Optimized Daily Diet Composition for a Nutritionally Balanced Diet: An Application of Fuzzy Multiple Objective Linear Programming

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***Abstract*—Nutrition related diseases such as Cardiovascular Diseases, type 2 diabetes, and certain types of cancers are widely prevalent, and increasing in both developed and developing countries. This escalates the need to consistently follow a nutritionally balanced diet. Formulation of nutritionally balanced Meals is a complex task, which requires considerable effort, time, and intellectual capability for evaluation of Menu items and analysis of a range of nutrient values. As a step towards automating this task, this interdisciplinary study presents a fuzzy optimization model applying Fuzzy Multi-objective Linear Programming (FMOLP) to compose a daily diet consisting of nutritionally balanced Meals which limit nutrients such as cholesterol, sugar, saturated fat, and sodium. An effective algorithm is developed to create a pareto optimal solution set of optimized daily diet choices. The model is tested using one hundred Menu items, for demonstrating the applicability of the model in composing a nutritionally balanced diet.**

Keywords— Nutritionally balanced diet, Fuzzy optimization, Multi-objective decision making, Fuzzy multi-objective linear programming

I. INTRODUCTION

Nutrition-related diseases such as Cardiovascular Diseases (CVD), type 2 diabetes, and certain types of cancers, are widely prevalent and increasing in both developed and developing countries. In Australia, more than 60% of the adult population is overweight or obese [1] and almost one million Australians are diagnosed with type 2 diabetes (with an additional two million at risk of type 2 diabetes) [2]. This reflects the latest patterns of nutrition transition which have occurred in the last few decades and resulted from significant increases in the consumption of packaged and processed foods; changes to the nutrient content of foods i.e., more added sugar, salt and refined carbohydrates; increases in the total number of eating events over a day (i.e. more snacking); increased reliance on foods prepared and purchased outside the home, and declines in the consumption of fresh foods in particular, fruits and vegetables [3].

As a result of the increased incidence of nutrition-related diseases and recognition of the need for large scale action many countries have established public food nutrient databases to support monitoring. Inclusion of nutrient information on food labels is mandatory in many countries and recently it has become mandatory for chain and fast food restaurants to provide consumers with nutrient details of menu items. On the other hand, it is a complex task that requires considerable effort and time to analyze and evaluate menu items, using available data, and subsequently choose or formulate/reformulate nutritionally balanced meals.

Currently, food sources of an individual's daily diet can be categorized as:

Category 1: Homemade meals only (HM)

Category 2: Combination of homemade and food purchased from other outlets (HM+FP)

Category 3: Food Away From Home (FAFH) only [4]

Typically an individual's daily diet consists of four to five meals and each meal can be a combination of many menu items. To assist in efficiently completing the task of formulating balanced daily diet, there is a need for a Ubiquitous Intelligence System that automates the diet formulation process and caters to users of any of the three categories of food sources mentioned above.

To formulate a balanced meal or diet, an individual needs to be able to evaluate available food items and compose meals by choosing appropriate items that meet objectives for energy and nutrient intakes and limiting the amount of undesired food components such as cholesterol, saturated fat, sugar, and excessive sodium. The complexity of this task can be confounding if a food or meal item is for example; high in protein and at the same time high in cholesterol or saturated fat and possibly conflicting with the user's nutritional preferences or requirements [5]. Fundamentally, multi-objective decision making (MODM) refers to making choices from identified options having multiple, possibly conflicting attributes [6]. Formulation of nutritionally balanced meals or diets is a typical multi-objective optimization problem.

This study presents the fuzzy optimization model, implementation of which forms part of a Dietary Intelligence System (DIligenS) [7] under development. DIligenS has the architectural components of knowledge base, inference engine, data base, data extraction and conversion modules in addition to the knowledge building and application interface. DIligenS facilitates the use of publicly available food nutrient database, and dietary requirements data thus minimizing the user data entry requirement.

This paper is organized into 6 sections. Section II provides an overview of previous work in the application of optimization techniques to diet formulation and fuzzy optimization.

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Section III defines the problem, describing the data used in the problem solution. Section IV details the research method and presents the fuzzy optimization model. Section V demonstrates the application of the model used to create five alternatives of balanced daily diets from one hundred (100) menu items and Section VI concludes the paper with briefing on further work.

