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A diet expert system utilizing linear programming models in a rule-based inference engine

Annette van der Merwe, Hennie Krüger and Tjaart Steyn

North-West University, Potchefstroom Campus, Potchefstroom, South Africa
{annette.vandermerwe, hennie.kruger, tjaart.steyn}@nwu.ac.za

Abstract. Linear programming is commonly used for solving complex problems in various fields, such as dietetics. Expert systems use expertise and inference procedures to solve problems that require advanced expert knowledge and are also applied to health related problems. Over the years many variations and facets of the diet problem and other related problems have been solved by means of linear programming techniques as well as expert systems. In this research, an expert system was created for the purpose of solving multiple facets of the diet problem, by creating a rule-based inference engine consisting of goal programming- and multi-objective linear programming models. The program was successfully applied to case studies specific to South African teenage girls, which were obtained through the knowledge acquisition phase. The resulting system compiles an eating-plan for a girl that conforms to the nutritional requirements of a healthy diet, includes the personal food preferences of the girl, and consists of food items that result in the lowest total cost. The system also allows prioritization of the food preference and least cost factors by means of weighted priorities.

Keywords: expert system; goal programming; multi-objective linear programming; diet problem

Introduction

Studies have shown that obesity and other eating disorders are on the increase in South Africa, especially among female adolescents Kimani-Murage (2013); Reddy *et al* (2012); Monyeki *et al* (2012). One of the reasons for this phenomenon as addressed by Schönfeldt *et al* (2010), is inefficient education regarding eating habits appropriate for an individual and the inability to gain the necessary education due to financial constraints. People also tend to deviate from eating plans to cater for their personal food preferences. Many free software solutions exist that can assist people in selecting healthy foods to include in their diets. However, when developing a healthy diet for an adolescent, Whitney and Rolfes (2008) considers factors like gender, age, height, weight, activity level and some values obtained through calculations.

Linear programming is commonly used for solving the diet problem which generally involves the optimization of an objective function describing the total cost or the total nutrient contribution of a diet. It originated during the late forties when George Dantzig (1990) started to develop a method that would help him formulate a diet consisting of all the nutrients necessary to sustain a healthy body. His work also cemented the concept of 'the diet problem' as a means to explain linear programming concepts such as the well-known simplex method, also studied by Rolf (2013). Linear programming and related extensions are now used widely for solving problems that contain many variables and restrictions. Other software solutions useful in solving the diet problem include expert systems. Giarratano and Riley (2005) state that an expert system utilizes expert knowledge and inference procedures to solve problems that require advanced human expertise. Many expert systems exist that aim to solve specific elements of diet- and health related problems.

In this research, an expert system was created with a rule-based inference engine consisting of linear programming models which generates an eating plan that conforms to the nutritional requirements and personal food preferences of a South African teenage girl.

The remainder of this paper is organized as follows: in the next section, the layout of the expert system is shown and the components briefly explained; this is followed by the formulation of the goal- and multi-objective linear programming models which constitute the inference engine after which the evaluation and results obtained through experiments are briefly discussed. The paper finishes with some concluding remarks on the incorporation of linear programming models in the inference engine and how the expert systems- and linear programming fields benefit from the research conducted.

Expert system layout

The expert system was created in the form of a Microsoft Excel Workbook, utilizing Visual Basic for Applications (VBA) code, which is discussed in detail in Albright (2012). An expert system is created by following a knowledge engineering process. During the knowledge acquisition phase of this process, six volunteer female teenagers in Potchefstroom, Northwest province were asked to partake in consultation sessions with a practicing dietician, Rankin (2012). The dietician was asked to create a healthy diet for each of the volunteers.

During the sessions it became evident that the dietician intuitively aims to select cheap food options for the diet so as to keep the total cost a minimum, but uses no formal calculations for this purpose. The dietician also emphasized that some difficulty is experienced in varying the food choices and that foods are usually selected habitually.

The girls were asked general questions related to food preferences and eating habits and a balanced eating plan was provided to each. These eating plans were used to evaluate the created expert system.

The basic components of the expert system are shown in Figure 1.

