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Application of Fuzzy Logic in Diet Therapy – Advantages of Application

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1. Introduction

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, the measurements are crisp whereas perceptions are fuzzy (Zadech, 1965, 1994, 1997, 2001; Wirsam et al., 1997; Hahn et al., 1995, 1995a; Darmon et al., 2002). 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 (Lehmann et al., 1992; Klir et al. 1997; Ray et al., 2002). Instead of Boolean logic, fuzzy logic uses a collection of fuzzy variables defined by membership functions and inference rules (Čerić & Dalbelo-Bašić, 2004; Gajdoš et al., 2001; Rumora et al., 2009).

Human nutrition, considering the daily intake of energy and nutrients, is often explained by computing with words (Brown et al., 1990; Bingham, 1987; Zadech, 1996; Wirsam & Hahn, 1999; Teodorescu et al., 1999), for instance the final conclusion regarding an analysed diet plan can result with phrases as: “the intake of Na should be considerably reduced” or “the consumption of fruits and vegetables must be increased”. An important nutritionist’s task is to improve the dietary habits of the whole population, on the long term, which would help to decrease the frequency of cardio-vascular disease and the morbidity of many chronic diseases such as diabetes (Katamay et al., 2007; Mahan & Escot-Stump, 2007). Hypertension, or high blood pressure, is one of the major diseases of the modern society. Hypertension has no initial symptoms but can lead to long-term diseases and complications. If it’s uncontrolled can cause arteriosclerosis, cerebrovascular accidents, myocardial infarction, and end-stage renal disease (Alderman, 1999) and because physivally devastating is called the "silent killer". It is well known that there is a direct and positive relationship between age and gender with increased prevalence and severity of hypertension. Burt et al. (1995) have published that hypertension is a huge problem for people aged 60–74 years, 72.6% of the African American population and

50.6% of the Caucasian population had hypertension during 1988–1991 (Burt et al., 1995). Also African Americans, women older than 59 years, and older people have a higher prevalence and, even when treated, a greater severity of hypertension than Caucasians, men, and younger people (Hajjar & Kotchen, 2003 Appel, et al, 1997).

Nonpharmacological approach to treatment of the hypertension is currently in focus because of the higher awareness of the growing risk for the possible, future heart problems (MacMahon & Rogers, 1993; Appel, et al, 1997). For this reason, numerous researchers are focused on the clinically efficacious and cost effective interventions of dietary change (McCarron, 1998, Little et al., 2004).

Cook et al. (1995) presented that sustained reduction of 2 mmHg in diastolic blood pressure throughout lifestyle modifications, would result in (i) a 17% decrease in the prevalence of hypertension, (ii) as well as a 6% reduction in the risk of coronary heart disease, in elderly population. Alarming is the forecasting mentioned in Little et al. (2004) that the life expectation is decreasing by increment of blood pressure. Nutrition-based approaches are recommended as a first-line therapy for the prevention of the hypertension. Most recommendations for lifestyle modifications are focused on reducing salt intake, weight loss, and moderation of alcohol consumption. Other dietary interventions, particularly modifying whole dietary patterns, might also effectively reduce blood pressure and thereby control hypertension (Siri-Tarino et al., 2010).

Food guidelines and nutrient intake recommendations are usually expressed as specific quantities (crisp values). In meal planning, crisp values are to rigorous limitations, such as restrictions on nutrient intake, like for instance, the limits for sodium in the DASH diet – 2300 mg/day. Crisp values define the exclusive affiliation in the set, yes or not (Boolean logic). If the daily sodium recommendations are defined as 2300 mg, the daily offer that contains for example, 2350 mg, is according to crisp logic decision completely unacceptable. The overload of 50 mg of sodium per day could be an acceptable overload, but this offer with 2.2% more sodium than recommended will be excluded if the crisp value is overdrawn (Rumora et al., 2009). Fuzzy logic is used to describe unreliable (imprecise) data and knowledge, using linguistic variables, such as slightly deficiency or surplus, much more or less of some nutrient, etc. (Gajdoš et al., 2001; Čerić & Dalbelo-Bašić 2007).

The theory of fuzzy logic in this chapter was used in the planning and management of expenses in social nourishment concerning also the nutritive structure of meals. Modelling and planning of nourishment include a number of unspecified characteristics, which are depended on nutrient offer and also on age, gender and profession of a person (concerning the physical activity level) or population group. Some recommended nutrient and energy intakes are given as single numbers (crisp values). But for most nutrients are also given the average requirements (AR), the lowest threshold intake (LTI) and the calculated population reference intake, PRI (DRI, 1999, 2001, 2001a, 2001b). 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 as crisp numbers are modelled as fuzzy sets (Wirsam et al., 1997, 1997a). 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.

This chapter follows the basics of use of fuzzy logic as:

a. fuzzification process – development of membership functions of fuzzy sets for input information's as nutrient and energy intake;
b. Optimisation in the Pareto sense that implies that all observed variables (energy and all nutrients) and their compliance with recommendations for the observed variables have equal importance
c. defuzzification process (Rödder & Zimmermann, 1977; Wirsam et al., 1997) - presenting results as a crisp values and compared to standard linear programming (LP) methodology.

Basic of the fuzzy logic use will be used in (a) menu offer analysis and (b) menu planning.

In the analysis and planning the main idea was to balance the daily energy and nutrient needs (Wirsam & Hahn, 1999; Wirsam et al., 1997) especially significant in the DASH diet (Gajdoš et al., 2001; Novák et al., 1999; Rumora et al, 2009). The algorithm used in the analysis and optimization is written in the programming system *W.R. Mathematica v.6.* (Stachowicz & Beall, 1995).

2. Diet therapy

Word "diet" implies the habitually amount and kind of food and drink taken by a person each day, so everyone is always on diet. From the medical point of view, diet means a prescribed selection of food. When this prescribed diet is related with therapy (what implies treatment) or a treatment of a disease – we are talking about diet therapy.

Diet therapy is concentrated on a diet planned to meet specific requirements of the individual, including or excluding certain foods.

2.1 DASH diet

Diet for hypertension is in the literature known as "DASH diet" (Dietary Approaches to Stop Hypertension). Basic DASH diet principle is a diversified diet. Studies have shown the Dietary Approaches to Stop Hypertension (DASH) is as effective for lowering blood pressure (BP) levels as the daily consumption of one prescription medication (Appel et al., 1997; Cook et al., 1995; Litle et al., 2004). Uncontrolled hypertension can cause arteriosclerosis, cerebrovascular accidents, myocardial infarction, and end-stage renal disease (Alderman, 1999) and because physically devastating is called the "silent killer" (Burt et al., 1995; Hajjar & Kotchen, 2003; Kumanyika, 1997). For a person with hypertension new eating style is a shock, and the following shock is a radical change in the costume eating habits (Cook et al., 1995). Effective DASH diet is abundant in dairy products (fat-free or low-fat), fruits and vegetables with a reduction in saturated fat, cholesterol, and total fat.