II. Related Work

Finding a nutritionally adequate diet at minimum cost has been a classical example of linear programming optimization [8]. More recently, nutritionally balanced diet formulation has become an active research topic applying optimization techniques into dietetic research realm. A number of multi-objective optimization techniques including genetic algorithm (GA) [9], quantum genetic algorithm (QGA) [10], differential evolutionary (DE) algorithm [11], Non-Dominated Sorting Genetic Algorithm (NSGA – II) [8, 12] and linear programming (LP) [13, 14] are used for optimized diet formulation. These techniques have been applied to formulate balanced diet with differing needs such as diabetes diet [12], vegan menu [13] nutritional treatment of hypertension [9], and diet formulation for black tiger shrimp [13]. There are differences between algorithms in terms of accuracy, speed, and suitability. For example, DE algorithm can be used for real coding of floating point numbers unlike simple GA that uses binary coding for representing problem parameters [11]. The balanced diet optimization problem does not have a single unique solution. Instead there are equally good solutions thus creating a Pareto optimal solution set [8, 9, 11].

Multiple objective problems are concerned with the optimization of multiple, and conflicting objective functions subject to constraints. Multiple objective liner programming (MOLP) is one of the popular methods for solving optimization problems. The objective functions and constraints involve many parameters whose values are often imprecisely or ambiguously known. Therefore, it may be appropriate to represent these parameters using fuzzy numbers. Fuzzy multiple objective linear programming (FMOLP) involving fuzzy numbers provides a tool for more realistic modeling [15].

Fuzzy programming is found to be very effective and promising for solving multi-objective optimization problems [16, 17]. Often, there will be lack of complete information, or precisely defined boundaries on the satisfiability or range of criterion dominion. In such cases fuzzy sets theory provides the tools to model reasonably and devise acceptable solution [15]. Inclusion of fuzzy logic in linear programming for diet optimization achieves two improvements: 1) enabling modelling of imprecise information related to food nutrients without losing the quality of information, and 2) facilitating numerical representation of qualitative factors such as subjective preferences of nutrients, taste, consistency etc. To adequately model the imprecision, linguistic terms [18] approximated by trapezoidal fuzzy numbers are used.

A fuzzy number is a convex fuzzy set [19, 20] characterized by a given interval of real numbers, each with a grade of membership between 0 and 1. Trapezoidal fuzzy numbers (TFNs) are a special class of fuzzy number, defined by four real numbers, often expressed as *(a, b, c, d)*. The class of trapezoidal fuzzy numbers is the most generic class of fuzzy numbers spanning entirely the class of triangular fuzzy numbers and has more applicability in scientific and engineering problems [21].

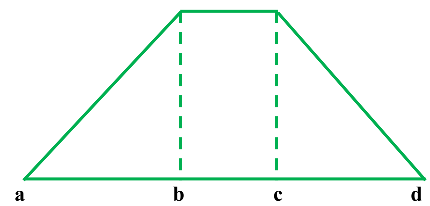

Fig. 1. Graphical Representation of a Trapezoidal Fuzzy Number

A. Trapezoidal Fuzzy Numbers (TFN)

Definition 2.1: The fuzzy set A is represented by membership function: $A(x) : R \to [0, 1] (0 \le A(x) \le 1; x \in X)$, *where x represents the criterion, and X is the domain space* [21].

The membership function has the following characteristics:

1) A(x) is a continuous mapping from R to the closed interval [0,1]
2) A(x) is normalized, which means that $A(x_0) = 1$, where $x_0 \in X$
3) A(x) is convex, which means if for $\forall p \in [0, 1]$ $A(px_1 + (1 - p)x_2) \ge \min(A(x_1), A(x_2))$

Definition: 2.2 A fuzzy number A = (a,b,c,d) is said to be trapezoidal fuzzy number (TFN) if its membership function is given by, A(x) where $a \le b \le c \le d$.

