FUZZY LOGIC MODELLING IN NUTRITION PLANNING - APPLICATION ON MEALS IN BOARDING SCHOOLS

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Abstract

Fuzzy logic modelling is applied for modelling and optimisation of nutritional requirements. According to the theory of fuzzy logic, this method is applicable to systems which cannot be precisely defined, such as human nutrient requirements.

Fuzzy membership functions are modelled to describe the range of nutrient intakes in the range from deficient to excess amounts. Defined are 23 fuzzy sets: fuzzy set for cost of a daily menu, fuzzy set of preference choice of offered meals and 21 fuzzy sets for amounts of energy and nutrients. Developed is a computer program in *Wolfram Research Mathematica* for modelling and optimisation of nutrient and energy intake.

A measurement of appropriate energy and nutrient intake with a respect to the recommendations, or optimal intake, is evaluated by Prerow value (PV). PV value was used to evaluate the efficiency of meal combinations concerning the daily costs, meal preferences and the amount of energy and nutrients. Presented are experimentally determined deviations of energy and nutrients intakes from the recommendations. Adjustments needed for improvement of nutrition requirements corresponding to linguistic variable were determined by use of fuzzy sets without major change of the menus.

The method is applied for menu planning in Croatian boarding schools where female and male students aged from 14 to 19 years are accommodated. At the same time the economic and meal preference aspects of meal planning are incorporated. Preferences are based on the fact that in different regions of Croatia nutrition habits are greatly different. The preferences for offered meals are included in the complete daily menu evaluation.

This study shows that the use of fuzzy sets can be used for Pareto optimisation by which multiple object optimisation is achieved. The fuzzy model represents recommended energy and nutrient intake more adequately then the Dietary Recommended Intake, DRI, intake presented as crisp values, as well as to obtain acceptable price and preferences of menu selection for a population group.

Key words: fuzzy sets, optimisation, nourishment, meal planning

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Introduction

Instead of Boolean logic, fuzzy logic uses a collection of fuzzy variables defined by membership functions and inference rules (1, 2, 3). Computing, in its usual sense, is centred on manipulation of numbers and symbols. In contrasts, computing with linguistic variables is a methodology in which the object of computation are words and propositions drawn from a natural language, e.g., significant increase in price, small, large, far from recommendations, etc. Computing with words is inspired by the remarkable human capability to perform a wide variety of physical and mental tasks without any measurements and any computation. A basic difference between perception and measurements is that, in general, measurements are crisp whereas perceptions are fuzzy (4, 5, 6, 7).

Most of traditional tools for formal modelling, reasoning, and computing are crisp, deterministic, and precise in character. This methodology is a part of mathematical theories of artificial intelligence (8, 9, 10).

The meal evaluation, considering the price, meal preferences and content of energy and nutrients, is often explained by computing with words (11, 12, 13, 14).

The aim of this work is to develop membership functions of fuzzy sets for input information (fuzzification), optimisation of model by including goal functions (interface) and to present the results as a crisp value (defuzzification) (15, 16).

A fuzzy logic control system was applied in modelling of membership functions of fuzzy sets for price of meals, energy, organic-chemical structure and meal preferences. Considering the fact that in Croatia, in different regions, the nutrition preferences are different, the preferences for offered meals are included in the complete daily menu evaluation. Developed are 23 membership functions that define following fuzzy sets: cost of a daily menu; preference choices of offered meals; and defined are 21 fuzzy sets for amounts of energy and nutrients. Fuzzy sets for nutrients include energy, water, proteins, fats, cholesterol, carbohydrates, dietary fibres, alcohol, vitamins (B_1, B_2, B_6, C, A, niacin) and minerals (Na, Ca, Fe, Zn, P, Mg, K). These membership functions describe the membership of a specific intake value to the corresponding fuzzy set ***optimal intake***. With the help of these sets, an evaluation as well as optimisation in the Pareto sense (considering the price, preferences and nutrient intake) is possible.

Fuzzy membership functions are constructed to describe the range of nutrients intake in the range from deficient to excess amounts. For optimisation three goal functions are considered: price, organic-chemical structure and meal preferences. Observing of two or more goal functions at the same time allows to optimise in the Pareto sense. The goal functions are optimised using originally developed program in W.R. *Mathematica* for modelling and optimisation in the Pareto sense. Developed software evaluates the optimal solutions considering the criterion of Prerow value (PV), which presents the modified harmonic mean and defines a rigorous criterion in the defuzzification process.

