REVISTA INVESTIGACIÓN OPERACIONAL VOL. 41, NO. 1, 67-79, 2020

SCHEDULING WEEKLY MENUS IN A HOSPITAL WITH INTEGER PROGRAMMING TECHNIQUES

Sebastián Guala*, Javier Marenco
Univ. Nacional de Gral. Sarmiento, Argentina.

ABSTRACT
Scheduling food services in health centres is a complex issue involving several factors. In this work we present an integer programming model for planning a weekly menu of meals for a hospital in Argentina. Lunches and dinners must be planned, and each meal involves a starter, a main course, a side dish, and a dessert. The goal is to propose a weekly menu that minimizes the total cost while fulfilling requirements of healthy food habits, variety, and local gastronomy. Our results show improvements in costs between 21% and 25% compared to existing manually-designed plans.

KEYWORDS: weekly menu, nutritional requirements, integer programming.
MSC: 94C10

RESUMEN
La programación de comidas en centros de salud siempre ha sido un área compleja que involucra varios factores: estándares alimentarios, variedad, costos y aspectos culturales. En este trabajo presentamos el desarrollo de un modelo de programación entera para la planificación de un menú semanal de comidas para un hospital de Argentina. En este contexto, la programación del menú contempla los almuerzos y las cenas, y cada comida se compone de primer plato, plato principal más acompañamiento y postre. El objetivo de la planificación es proponer un menú semanal que minimice los costos respetando las exigencias de variedad de platos que se ajusten al gusto local. Los resultados muestran mejoras de un 21% a un 25% comparados con los costos obtenidos por los métodos manuales utilizados actualmente.

PALABRAS CLAVE: menú semanal, requerimientos nutricionales, programación entera.

1. INTRODUCTION

Food services in health centres is a sensitive area due to its implications in patients' recovery time and in the well-being of patients and hospital employees [2]. A proper scheduling of menus is necessary to ensure a balanced diet with positive impact on the patients' health. Determining the weekly menu implies a complex task due to the large number of variables that must be considered, among them maximum and minimum nutritional requirements (carbohydrates, proteins, fat, cholesterol, calcium,

*sguala@ungs.edu.ar

iron, etc.), preferences concerning local gastronomy (i.e., culturally acepted dishes), variety of courses, and menu costs.

There are relevant works related to the diet problem which develop models of alimentary planification that satisfies daily nutritional requirements at minimum cost [2, 3, 4, 5, 11, 14]. However, the proposed planification in those models is made at the ingredient level, i.e., not considering dishes and meals. In other words, these models seek a combination of ingredients (such as milk, crops, meat, vegetables, etc.) satisfying daily requirements with minimum cost, but such models do not address the way these ingredients combined and cooked. As a consequence, such optimization models do not provide feasible gastronomical proposals, but an ideal lower bound on the total cost is obtained instead.

The aim of this work is to introduce an integer programming model able to propose manus for lunches and dinners including dishes selected from a set of candidate preparations, considering the kind and amount of ingredients and their nutritional qualities. Integer programming is the most natural mathematical and computational tool for tackling this problem, as it admits a clean combinatorial optimization structure [13, 16]. Although this model can be applied to food services in general, the development described in this work was motivated by the specific requirements of a hospital in the Province of Buenos Aires, Argentina. The planning must take into account established nutritional standards and other cultural and variety considerations, while minimizing total costs. This model seeks to optimize the weekly cost of alimentation of employees and patients with no alimentary restrictions (patients with diabetes, cardiac risk, celiac desease, etc., receive a special diet).

The present work is organized as follows: in Section 2. we define the problem as well as the kinds of dishes and courses that compose a meal and a general description of constraints that must be taken into account. In Section 3. we introduce integer programming and present the proposed model. Section 4. presents the model implementation and reports the results obtained according to two alternatives: either (a) the model is strictly restricted to nutritional recomendations of international organizations, or (b) a slightly more flexible policy for some parameters is considered in order to adapt the results to local food preferences. Finally, Section 5. presents the conclusions and considerations for future applications.