1. $$A(x) = \begin{cases} 0, & x < a \\ \frac{x-a}{b-a}, & a < x \le b \\ 1, & b < x < c \\ \frac{d-x}{d-c}, & c \le x < d \\ 0, & x > d \end{cases}$$

2. A matrix $A = (a_{ij})$ is called a fuzzy matrix if each element of this matrix is a fuzzy number [21].

1) Arithmetic Operations on trapezoidal fuzzy numbers (TFNs)

Let $A_1 = (a, b, c, d)$ and $A_2 = (k, l, m, n)$ be two non-negative trapezoidal fuzzy numbers then,

1. Addition of two TFNs $\oplus$,
   $A_1 \oplus A_2 = (a, b, c, d) \oplus (k, l, m, n) = (a+k, b+l, c+m, d+n)$

2. Multiplication of two TFNs $\otimes$,
   $A_1 \otimes A_2 = (a, b, c, d) \otimes (k, l, m, n) \cong (ak, bl, cm, dn)$

3. Subtraction of two TFNs $\ominus$,
   $A_1 \ominus A_2 = (a, b, c, d) \ominus (k, l, m, n) = (a-n, b-m, c-l, d-k)$

4. Inversion of a TFN,
   $1/A_1 \cong (1/d, 1/c, 1/b, 1/a)$

The graphical representation of a trapezoidal fuzzy number (TFN) is illustrated in Fig. 1, satisfying the relationship $a \leq b \leq c \leq d$.

III. Problem Definition

The clarity and readability can be improved by defining some of the terms regularly used in this paper. These definitions are given below.

Definition 3.1: Menu Item is referred to as food or beverage either prepared at residence or purchased from an outlet such as restaurants or take away places.

Menu Items can be prepared from fresh raw food products, or from pre-prepared or processed products.

Definition 3.2: Meal consist of one or more Menu Items consumed at any one time in a day.

Definition 3.3: Recommended Dietary Intake (RDI) is the average daily dietary intake level of essential nutrients that is sufficient to meet the known nutritional needs of healthy persons that includes macronutrients, minerals, and vitamins as defined by NHMRC based on collaborative studies conducted by Australia and New Zealand [5].

Definition 3.4: Nutrient Reference Value (NRV) is the amount of nutrient required on an average daily basis as set by the RDI of macronutrients, vitamins and dietary energy.

Even though this study has used NRVs from the NHMRC document [5], other location specific dietary intake guidelines followed in other countries or geographic regions can be easily used without major changes in the model developed as part of this study.

The following Meals are considered in this study constituting the daily consumption of an individual.

- *Breakfast:* the first Meal of the day.
- *Morning Snack* abbreviated to M Snack: the second Meal of the day consumed later in the morning.
- *Lunch*: the third Meal of the day consumed around midday.
- *Afternoon Snack* abbreviated to A Snack: the fourth Meal of the day consumed later in the afternoon.
- *Dinner*: the fifth Meal of the day consumed in the evening.

It is possible to include or exclude Meals as required.

Choosing Menu Items satisfying subjective interest and formulate Meals achieving a nutritionally balanced diet is cumbersome and time consuming. The RDIs are guidelines only and the requirement is to set Meals such that the nutrient requirements are met within an optimal level. This problem is inherently imprecise for the reasons of 1) lack of precise solution, 2) subjective nature of choice, and 3) complexity due to same Menu Items containing mix of nutrients meeting objectives and those posing constraints. For example a particular Menu Item may be subjectively interesting and meets the nutrient requirements of protein, and fibre, but at the same time can be high in cholesterol which is undesirable.

There is no specified minimum requirement of sugar consumption as per the RDI and therefore any amount of sugar consumed can be taken as a deviation. Certain nutrients have not only the minimum required intake, but also have the highest average daily nutrient intake level, Upper Level (UL) intake, as per the RDI. This means that consumption of these nutrients exceeding the UL increases the potential of developing adverse health effects.

The reference document for Recommended Dietary Intakes (RDI) contains recommendations for 19 nutrients, and dietary energy [5], of which eight nutrients and dietary energy are chosen for this pilot study. The Nutrient Reference Values (NRVs) for the eight nutrients and dietary energy are taken as the evaluation criteria for demonstrating the application of the model developed. These are numbered C_1 to C_9 and are defined below.