However, long-term adherence to dietary modification is difficult for most people (Little et al., 2004) and, there is a need for interventions that help people adhere to dietary modifications. The DASH diet leads to an establishment of these goals. DASH diet that emphasizes consumption of fruits, vegetables, and low-fat dairy products, includes whole grains, poultry, fish, and nuts, and is reduced in fat, red meat, sweets, and sugar-containing beverages with restriction of sodium intake.

Guidelines given by the DASH diet are valuable for those who know their daily intake, but the less troublesome step from the guidelines could be the reduction of sodium intake as well increase of fruit and vegetable consumption. Sometimes the first step is searching of readymade recipes based on the DASH diet guidelines (AHA, 2004). This is the reason way we have analysed such offers (recipes available from internet resources: AHA, 2004), what was the first goal in this work. The second goal was to propose – computer based menus that will help in the further menu planning. Having crisp values for daily needs it is possible to use them in computer-based planning of optimal menus with respect to agreed evidence-based dietary recommendations and guidelines.

Despite a reputation for genesis of cardiac disease, there is strong evidence for the cardiovascular benefits of saturated fats (McCarron, 1998) In 2010, a meta-analysis of prospective cohort studies including 348,000 subjects found no statistically significant relationship between cardiovascular disease and dietary saturated fat (Siri-Tarino et al, 2010) However, the authors noted that randomized controlled clinical trials in which saturated fat was replaced with polyunsaturated fat showed a reduction in heart disease, and that the ratio between polyunsaturated fat and saturated fat may be a key factor. In 2009, a systematic review of prospective cohort studies or randomized trials concluded that there was "insufficient evidence of association" between intake of saturated fatty acids and coronary heart disease, and pointed to strong evidence for protective factors such as vegetables and a Mediterranean diet and harmful factors such as trans fats and foods with a high glycemic index (Siri-Tarino et al., 2010). Pacific island populations who obtain 30-60% of their total caloric intake from fully saturated coconut fat have low rates of cardiovascular disease (McCarron, 1998).

3. Fuzzy sets

The foundation for the development of the fields of artificial intelligence and expert systems has become fuzzy set theory, especially in the applications of knowledge-based systems.

Fuzzy logic deals with reasoning that is approximate instead of fixed and exact. In contrast with Boolean logic theory, where binary sets have two-valued logic: true or false, fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false (Novák et al., 1999). Implying, when linguistic variables are used, these degrees may be managed by specific functions (Leventhal, et al, 1992).

While variables in mathematics usually take numerical values, in fuzzy logic applications, the non-numeric linguistic variables are often used to facilitate the expression of rules and facts (Zadech, 1996).

A linguistic variable such as *quality* may have a value such as *good* or its antonym *bad*. However, the great utility of linguistic variables is that they can be modified via linguistic hedges applied to primary terms. The linguistic hedges can be associated with certain functions. Linguistic variables are very often used in nutrition, ie. in analysis of nutrient intake, where an nutrient amount can be, sufficient, optimal or insufficiency. The application of fuzzy sets in nutrition will be explained in the following text.

3.1 Crisp and fuzzy interpretation of DRIs

Hahn and his co-workers (1995 & 1995a) have been the first that have applied fuzzy logic in defining nutrient intakes using membership functions. For each nutrient was determined a fuzzy set, $\mu(x_i)$. The tendency is to achieve maximal value (value 1) of the membership function μ, for each observed nutrient, which would mean that the input of the nutrient is optimal (Hahn et al., 1995). In Croatia are accepted the recommended dietary intakes (DRIs) 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 (Wirsam et al., 1997a; Gajdoš et al., 2001; Rumora et al., 2009; Teodorescu et al., 1999), these numbers describe a range of allowed intake, x_a, of a nutrient ***a*** as followed:

$$x_{a,min} \leq x_a \leq x_{a,max} \tag{1}$$

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 $\mu(x_a)$:

$$\mu(x_a) = \begin{cases} 1, \ for \ \ x_{a,\min} \leq x_a \leq x_{a,\max} \\ 0, for\, unaceptable\ intake \end{cases} \tag{2}$$

Fuzzy sets are used to represent the inherent imprecision and fuzziness of food quantities and nutrient values as well as to model the gradual boundaries of the daily recommended values associated with each nutrient. Knowing that cardiovascular diseases are considered as one of the leading causes of today mortality, especially for men aged 31-50 years, who conducted low active way of life with a diet that is mainly consumption of ready to eat or fast food, and that small interventions in the nourishment can achieve significant positive impact, fuzzy approach was used to plan daily menus.

3.2 Fuzzification

The process of transforming crisp values into grades of membership for linguistic terms of fuzzy sets comprises fuzzification. The membership function is used to associate a grade to each linguistic term. The fuzzification process is a modelling process where the membership functions of fuzzy sets for input information's as nutrient and energy intake are development.

Fuzzy membership functions are constructed to describe the range of nutrients intake 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 optimising in the Pareto sense. 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.

This study shows that the use of the fuzzy sets can be utilised 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.

Objective of the research is to propose a method of modelling 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.

In the fuzzy set modelling of nutrients is important to construct the function following the basic properties of a fuzzy set (Dalbelo-Bašić, 2002; Buisson, 2008). Each membership function is defined by its core, height and support (Figure 1).

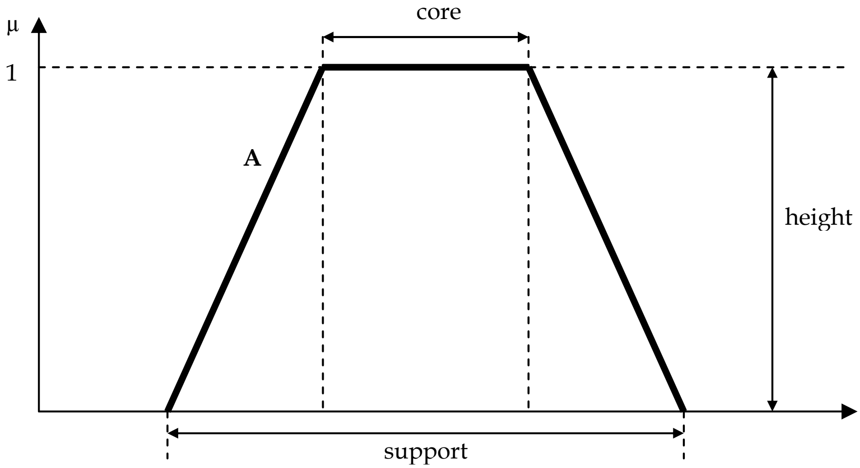


Fig. 1. Properties of a fuzzy set A.

