A Study on Menu Planning Method for Managed Meal -Consideration of the Cost of Ordering Ingredients-

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Abstract. Japan's aging is rapidly progressing, and it is important to extend healthy life expectancy considering the increase in social security costs such as medical expenses and long-term care benefits and the decline of local cities. Nutritional management is considered to play a major role in extending healthy life expectancy. This study focuses on the menu plan for managed meals provided by hospitals or nursing homes. This study has proposed a menu planning method using Genetic Algorithm for 30 days (90 meals) in consideration of the order of provision so as not to get tired of a meal. This paper proposes a menu planning method that takes into account not only the variety of meals but also the cost of ordering ingredients.

Keywords: Genetic Algorithm · Menu Planning · Managed Meal

1 Introduction

In Japan, the aging is rapidly progressing, and the average life expectancy is expected to further increase. By 2025, households with only elderly people aged 65 and over are expected to account for more than a quarter of all households. Considering the increase in social security costs such as medical and nursing care benefits and the decline of local cities, it is important to extend healthy life expectancy. Improving the quality of nutrition assessment and management of the people leads to maintenance and promotion of health, prevention and severity of lifestyle-related diseases, and prolongs healthy life expectancy. In this research, the menu of meals provided in hospitals and nursing homes (hereinafter called managed meal) has been focused on. The requirements for menus of managed meal are following[2].

- Three meals a day, long-term (4 or 6 weeks) menu planning
- To take into account changes and duplication of foods so that the meal can be enjoyed

- To adjust the nutrient amount based on the dietary intake standards[3] and the nutrient amount depending on the disease state
- To take into account food costs

Dietitians have prepared menus that take the above into account, but it is difficult to consider all of them by using only their experience and intuition. Therefore, the purpose of this research is to automate planning menus for managed meal.. This study extended the method of the previous study[4] and has proposed a menu planning method that considers three points of "long-term menu," "change and duplication of food," and "nutrition management," and has verified its effectiveness. This paper proposes a menu planning method that takes into account not only above three points but also the cost of ordering ingredients. The less the types of ingredients used, the lower the cost of ingredients, while it is difficult to have variations in the menu. Therefore, this paper confirms that there is actually a trade-off relationship by conducting experiments while changing the severity of restrictions on food costs. Nutrition management is intended for low-salt food, taking into account salt and calories. The upper limit of the salt amount is the amount recommended by the Japanese Society for Hypertension[5]. The target amount of energy shall be the value specified in the dietary intake standard[3].

2 Menu planning using genetic algorithm

2.1 Database of dishes

The databese of dishes is created from the recipe site "Delicious Health: Delicious Daily Food and Health Management"[6], and the number of dishes registered in the database is 300. The information of each dish data is as follows.

- Index numbers assigned to the dish (1-5: staple for breakfast, 6-10: staple for lunch/dinner, 11-50: staple for breakfast, 51-160: staple for lunch/dinner, 161-1200: breakfast side dishes, 201-300: lunch and dinner side dishes)
- Name of the dish
- The amount of salt and energy contained in the dish
- Numbers that represent the characteristics of the dish

In consideration of variations in the characteristics of the dishes, the characteristics of the main and side dishes are quantified as follows. Staple foods are not considered in this study because they have few features.
The characteristics of the main dish are quantified as shown below.

Characteristic 1 (genre of dishes)
1：Japanese 2：Western 3：Chinese
Characteristic 2 (foodstuff)
1：Pork/Beef 2：Chicken 3：Fish 4：Other
Characteristic 3 (cooking method)
1：Grilling 2：Stewing 3：Frying 4：Stir frying 5：Other

The characteristics of the side dish are quantified as shown below.

Characteristic 1 (genre of dishes)
1 : Japanese 2 : Western 3 : Chinese
Characteristic 2 (vagetable genre)
1 : Fruit vegetables 2 : Leaf vegetables 3 : Root vegetables 4 : Other
Characteristic 3 (cooking method)
1 : Raw 2 : Dressing/Pickling 3 : Frying 4 : Poaching/Stir frying

2.2 Genetic Algorithm

The flow of the genetic algorithm (GA) in this study is shown below.