1. *Calorie (C_1)* is provided in the nutritional information of a Menu Item indicating the total dietary energy that could be obtained by the consumption of that item.
2. *Protein (C_2)* is a macronutrient required for the body and it is set that 15% - 25% of the total energy required can be from protein to prevent adversary effects. This may vary for people following highly active lifestyle.
3. *Carbohydrate (C_3)* is one of the nutrients that can provide energy. In this way it has become a prominent part of our diet. There is no scientifically proven minimum or maximum amount to be consumed. But the general guideline that can be followed is that 45% - 65% of total dietary energy required can be from carbohydrate.
4. *Total Fat (C_4)* contributes to the provision of total energy. This can provide 20% - 35% of dietary energy.
5. *Dietary fibre (C5)* promotes weight reduction by reducing the energy density of foods [5].
6. *Sodium (C_6)* is an essential nutrient. High sodium consumption can increase risks of hypertension and CVD [5].
7. *Saturated Fat (C_7)* increases the risk of CVD and obesity.
8. *Cholesterol (C_8)* is included in the critical criteria due to its effect on Cardiovascular Diseases (CVD).
9. *Sugar (C_9)* is present in many Menu Items naturally or added for taste. Consumption of high amounts of added sugar is associated with unhealthy weight gain and nutrition related diseases.

A small sample of Menu Items consumed for various Meals are listed in Table I with information on the nutrient content. The nutrient value provided is referred from the AUSNUT 2011-2013 food nutrient database where each nutrient value is presented on a per 100 gm. edible portion basis [22].

IV. Research Method

The Nutrient Reference Values (NRVs) of the eight nutrients and dietary energy are listed in Table II. These are the most commonly available nutrients included in Nutrient Information Panels (NIP) presented on food products in Australia. These include dietary energy (calories), Protein, Carbohydrate, Total fat, Cholesterol, Fibre, Saturated fat, Sodium, and Sugar. The dietary energy is referenced from the table of estimated energy requirements (EERs) of adults using predicted BMR (Basal Metabolic Rate) and Physical Activity Level (PAL) [5]. Reference body weights used are: male – 71.3kg

TABLE I. A SAMPLE SET OF MENU ITEMS WITH NUTRIENT VALUES

Menu Item	**Meal**	**C_1(Cal)**	**C_2(g) Prot.**	**C_3 (g) Carb.**	**C_4 (g) Fat**	**C_5(g) Fibre**	**C_6 (mg) Sod.**	**C_7 (g) Sat. Fat**	**C_8 (mg) Chol.**	**C_9 (g) Sugar.**
Orange juice, commercial	Beverage	176	0.2	10.4	0	0.1	8	0	0	10.4
Carrot Juice	Beverage	133	0.8	5	0.1	4	38	0	0	5
Cappuccino with skim	Beverage	116	2.7	4	.2	0	41	3	.09	4
Corn flakes	Breakfast	1587	6.3	75.2	3.6	10.5	120	0	0.58	14.9
Raw Banana, lady finger	M Snack	445	1.5	25	0.1	3.7	2	0	0	18.2
Mexican Wrap	Lunch	544	5.5	18.1	4.5	2.8	34	9	2.03	1.6
Risotto, chicken & mixed vegetables	Dinner	619	6.9	20.6	3.9	1.4	159	16	1.53	1.1
Carrot cake	Dessert	1513	4.7	42.5	19.9	2.6	231	61	2.15	29.2

TABLE II. NUTRIENT REFERENCE VALUES (NRVs)

RDI	**Nutrients meeting objectives (N_o)**					**Nutrients posing constraints (N_c)**			
NRV	C_1 Calories	C_2 Protein g/day	C_3 Carbohydrate g/day	C_4 Total Fat (g)	C_5 Fibre (g)	C_6 Sodium (mg)	C_7 Saturated Fat (g)	C_8 Cholesterol (mg)	C_9 Sugar (g)
Male	2700	64	325	14	30	460-920	< 30	< 300	< 5
Female	2200	46	275	9	25	460-920	< 25	< 300	< 5

