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APPLICATION OF THE SIMPLEX METHOD TO CREATE A WEEKLY MENU PLANNER

– Short communication –

Emil HADZHIKOLEV, Stanka HADZHIKOLEVA[1]

Plovdiv University "Paisii Hilendarski", Bulgaria, Department of Mathematics and Informatics

Abstract: Organized meals for different groups - students, servicemen, employees working in specific businesses and organization of work - is invariably care for people's health. An important task in this process is the preparation of menu plans that correspond to the norms for full, balanced and healthy nutrition for the respective age group and working conditions. They must provide the energy and nutrients necessary for the organism - proteins, carbohydrates, vitamins, fats (of animal and plant origin), etc. In some cases, menu planning must be consistent with the use of available food products or the use of interchangeable or similar foods. Problems arise when it comes to assessment and proving compliance with the quality and quantity standards of the products in the weekly menu plan. A commonly used solution is through the formal substitution of food products from the menu plan with the basic products defined by the norms. The mathematical model we offer creates an optimal solution that leaves minimal quantities of unchanged products.

Keywords: simplex method, weekly menu, weekly menu planner, organized eating

1. INTRODUCTION

To ensure a balanced and healthy diet, some governmental structures and private organizations set up organized group meals. In general, for this purpose there are established conditions, rules and norms, often governed by regulations and laws. A typical example of this is the Ministry of Defense of the Republic of Bulgaria, where the conditions for providing free food to the servicemen, the Bulgarian Army and the students in the higher schools are regulated by law (Ordinance №H-5 / 2 April 2015, Ministry of Defense). Free meals are also provided to workers and employees who work in enterprises of specific nature and organization of work, for example – underground mine workers, ship crews, divers, people working in the extraction and processing of ferrous and non-ferrous metals, laboratories dealing with biological agents, people working at very high or very low average daily temperatures, etc. (Ordinance № 11 / 21 December 2005, Ministry of Health).

The menu planner defines the meals consumed by a certain organized group in a certain period, usually one week, as well as the amounts of products in them. The groups for which menu planners are created are homogeneous - children (in kindergartens and schools), students, military officers, vacationers in recreation centers etc. The menu plan must be in accordance with the norms for a balanced and healthy nutrition for the respective age group, and the meals' ingredients should provide the energy and nutrients necessary for the organism - proteins, carbohydrates, vitamins, fats - of animal and plant origin. Organized meals are planned by following science-based standards for the use of specific products and their amounts in the weekly menu. In Bulgaria, for instance, a special regulation and annexes for it stipulate specific rules on the Bulgarian army diet, including the recommended daily amounts of basic food products for various types of army units and additives in case of certain activities (Ordinance №H-5 / 2 April 2015, Ministry of Defense).

Numerous studies and analysis conducted over the past decade show a steady trend towards unhealthy eating patterns. In the annual report of 2015 on the state of Republic of Bulgaria citizens' health (Annual Report, 2015), alarming conclusions are drawn about the dietary intake: low energy share of carbohydrates and a high share of fats; risk of deficiency of vitamins (A, B1, B2) and minerals - calcium, magnesium, zinc and iron; high daily sodium intake, and so on. Similar conclusions were made about the

[1] Corresponding author. E-Mail address: stankah@gmail.com

diets of servicemen (Glushkov et al., 2016), students (Birdanova et al., 2012) etc.

On the other hand, researches for development of new food products are constantly being conducted. Studies are made on the possibilities for developing low-fat products and the advantages of their use (Tufeanu and Tita, 2016), the creation of quality gluten-free food products (Nour et al., 2017), the use of low-carb sweeteners (Weiffert, 2018), optimization of processes for the creation and processing of food products (Malekjani and Jafari, 2018) (Ignatova et al., 2009) and so on. The use of appropriate quantities of natural oils and extracts as spices against pathogens and preservatives increases the food quality while not affecting the amount of essential nutrients - proteins, fats and carbohydrates (Teneva et al., 2016) (Mureșan, 2015).

One of the main reasons for not complying with the established eating standards and norms is the difficulty of creating well-balanced menus. In general, regulations on the organization of group eating do not define specific menus, but only list the recommended daily amounts of basic food products (for example, about 30). Additionally, random products may be present in the meals prepared according to certain recipes, including ones outside the approved list. The task is further complicated by the fact that, in some cases, the created menu plan must be in compliance with the use of available food products.