In the construction of nutrient membership function of the following properties for fuzzy sets were used:

The core of fuzzy set A, *core(A)*, is a subset universal set X with the property μ_A (x) = 1, ie

$$core\ (A) = \{(x \in X \mid \mu_A\ (x=1)\} \tag{3}$$

The support of the fuzzy set A, *supp (A),* is a subset of the universal set X with nonzero membership grades ($\mu_A(x) > 0$), ie

$$supp\ (A) = \{(x \in X \mid \mu_A\ (x > 1)\} \tag{4}$$

The height of a fuzzy set, hgt(A), is the supremum (maximum) of the membership grades of A. So,

$$hgt\ (A) = max_{x \in X}\, \mu_A(X) \tag{5}$$

A fuzzy set A is normal if the height equal to 1, hgt(A) = 1. Any set that is not normal is called subnormal.

Core and support of a fuzzy set are ordinary subsets of X, while the height is a real number from the interval [0, 1].

The shape of the fuzzy set presented on figure 1 is the so called "bell-shape". Beside the bell-shape, commonly used shapes in nutrition evaluation and/or planning are: S and Z shape. Those two shapes depend on the preferred amounts of nutrient intakes (presented on Fig. 2).

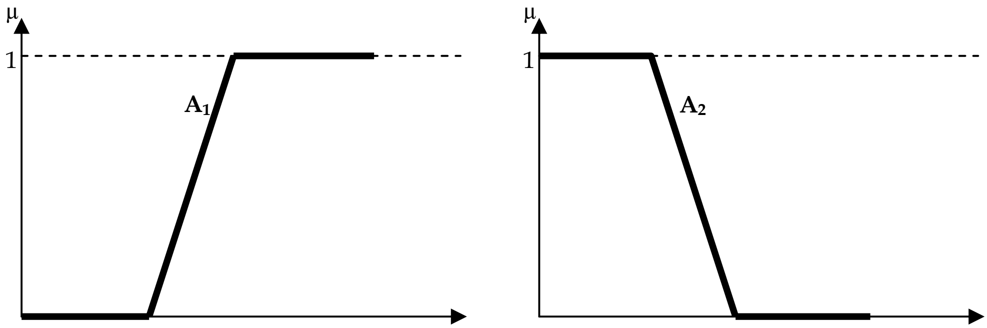


Fig. 2. Shape of a fuzzy set when the intake of the observed nutrient is preferred not be low $\mu(A_1)$ or, to be as lower as possible $\mu(A_2)$.

Example of the nutrient intake where low amounts are not preferred is the daily intake of dietary fibres. Nutrients that are not welcome in high amounts per day are alcohol and cholesterol.

3.3 Defuzzification

Fuzzy approach in nutrition planning is based on the use of the linguistic approach and its application to solve decision problems with linguistic information (Buisson, 2008). Computing with Words (CW) is defined as use of linguistic computational techniques to process linguistic information. An example can be given if one considers an ordinal scale with seven linguistic terms (T):

$$T=\{T_0=\text{"none"}, T_1=\text{"Very Low"}, T_2=\text{"Low"}, T_3=\text{"Medium"}, T_4=\text{"High"}, T_5=\text{"Very High"}, T_6=\text{"Perfect"}\} \quad (6)$$

Reproducing the mentioned linguistic terms (eq. 6) on the daily intake of alcohol and connecting it with the Z shape of its fuzzy set, the terms used would be connected as follows:

$$T=\{T_0=\text{"Preferred"}, T_1=\text{"Medium"}, T_2=\text{"Unacceptable"}\} \quad (7)$$

The approximate computational model processes the membership functions of the fuzzy terms and results in an aggregated fuzzy number. These aggregated fuzzy numbers do not necessarily belong to the initial set of linguistic terms. The ordering of the aggregated fuzzy values can be achieved by using a fuzzy ranking method to compare them. However, this comparison process can be quite complex and produce unreliable results, as it may: (i) involve considerable computations, (ii) produce inconsistency via respective fuzzy ranking methods, and (iii) generate counter-intuitive ranking outcomes for similar fuzzy numbers.

The process of producing a quantifiable result in fuzzy logic, given fuzzy sets and corresponding membership degrees is defuzzification. This means that for every possible value μ, should be given a result with a grade of membership that describes to what extent this value μ is reasonable to use. Defuzzification is a process of transformation of this fuzzy information into a single value μ' that will actually be applied in the decision making process. This transformation from a fuzzy set to a crisp number (defuzzification) is necessary because humans are more familiar with crisp values.

The goal, of using the fuzzy sets in nutrition is to optimize the diet so that the requirements for all observed nutrients are achieved. For example if there is too little dietary fibre and too much energy in the diet, adding wholemeal bread gives more dietary fibre but also more energy – so there is a conflict (Wirsam et al., 1997; Wirsam & Hahn, 1999; Teodorescu et al., 1999; McBride, 1997). To solve this conflict and to represent the logical "and" (because it is desirable to optimize both dietary fibre and energy), compromises are made (Wirsam & Hahn, 1999; Wirsam et al., 1999). Wirsam suggested the application of the product of the minimal membership vale and the harmonic mean to the fuzzy sets of the rest of observed nutrients, gives the name to the crisp value that defuzzifies the optimisation – the Prerow value (PV):

$$PV = \min[\mu(x_i)] \cdot (n-1) / \left(\sum_{i \neq i_{min}}^{n} \frac{1}{\mu(x_i)} \right) \tag{8}$$

$\mu(x_i)$ are the fuzzy sets for *i* nutrients that are observed. So defined Prerow value is now a measure for how close on average one comes to the recommendations - or how healthy our food is. With the Prerow value one can decide whether a certain nutrition situation is better or worse than the other. Wirsam has graded the PV values (between 0 and 1) of a nutritive offer concerning their impact on health (Wirsam & Hahn, 1999; Wirsam et al., 1999). In accordance with the health impact, the preferred PV values are PV>07, and an acceptable meal or menu offer with balanced energy and nutrient offers. Those offers that result with PV > 0.9 would be considered as optimal offers with highly appreciated energy and content of nutrients. Prerow value, so defined, is a measure of closeness of analysed or planned meal (menu) to the recommendations; in other words it means an index of measure how healthy is a given meal or a menu.

Its value can be between 0 and 1, the acceptable value is PV >0.7, what is according to Wirsam and co-workers (1997) a nutritionally acceptable offer. Combinations with PV<0.7 are nutritionally unacceptable because they can have a number of adverse effects on human health, especially over a longer period of time (Wirsam & Hahn, 1999).

4. Fuzzy logic based menu planning – Case study: DASH diet

The DASH diet is considered as a case study for fuzzy logic modelling and optimisation in nutrition, considered is the DASH diet. This diet is proven as a good treatment in the prevention of height blood pressure for the high-risk population, correcting inadequate nutrition. The principles of fuzzy logic were used in the analysis and optimization process, based on developed membership functions for nutrients and food groups, for the target population of men aged 31-50 years, according to guidelines that are outlined in the treatment of hypertension (DASH guidelines: AHA, 2004).

Basic emphasis was on nutrients whose intake, in the DASH diet, is generally important in the treatment. Emphasis was on the control of the daily intake of energy, intake of fats, saturated fats, cholesterol, magnesium, potassium, calcium, sodium, dietary fibre, proteins and carbohydrates.