The function of the user interface is to obtain necessary information from the user and provide the output in the form of an eating plan. The working memory is the dynamic memory of the system which temporarily holds the information entered by the user, and processes it into the format necessary for transfer to the inference engine.

The inference engine can generally be described as the brain of the system and usually contains a set of production rules. A production rule can be described as an IF-THEN operation, where an action is typically performed (THEN-portion of the rule) only after a condition is satisfied (IF-portion of the rule).

The inference engine in this system, implemented two interactive linear programing models by means of MS Excel Solver that apply the data acquired from the user, to the knowledge base in order to develop an eating plan. The inference engine will be discussed in more detail in the next section.

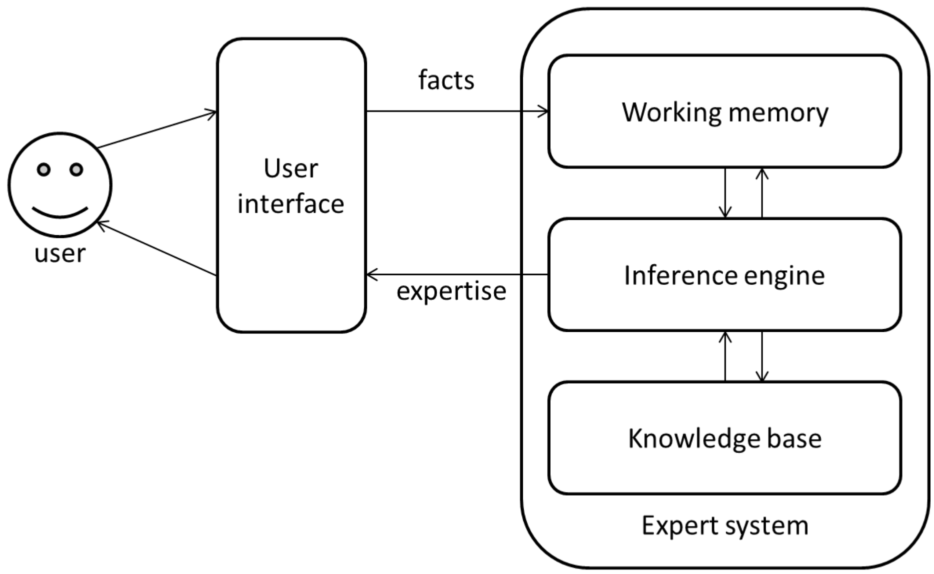

Fig. 1. Layout of the expert system components

The knowledge base consists of pre-compiled lists of foods native to South Africa, grouped according to the proportions of carbohydrate (CHO), protein and fat they provide. These lists are called exchange groups which are dietary tools used to assist a dietician to organize foods according to their macronutrient content. The exchange groups include fruit, vegetable, starch, dairy, fat, and meat and legumes. A dietician typically selects a certain number of foods, or exchanges, from each exchange group for incorporation into the final eating plan.

Goal programming and multi-objective linear programming

The general information required from the user includes factors like age, gender, weight, height, and activity level. The program starts by calculating the basal metabolic rate (BMR) using the Harris-Benedict formulas, which according to Nienaber-Rousseau *et al* (2012) are the following:

For males: $BMR = (66.5 + 13.8m + 5h - 6.8a) \times 4.2$

For females: $BMR = (655 + 9.6m + 1.8h - 4.7a) \times 4.2$

where m denotes the mass of the person in kg, h denotes the height of the person in cm, and a denotes the age of the person in years.

The BMR, activity level and energy required for growth based on the person's age are then used to determine the daily required energy (RE) for the individual. The user is required to enter the preferred distribution percentages of the RE into the three macro-nutrients protein, carbohydrates (CHO) and fat. The specific amounts of each macronutrient are then calculated from the RE, using the following formulas:

$$protein(g) = \frac{\%\,protein \times total\ daily\ energy\ requirement(kJ)}{17(kJ/g)}$$

$$CHO(g) = \frac{\%\,CHO \times total\ daily\ energy\ requirement(kJ)}{17(kJ/g)}$$

$$fat(g) = \frac{\%\,fat \times total\ daily\ energy\ requirement(kJ)}{38(kJ/g)}$$

where 17kJ of protein, 17kJ of CHO, and 38kJ of fat weighs 1g.