The pursuit of balanced nutrition motivates the creation of software applications that facilitate the planning process. The existing menu planner apps are primarily aimed at single users and offer the option of self-planning the menu based on pre-set recipes. They provide features such as standard weekly plans (Cook Smarts App), management of preferred recipes (Pepperplate App), easy creation of user menu plans (Plan to Eat App), and recommendations for preparing recipes. Some of the apps provide information about the calories, fat, sugar, salt and other characteristics of the ingredients found in the recipes (Tesco Real Food App). The apps reviewed do not allow the user to evaluate and modify the products in specific recipes with other similar products.

When making a menu plan, the question arises as to whether the menu plan is relevant to the respective established norms and requirements. ***One possible solution to this task is to equate the amounts of the menu products in the most optimal way to the recommended amounts of basic products.*** This would allow the evaluation of which basic food products are less and which are more than needed - and make further corrections in the menu plan.

To solve this task, we need data on the main composition (proteins, fats, carbohydrates) and energy value of specific food products, as well as data on groups of interchangeable products. For each product in a menu, specific coefficients can be set for its exchange with the basic recommended products (if this information is not explicitly regulated). Thus, the task is limited to the optimal selection of basic products to equate the menu products to, leaving minimal amounts of basic products not equated to menu products.

To solve the problem, in this paper we apply the simplex method, making some appropriate transformations in advance.

2. PROBLEM SETTING

Data given:

- total ***quantities of the required products*** are determined from the weekly meal plan;
- a ***list of basic food products*** containing the recommended amounts that should be present in a daily / weekly menu plan;
- an ***expanded list of products*** that can be used when creating menus enumerating the required products and those that are available (e.g., in stock);
- a table of ***replacement coefficients*** defining the possible replacements of ***basic food products with products from the extended list***.

The problem:

Dietary standards require the use of certain quantities of basic products in the preparation of meals in a daily/weekly menu plan. Base products in turn can be replaced with other products in certain proportions (Ordinance No. H-5/2 April 2015, Ministry of Defense). The preparation of dishes for large organizations in some cases should take into account the food products available in stock and on the market. The requirement for meals to comply with predetermined standards and the need for some (unavailable) products to be replaced by other (available) products, sets the following specific optimization task: ***to determine the quantities at which products not available in the menu plan***

can be replaced by available products, so that to minimize the sum of the quantities of unreplaced products.

Reasoning:

By successive reasoning, we reach the mathematical model of the simplex method.

We define two lists of products and amounts as follows:

- ***LessProductsTable*** – *basic food products and corresponding amounts* that, according to regulations, are necessary to properly feed an individual from a particular group;
- ***MoreProductsTable*** – *products needed for the preparation of the weekly menu meals and the corresponding amounts.*

We denote with:

- ***NumLess*** – *the number of LessProductsTable products that can be replaced with MoreProductsTable products*;
- ***NumMore*** - *the number of MoreProductsTable products that can replace products from LessProductsTable*.

Using the table of product exchange coefficients, *we create a table of possible exchanges: PossibleExchangesTable* for the evaluated menu plan containing these *LessProductsTable* products that can be replaced with *MoreProductsTable* products. In this table we record all possible exchanges like this: *$LessProduct_j$ – $coefficient_{jk}$ – $MoreProduct_k$,* where $LessProduct_j$ is a product of the LessProductsTable list, $MoreProduct_k$ is a product of the MoreProductsTable list, $coefficient_{jk}$ is the coefficient for replacing a $LessProduct_j$ with a $MoreProduct_k$. That is, $MoreProduct_k = LessProduct_j * coefficient_{jk}$.

The main products and the products used in the meals can be found repeatedly in the respective table columns if, for example, a basic product can be replaced with several menu products having different exchange coefficients. Some menu products may not be present in the table in case no possible exchanges with basic food products are defined.

We determine the number of possible exchanges from the PossibleExchangeTable and denote it with *NumPossibleExchanges*.

As a final result, we get another table with realized exchanges: *ExchangesTable*, designed for recording how much of a basic product is exchanged for a product used in a meal from the weekly menu plan.

We apply the next solution only on the products for which possible exchanges with basic products are defined. The amounts of non-exchangeable menu products will be present in the final solution without any change.