TABLE III. PERCENTAGE DISTRIBUTION OF NRVS ACROSS MEALS

R_i	**Breakfast**	**MSnack snack**	**Lunch**	**ASnack**	**Dinner**
Food	18-20%	10.0%	18-20%	5%	18-20%
Beverage	5-7%	5%	5-7%	5%	5-7%
Total	25.0%	15%	25%	10%	25%

and female – 61 kg. This study has taken two specific sets of RDIs for one male and one female, with 1.8m height, PAL 1.6, in the age group of 31- 50 years. The Acceptable Macronutrient Distribution Ranges (AMDR) for Protein, Fat and Carbohydrate are: 1) 15% to 25% of energy from Protein, 2) 20% to 35% of energy from Fat, and 3) 45% to 65% of energy from Carbohydrate [5]. The values of Carbohydrate indicated in Table II are calculated to obtain 50% of energy intake from Carbohydrate. The nutrients are grouped into two groups, 1) N_o, the group of nutrients required for meeting the NRVs or objectives of the user, and 2) N_c, the group of nutrients present in many food items or added for taste, but it is necessary to limit the intake of these nutrients within Upper Level of Intake (UL). Table III shows percentage distribution of NRVs across Meals used in this study.

Individual Menu Items can be ranked based on a number of criteria set by the user as per the model developed in [23]. The problem of formulating balanced diet for a day can be resolved in a two level optimization process.

1. The first level is to compose individual Meals such that the objectives are met for the RDI distribution in case of nutrients under group N_o while minimizing the undesirable nutrients under group N_c, such as sodium, cholesterol, sugar, and saturated fat.
2. The second level is to compose daily diet consisting of individual Meals such as the objective of RDI requirements are met while minimizing the consumption of group N_c nutrients.

Fuzzy Multi-objective Linear Programming (FMOLP) is used to model the solution [15, 24, 25]. The application of fuzzy numbers also helps in the implementation of the model using expert system and the ability to reasonably explain the results using linguistic terms after the defuzzification process. Therefore, the NRVs for each Menu Item is fuzzified using the trapezoidal fuzzy numbers which is the most generic class of fuzzy numbers allowing a wider span of optimal range suitable in this case.

A. A Fuzzy Optimization Model

The NRVs of the Menu Items can be represented by matrix N_{kj} where $1 < k \leq t$, t is the total number of nutrients considered, $1 < j \leq n$, n is the total number of Menu Items used in a particular Meal. This Matrix is illustrated in Figure 2.

The objective is to reduce the difference between the nutrients present in a Meal and the RDI requirement so that the Meal is healthy or nutritionally balanced. If ∂ is the difference the objective function can be written as:

$$\textit{Minimize} \quad \delta = \sum_{s=1,j=1}^{t,n} N_{kj} - R_i * R_s \tag{1}$$

where N_{pj} represents the nutrient p obtained from Menu Item j; $1 < j \leq n$, n is the total number of Menu Items used in a Meal and $1 < p \leq s$, s is the total number of nutrients from group N_o.

R_i is the percentage distribution of nutrients in Meal i and R_p is the RDI for nutrient p. For example, if breakfast consists of 3 Menu Items and Protein is the 3rd (p) nutrient then (N_{31} +N_{32} + N_{33}) – 0.25* 64 should be minimum where breakfast meets 25% of RDI of Protein which is 64gms as per Tables II and III.

The cost is the unhealthy elements present in the Menu Items grouped under N_c and listed in Table 2. It is required to minimize the consumption of these nutrients or reduce the cost. If α represents the consumption of these, then the cost function is given by

$$\text{Minimize} \qquad \alpha = \sum_{q=1, j=1}^{t, n} N_{qj} \tag{2}$$

where, N_{qj} represents

the nutrient q obtained from Menu Item j;$1 < q \leq t$, t is the total number of nutrients from group N_c and $1 < j \leq n$, n is the total number of Menu Items used in a Meal.

Equations (1) and (2) represent the objective and cost functions for optimizing each Meal.

The next step is to optimize the whole day's diet. Here, if λ is the difference between nutrients obtained from the whole day consumption of Meals and the RDI requirement, it is required to minimize λ and this can be expressed by the function below

$$\text{Minimize} \qquad \lambda = \sum_{p=1, i=1}^{s, a} N_{pi} - R_p \tag{3}$$

where, N_{pi} represents nutrient p present in Meal i; $1 < i \leq a$, a is the total number of Meals and $1 < p \leq s$, s is the total number of nutrients from group N_o.