The theory of fuzzy logic was used in the planing and management of expenses in social nourishment concerning also the nutritive structure of meals. Modelling and planning of nourishment includes a number of unspecified characteristics, which are depended on nutrient offer and also on age, gender and profession of a person or population group. For most nutrients the recommended nutrient and energy intakes are given as single numbers. But for nutrients are given the average requirements (AR), the lowest threshold intake (LTI) and the calculated population reference intake (PRI) (17, 18, 19, 20, 21, 22). These intervals and the values of LTI, AR and PRI do not represent the full reality, which is a continuous transition from critical low intake to adequate intake to excess or even toxic amounts. In this work the daily recommendations are not presented as crisp numbers but as fuzzy sets (7, 23). The daily recommended intake (DRI) for each observed nutrient and energy intake is “softened” by introduction of membership function of fuzzy sets defined for each individual nutrient.

Crisp and fuzzy interpretation of DRIs

In Croatia are accepted the DRI recommended dietary intakes for nutrients given as a range of allowances described by crisp numbers, DRIs, or an interval of estimated safe and adequate daily dietary intake (ESADDI). As crisp values (23, 24, 25), these numbers describe a range of allowed intake, x_a, of a nutrient ***a*** as followed:

$$\boldsymbol{x}_{\boldsymbol{a},min} \leq \boldsymbol{x}_{\boldsymbol{a}} \leq \boldsymbol{x}_{\boldsymbol{a},max} \qquad (1)$$

This is the crisp formulation of allowances and can be used, for example, as restrictions in linear optimisation. The corresponding fuzzy set ***allowed intake*** can be defined by a characteristic membership function μ (x_a):

$$\mu(x_a) = \begin{cases} 1, \text{ for } x_{a,min} \leq x_x \leq x_{a,max} \\ 0, \text{unacceptab le intake} \end{cases} \qquad (2)$$

Objective of the research is to propose a method of modeling and optimization that will consider the daily expenses, meal preferences in different regions and the energy and nutrient requirements of some gender and age group**.**

Methods

Modelling of fuzzy sets

Expenses for meals and meal preferences can not be presented as crisp values and likewise recommended daily intakes for nutrients can not be presented as one single optimal intake. In construction of a membership function the recommended dietary intake, DRI, or reference nutrient intake is intended to be at the top of the slope bordered with deficient intake on one side and the dangerous toxic area on the other side (7, 23, 26, 27). This description can be also used to define a fuzzy set of ***optimal intake*** as shown on Figure 1. The fuzzy set ***optimal intake*** $\mu(x_a)$ presents the membership function or a grade of membership of the intake x_a in the fuzzy set $\boldsymbol{A_a}$. The membership can wary between 0 and 1. The value 0 represents the worst status (deficit or toxic area), and the value 1 represents the absolute optimum. The definition of the fuzzy sets is based on the Dietary Recommended Intake (DRI). For modelling of the fuzzy sets, five points are used (Figure 1): (a) the fuzzy value for zero intakes; (b) safe minimum limit, (μ=0.9); (c) optimal intake, (μ=1); (d) safe upper limit, (μ=0.9); (e) the toxic perilous area (μ=0).

Defuzzification by Prerow value

Measurement of closeness of meal selection and nutrient intake to the optimal and acceptable price and preferences of meals, and to the recommendations, for nutrients, is evaluated using the Prerow value (PV). PV is defined as a weighted harmonic mean with a factor corresponding to the most deficient nutrient. Evaluation by fuzzy logic is based on the modified harmonic mean, PV. All membership functions are connected with the logic “and” (price; + preferences; + energy + one by one nutrient). Evaluation of the final result with crisp values will for optimal solutions reach good daily intakes for nutrients, will be in accordance with different regional preferences and what is most important, the optimal result or group of acceptable results will be financially very acceptable. PV value can vary between 0 and 1. Closeness to zero value represents unpreferable results, and closeness to one, represents highly preferable results.

$$PV = \min(\mu(x_a)) \cdot \frac{1}{\frac{1}{n-1}\sum_{a\neq \min}^{n}\frac{1}{\mu(x_a)}}, \quad a = 1,2,...,23 \tag{3}$$