3. MATHEMATICAL MODEL OF THE SOLUTION

For each row of the table of possible exchanges *PossibleExchangesTable*, let us denote by X_i the quantity of the relevant basic product that can be replaced with a menu product, where $i \in [NumLess + NumMore,\ NumLess + NumMore + NumPossibleExcanges]$. Thus, for example, the basic product $LessProduct_1$ of the first row in the PossibleExchangesTable will correspond to the quantity $X_{\text{NumLess+NumMore}}$. For the same row in the table, we can determine an unknown quantity of a meal product with $Y_i = X_i coeff_i$.

We introduce a function with several variables X_i:

$$(1)\quad f(X_i) = \sum_{i=NumLess+NumMore}^{NumLess+NumMore+NumPossibleExcanges} (1 + \mathrm{coeff}_i) X_i$$

It gives us the sum of all replaced quantities of basic products and menu products. The problem for finding the minimum of the remaining unexchanged quantities (which was the original purpose) is equivalent to finding the maximum of the function (1) i.e. the maximum of the sum of exchanged quantities.

To be able to apply the simplex method, we need to define limitations for the variables.

Let us remind that a basic product $LessProduct_j$ can participate in several exchanges with quantities $X_i, j \in [1, NumLess]$ and $i \in [NumLess + NumMore,\ NumLess + NumMore + NumPossibleExcanges]$.

Similarly, $MoreProduct_k$ can participate in several exchanges with quantities $Y_i, k \in [1, NumMore]$, and $i \in [NumLess + NumMore,\ NumLess + NumMore + NumPossibleExcanges]$.

We write *NumLess* limitations which specify that the sum of the exchanged quantities for one basic product with menu products cannot exceed the recommended amount of this product:

$$(2)\ X_{j1} + X_{j2} + \cdots + X_{jm_j} \leq QuantityLessProduct_j, j \in [1, NumLess]$$

For each $LessProduct_j$ product, m_j is a numeral defining the number of times the product exists in the table of possible exchanges: *PossibleExchangesTable*. It's obvious that $\sum_{j=1}^{NumLess} m_j = \text{NumPossibleExchanges}$.

Similarly, for the *MoreProducts* we write *NumMore* limitations which specify that the sum of the quantities of a menu product cannot exceed the quantity specified in the recipes:

$$(3)\ coeff_{k1}X_{k1} + coeff_{k2}X_{k2} + \cdots + coeff_{kn}X_{kn_k} \leq QuantityMoreProduct_k, k \in [1, NumMore]$$

In (3), $coeff_{ki}X_{ki}$ is the quantity of product Y_{ki} in the meals, expressed by the quantity of a relevant basic product and the exchange coefficient. For each $MoreProduct_k$ product, n_k is a numeral defining the number of times the product exists in the table of possible exchanges *PossibleExchangesTable*.

$\sum_{k=1}^{NumMore} n_k = NumPossibleExchanges.$

We convert the constraints (2) and (3) into a form suitable for the simplex method. They can only be expressed through equations. For this purpose, to the left-hand side of each equation we add one more variable $X_i, i \in [0, NumLess + NumMore]$. The limitations now become (2^l) and (3^l):

$$(2^l)\ X_{j-1} + X_{j1} + X_{j2} + \cdots + X_{jm_j} = QuantityLessProduct_j, j \in [1, NumLess]$$

$$(3^l)\ X_{k+NumLess-1} + coeff_{k1}X_{k1} + coeff_{k2}X_{k2} + \cdots + coeff_{kn}X_{kn_k} = QuantityMoreProduct_k,\ k \in [1, NumMore]$$

Then the function (1) becomes (1^l), where the multiplier in front of X_i is 0 for $i \in [0, NumLess + NumMore]$:

$$(1^l)\ f(X_i) = \sum_{i=0}^{NumLess+NumMore+NumPossibleExcanges} (1 + \text{coeff}_i)X_i,$$

$$(1 + coeff_i) = 0\ \forall\ i \in [0, NumLess + NumMore), i.e. coeff_i = -1$$

We add one more system of limitations to express the fact that the unknown quantities are non-negative numbers:

$$(4)\ X_i \geq 0, i \in [0, NumLess + NumMore + NumPossibleExchanges]$$

We apply the simplex method to find a maximum of the function (1^l) at limitations (2^l), (3^l) and (4), with which the initial problem of finding a minimal remainder of unexchanged quantities of basic products and menu products is solved. Here, it should be noted that the problem always has a solution - if, for example, no exchange is made, the maximum of the function will be 0.