2. PROBLEM DEFINITION

Combinations of dishes and courses of lunches and dinners must be scheduled for a 7-day period. In this particular case, hospital employees and patients (without alimentary restrictions) receive the same menu in lunches and dinners. Hospital employees having lunch are different from those having dinner, due to hospital shifts. Both meals must include a series of courses ordered as *starter*, *main course*, *side dish*, and *dessert*. A main course with side dish may be replaced by a unique course typically served without side dish (as, e.g., pasta), and we call such a course a *strong course* throughout this work. A menu is obtained from a list of available dishes, each dish belonging to exactly one kind of course and being specified by the amount of needed ingredients for its preparation. Additionally, each ingredient has its nutritional infomation and cost.

The menu must obey the following constraints:

- Each meal must consist of exactly a starter, a main course with side dish, and a dessert. The main course with side dish may be substituted by a strong course.

- Neither main courses nor strong courses can be repeated in the 14 scheduled meals along the week. This constraint is motivated by the need of a reasonable food variety.
- Any starter, side dish, or dessert may appear at most twice in the weekly menu and, in that case, there must be at least two meals between the two appearences of the same dish. This ensures that no average patient repeats a dish, since the average staying time in the hospital is of about 2 days. Also, since employees at lunchtime differ from employees at dinnertime, this constraint ensures that each shift will not repeat starters, side dishes, nor desserts for at least three days.
- The daily meals must contribute acceptable values of each nutrient (such as carbohydrates, proteins, sodium, etc.). Since breakfast and afternoon snacks are not considered in our scheduled menu, the typical contributions of these meals are substracted from the daily nutritional requirements.

As far as variety and nutritional requirements are concerned, the constraints above are enough to get a satisfactory menu. However, nutritionists in charge of programming the menu asked for some qualitative features associated to healthy eating habits in general, which exceed the simple fulfillment of nutritional values:

- At least one dessert per day must be a fruit or must contain fruit.
- At most one course per day may be pasta, rice, or flour in general. These courses are in the category of *strong courses* since they do not have side dishes. Additionally, if one of these courses appears in a meal, then the meal must include a vegetable-based starter.

A final group of constraints was included in order to satisfy local food preferences. Two scenarios are considered. In the first scenario, the menu is strictly restricted to daily maximum and minimum nutritional values suggested by the World Health Organization (WHO) [6, 7, 15] and others [8, 9, 10]. In the second scenario, we allow maximum values of some nutritional parameters to be slightly exceeded and certain dishes to be avoided, in order to consider local food preferences. Proteins and cholesterol, mainly associated to meat intake, are exceeded parameters whereas fish is avoided as much as possible:

- Fish is not allowed in lunches and at most a dish with fish is allowed in dinners. This is due to the poor tradition on fishes and seafood in the region of Argentina where the model was implemented. In particular, fish was forbidden in lunches due to a special petition of the employees in the day shift.
- Every lunch must include a course with at least 100 grams of meat (farm animals, no fish), and dinners may include at most a dish with more than 40 grams of meat (fish included). As with these levels there was no feasible solution within the WHO suggestions, this forced the limits of maximum daily accepted values of proteins and cholesterol to be increased by about 15%, trying to hold the diet within safe levels.

Nutrient (t)	$\min_t$	$\max_t$ (WHO)	$\max_t$ (local)
Carbohydrates (g)	200	400	400
Proteins (g)	30	70	80
Fats (g)	30	70	70
Calories (Kcal)	1000	2500	2500
Sodium (mg)	300	2000	2000
Cholesterol (mg)	0	300	400
Iron (mg)	2	N/A	N/A
Calcium (mg)	400	N/A	N/A
Fibre (g)	7	N/A	N/A
Phosphorus (mg)	300	N/A	N/A
Potassium (mg)	1000	N/A	N/A

Table 1: List of nutrients involved in the model, with their minimum and maximum daily requirements for both scenarios. "N/A" entries denote that in a regular diet there are no risks associated to excesive consumption (within reasonable values).