Optimization

The theory of fuzzy logic was used in modeling membership functions and those results were used for determination of fuzzy control statements and was used for a program development in *Wolfram Research Mathematica* (28, 29, 30). The method is used for menu planning in Croatian boarding schools where are accommodated female and male students aged from 14 to 19 years. For this population group is very important that the energy and nutrition intake is in accordance to recommendations considering the fact that teenagers at this age are in a stage of intensive growth and development. At the same time the economic aspect of meal planning is important. The optimization was based on input variables that presented 5 offers for breakfasts, 30 offers for lunches and 5 suppers. The aim is to optimize the daily meal offer concerning the price, preferences and nutrient offer. Optimal solution that observes more objective functions at the same time (price, preferences, nutrient intake) and does not violate optimal solutions considering just one objective function, is observed as a Pareto optimum. The results of the optimization process are presented with a set of optimal meal offers per day that are optimal in Pareto's sense. This presumes meal combinations (one breakfast, one lunch and one supper) that are acceptable with the price, nutrient content and is preferable by the consumers acceptable in the Pareto sense. The developed program also allows the analysis of content of nutrients in a daily meal offer. PV value was used to evaluate the boarding school meal offers. Given are experimentally determined deviations of energy and nutrients intakes from the recommendations. By use of fuzzy sets are determined adjustments needed for improvement of social nourishment corresponding to linguistic variable without major change of the menus.

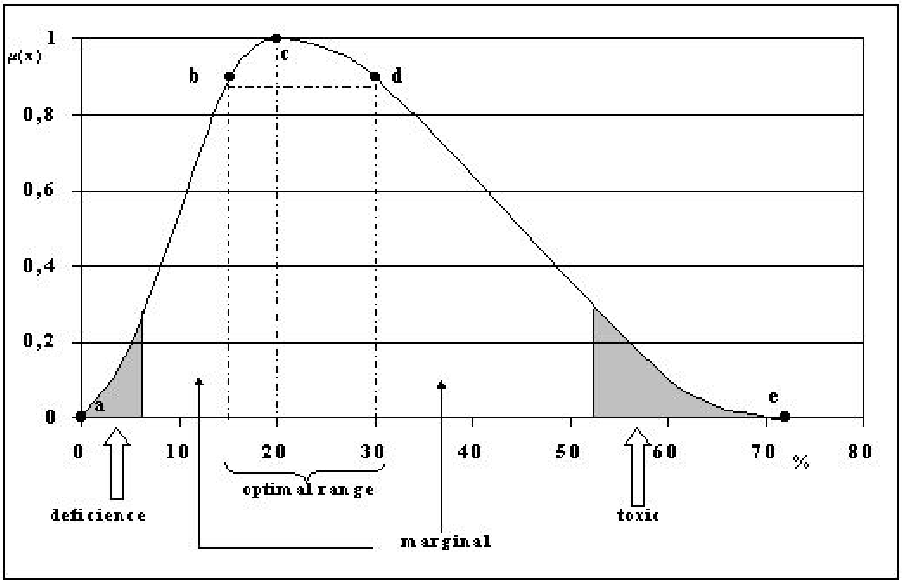

Figure 1. Membership function for the fuzzy set ***fats*** *with the degree of acceptance for the nutrient amount.*

Results and discussion

For essential nutrients the membership function have zero value at zero intake level. For other substances, such as cholesterol and alcohol, the optimal status is reached at no intake, so the fuzzy value at zero intake starts with μ=1, and for some semi-essential nutrients, like dietary fibre, the initial value of the membership function lies between 0 and 1. Those main points with additional interior points were fitted to obtain smooth curves. Models of the membership functions modelled for fuzzy sets are given on Figure 2. Presented are membership functions for the fuzzy set energy intake for females of all age groups.

Likewise are defined fuzzy sets for daily costs, meal preferences, energy and nutrient requirement for students from 14 to 19 years of age who lived in boarding schools. Nutrient requirement include proteins, fats, carbohydrates, water, cholesterol, alcohol, dietary fiber, vitamins: A, B_1, B_2, niacin, B_6, C and minerals: Ca, Mg, P, Fe, Zn, K, Na.