In most cases, there is only one solution to the problem. The problem can also have countless solutions if there are matching exchange coefficients for one basic product with several menu products. Even if only one basic product can be replaced by two menu products with the same exchange coefficient, we can easily get another solution by changing the quantities exchanged for these two products, but leave their sums equal. Then any convex combination of two solutions is a solution. For the final solution of the problem in this case, the specific exchanges do not matter.

4. SIMPLE EXAMPLE

For clarity, we will illustrate the proposed solution with a small simplified example. Let's say we have defined the lists of basic products LessProductsTable (Table 1) and meal products MoreProductsTable (Table 3). Respectively, NumLess = 10 and NumMore = 12.

The products are presented in Tables 1 and 3 with their names, amount in grams, and numeric identifier. Table 2. PossibleExchangesTable shows the possible exchanges of only the products present in the first two tables, 18 altogether - *NumPossibleExchanges* = 18. In the first column of the three tables, we use common numbering that we also refer to in the subsequent calculations. It can be seen that some products in columns *lessId* and *moreId* of *PossibleExchangesTable* are present more than once.

We create the function (1) or (1^l), whose maximum we're looking for, as well as the equations (2^l) and (3^l), which we show only partially:

$$(1)\ f(X_{22},\dots,X_{39}) = (1+0.5)X_{22} + \dots + (1+0.80)X_{39}$$

$$(1^l)\ f(X_0, X_1,\dots,X_{21},X_{22},\dots,X_{39}) = 0X_0 + 0X_1 + \dots + 0X_{21} + (1+0.5)X_{22} + \dots + (1+0.80)X_{39}$$

(2^l) $X_0 + X_{22} + X_{23} + X_{24} = 450$ – quantities taking part in exchanges, for a basic product with lessId =1

$X_1 + X_{25} + X_{26} + X_{27} + X_{28} = 105$

…

$X_9 + X_{37} + X_{38} + X_{39} = 2470$

(3^l) $X_{10} + 0.5X_{22} = 100$ – quantities taking part in exchanges, for a meal product with moreId =40

$X_{11} + 0.66X_{23} + 0.99X_{26} = 50$

…

$X_{21} + 0.80X_{39} = 430$

We also have the conditions (4):

(4) $X_i \geq 0, i \in [0, 39]$

Obviously, under these conditions, the simplex method can be applied.

The final result in this particular example is presented in three tables - quantities of products left unexchanged (Table 4 and Table 5), as well as a table of the 14 specific optimal exchanges (Table 6).

Table 1. LessProductsTable in the beginning

№	lessId	lessQty	lessName
0	1	450	Dobrudja bread
1	2	105	White flour
2	13	200	Meat on the bone
3	14	280	Poultry meat
4	15	140	Durable sausages
5	16	280	Fish
6	19	35	Lard
7	22	20	Halva
8	23	3150	Fresh fruits

Table 2. PossibleExchangesTable

№	lessId	coeff	moreId
22	1	0.5	40
23	1	0.66	4
24	1	0.88	3
25	2	1.32	3
26	2	0.99	4
27	2	1.11	5
28	2	0.43	6
29	13	0.63	34
30	14	0.39	34
31	15	0.96	34
32	16	0.15	34
33	19	1	18
34	22	1.03	21
35	23	0.25	21
36	23	0.45	39
37	24	0.80	35
38	24	0.80	36
39	24	0.80	37

Table 3. MoreProductsTable in the beginning

№	moreId	moreQty	moreName
10	40	100	Rusk
11	4	50	Semolina
12	3	130	Dobrudja flour
13	5	130	Pastry
14	6	5	Farina
15	34	476	Canned meat
16	18	35	Vegetable oil
17	21	80	Jam
18	39	180	Canned compote
19	35	460	Canned tomatoes
20	36	210	Canned string beans
21	37	430	Canned peas

Table 4. LessProductsTable at the end

№	lessId	lessQty	lessName
0	1	26	Dobrudja bread
1	2	0	White flour
2	13	0	Meat on the bone
3	14	0	Poultry meat
4	15	0	Durable sausages
5	16	0	Fish
6	19	0	Lard
7	22	20	Halva
8	23	2430	Fresh fruits

Table 5. MoreProductsTable at the end

№	lessId	coeff	moreId
10	40	0	Rusk
11	4	0	Semolina
12	3	0	Dobrudja flour
13	5	13	Pastry
14	6	5	Farina
15	34	65	Canned meat
16	18	0	Vegetable oil
17	21	0	Jam
18	39	0	Canned compote
19	35	0	Canned tomatoes
20	36	0	Canned string beans
21	37	0	Canned peas