Summarizing, constraints implemented for the schedule are splitted in (a) a basic group caracterizing internationally suggested nutritional parameters, (b) a second group contributing to general good practices not explicitly included in the nutritional parameters, and (c) a third group making the menu more palatable to Argentine patients. By omiting or applying the last group we can get two alternative scenarios: the first one strictly considers the WHO suggestions, and the second one allows some controlled "licences" due to local food preferences.
The set of available dishes to construct the menu comes essentially from the local gastronomy, meaning that, from a qualitative point of view, any combination of them should produce a socially-acepted menu. However, in our first experiments this not always turned out to be the case, hence the third group of constraints was added in order to further limit the acceptable combinations of dishes.

3. THE INTEGER PROGRAMMING MODEL

In this section we introduce and integer programming model formulating the optimization problem described in the previous section. An integer programming model is composed by a set of *variables* that represent feasible solutions and take integer values, a linear *objective function* to be optimized, and a set of *constraints* limiting the feasible values that variables can take. In our case the variables will be restricted to be *binary*, i.e., taking values in the set $\{0, 1\}$, and the constraints will ask them to define a feasible combination of dishes.
As a part of the model input we consider the parameters and nutritional contents shown in Table 1. We call *ingredients* to the aliments the hospital has to buy (i.e., apple, beef, milk, tomato, etc.). Each ingredient contributes with its *nutritional contents* and are used by cooks to prepare *dishes* (roast meat, pastas with savoury liquid, salads, etc.).
For the model formulation we consider the following sets:

- I: set of *ingredients*. We use the index $k \in I$ to denote ingredients, and assume the set partitioned into $I = \text{Vegetable} \cup \text{Fruit} \cup \text{Meat} \cup \text{Fish} \cup \text{Chicken} \cup \text{Flours} \cup \text{Others}$.
- P: set of *available dishes*. We use the index $i \in P$ to denote dishes, and assume the set partitioned into $P = \text{Starter} \cup \text{MCourse} \cup \text{SDish} \cup \text{SCourse} \cup \text{Dess}$, as follows:

  1. Starter: Starters,
  2. MCourse: Main courses,
  3. SDish: Side dishes,
  4. SCourse: Strong courses (main courses that do not come with a side dish),
  5. Dess: Desserts.

- $J = \{1, \ldots, 2n\}$: set of *meals* for a n-day long scheduling horizon. For $d = 1, \ldots, n$, the d-th day lunch is the meal $2d - 1$, and the d-th day dinner is the meal $2d$. We use the index $j \in J$ to denote meals. Note that according to this definition, lunches have odd indices and dinners have even indices.
- T: set of *nutritional contents*, given by Table 1. We use the index $t \in T$ to denote elements of this set.

Besides, we assume the following input data:

- bp_k: pattern quantity to the proportional computation of the contribution for the ingredient k, by default all the ingredients have $\text{bp}_k = 100$ grams.
- prop_{kt}: Content of nutrient t (in grams or miligrams) per bp_k units of ingredient k.
- min_t: Minimum suggested daily consumption of nutrient t (in corresponding units).
- max_t: Maximum suggested daily consumption of nutrient t (in corresponding units).
- price_k: Unit price of ingredient k (in \$/kilogram).
- gross_{ik}: Gross weight bought of ingredient k to be used in the dish i (in grams). This value represents the amount of ingredient k that must be purchased in order to prepare dish i. The gross weight includes all those parts that must be removed during the dish preparation but are included in the total weight as, e.g., seeds, pits, bones, skin, shell, etc.
- net_{ik}: Net weight of ingredient k in dish i (in grams). This value represents the amount of ingredient k served to be eaten in dish i and is, therefore, the quantity we must consider for the nutritional computation.