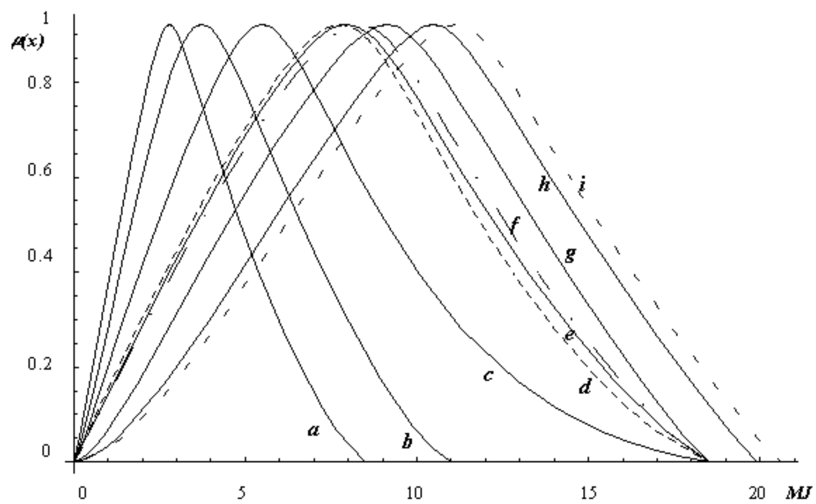

Figure 2. Membership functions for the fuzzy set ***energy intake*** *for females of all age groups* ***a****: 0-0.5;* ***b****: 0.5-1;* ***c****: 1-3;* ***d****: 4-6;* ***e****: 7-10;* ***f****: 11-14; 15-18; 19-24; 25-50;* ***g****:>51;***h****: pregnant woman; nursing woman-second 6 mo.;* ***i****: nursing woman-firs 6 mo.*

Typical shapes of membership functions for monitored fuzzy sets as presented on Figure 3. They are bell-shaped (for example energy, macro-nutrients, Ca, etc.), or S-shaped (for example meal preferences, most vitamins) and Z-shaped (for example daily costs, alcohol, cholesterol). For description of the membership function of the fuzzy set ***daily price*** important are just three, instead of five points. (a) zero cost (μ=1). (b) still optimal expenses (μ=0.9) and (c) unacceptable cost of money per day (μ=0). For modeling of membership function for meal preference is important that the consumers evaluate the daily meal offer with the following notes: 1-for not preferable; 3-for acceptable and 5-for highly preferable. The final evaluation of the daily offer presents the sum of notes for three offered meals per day. Three points define the membership function of meal preference (a) zero sum (μ=0), (b) safe limit or acceptable sum (μ=0.9) and (c) preferable or optimal sum of notes (μ=1). The fuzzy set meal preference is included in the meal optimization observation concerning the fact that Croatia can be divided in minimal two different regions (31, 32) concerning meal customs like for instance: the continental part, Slavonia and Zagreb surrounding, and Istria and Dalmatia as a coastal part of Croatia.

The goal of the developed software is to optimize the diet so that the objective functions, optimal price, optimal preferences and the requirements for all nutrients are met. Also, if nutritional intervention is necessary, to optimize the diet. It is important that recommended changes in dietary habits are not great. In real situations, optimization of single nutrient is difficult. For example, if there is too little calcium and too many proteins in the diet, adding milk gives more calcium but also more proteins what presents a conflict. Therefore the logical operator "and" was used to make a compromise by optimizing calcium and proteins at the same time. In the fuzzy logic system presented here, this is accomplished by optimization of PV (eq. 3).

The developed software based on membership functions of 23 fuzzy sets allows also a detailed analysis presented in Table 1. As it is shown in Table 1, that PV value indicates success of optimization when PV is clos to 1. As presented in Table 1, the third combination has PV=0.005, because the price of this combination is not acceptable according the membership function of fuzzy set ***daily price***. But considering the preferences and nutrient quality, the PV value is 0.68 what is in the range of acceptable, this combination could be also accepted but not often, because the management of expenses is very important in social nourishment.

Table 1. Analysis of critical points for different meal combinations for students in boarding schools (B-breakfast, L-lunch, S-supper).