Similarly the cost function for the whole day consumption of Meals is given by

$$\text{Minimize} \qquad \beta = \sum_{q=1, i=1}^{t, a} N_{qi} \tag{2}$$

where N_{qi} represents the nutrient, q obtained from a Meal i;. $1 < i \leq a$, a is the total number of Meals and $1 <$ q $\leq t$, t is the total number of nutrients from group N_c.

To adequately model the imprecision, linguistic terms approximated by trapezoidal fuzzy numbers are used and the linguistic terms are defined as given in Table IV. For all the nutrients C_1- C_6 *Optimum* is the best, whereas for nutrients C_7 – C_9 *Allowed* is the best. An example on the use of the trapezoidal fuzzy numbers for representing Protein with different linguistic terms is shown in Figure 3. The numeric values and linguistic terms for Protein are given in Table V. Similarly, all other nutrient values are converted into fuzzy numbers. The application of fuzzy numbers also helps in the implementation of the model using expert system and the ability to reasonably explain the results using linguistic terms after the defuzzification process.

$$\begin{bmatrix} N_{11} & N_{12} & N_{1j} & N_{1n} \\ N_{21} & N_{22} & N_{2j} & N_{2n} \\ & & & \\ N_{k1} & N_{k2} & N_{kj} & N_{kn} \\ & & & \\ N_{t1} & N_{t2} & N_{tj} & N_{tn} \end{bmatrix}$$

Fig. 2. Matri x of Nutrients Across Menu Items in a Meal

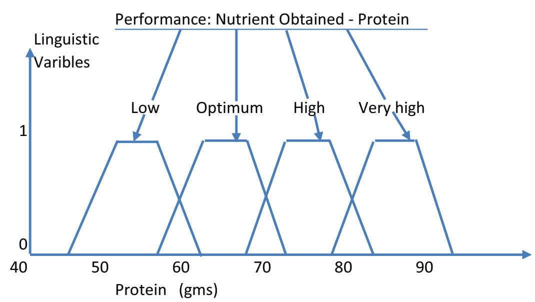

Fig. 3. Trapezoidal Numbers Representing Nutrient Values of Protein

TABLE IV LINGUISTIC TERMS FOR NUTRIENTS

Nutrients	**Linguistic terms**			
	Term 1	Term 2	Term 3	Term 4
Calorie C_1	Low	Optimum	High	Very high
Protein C_2	Low	Optimum	High	Very high
Carbohydrate C_3	Low	Optimum	High	Very high
Total Fat C_4	Low	Optimum	High	Very high
Fibre C_5	Low	Optimum	High	Very high
Sodium C_6	Low	Optimum	High	Very high
Saturated Fat C_7	Allowed	High	Very high	Extreme
Cholesterol C_8	Allowed	High	Very high	Extreme
Sugar C_9	Allowed	High	Very high	Extreme

TABLE V TRAPEZOIDAL FUZZY NUMBERS AND LINGUISTIC TERMS FOR PROTEIN

Trapezoidal fuzzy numbers for Protein, 64.00	Linguistic terms
56.00, 60.80, 67.20, 72.00	Optimum
44.80, 49.60, 56.00, 60.80	Low
67.20, 72.00, 78.40, 83.20	High
78.40, 83.20, 89.60, 94.40	Very high