Step1 Generate individuals randomly. If there is a constraint violation, the individual is discarded, and the individual is regenerated until the predetermined number of individuals is obtained.
Step2 Calculate the evaluation value of the individual.
Step3 If the number of generations has not been reached, go to step 4. If it has, end.
Step4 Individuals to leave for the next generation are selected according to the evaluation value of each individual. At that time, the best individual in that generation remains in the next generation.
Step5 Two individuals are selected at random, and uniform crossover is performed with a certain probability. If a constraint is violated, the individual is discarded and crossover is performed until a predetermined number of individuals are obtained.
Step6 Mutation is performed for each individual with a certain probability. If there is a constraint violation, the mutation is repeated until the individual has no constraint violation. Return to step 2.

Regarding gene coding, genes are arranged in the order of staple food for breakfast, main dishes for breakfast, side dishes for breakfast, staple food for lunch, main dishes for lunch, side dishes for lunch, staple food for dinner, main dishes for dinner and side dishes for dinner. The genes in each of these nine categories are ordered in the order of dishes served on day 1, day 2, day 3, ..., day 30, respectively. Each gene has a corresponding index numbers assigned to the dish.

2.3 Evaluation value calculation

Based on the evaluation calculation method in the previous study[4], the entropy of the moving section that measures the variation in the order of appearance of each feature of the main and side dishes is calculated. The sum of these values and the ratio of the genres (Japanese, Western and Chinese) of the main dish and side dish in one meal is used as the evaluation function, and the calculated value is used as the evaluation value of the genetic selection. The calculation of the entropy of each feature is the number of items of the feature. The following shows the formulas and the meaning of the characters in the formulas.

$$H = \sum_{m=1}^{M} \sum_{i=1}^{I} \frac{H_{m,i}}{H^*_{m,i}} + G \tag{1}$$

$$H_{m,i} = -\frac{1}{T_{m,i} - J|_{m,i} + 1} \sum_{t=1}^{T_{m,i}-J|_{m,i}+1} \sum_{j|_{m,i}=1}^{J|_{m,i}} P_{j|_{m,i}}(t) \log P_{j|_{m,i}}(t) \tag{2}$$

$$P_{j|_{m,i}}(t) = \frac{1}{J|_{m,i}} \sum_{p=0}^{J|_{m,i}-1} \alpha_{j|_{m,i}}(t+p) \tag{3}$$

$$T_{m,i} = D + 2(J|_{m,i} - 1) \tag{4}$$

$$G = \frac{\sum_{d=1}^{D} \beta_t}{D} \tag{5}$$

- $m = 1, 2$: Type of dish (1: main dish, 2: side dish)
- $i = 1, 2, ..., I$: Characteristic of dish
- $j|_{m,i} = 1, 2, ..., J|_{m,i}$: Items of characteristic i where the type of dish is A
- $t = 1, 2, ..., T_{m,i}$: Gene ordinal numbers rearranged at the time of calculating the evaluation values for dish type m and characteristic i
- $P_{j|_{m,i}}$: Serving frequency ratio in one section from t for dishes with characteristic $j|_i$ of type m
- $\alpha_{j|_{m,i}}(t)$: 1/0 binary variable indicating the provision / non-supply of a dish with a feature $j|i$ of a dish type m in t
- β_t : 1/0 binary variable indicating the genre of main and side dishes in t is the same / not the same
- $H_{m,i}$: Average of entropy of characteristic i of all sections of dish type m
- $H^*_{m,i}$: Maximum value of $H_{m,i}$
- H : Sum of $H_{m,i}$ divided by $H^*_{m,i}$
- $d = 1, 2, ..., D$: Ordinal number of meal in menu planning
- G : Rate of total meals that have the same genre of main and side dishes (Japanese, Western and Chinese)

In the entropy calculation of Equation (1), because the evaluation value of the main dish and the side dish are calculated separately, they are rearranged in the order of appearance separately. In addition, in order to consider the boundary conditions, the entropy calculation is performed by adding, at the beginning and the end, dishes that are one less than the number of feature items; additional dishes are not included in the menu.