Table 6. ExchangesTable

lessId	lessQty	xCh	moreId
2	105	-	5
13	200	-	34
14	280	-	34
15	140	-	34
16	280	-	34
19	35	-	18
1	200	-	40
1	76	-	4
1	148	-	3
23	320	-	21
23	400	-	39
24	575	-	35
24	263	-	36
24	538	-	37

5. SOFTWARE APPLICATION

It is inconceivable to solve problems with a huge number of variables on paper. The matrix of the simplex method goes through multiple transformations and iterations until the final solution is reached. In addition, in this case, the problem must be solved repeatedly for different menu planners. To automate and accelerate the calculations, we have created a prototype of a software application implemented in the C ++ programming language.
The software application core (Figure 1) is the *Simplex* class whose role is the performing of the simplex method on input data, set as parameters, and the return of the calculations result. The *Equalize* class is used for the convertion of the user input data (which are arrays containing the initial data of the tables *LessProductsTable* and *MoreProductsTable*, as well as the data about possible exchanges in *PossibleExchangesTable*) to data appropriate for the *Simplex* class. The *Equalize* class converts the result of *Simplex* into a user-friendly type – arrays with the final data in *LessProductsTable* and *MoreProductsTable*, and the table for exchanges made *ExchangesTable.*

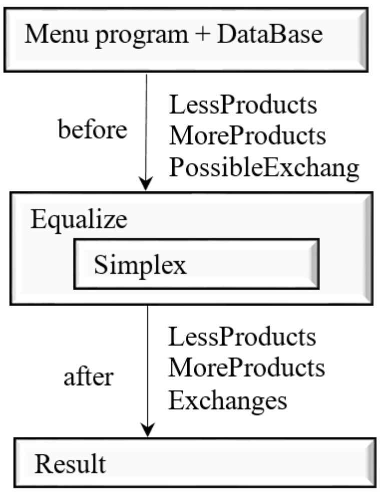

Figure 1. Model of a software tool for creating a menu

The scheme in Figure 1 shows the work process of a software application based on the prototype. The database contains the requirements for recommended amounts of basic products in the weekly menu plan, recipes made up of random products and exchange coefficients for replacing the basic products with the menu products.
When creating a weekly menu plan, data tables are automatically created for the necessary basic products *LessProducts*, the meal products *MoreProducts* and the possible exchanges of the two product types *PossibleExchanges*. This data is provided to the *Equalize* module which, by automated execution of the simplex method, checks whether the menu complies with the desired nutrition norms. As a result of the optimal exchanges made, data tables are produced for the quantities of unexchanged products in the tables *LessProducts* and *MoreProducts*, as well as the specific quantities of exchanged products *Exchanges*. If the obtained result differs significantly from the norm, the menu creator should make changes to the menu plan by replacing, adding or removing meals. Another option is to change only certain recipes by removing or adding certain quantities of products so that the recipe does not change significantly.

6. CONCLUSION

The creation of a varied, balanced and healthy weekly menu plan when organizing the feeding of different groups - students, servicemen, etc., according to scientific research and normative documents is an important and responsible task. A quick and easy creation of various menus plans requires the availability of software tools that would also enable the evaluation of the menus relevance to predetermined standards.
Existing applications for creating and managing menu plans support many useful features for individual users - creating weekly and monthly menus based on predefined recipes, creating balanced custom menus, and more. Organized

meals for large groups of people are characterized by specific requirements. Sometimes the menu plan should include specific products that are available in the store, or alternative products that have to replace the basic products missing at the market.

The article proposes one solution to the task of evaluating a menu plans by defined criteria. By using the simplex method, we make quantitative evaluation of how close the meal products of a certain menu plan are to predetermined quantities of specified basic products.

The mathematical method has been tested with a software tool developed by us. It can be used in more sophisticated software applications such as the weekly menu planner. The software application can be expanded to provide automatically a variety of weekly menus on pre-established recipes complied with the relevant regulations. It is possible to modify the algorithm to optimize other parameters, such as: optimal price - one product can be replaced with a cheaper or a more expensive one of the same product group in order to achieve a certain price framework set by the institution; nutrition balance - strict observance of the daily energy and nutritional values of the products; variety – meals preparation based on various recipes, avoiding the use of the same products daily, and so on.

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