For each dish $i \in P$ and each meal $j \in J$, we introduce the binary variable x_{ij}, such that $x_{ij} = 1$ if dish i is served in meal j, and $x_{ij} = 0$ otherwise. With these definitions, the model can be formulated as follows.

1. The objective function asks to minimize the total cost:

$$\min \sum_{i\in P}\sum_{j\in J} x_{ij}\Big(\sum_{k\in I} \text{price}_k \frac{\text{gross}_{ik}}{10^3}\Big).$$

2. Exactly one starter per meal:

$$\sum_{i\in \text{Starter}} x_{ij} = 1, \qquad \forall j \in J.$$

3. Either a strong course or a main course with side dish per meal:

$$\sum_{i\in \text{SCourse}} 2x_{ij} + \sum_{i\in \text{MCourse}} x_{ij} + \sum_{i\in \text{SDish}} x_{ij} = 2, \quad \forall j \in J.$$

4. At most one main course per meal:

$$\sum_{i\in \text{MCourse}} x_{ij} \leq 1, \qquad \forall j \in J.$$

5. At most one side dish per meal:

$$\sum_{i\in \text{SDish}} x_{ij} \leq 1, \qquad \forall j \in J.$$

6. Exactly a dessert per meal:

$$\sum_{i\in \text{Dess}} x_{ij} = 1, \qquad \forall j \in J.$$

7. Neither main courses nor strong ones can be repeated along the $2n$ meals:

$$\sum_{j\in J} x_{ij} \leq 1, \qquad \forall i \in \text{MCourse} \cup \text{SCourse}.$$

8. Desserts, starters, and side dishes can appear at most twice along the $2n$ meals:

$$\sum_{j\in J} x_{ij} \leq 2, \qquad \forall i \in \text{Starter} \cup \text{SDish} \cup \text{Dess}.$$

9. Desserts, starters, and side dishes cannot appear twice in a three-meal window:

$$x_{ij} + x_{i,j+1} + x_{i,j+2} \leq 1, \qquad \forall j \in J, j < 2n-1,\ i \in \text{Starter} \cup \text{SDish} \cup \text{Dess}.$$

10. Daily intake of every nutritional contribution must be within suggested minimum and maximum values:

$$\min_t \leq \sum_{i\in P} (x_{ij} + x_{ij+1})\Big(\sum_{k\in T} \frac{\text{prop}_{kt}\ \text{net}_{ik}}{\text{bp}_k}\Big) \leq \max_t,$$
$$\forall t \in T,\ j \in J, j \text{ odd}.$$

11. Exactly one dish of red or white meat to be served for lunch. We define the set C of *dishes with meat* as those with at least 100 grams of meat, i.e., $CA = \{i \in P : \sum_{k \in \text{Meat} \cup \text{Chicken}} \text{net}_{ik} \geq 100\}$. The set Meat includes any meat of origin bovine, porcine, and ovine. This is the most remarkable constraint to adapt the menu to the local gastronomy, and its inclusion forced us to increase the upper bound of both proteins and cholesterol intake, although keeping safe values:

$$\sum_{i \in CA} x_{ij} = 1, \qquad \forall j \in J, j \text{ odd.}$$

12. At most one dish with more that 40 grams of meat (red, white or fish) for dinner. We define the set $CN = \{i \in P : \sum_{k \in \text{Meat} \cup \text{Chicken} \cup \text{Fish}} \text{net}_{ik} \geq 40\}$:

$$\sum_{i \in CN} x_{ij} \leq 1, \qquad \forall j \in J, j \text{ par.}$$

13. Fish for lunch is forbidden. We define the set PP of dishes with fish as $PP = \{i \in P : \sum_{k \in \text{Fish}} \text{net}_{ik} > 0\}$:

$$\sum_{i \in PP} x_{ij} = 0, \qquad \forall j \in J, j \text{ odd.}$$

14. At most one dish with fish for dinner:

$$\sum_{i \in PP} x_{ij} \leq 1, \qquad \forall j \in J, j \text{ even.}$$

15. Dinners entirely composed by vegetables are not allowed. We define the set of dishes with at least one vegetable ingredient as $PV = \{i \in P \setminus \text{Dess} : \sum_{k \notin \text{Vegetable}} \text{net}_{ik} > 0\}$:

$$\sum_{i \in PV} x_{ij} \geq 1, \qquad \forall j \in J, j \text{ even.}$$

16. Pasta, rice, and any flour-based preparation must be served with vegetables (at least 50 grams in the starter). We define the set EV of starters with vegetables as $EV = \{i \in \text{Starter} : \sum_{k \in \text{Vegetable}} \text{net}_{ik} > 50\}$, and define the set CH of flour-based strong courses as $CH = \{i \in \text{SCourse} : \sum_{k \in \text{Flours}} \text{net}_{ik} > 0\}$:

$$\sum_{i \in EV} x_{ij} \geq \sum_{i \in CH} x_{ij}, \qquad \forall j \in J, j \text{ even.}$$

17. At most one dish of pasta, rice, or any flour-based preparation (at least 20 grams of flour) per meal. We define the set PH of dishes with flour to be $PH = \{i \in P : \sum_{k \in \text{Flours}} \text{net}_{ik} \geq 20\}$:

$$\sum_{i \in PH} x_{ij} \leq 1, \qquad \forall j \in J.$$

18. At least a fruit per day. We define the set PF of fruit-based desserts as $PF = \{i \in \text{Dess} : \sum_{k \in \text{Fruit}} \text{net}_{ik} > 0\}$:

$$\sum_{i \in PF} x_{ij} + x_{ij+1} \geq 1, \qquad \forall j \in J, j \text{ odd.}$$

19. The variables must be binary:

$$x_{ij} \in \{0, 1\}, \qquad \forall i \in P, j \in J.$$

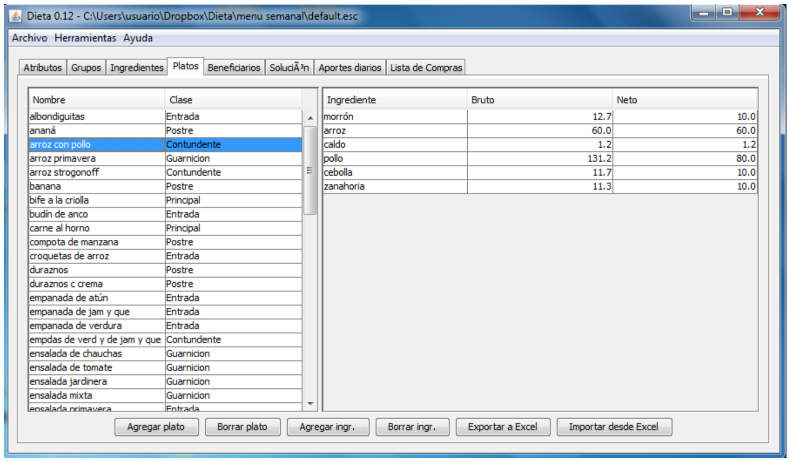

Figure 1: Main interface of the computational application implemented to manage the input data, solve the model, and visualize the results.

4. RESULTS

In this section we report the model results for the two evaluated scenarios (following the WHO suggestions and following local criteria), and we compare these results with the manually-designed menu in use before this work. In order to exclusively consider the WHO suggestions, constraints (12) to (16) are removed. The model was executed with a total of 63 dishes: 13 starters, 10 main courses, 9 side dishes, 14 strong courses, and 17 desserts. In addition, dishes are composed of a total of 75 ingredients. All data was provided by the hospital employees in charge of the food service.