Observed nutrients in DASH diet	**DASH recommendations** based on a daily eating plan of 2100 kcal (8790 kJ)
Total fat	27% of daily energy intake
Saturated fat	6% of daily energy intake
Protein	18% of daily energy intake
Carbohydrate	55% of daily energy intake
Cholesterol	150 mg
Sodium	2300* mg
Potassium	4700 mg
Calcium	1250 mg
Magnesium	500 mg
Dietary Fibre	30 g

* 1,500 mg sodium was a lower goal tested and found to be even better for lowering blood pressure. It was particularly effective for middle-aged and older individuals, African Americans, and those who already had high blood pressure. g = grams; mg = milligrams

Table 1. DASH diet guideline for a 2 100 kcal Eating Plan

Fuzzy logic modelling is applied for modelling and optimisation of nutritional requirements given by DASH diet guidelines that present crisp values, as presented in table 1 where are given crisp values that should be achieved for a daily intake based on 2,100 kcal (8790 kJ) eating plan (AHA, 2004).

4.1 Membership functions modelled according DASH guidelines

In order to visualize fuzzy concept, intake of a nutrient will be estimated with a value between 0 (not belonging to the set) and 1 (completely belongs). This value of belonging to a set is defining the acceptability or unacceptability grade regarding the DASH diet.

The modelling of a fuzzy set followed the instruction of Wirsam and co-workers (1997) where 5 points are crucial in the fuzzy set construction. Those five points will be explained on the presented example for sodium intake (Figure 3). The value y is the value of the fuzzy value μ.

Five points used in the construction of the fuzzy set:

- Fuzzy value for zero intake of a nutrient (y=0)
- Safe minimum limit of intake of a nutrient (y=0.9)
- Optimal intake of a nutrient (y=1)
- Safe upper limit of intake of a nutrient (y=0.9)
- The toxic perilous area (y=0)

This approach in modelling of fuzzy set membership functions for the daily input was presented in some other studies what indicates the successful applicability (Wirsam & Hahn, 1999; Wirsam et al., 1997; Gajdoš et al., 2001; Rumora et al.,, 2009).

As Wirsam and co-workers (1997) have pointed out, the 5th point is "approximately 3 times the recommended intake for the nutrient". They have also advised to smooth the parabolas, what has been done in presentation of membership function presented for sodium.

Daily intake of Na concerning the crisp values that define the daily recommended intake is very simple based on equation 1: $x_{Na,min} \leq x_{Na} \leq x_{Na,max}$, where the $x_{Na,min}$= 500 mg, and the $x_{Na,max}$ = 2300 mg.

Fuzzy membership functions are modelled to describe the range of nutrient intakes in the range from deficient to excess amounts.

The data used in construction of fuzzy sets, as well as for the presentation of sodium intake based on crisp values are given in table 2.

poi nt	y = μ value	Intake of Na for normal diet (mg)	Intake of Na according DASH diet guidelines (mg)
1	0	0	0
2	0,9	500	500
3	1	1500	1000
4	0,9	2300	2000
5	0	6000	3000*

(*) Although the previous studies (Wirsam et al., 1997) have advised to use as a value for the 5th point – approximately 3 times the recommended intake for the nutrient – this was not applied, because the basic idea of the DASH diet is to reduce the intake of sodium.

Table 2. Values used in construction of membership functions (a) for normal daily intake of Na, (b) daily intake of Na based on DASH diet guidelines.

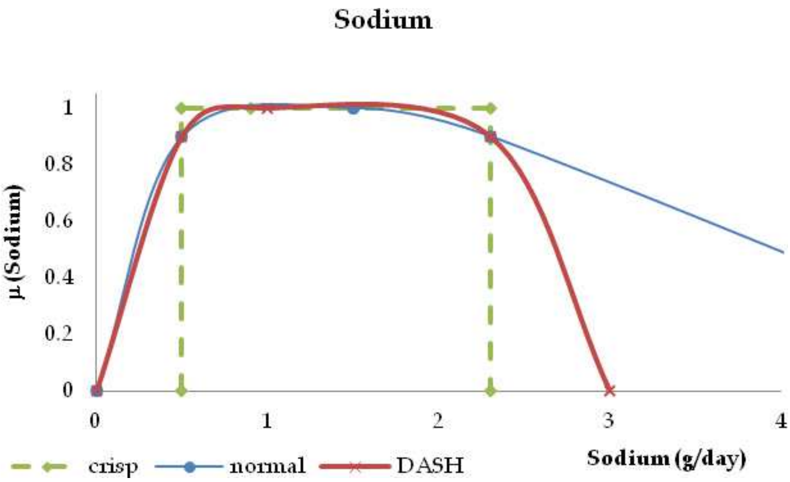
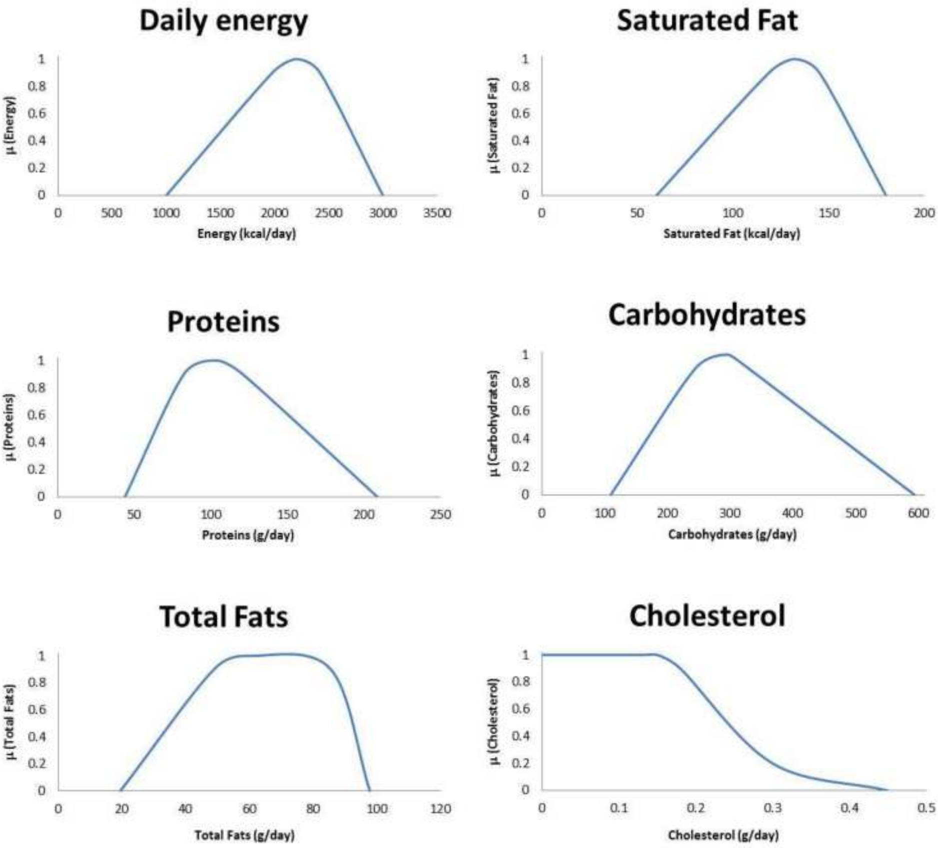


Fig. 3. Membership function, of (i) sodium as recommended by DRI and (ii) sodium according DASH guidelines and definition of the sodium daily intake based on crisp values

The aim of the study was to use fuzzy logic in planning of the diet guidelines for people suffering from hypertension based on membership functions, for energy and nutrients of significance in the DASH diet with a balanced level of foods from different food groups. Regarding the issue of hypertension, the most vulnerable group in the population is the male population aged 31-50 years. The membership functions for energy and nutrients according to guidelines of DASH diet were developed. In the target population there are many individuals who have an inactive sedentary lifestyle, so the energy level was created according the males with low physical activity.

