soy and milk	15	1	3
4	Vegetables	18	2	5
5	Fruits	20	2	5
6	Dessert, bread & snacks	17	1	2
7	Beverages	36	1	2

Table 3. Required information related to items.

	Name	Unit	Weight (g)	Calories (kcal)	CO_2 (kg)
A01	Rice	bowl	205	225	0.096
A02	Pasta	serving	248	330	0.160
A03	White bread	piece	25	75	0.058
A04	Mashed Potatoes	piece	100	178	0.054
⋮			⋮	⋮	⋮
A15	Lunch box	serving	500	700	1.0

total number of selected items cannot be too small. On the other hand, the best solution for different values of N_L and N_U occur at $N_L = N_U = 13$ (Tables 5 and 6).

As the number of candidate items increases, the results seem better than the small-sized ($n_{tot} = 147$) case. The emission amounts of CO_2 are generally smaller for $n_{tot} = 234$. Note that part of the carbon footprint data are simulation data since the collected real data are limited.

Table 4. The results with different values of N_L and N_U for ntot = 147 and $(CO_2)_{\text{lmt}} = 5.63$.

N_L	N_U	**Calories (kcal)**	**CO2 (kg)**
10	10	infeasible	
11	11	2,200	5.054
12	12	2,200	3.538
13	13	2,200	4.332
14	14	2,200	3.670
15	15	2,200	5.534
16	16	2,200	4.639
17	17	2,200	5.585
18	18	2,200	5.375
19	19	2,200	4.815
20	20	2,200	2.948
10	20	2,200	3.105
11	20	2,200	3.105
12	20	2,200	3.105
13	20	2,200	3.105
14	20	2,200	3.105
15	20	2,200	3.105
16	20	2,200	**2.914**
17	20	2,200	**2.914**
18	20	2,200	3.000
19	20	2,200	4.647

Special notice must be taken is that all the solutions are based on using the total amount of calories as an objective function, causing the total quantity of CO_2 emission depends apparently on the lower and upper bounds of items. To ensure that diet lists with more stable and lower total quantity of CO_2 emission are produced, one may use the total quantity of CO_2 emission as an objective function instead. Some results with using the total quantity of CO_2 emission are shown in Table 7.

Table 5. The results with different values of N_L and N_U for $n_{tot} = 147$ and $(CO2)_{lmt} = 2.89$.

N_L	N_U	**Calories (kcal)**	**CO2 (kg)**
10	10	infeasible	
11	11	2,200	2.050
12	12	2,200	2.862
13	13	2,200	**2.035**
14	14	2,200	2.828
15	15	2,200	2.776
16	16	2,200	2.306
17	17	2,200	2.614
18	18	2,200	2.887
19	19	2,200	2.877
20	20	2,200	2.798
11	20	2,200	2.612
12	20	2,200	2.612
13	20	2,200	2.612
14	20	2,200	2.612
15	20	2,200	2.887
16	20	2,200	2.869
17	20	2,200	2.836
18	20	2,200	2.779
19	20	2,200	2.886

A table-based input mode facilitates regeneration of a diet list and is very suitable to multi-objective selection. If one does not like a specific item in the diet list generated by the program, just setting the lower and upper bounds of this item to be 0 and rerunning the program, a new result will be generated in a few seconds. Note that some additional attributes can be added to generate more personalized results. For example, some people are vegetarians, while some other persons refuse to eat pork. By changing the bounds, the satisfactory solutions can be produced quickly.

麥當勞可樂1兒童杯82卡;
健怡可樂1罐350克4卡;
黑咖啡1杯250克1卡;
丹麥奶酥餅乾1份30克148卡;
蘋果派1塊135克345卡;
冰淇淋1杯173克375卡;
雞腿麵1碗500卡;
芒果1個100卡;
哈密瓜1片240克60卡;
青椒1個74克15卡;
香菇1把70克20卡;
豆芽菜1把125克35卡;
全脂牛奶1杯244克150卡;
羊肉1片85克235卡;
燕麥喜瑞爾(熱食)1杯240克130卡;

Fig. 2. A typical diet list with $N_L = N_U = 14$.

Table 6. The results with different values of N_L and N_U for $n_{tot} = 234$ and $(CO_2)_{lmt} = 5.63$.

N_L	N_U	**Calories (kcal)**	**CO2 (kg)**
10	10	infeasible	
11	11	2,200	3.049
12	12	2,200	2.350
13	13	2,200	3.435
14	14	2,200	1.851
15	15	2,200	**1.735**
16	16	2,200	1.974
17	17	2,200	2.992
18	18	2,200	3.624
19	19	2,200	3.902
20	20	2,200	3.247
10	20	2,200	2.634
11	20	2,200	2.634
12	20	2,200	2.634
13	20	2,200	2.634
14	20	2,200	2.634
15	20	2,200	2.634
16	20	2,200	2.634
17	20	2,200	2.634
18	20	2,200	2.634
19	20	2,200	2.634

Table 7. The results with different values of $N_L$and N_U for $n_{tot} = 147$ and $(CO_2)_{\text{lmt}} = 5.63$. Note that the objective function is the total quantity of CO_2 emission.

N_L	N_U	**Calories (kcal)**	**CO2 (kg)**
11	11	2,193.9	0.457
12	12	2,190.9	**0.439**
13	13	2,191.8	0.449
14	14	2,195.0	0.465
15	15	2,191.9	0.509
10	15	2,190.9	**0.439**

5 Conclusions

In this study, we have developed an optimization model to deal with the diet list problem. The carbon footprint as well as the calories related to diet are considered in the model. Integer programming is employed to help users find solutions and compose suitable diet lists. A variety of experiments have been performed under different scenarios. Results from this study shows that the proposed approach we developed can provide good solutions satisfying personal needs. In addition, better diet lists with lower CO_2 emissions can be obtained as the number of candidate items increases. When using the amount of calories as an objective function, the solutions depend considerably on the bounds of items.

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