The integer programming model has 882 binary variables and 838 constraints (including those due to local preferences). As the work was developed for a public hospital that provides medical care free of charge for a low-income population, we only focused selection on non-commercial computational tools. The model was coded in the ZIMPL modeling language [12] and it was solved by the package SCIP 3.0.0 [1] in a computer with an Intel Core 2 Duo processor running at 2 GHz and equipped with 4 GB of RAM memory. After a running time of 3 minutes, a feasible solution was found with a 8% of optimality gap (meaning that the total cost is at most 8% from the optimal cost). These values are aceptable to the users. Opposed to linear programming models, not every integer programming model arising in practice can be routinely solved by standard computational machinery. This is a typical situation even with small-sized integer programming models, so the fact that the obtained solution is not guaranteed to be optimal is not surprising in this case.

A Java aplication was coded and implemented in order to manage the input data, solve the model, and visualize the results (see Figure 1). The application can handle many scenarios, so the user can perform “what-if” analyses by adding/removing meals or modifying the purchase prices for the ingredients (this last feature is quite important in an inflationary context). The implementation of such a user interface allowed non-techinical users to manipulate the input data and analyze the resulting solutions, a main goal within this work.

Day	Lunch	Dinner
1	soup of vegetables taglierini pasta with chicken sauce caramel rolls	vegetables pasties breaded meat garden salad apple compote
2	sausages in rolled bread hamburguer roast potatoes tangerine	spring salad pizza two-flavour jelly
3	rice croquettes sautéed chicken and vegetables potatoes pourée apple compote	vegetable soup spaghetti with scallion cream sauce crème caramel flan with vanilla cookies
4	vegetables pasties rice with chicken caramel rolls	butternut squash pudding fusilli pasta with sauce of chicken peach
5	scrambled egg and globe squash taglierini bolognese croissant	sausages in rolled dough chicken pie garden salad jelly with fruits
6	herb bread chicken with scallion cream sauce roast potatoes tangerine	butternut squash pudding lasagna marmalade pie
7	spring salad cornflour pudding with bolognese sauce peaches with cream	herb bread breaded chicken potatoes pourée crème caramel flan

Table 2: Weekly menu following the WHO nutritional sugestions.

Table 2 contains the menu obtained from the available dishes, thier costs and nutritional content of ingredients, according to the daily nutritional WHO suggestions. As mentioned before, this menu is not an abstract formulation given that planning from a list of pre-established dishes certainly implies a first adaptation to local preferences.

Table 3 shows the daily nutritional content of the menu proposed in Table 2. Note that the combination of dishes gets a satisfactory nutritional balance with similar contents, not going from the maximum allowed value to the minimum allowed value in consecutive days. This fact was carefully followed in this work, since previous models in the literature solve problems with continuous variables asociated to ingredients, thus keeping much more flexibility to fullfil nutritional requirements (although these models have the problem of proposing attractive menus). The use of binary variables (motivated by the need of designing attractive combinations of dishes) constrains this flexibility, hence this fact was carefully measured in this work.

Similarly, Table 4 and Table 5 show the proposed menu and its daily contents conditioned to local preferences. The increase of dishes with higher content of meat is evident, which has an effect on levels of ingested proteins and cholesterol when compared to Table 3. However, the higher levels of

Day	1	2	3	4	5	6	7
Cost	11.16	9.32	9.11	9.04	9.54	10.16	9.92
Carbohydrates	206.48	201.52	201.03	209.77	226.20	200.52	202.45
Proteins	62.30	48.66	41.98	56.1	50.26	51.14	57.71
Fats	33.75	44.30	32.05	30.75	47.35	35.84	30.69
Calories	1379.35	1399.45	1260.45	1340.75	1532.00	1329.16	1316.81
Sodium	594.78	751.68	335.55	555.83	787.50	436.13	474.13
Cholesterol	288.00	292.30	299.30	284.0	295.30	294.20	298.80
Iron	15.24	11.92	23.60	13.89	9.98	9.69	11.15
Calcium	430.00	538.64	451.25	405.2	426.64	515.49	479.79
Fibre	19.67	13.93	19.19	18.44	15.88	16.38	17.31
Phosphorus	934.68	747.74	772.60	761.13	950.96	951.89	957.64
Potassium	2701.05	2098.05	2405.20	1924.6	2220.15	2373.53	2799.68

Table 3: Daily nutritional contribution according to solution from Table 2.

proteins and cholesterol are kept within values considered safe to adults with no special alimentary prescriptons. The judgment of safe consumption is evaluated according to the opinion of the experts, based on their medical experience.