Concerning the basic aim of the DASH diet approach, the end point (5^{th} point) of a membership function could be approximately 3 times the recommended intake for the nutrient (Wirsam et al., 1997) but this was not applied for most of the nutrients due to the success of a DASH diet which occurs if the recommendations are respected.

The 11 fuzzy sets for amounts of energy and nutrients most that are the most important in the DASH guidelines are constructed based on the daily energy intake of 2100 kcal and according the DASH recommendations (Figure 4).



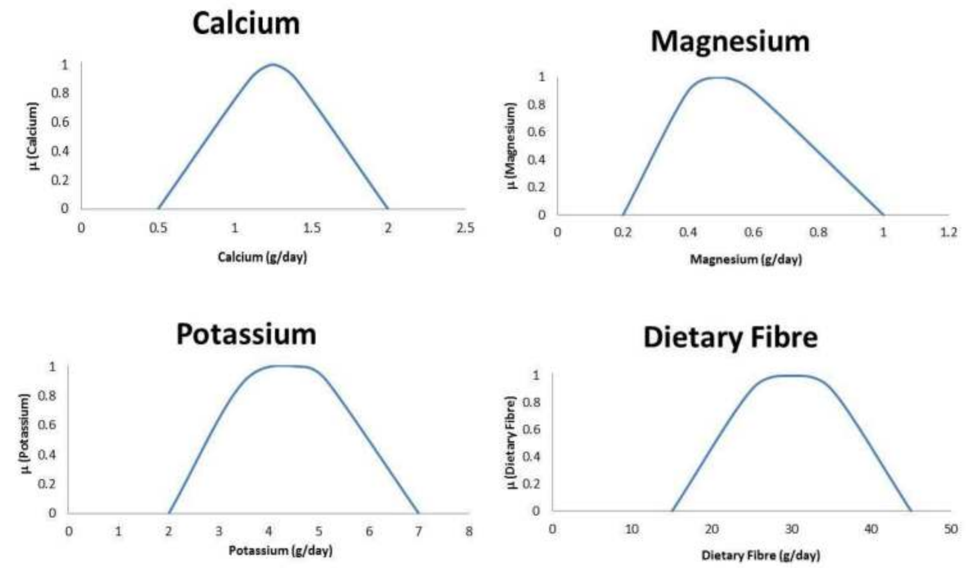


Fig. 4. Membership functions for nutrients important in the DASH diet (according table 1)

4.1.1 Application of membership functions of nutrients in menu evaluation

Database of meals with nutritional content is created in Excel using the USDA database rel. 22 (USDA, 2009) based on 7 days menus taken from the official site of the American Institute of Heart, Lung and Blood (NHLBI, 2010). It is assumed that seven-day menu suggested by NHLBI according guidelines of DASH diet (Table 3) is properly conceived and would be acceptable also for pregnant women regarding the average daily energy offers ranged from 8785 – 10344 kJ. Each day offers consisted of breakfast (B), lunch (L), snack (S) and dinner (D). So, the data basis of meals was built up of 28 dishes (7 B x 7 L x 7 S x 7 D) and an ideal case result would be 2401 daily offers.

Upon creation of an eating plan for individual or group, including the person that provides the DASH eating plan, it is necessary to determine its energy and nutritional needs what is presented in table 4, for the meals given by AHA (2004).

On-line found daily offers for a weak were (i) analysed in order to evaluate the eligibility with DASH diet guidelines, and using the optimisation tool, (ii) the dish offers were combined in daily menus and (iii) new menu offers were evaluated with the corresponding PV value. In the fuzzy logic analysis, the goal is to determine the adequacy of mutual combining the individual dishes of daily meals, and to determine the number of daily combinations that are nutritionally acceptable (PV > 0.7).

The aim was to (a) analyse the daily offers and to identify the critical variables (individual nutrients), (b) optimise a set of applicable menus that are nutritive balanced.

	Breakfast	Lunch	Dinner	Snack
Day 1	Bran flakes cereal with banana, low-fat milk, whole wheat bread with margarine & orange juice	Chicken salad with Italian dressing & fruit cocktail	Beef, eye of the round	Unsalted almonds, raisins & fruit yogurt
Day 2	Instant oatmeal, whole wheat bagel with peanut butter, banana & low-fat milk	Chicken breast sandwich & apple juice	Vegetarian spaghetti & canned pears	Unsalted almonds, dried apricots & fruit yogurt
Day 3	Bran flakes cereal with banana, low-fat milk whole wheat bread with margarine & orange juice	Beef barbeque sandwich with new potato salad & orange	Salad from different vegetables & cornbread muffin	Fruit yogurt, graham cracker rectangles & peanut butter
Day 4	Whole wheat bread with margarine, fruit yogurt, peach & grape juice	Ham and cheese sandwich &carrot sticks	Chicken with Spanish rice & low-fat milk	Unsalted almonds, apple juice, apricots & low-fat milk
Day 5	Whole grain oat rings cereal, banana, low-fat milk, raisin bagel with peanut butter & orange juice	Tuna salad plate, canned pineapple & unsalted almonds	Turkey meatloaf, whole wheat roll & peach	Fruit yogurt & unsalted sunflower seeds
Day 6	Low-fat granola bar, banana, fruit yogurt, orange juice & low-fat milk	Turkey breast sandwich with broccoli & orange	Baked fish (spicy) with cooked carrots, whole wheat roll & cookie	Unsalted peanuts, low-fat milk & dried apricots
Day 7	whole grain oat rings with banana, low-fat milk & fruit yogurt	Tuna salad sandwich, apple & low-fat milk	Zucchini lasagne salad, whole wheat roll with margarine & grape juice	Unsalted almonds, apple juice, dry apricots & whole wheat crackers