2.4 Constrains

Equation (6) shows a constraint equation regarding the amount of salt. Equation (7) shows a constraint equation regarding the amount of energy. Equation (8) shows the constraint equation relating to the cost of ordering ingredients.

The ordering cycle shall be 5 days, and the ingredients shall be ordered at the beginning of each period in 1 to 6 periods.

$$\sum_{l=1}^{L} s_l < S \tag{6}$$

$$\frac{|E - \sum_{l=1}^{L} e_l|}{E} \leq \delta \tag{7}$$

$$\frac{1}{N} \sum_{k=1}^{K} \sum_{f \in F_k} n_{k,f} P_f \leq C \tag{8}$$

$$n_{k,f} = \underset{n \in \mathbb{N}, nR_f > w_{k,f} - s_{k,f}}{\arg\min} \; nR_f - (w_{k,f} - s_{k,f})$$

l is the locus, s_l is the amount of salt contained in the dish with the dish number of the locus l, e_l is the amount of energy contained in the dish with the dish number of the locus l, and S is the upper limit of salt intake in 30 days , E is the target value of energy intake, and δ is the difference between the target value of energy intake and energy intake. N is the number of meals served, k is the ordering period, F_k is the set of ingredients required for menu in the k period, $w_{k,f}$ is the weight required for the k period of the ingredients f, $s_{f,k}$ is the weight of ingredient f in stock during k period, R_f is the minimum lot of ingredients f, P_f is a lot ordered in the k period of ingredients f, P_f is the purchase price of the minimum lot of ingredients f, and C is the upper limit of the quantity of ingredients ordered per person. Ingredient purchase price data (minimum lot and its price) is created with reference to “M-Mart Co., Ltd.[7]” .

3 Computer experiments

3.1 Experimental conditions

In the experiment, the cooking data described in section 2.1 is used. To meet the salt requirement of less than 6 grams per day recommended by the Japanese Society for Hypertension[5], the salt intake in 30 days is less than 180 grams ($S = 180$). The target amount of energy is 66000 kcal ($E = 66000$), which is defined as the estimated energy requirement for men aged 70 and over based on dietary intake standards[3]. Restrictions are set so that the error between the energy intake and the target value is within $\pm$ 5% ($\delta = 0.05$). Three cases are performed in the experiments; in the case where there is no restriction on food costs, the case where the value of C (upper limit of the order quantity of food per person) is set to 18000 and the case where it is set to 20000. The experiments were performed 10 times. Regarding the parameters in GA, the population is set to 300, the number of generations is 10000, the selection method is tournament selection, the crossover method is uniform crossover, the crossover rate is 0.9, and the mutation rate is 0.1.

3.2 Experimental results

Table 1 summarizes the average evaluation values H and the value of the food cost per person in 10 trials when there is no restriction on the food ordering cost, C is 20000, and C is 18000. A menu is obtained in which the cost of ordering

Table 1. Experiment result

C	H	Cost per person
no constraint	4.86	21221.48
20000	4.50	19208.00
18000	4.22	17768.09

ingredients is within the set upper limit. In addition, the constraints on salt content and energy content were satisfied in all cases, and high evaluation values were obtained. In other words, a menu satisfying the points that "similar dishes do not last" and "the amount of nutrition required" was obtained. However, the more restrictive, the lower the evaluation value, confirming that the variety of menu dishes is lost. In order to reduce the cost of ordering ingredients, it is effective to reduce the types of ingredients used, so that the variety of dishes is lost.

4 Conclusion

This paper proposed a 30-day menu planning method for managed meals provided at hospitals and nursing homes, taking into account the order of serving so as not to get tired of meal, nutrition, and food ordering costs. As results of a computer experiments, a menu was obtained in which the cost of ordering food was kept within the set upper limits. However, it was confirmed that the entropy, which is the evaluation value, became lower as the constraints became stricter. As a future task, it is necessary to create a menu that keeps the variety of dishes and reduces the cost of ingredients. Since there is a trade-off between food ordering cost and variety of dishes, it is considered effective to define the food ordering cost as an objective function and solve it as a multi-objective optimization problem.

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