TABLE IV. ALTERNATIVES OF OPTIMIZED MEAL MENUS FIVE DIFFERENT MEALS

Daily diet Alternatives	Breakfast	Morning snack	Lunch	Afternoon snack	Dinner	Over all nutrient values
Alternative 1	Muesli and orange juice	Rice cracker biscuit and carrot juice	Quiche Lorraine and cappuccino	Banana and water	Stir-fry chicken, carrot cake and water	Calorie, Protein, Carb., Total fat, Fibre, Sodium: *Optimum*, C_7- C_9 *Allowed*
Alternative 2	Scrambled egg and orange juice	Rice cracker biscuit and flat white	Chicken sushi and water	Curry puff and orange juice	Wheat noodle with egg, carrot cake and water	Calorie, Protein, Total fat, Fibre, Sodium: *Optimum*, Carb.: *High*, C_7- C_9: *Allowed*
Alternative 3	Flakes of corn cereal and coffee	Apple and water	Mexican wrap and orange juice	Savoury rice cake biscuit and carrot juice	Risotto, chicken & mixed vegetables, sticky date pudding, chai latte	Calorie, Protein, Carb., Fibre,: *Optimum*, C_7- C_9: *Allowed*, Sodium: *Low*
Alternative 4	Rolled oats porridge and cappuccino	Banana and water	Mexican wrap and water	Chocolate chip biscuit and flat white	Cheese & tomato pizza, ice cream and carrot juice	C_1, Protein, Total fat, Fibre, Sodium: *Optimum*, Carb: *High*, C_7- C_8: *Allowed*, Sugar: *High*
Alternative 5	Rolled oats porridge and water	Muffin and cappuccino	Chicken sushi and carrot juice	Crumpet and flat white	Risotto, chicken & mixed vegetables, carrot cake and water	Calorie, Total fat, Fibre, Sodium: *Optimum*, Protein, Carb, Sugar: *High*, C_7- C_8: *Allowed*

V. RESULTS AND DISCUSSION

To demonstrate the applicability of the proposed fuzzy optimization model above, an example of creating optimized daily diet combining Menu Items for a nutritionally balanced diet is presented. This study has selected twenty (20) Menu Items each for the five considered Meals, totaling 100 Menu Items for the evaluation process. Both the Menu Items and the NRVs for these Menu Items are referred from the NHMRC database [22]. Nine evaluation criteria including Calorie (C_1), Protein (C_2), Carbohydrate (C_3), Total fat (C_4), Fibre (C_5), Sodium (C_6), Saturated fat (C_7), Cholesterol (C_8), and Sugar (C_9) are identified. These criteria are defined in Section III and the Nutrient Reference Values used are given in Tables II and III.

The evaluation process starts with the application of LINDO software to solve the evaluation problem. Firstly, the problem specification is derived based on Model (1)-(4) to compose optimized daily diets based on the one hundred Menu Items. Then, the problem is solved by using LINDO and the output file is generated. Table VI shows the results displaying the optimized Meals consisting of five different alternatives for daily diets.

The use of linguistic terms makes the results almost self-explanatory.The Alternative 1 has nutrients C_1-C_6 at *Optimum,* and C_7- C_9 at *Allowed* levels which are the best. The Alternative 2 has Carbohydrate at *High* level whereas energy and nutrients C_2 – C_6 at *Optimum* levels, and nutrients C_7-C_9 at *Allowed* levels. The alternatives 4 and 5 have sugar at *High* level even though other nutrients are at *Optimum* or *Allowed* levels. For example, a consumer can opt for Alternative 1 for a day's Meals and thereby consume a diet nutritionally balanced with *Optimum* levels of intake for energy and five nutrients, and intake for other nutrients within the *Allowed* limit. A consumer can choose Alternative 2 to follow a diet with high Carbohydrate content. Including more Menu Items can increase the number of alternative to choose from.

The results obtained demonstrates that formulation of nutritionally balanced diet from available Menu Items is an optimization problem with a pareto optimal solution set rather than the best solution. Based on the results in Table VI, it can be seen that the fuzzy optimization model is a very useful tool for effectively composing nutritionally balanced daily diet limiting the consumption of elements such as sugar, sodium, saturated fat, and cholesterol

VI. CONCLUSION

Although awareness of nutrition related diseases is growing and food nutrition details are available evaluating Menu Items and formulating diet is time consuming. The diet formulation which is a typical multi-objective optimize problem with pareto optimal solution set can be successfully automated using Fuzzy Multi-objective Linear Programming model. As part of an interdisciplinary research, an effective algorithm is developed and its applicability is demonstrated with an example.

Further work is required to incorporate this model to the expert system named Dietary Intelligence System (DIligenS) and more studies need to be conducted to refine the model to incorporate customization with user specific health constraints and dietary preferences.

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