Table 3. Daily offers given by AHA (2004), based on DASH diet guideline

Observed	DASH Recommendations	Different daily offers						
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Ed, kJ	8800	9063	8805	9844	9362	10344	9086	8785
Total fat , % Ed	27	21.2	23.9	25.3	23.5	22.3	32.4	24.2
Saturated fat , % Ed	6	6.5	6.6	6.3	6.0	5.0	6.1	6.6
Cholesterol , mg	150	143.4	124.3	131.9	162.1	166.4	115.4	83.0
Magnesium, mg	500	529.3	428.0	609.7	535.5	558.9	579.9	545.5
Potassium, mg	4700	4359.5	4445.6	6124.3	4782.2	4984.9	4484.7	4147.3
Calcium, mg	1250	1885.3	1533.3	1487.5	1602.7	1244.1	1294.8	1443.7
Sodium, mg	2300	2292.3	1891.8	2115.6	2190.3	2101.5	1619.6	1714.0
Dietary fiber, g	30	32.0	24.7	31.1	32.6	32.3	38.0	37.7
Protein, % Ed	18	19.1	18.8	20.4	20.8	20.3	17.8	18.1
Carbohydrate, % Ed	55	59.4	57.2	54.3	55.8	57.5	49.8	57.7

Table 4. Energy and nutrient content of daily offers given by AHA (2004), based on DASH diet guideline

To get an acceptable range of macro and individual entries micronutrients from existing recommendations (which represents an expression value), modelled are membership function.

Membership functions were modelled for the male population group aged 31-50, with low physical activity (PA=1), and potentially suffering from hypertension. Basic emphasis was on nutrients whose intake in the diet is general important in the treatment measures: energy, fat, saturated fat, cholesterol, magnesium, potassium, calcium, sodium, dietary fibre, proteins and carbohydrates. DASH diet guidelines emphasize the quality of fat, or fat consisting mostly n-3 and n-6 unsaturated fatty acids. Their membership functions were modelled according to their share in the total daily fat share. In addition, membership functions for individual nutrients were developed according the DASH diet guidelines.

Additionally, reviews by the American Heart Association led the Association to recommend reducing saturated fat intake to less than 7% of total calories according to its 2006 recommendations (Little et al., 2004).

The nutrient composition of the daily intake was analysed and planed following the flow chart presented on Fig. 5.

Basic guidelines for balanced energy and nutrient intake are the daily recommendations (DRI, 1990 & 2005) that define recommended daily needs of energy as well as macro and micronutrients (table 1).

5. Results

Our developed algorithm used in the daily menu analysis and optimization is written in the programming system *W.R. Mathematica v.6.*The algorithm included a feature that the solution may re-marked character (specific number) that allows decoding fuzziness, and also allows a man to understand and compare the results. Fuzziness was decoded with the assistance of Prerow features (PV value), which assesses the acceptability or unacceptability of a menu offer (a combination for a day). The combinations that resulted with a crisp value (PV value) within 0.7 to 1, was considered as acceptable daily offer, what is according to Wirsam et al. (1997) a nutritionally acceptable offer. What is the PV value closer to the value 1, the menu combination consists of nutrient amounts whose daily intake is optimal (0.9<PV<1).

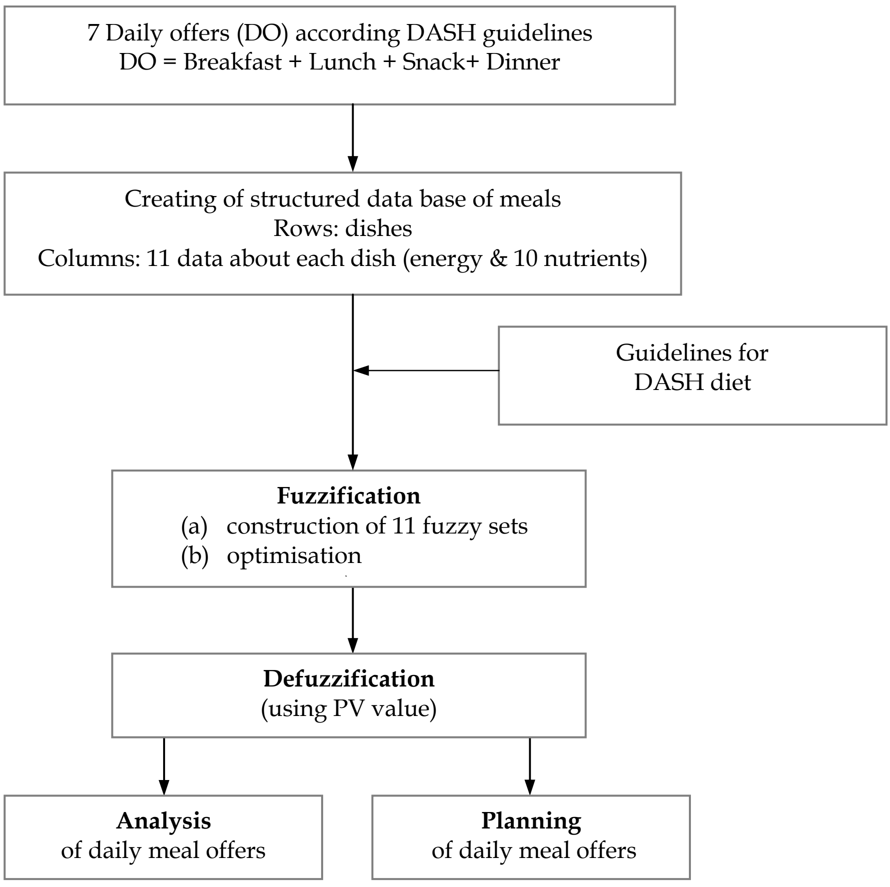


Fig. 5. Flow chart of the methodology used in evaluation and optimisation of meal offers

5.1 Results of the menu analysis

During the analysis the goal was to determine the adequacy of mutual combining of individual dishes of daily meals, and to determine the number of daily combinations that are nutritionally acceptable (PV > 0.7 connotes energy and nutrient intake of all observed nutrients in the acceptable range). Results of it are presented in table 5.

Daily combination		Prerow value (PV)
Day 1	B_1, L_1, S_1, D_1	0.533
Day 2	B_2, L_2, S_2, D_2	0.765
Day 3	B_3, L_3, S_3, D_3	0.831
Day 4	B_4, L_4, S_4, D_4	**0.433**
Day 5	B_5, L_5, S_5, D_5	0.761
Day 6	B_6, L_6, S_6, D_6	0.818
Day 7	B_7, L_7, S_7, D_7	0.841

Table 5. Evaluation of daily meal combinations based on one weak DASH diet plans

As the results of the defuzzification using PV value show, not all combinations have reached the limit value of 0.7, what was an indicator of acceptance of a daily offer. Using of membership functions constructed for nutrient intake allow also identifying critical nutrient(s), as presented in the following table (Table 6).