A goal programming model was implemented to determine the number of exchanges to be chosen from each exchange group so that the macronutrient distribution is as close as possible to the percentages entered by the user. The model is formulated as follows:

$$Minimise \quad \sum_{i=1}^{k} (u_i + v_i)$$

$$subject\ to$$

$$\sum_{j=1}^{n} a_{ij}x_j + u_i - v_i = M_i \quad (i = 1, \ldots, k)$$

$$l_j \leq x_j \leq b_j \quad (j = 1, \ldots, n)$$

$$u_i, v_i \geq 0 \quad (i = 1, \ldots, k)$$

$$x_j, l_j, b_j\ integer \quad \forall j$$

where u_i and v_i represent the positive and negative deviations of the i^{th} macronutrient; l_j and b_j represent the lower- and upper bounds for exchange group j; M_i represents the weight amount required from the i^{th} macronutrient; k is the number of macronutrients; and a_{ij} represents the contribution of exchange group j to the i^{th} macronutrient.

The upper and lower bounds for each exchange group are constrained to integer values and are determined using the food guide pyramid as developed by the United States Department of Agriculture (http://fnic.nal.usda.gov/dietary-guidance/myplatefood-pyramid-resources, 15 December 2013), which is a set of dietary guidelines that is internationally accepted. This model provides a concrete integer number that indicates how many food selections should be made from each of the exchange lists.

The next phase of the program uses a multi-objective linear programming model to select foods from each exchange group. The model is formulated as follows:

$$Minimise \quad Q$$
$$subject\ to$$
$$\frac{w_{pref}\left(\sum_{j=1}^{n} p_j x_j - t_{pref}\right)}{t_{pref}} \leq Q$$
$$\frac{w_{cost}\left(\sum_{j=1}^{n} s_j x_j - t_{cost}\right)}{t_{cost}} \leq Q$$
$$\sum_{j=1}^{n} x_j = N$$
$$x_j = 0\ or\ 1$$

where N denotes the number of selections to be made; $x_j = 1$ if food j is selected and 0 otherwise; p_j depicts the user's preference for food item x_j; s_j represents the cost of food item x_j; w_{pref} represents the weight as selected by the user for the food preference as priority; w_{cost} represents the weight for cost; t_{pref} represents the optimum target for preference rating; and t_{cost} represents the optimum target for cost.

This model determines, for each of the exchange groups, a selection of food items that provides the optimal level of cost and user food preference. It uses the number of foods to select from each of the exchange groups, as calculated in the goal programming model, and the food preferences of the user as inputs.

Evaluation and results

The created expert system was evaluated in terms of two criteria: the effect of changing the weighted priorities for cost and preference was inspected; and the system was applied to real-world case studies and the results compared.

For demonstrating the effect that changes in the cost- and preference priority have on the resulting eating plan, an experiment was conducted by applying one of the case studies to the system with varying priority levels. The particular eating plan was created for a 6164 kJ daily energy requirement and the priorities were varied as follows:

Table 1. Cost versus preference weights used for applying the case study to the system

Application	*1st*	*2nd*	*3rd*	*4th*	*5th*
Cost weight	4	3	2	1	0
Preference weight	0	1	2	3	4