Concerning the total cost, Table 6 shows a better use of resources by planning the menu with the tools proposed in this work than with the previous methods. As expected, the version that takes into account the WHO suggestions obtains lower costs than the local one asking for more consumption of meat.

5. CONCLUSIONS

The developed model allows to generate concrete and feasible gastronomic proposals to food services. In our experience with a hospital in Argentina, the model helped to drive down the total costs by 21% and 25% for the local and the WHO versions, respectively, compared to the manually-designed menus previously used at the hospital. However, as the hospital food service is based on the local gastronomy, we must consider the improvement close to the 21%. Also, the obtained menus guarantee a balanced intake of nutrients, which cannot be absolutely ensured when the schedule is manually designed.

Concerning running times, manually design a menu takes some hours to the food service personnel and the result is just a “reasonable” schedule for both the nutritional and cost points of view. The remarkable time reduction achieved by using the proposed tool allows the nutritionists to analize multiple scenarios (that furthermore have an optimality guarantee) and react rapidly to changes in prices of the ingredients.

The model described in this work was implemented to schedule weekly menus at the hospital. The good results encouraged to the employees in charge of the food service to ask for new features:

- Include constraints that consider combinations of colors among dishes, in order to improve the gastronomic experience. This new set of constraints implies a new set of binary variales that affects the processing time. The complexity of including this new feature is based on the lack

Day	Lunch	Dinner
1	ham and cheese rolls breaded chicken garden salad marmalade pie	vegetables pie taglierini bolognese tangerine
2	rice croquettes roast meat roast potatoes crème caramel flan with vanilla cookies	spring salad spaghetti with scallion cream sauce jelly with fruits
3	herb bread hamburguer potatoes pourée crème caramel flan	butternut squash pudding cornflour pudding with bolognese sauce peaches with cream
4	rice croquettes chicken with scallion cream sauce tomatoes salad caramel rolls	spring salad pizza jelly with fruits
5	ham and cheese pasties sautéed chicken and vegetables roast potatoes croissant with jam	vegetables soup lasagna apple compote
6	vegetables pastries potato and meat pie tangerine	vegetables pie taglierini pasta with chicken soup marmalade pie
7	butternut squash pudding breaded meat garden salad apple compote	herb bread chicken pie potatoes pourée crème caramel flan with vanilla cookies

Table 4: Weekly menu according to local preferences.

Day	1	2	3	4	5	6	7
Cost	10,56	10,72	9,42	8,18	11,78	11,48	8,93
Carbohydrates	235,95	211,48	211,05	205,35	219,43	201,68	200,13
Proteins	65,15	72,27	49,41	46,70	55,75	62,00	57,51
Fats	43,50	35,85	32,29	34,60	62,65	32,05	36,44
Calories	1595,90	1257,65	1332,41	1320,10	1664,55	1343,15	1358,46
Sodium	1067,50	314,30	366,38	517,75	1147,27	549,58	470,10
Cholesterol	388,40	388,90	351,49	380,40	392,20	387,30	359,90
Iron	12,41	25,37	11,05	10,26	11,16	15,08	25,45
Calcium	413,15	442,58	463,20	575,63	483,15	448,00	464,80
Fibre	15,38	15,60	16,63	11,35	16,94	18,42	22,23
Phosphorus	976,70	777,25	894,69	660,35	937,08	1031,08	1039,17
Potassium	2442,00	2199,05	2646,83	1417,55	2395,05	2773,05	3142,58

Table 5: Daily nutritional contribution according to solution from Table 4.