	Meal combination		
	B2+L6+S5	**B5+L1+S1**	**B3+L7+S3**
PV *(totally)*	**0.94**	**0.51**	**0.005**
Critical point(s)	Fe=13.57 mg *PV*(Fe)=*0.94*	Ca=672.2 mg *PV*(Ca)=*0.53* Na=3887.6 mg *PV*(Na)=*0.94* Fe=11.4 mg *PV*(Fe)=*0.82* E=10851.8 kJ *PV*(E)=*0.82*	Ca=832.7 mg PV(Ca)=*0.7* Na=3891.5 mg PV(Na)=*0.78* Price=40 kn PV(price)=*0.005*

Conclusions

This study shows that application of fuzzy logic can be used to represent recommended energy and nutrient intake more adequately then by DRI crisp values, as well as to present acceptable price and preferences of menu selection for a population group. The PV value can be used not only to measure degree of healthfulness of energy and nutrition intake, but also to measure management of expenses and preference of the proposed menus in Croatian boarding schools. The ability of fuzzy modeling and optimization is to provide optimal solutions in Pareto sense of optimization.

The final result of optimization is not a single solution. Final result is a set of results that allows selection of a single result, but among a large number of optimal solutions.

Due to fuzzy logic optimization it is possible to plan menus for an extended period of time, for example weekly or monthly menus with significant improvement in economies.

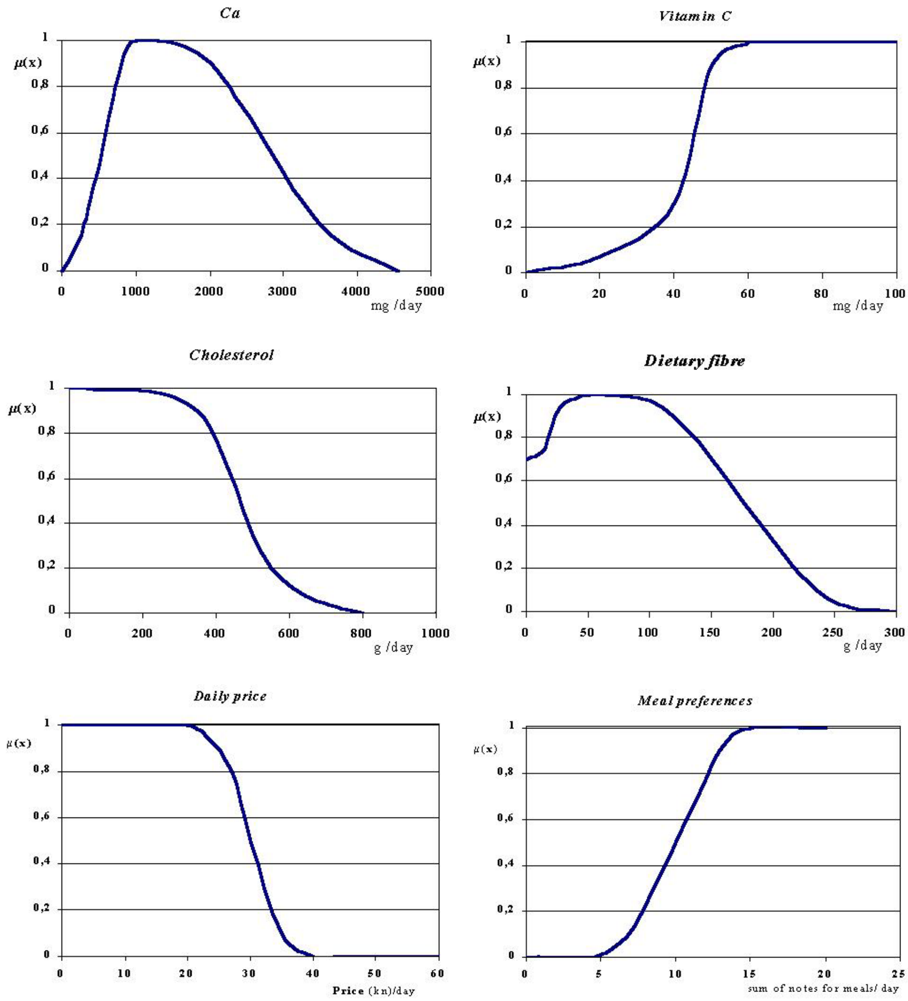

Figure 3. Different shapes of membership functions presented for fuzzy sets for students and meals in boarding schools: ***Meal preferences, Daily price, Ca, Vitamin C, Cholesterol, Dietary fibre****.*

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