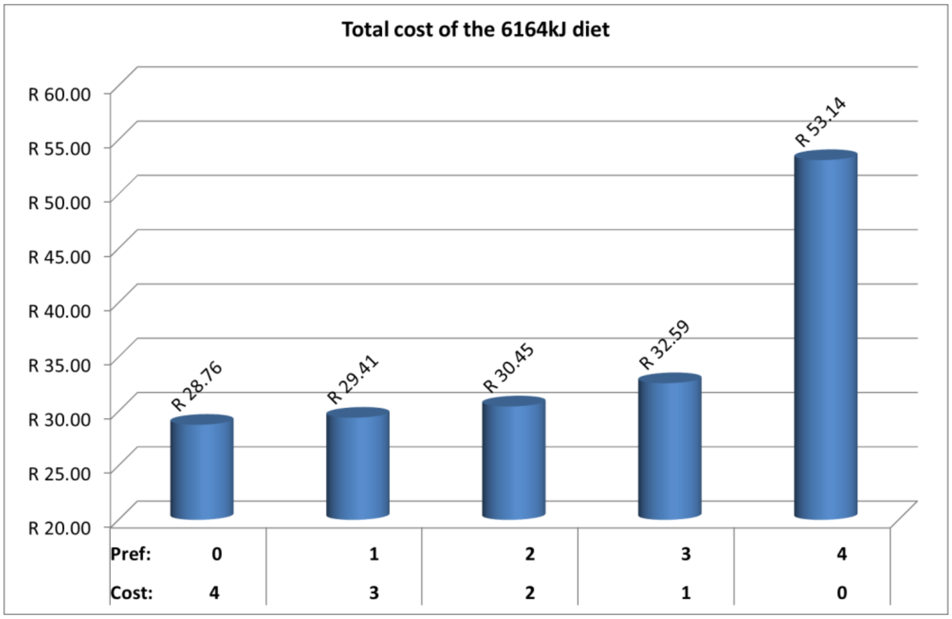

Fig 2. Effect of changes in cost- versus preference priority on the price of the resulting diet

Figure 2 presents the results of the experiment. The results show that when the priority of cost was high, not all the user's preferred foods appeared in the final eating plan because the system aimed to find a least cost diet. Similarly when the priority for the preference was at the maximum level, the total cost of the resulting diet was disregarded when selecting food items, due to the cost priority of zero. The results are summarized as follows, where cost is indicated in R, South African currency:

Table 1. Statistics for the 6164 kJ eating-plan generated by the expert system

Personalized diet for a total of 6164 kJ			
Total carbohydrates: 188.55 g			
Total protein: 68.89 g			
Total fat: 47.04 g			
Cost	*Pref.*	*Total cost of the diet:*	*Food Preference satisfied:*
4	0	R 28.76	79.17%
3	1	R 29.41	82.14%
2	2	R 30.45	82.81%
1	3	R 32.59	84.72%
0	4	R 53.14	88.16%

The statistics show that as the priority for cost decreases and that for food preference increases, the price of the resulting diet increases and the food preference satisfaction rises. To compare the eating plans generated by the expert system with those received from the dietician in the case studies, all of these sessions were imitated by supplying the exact same information given by the volunteers to the program.

The priorities for the total cost versus user food preference were set to equal weights because they were not considered during the sessions with the dietician. Table 2 shows how the eating plans generated by the system compares to those received from the dietician.

Table 2. The number of food matches, group matches and exceptions between the eating-plans

	Total food items in the plan	*% similarity between the plans*	*% variation provided by the program*	*% exceptions*
Volunteer 1	26	76.92%	19.23%	3.85%
Volunteer 2	26	65.38%	26.92%	7.69%
Volunteer 3	21	57.14%	33.33%	9.52%
Volunteer 4	23	60.87%	34.78%	4.35%
Volunteer 5	24	75.00%	12.50%	12.50%
Volunteer 6	26	73.08%	23.08%	3.85%
	Average:	*68.07%*	*24.97%*	*6.96%*

For a total of 146 food items used in the system generated plan, the average number of food items similar to those in the dietician's plans was 68.07%, with 24.97% of food items from the same exchange groups, and 6.96% of foods that were selected from different exchange groups.

Conclusions

The study provided evidence that expert system technology could be successfully combined with mathematical programming techniques by incorporating linear programming models to perform rule-based inference. The combination of two powerful solution techniques provided the possibility of solving more than one facet of the diet problem simultaneously. A least cost diet that conforms to the daily energy requirements and consists of food choices preferred by that individual, is generated by the expert system.

The system also generates eating plans that are unique to South Africa, as the food lists in the knowledge base had been compiled from South African sources and reflect price information current at the time of coding. The program successfully implemented weighted priorities with which the user can determine the importance of having a least cost eating plan or rather one that contains as many favorite foods as possible. Through the use of multi-objective linear programming models, the system presents a solution to providing some variation in food selections for the resulting eating plan.

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