Observed (x_i)	**$\mu(x_i)$**	**Amount**
Ed, kJ	0.818636	9362
Total fat , % Ed	0.477551	23,5
Saturated fat , % Ed	0.905263	6,0
Cholesterol , mg	0.976364	162,1
Magnesium, mg	0.994118	535,5
Potassium, mg	0.900000	4782,2
Calcium, mg	0.909500	1602,7
Sodium, mg	0.837000	2190,3
Dietary fiber, g	0.800000	32,6
Protein, % Ed	0.986239	20,8
Carbohydrate, % Ed	0.990323	55,8
Total PV	0.433	

Table 6. Analysis of the offer of day 4 with aim to detect the critical point

Experimentally determined deviations of energy and nutrients intakes from the recommendations are presented. 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 intake of total fats ($\mu(x_i) = 0.477551$) is identified as a critical nutrient. As can be seen, all other 10 observed variables (x_i) have acceptable amounts. But because of that one critical nutrient – this daily meal combination will not be preferred.

5.2 Results of the menu optimisation

Membership functions were also used for planning new daily menu offers, based on a weekly offer that is recommended as appropriate menus for people who conducted the program according to the DASH diet principles, for 7-days (tables 3 & 4). According to the principle of modelling and optimisation (Fig. 5), the input variables (menu for 7 were evaluated using membership functions, $\mu(x_i)$, and estimated after the defuzzification with the crisp value PV.

As it was mentioned, possible number of combinations is 2041, but how many of them are acceptable (PV>0.7) based on their nutrient and energy content will show on the defuzzification (Table 7).

Daily combination		Prerow value (PV)
1	B_4, L_4, S_4, D_4	0.433
2	B_4, L_4, S_5, D_4	0.477
3	B_1, L_1, S_1, D_1	0.533
. . .	. . .	. . .
2398	B_3, L_2, S_5, D_1	0.892
2399	B_1, L_3, S_5, D_2	0.893
2400	B_1, L_3, S_1, D_3	0.893
2401	B_1, L_2, S_5, D_3	0.894

Table 7. Daily offer combinations sorted according PV value (3 worst & 3 best)

A measurement of appropriate energy and nutrient intake with a respect to the recommendations, or optimal intake, is evaluated by Prerow value. PV value was used to evaluate the efficiency of meal combinations concerning the daily amount of energy and nutrients. The goal functions are optimised using originally developed program in W.R. *Mathematica* for modelling and optimisation in the Pareto sense. Sorted results, from those which are less appreciated to those that are highly recommended, have shown that 65 % are acceptable (PV>0.7), but the 35% of combinations should be avoided in the consummation (Table 7).

Buisson (2008) has in his study stressed out that use of fuzzy logic in meal planning results with applicable meal offers that are balanced regarding the energy and nutritive contents. Optimisation solutions provide assistance in the selection of foods and meals, and their combination with each other.

From the results of optimization using fuzzy logic, the proposed food guide, the DASH diet principles, can be used either for health reasons (decrease hypertension) or simply for a healthier diet. Developed software evaluates the optimal solutions considering the criterion of Prerow value, which presents the modified harmonic mean and defines a rigorous criterion in the defuzzification process.

Is there possibility that another computing approach could be more effective, can be answered only then if the same problem is solved with another tool. Fuzzy approach is placed in the nonlinear approach, so the alternative could be the linear approach, such as linear programming used in DASH diet planning.

5.3 Linear programming in DASH menu planning

The same goal (optimal daily meal offer) but solved by another tool is used in order to compare the final results and to extract advantages or disadvantages of menu planning based on fuzzy logic.

Linear programming is designed to address the problem by choosing between several possible or available variables in order to achieve the most suitable combination of the selected (optimal) result (Kalpić and Mornar, 1996; Deb, 2001, Darmon et al, 2002). Applying these premises (goal and constrains), models were constructed in order to find the so called – optimal solution. Models containing such target function and a set of admissible constrains are called linear models (Eckstein, 1967; Martić, 1996; Kalpić and Mornar, 1996) and are often used in menu planning (Gajdoš et al., 2001; Koroušić Seljak, 2009). Using linear optimisation in menu planning, it is very important to indicate the upper and lower limits, i.e. minimum and/or maximum value that is needed to satisfy the daily nutrition needs (Bhatti, 2000):

$$\textbf{Minimum} \leq \textbf{acceptable nutrient amounts} \leq \textbf{Maximum} \quad (9)$$

Nutrient needs are often defined in ranges as mentioned in eq. 1) what will be in detail explained in materials and methods (especially in table 2 and figure 1).

According to the target group, males aged 30-51, it was important, from a set of data, choose those items that are crucial for the DASH diet (Table 8).

Observed	DASH Recommendations	*Daily recommendations* used for LP*	
		Minimum	**Minimum**
Ed, kJ	**8800**	8000	9600
Total fat , % Ed	**27**	24.3	29.7
Saturated fat , % Ed	**6**	5.4	6.6
Cholesterol , mg	**150**	135	165
Magnesium, mg	**500**	450	550
Potassium, mg	**4700**	4230	5170
Calcium, mg	**1250**	1125	1375
Sodium, mg	**2300**	2070	2530
Dietary fiber, g	**30**	27	33
Protein, % Ed	**18**	16.2	19.8
Carbohydrate, % Ed	**55**	50	60

*the range of the minimum and maximal value is ± 10% of the recommended value

Table 8. Recommended intake of energy and macronutrients according DAH guidelines and their limitations used in meal planning using linear programming

The aim is to reach a result that presents a daily energy and nutritive balanced offer with minimal cost. Price was placed in the aim function of the linear model where energy and 10 nutrients (total Proteins, Fats, Carbohydrates, Saturated Fats Dietary Fibres, Cholesterol, Calcium, Magnesium, Sodium and Potassium) were included in the constrains subjected to the goal function, as follows in the basic linear model.

Basic structure of the linear model:

Goal function:

$$\min F= p_1 \cdot B_1 + \ldots + p_7 \cdot B_7 + p_8 \cdot L_1 + \ldots + p_{14} \cdot L_7 + p_{15} \cdot S_1 + \ldots + p_{21} \cdot S_7 + p_{22} \cdot D_1 + \ldots + p_{28} \cdot D_7 \quad (10)$$

Constrains that will restrict energy and nutrient content of daily offers:

$$a_{ij} \cdot B_j + a_{ij} \cdot L_j + a_{ij} \cdot S_j + a_{ij} \cdot D_j \geq b_{i,\,min} \tag{11}$$

$$a_{ij} \cdot B_j + a_{ij} \cdot L_j + a_{ij} \cdot S_j + a_{ij} \cdot D_j \leq b_{i,\,max} \tag{12}$$

Where:

- $\mathbf{p_j}$ - Meal price
- $\mathbf{x_j}$ - Meals, number of the meals (j), j=1, ... , 7
- $\mathbf{a_{ij}}$- Content of energy, water or nutrients, i, i=1, 2, . . ., 20, for observed meals, j
- $\mathbf{b_i}$ - Recommended intakes of energy, water or nutrients

In order to construct a linear models as similar as possible to the fuzzy model, the price of all offers was set equal to one, what would allow to optimise without of price influence (because the price was not included in the meal planning based on fuzzy logic). Program LINDO was used as linear optimisation program.