Criterium	Weekly cost	Difference	Improvement
International(WHO)	\$68.24	\$22.21	24.56%
Local	\$71.07	\$19.38	21.43%

Table 6: Weekly cost per person of obtained menus comparing to the \$90.45 cost of the handmade menu.

of a clear and uniform criterion about desirable combinations of colours for foods.

- Extend the schedule from a week to two weeks or even a month. This requires the inclusion of new dishes to extend the possible combinations and also implies to revisite some constraints as, e.g., the prohibition to repeat main courses. This new feature may also affect the processing time.

The use of integer programming techniques and the modeling language *zimpl* was crucial for the development of this work. Integer programming software packages allow to obtain optimal or near-optimal solutions for many integer programming models arising in practice, hence providing consistently good proposals for the nutritionists to evaluate. Also, the use of a modeling language allowed us to quickly edit the model and activate/deactivate constraints, bringing down the development times and this making the resulting model a very flexible tool in the hands of the hospital employees in charge of the food service. Both the model and the software tool are available at request to the authors.

Acknowledgement. The authors thank Lic. Cecilia Volk for her support, information, and useful comments on this work.

RECEIVED: SEPTEMBER, 2018.
REVISED: DECEMBER, 2018.

REFERENCES

[1] T. ACHTERBERG (2009): SCIP: solving constraint integer programs. **Mathematical Programming Computation**, 1(1):1-41.

[2] J.L. BALINTFY (1975): A Mathematical Programming System for Food Management Applications. **Interfaces**, 6:13-31.

[3] J.L. BALINTFY (1979): The Cost of Decent Subsistence. **Management Science**, 25(10):980-989.

[4] G. DANTZIG (1990): The Diet Problem. **Interfaces** 20:43-47.

[5] G. DANTZIG. (1963): **Linear Programming and Extensions**, Princeton Press, Princeton, New Jersey.

[6] FAO/WHO EXPERT CONSULTATION (1998): **Carbohydrates in human nutrition**. FAO Food and Nutrition paper No. 66. Rome.

[7] FAO/WHO/UNU EXPERT CONSULTATION (2004): **Report on Human Energy Requirements**. Interim Report, Rome.

[8] FOOD AND NUTRITION BOARD-COMMISSION ON LIFE SCIENCES-NATIONAL RESEARCH COUNCIL (1989): **Recommended Dietary Allowances** (10th ed). Washington DC: National Academy Press.

[9] FOOD AND NUTRITION BOARD/INSTITUTE OF MEDICINE (2002): **Dietary Reference Intakes (DRI) and Recommended Dietary Allowances (RDA) for energy, carbohydrate, fiber, fats, fatty acids, cholesterol, proteins and amino acids.** Institute of Medicine of the National Academies. Washington DC. The Nacional Academy Press.

[10] FOOD AND NUTRITION BOARD/INSTITUTE OF MEDICINE (2002): **Dietary Reference Intakes (DRI) for Calclium, Phosphorus, Magnesieum, Vitamin D and Fluoride.** Institute of Medicine of the National Academies. Washington DC. The Nacional Academy Press.

[11] S.G. GARILLE and S.I. GASS (2001): Stigler's Diet Problem Revisited. **Operations Research**, 49:1-13.

[12] T. KOCH (2004): Rapid Mathematical Programming. ZIB-Report 04-58.

[13] G. NEMHAUSER, and L. WOLSEY (1988): **Integer programming and combinatorial optimization**. John Wiley and Sons.

[14] STIGLER, G.J. (1945): The Cost of Subsistence. **Journal of Farm Economics, 27:303-14, 1945.**

[15] WHO/FAO Joint WHO/FAO Expert Consultation (2003): Diet, Nutrition and the Prevention of Chronic Diseases. Technical Report Series No. 916. Geneva.

[16] WOSLEY, L. (1998): Integer programming. John Wiley and Sons.