Each daily offer included the same offer as in the previous example: one breakfast (B), lunch (L), snack (S) and dinner (D). Again, the data basis of meals was built up of 28 dishes (7 B x 7 L x 7 S x 7 D) and an ideal case result would be 2401 daily offers. But using the optimisation tools, it will be cleared if all combinations (daily offers) are well balanced concerning the required energy and nutrient content. The aim was also to examine whether the target group will satisfy all energy and nutrient needs, without additional changes of the offers, through menu offers.

Daily meal offer, LP	
No. 1	B_1, L_2, S_5, D_1
No. 2	B_2, L_2, S_1, D_2
No. 3	B_1, L_2, S_1, D_7
No. 4	B_7, L_3, S_2, D_1
No. 5	B_1, L_1, S_2, D_5

Table 9. First five daily offers as a result of using linear optimisation tools

The nutrient compositions of daily intakes were based on restrictions selected with respect to the target group of men aged 31-50 with the emphasis to sedentary job. Based on the composition, weekly plan have been proposed that consisted of 7meals distributed during the day as breakfast, lunch, snack and dinner (Table 9). The average values of energy and nutrients of the offers can, without problems, composed menu offers for almost 2 months (even 63 daily offers satisfied all demands on energy and nutrients).The present study combines the limitations of menu offers (NHLBI, 2010) and of modelling approaches. In particular, the validity of results obtained with diet modelling analysis is dependent on how well the models simulate reality and on the quality of input data.

In order to identify the critical variables (individual meals) or constrains (nutrient requirements), the sensitivity test was used (Gajdoš et al., 2001). But collection of those result are much more demanding because each new solution requires repetition performance of the optimisation process. Until now, it has been used to design either individual diets (Soden and Fletcher, 1992; Colavita and D`Orsi, 1990) or population diets (Maes et al., 2008; Carlson et al., 2007; Cleveland et al., 1993; Darmon et al., 2002) and their implications in terms of food choices (Ferguson et al., 2006).

As some studies show (Carlson et al., 2007; Murphy and Britten, 2006; Katamay et al., 2007; Cleveland et al., 1993; Soden and Fletcher, 1992) the main goal of linear programming used in meal planning is to reach the nutrient-based recommendations and also translation of the set of nutrient-based recommendations into foods (not food composites) for each individual or group that is a representative sample of the target population (Maillot et al., 2010), that are in accordance with set limits and the goal function.

6. Conclusion

The menu planning based on fuzzy logic considered and including: i) recommendations as crisp values, ii) modelling of membership functions for daily energy and nutrient intake as well as for preferences and price (Pareto optimisation), iii) defuzzification and iv) identification of deviations in order to improve the daily intake.

The final result of the optimisation process was a set of daily menus, 65% of which are nutritional acceptable. The acceptable daily combinations can be used in healthy meal planning and in prevention and treatment of hypertension, changing nutritional habits according DASH guidelines. This would also help to avoid consumption of unacceptable daily offers (almost 35%) from the set.

The use of fuzzy logic has also highlighted the possibility of insufficient energy and nutrient intake when dishes from different daily offers are combined in an inadequate way.

Using optimisation in meal planning showed that the energy amount in the optimised meals is in proportion with DASH recommendations with no fear of the influence on health, as Wirsam and Hahn (1999) pointed out.

The results indicated that use of fuzzy logic is well suited to deal with the inherent imprecision of data associated with food quantities and their nutrient values, and to propagate it through computations in a mathematical way with a great applicability in diet planning as well as in the demanding cases as DASH diet planning.

From one weekly offer undertaken from NHLBI (2010) that is consisted from 7 daily offers based on 4 dishes (breakfast, lunch, snacks, and dinner) was possible to gain 2401 daily offers but using the optimisation approach it was shown that it is not possible to combine all dishes in new a daily offers because the nutrient composition will not satisfy needs of the target group, man aged 30-51 with the emphasis to hypertension.

From possible 2401 daily offers (new daily menus) the final menu set was reduced on 63 daily offers, almost 2 months. Each weekly plan that has been proposed consisted of 4 meals distributed during the day as breakfast, lunch, snack and dinner. This indicates the limitation of the optimisation approach regarding the input data set, the weekly offer undertaken from NHLBI (2010). This example has shown that when the importance of the objective function is reduced (equal for all offers), this is a deficiency of the LP in meal planning and is no competition at all to the application of fuzzy logic in meal planning.

But the great advantage of using fuzzy arithmetic in menu planning is the suitability to deal with the inherent imprecision of data associated with nutrient values. The fuzzification and defuzzification process are a great help in achievement of analysis or balanced menu offers.

In the future research, new variables will be added to the set of membership functions of energy and nutrients. Those two variables are (i) preferences of the consumer and (ii) the price of a daily menu combination. The following aim is to balance the menu offers globally, including all mentioned membership functions (11 presented in this chapter + 2 new: preference and price).

Before the construction of the membership function for the consumer preference, it is necessary to carry out the evaluation of the offers, i.e. of each meal (Breakfast, Lunch, Dinner and Snack). The evaluative scale can be arbitrary, for example, if the Likert-type scale from 1 to 5 is used, the values used in the construction of the curve should be as following: 1 - "totally unacceptable", 2 - "not acceptable" 3 - "moderately acceptable" , 4 - "acceptable", 5 - "very acceptable". Membership function that describes the preference of the consumer will have the shape “S” (Fig. 2, $\mu(A_1)$), because for the consumer is not acceptable to consume something that is not preferable. The membership function of acceptability (consumers preference) can also be used to exclude any food ingredient that is a potential allergen (a meal that contains any allergen is "totally unacceptable"). Allergens that could be removed in such menu planning are milk, eggs, nuts, grains, etc. Each offer that contain allergens would be unacceptable ($\mu(x) < 0.5$) and according the equation 8., the final PV value would not be acceptable.

Membership function for the price (daily price acceptance) of the daily menu offer should have the form “Z” (Fig. 2, $\mu(A_2)$), because user-friendly is the lower price ($\mu(x) > 0.7$), although daily offers that are expensive should not be excluded because such offer can be nutritionally very acceptable.

This software should be also used in education of users (either healthy or sick) to enlarge their knowledge regarding food combining and menu planning. Efficient education based on the software that is based on using fuzzy logic, intended for nutrient intake analysis and/or planning, would be a powerful tool in the fight with the growing world problem – obesity.

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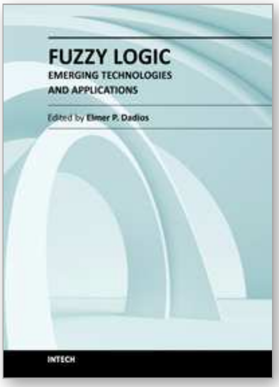

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The capability of Fuzzy Logic in the development of emerging technologies is introduced in this book. The book consists of sixteen chapters showing various applications in the field of Bioinformatics, Health, Security, Communications, Transportations, Financial Management, Energy and Environment Systems. This book is a major reference source for all those concerned with applied intelligent systems. The intended readers are researchers, engineers, medical practitioners, and graduate students interested in fuzzy logic systems.