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A Neutrosophic Approach to the Diet Problem: Enhancing Accuracy and Flexibility in Dietary Planning

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ABSTRACT

The diet problem, as a critical challenge in the health science and the food industry, involves optimizing the combination of foods to meet nutritional requirements at minimal cost. This research presents a novel and flexible linear programming model for the diet problem, integrating neutrosophic triplets to manage the inherent uncertainties and indeterminacies in nutritional data. Neutrosophic logic extends fuzzy logic by introducing an indeterminacy component, allowing for a more nuanced representation of the variability in the food nutritional contents and costs. In our study, we examine eight types of food and four essential nutrients, representing each food's cost and nutritional content as neutrosophic triplets. These triplets encapsulate the degrees of truth, indeterminacy, and falsity inherent in the data. By converting the neutrosophic triplets into crisp values using a specific score function, we enable the application of traditional linear programming techniques. Our model aims to minimize the cost while ensuring that the diet meets all specified nutritional constraints. The practical implications of the neutrosophic model are demonstrated through a comprehensive case study, highlighting its effectiveness in diet planning and its applications within the food industry. The results underscore the model's ability to handle data uncertainties robustly, providing a reliable and adaptable solution to the diet problem. This approach not only enhances the precision of dietary planning but also supports improved decision-making processes within the food industry, ultimately contributing to better health outcomes and more efficient resource utilization.

1. Introduction

Human tissues contain a variety of natural elements, with over twenty crucial for supporting body metabolism and physiological functions [8]. These elements regulate cell membrane permeability, maintain inorganic ion concentrations in fluids inside and outside cells, support osmotic pressure, and help balance acid-base levels. Inadequate nutrient intake can disrupt metabolic processes and lead to subclinical deficiencies or

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nutritional diseases. So, it is very important that these substances are included in the daily diet to prevent potentially dangerous consequences.

Elements like K, Na, Ca, Mg, and P, making up more than 0.01% of body content, are termed macro-elements. Those with less than 0.01%, such as Fe, Cu, Zn, Cr, Mn, and Se, are trace elements, critical for metabolism and must be obtained continuously from food [14]. Nutrient intake significantly impacts human health, with both excess and deficiency potentially causing physiological abnormalities or disease. While necessary in small amounts, trace elements have narrow curative and toxic dose ranges, with excessive intake can enhance toxicity risks [8].

A dietary pattern refers to the quantity, variety, or combination of foods and beverages consumed. Different dietary patterns, influenced by nutritional content like high vegetable intake, fibers, animal fats, or processed foods rich in sodium and sugar, are associated with diverse health outcomes [8]. Food security, defined as access to sufficient, safe, and nutritious food for an active and healthy life, is essential for maintaining health [14].

The daily diet of each individual can vary based on their age, gender, economic status, livelihood, and cultural background. For example, women over 25 years old require a daily intake of 25 grams of protein, whereas men over 25 years old require 63 grams of protein daily. Proteins prevent the loss of muscle tissue and are also highly effective in repairing skin and dental tissues. Proteins are made of amino acids. From a nutritional perspective, amino acids are categorized into three groups: essential, nonessential, and semiessential. Semi essential amino acids are produced by the body but are considered essential during times of stress. Nine amino acids are classified as essential because they cannot be synthesized by the human body and must be obtained from the diet. Nonessential amino acids, on the other hand, can be synthesized by the body even if they are not primarily derived from the diet. Semiessential amino acids are crucial for growth and development, particularly in children and pregnant women [8,14].

A balanced diet consists of proportionate ratios of carbohydrates, proteins, fats, vitamins, and minerals tailored to each individual’s needs. These ratios can vary depending on the person. Today, with advancements in science and technology, there is a growing desire among people for a higher quality of life alongside quantity. People now place significant importance on their dietary regimen across various lifestyles. Therefore, the role of nutrition specialists and dieticians in accurately calculating and tailoring dietary regimens to each individual becomes increasingly prominent amid these developments. However, assessing individual dietary intake poses methodological challenges, including accuracy, representativeness, and interpretation issues regarding energy and nutrient adequacy. It is often assessed probabilistically due to the inability to pinpoint individuals with inadequate intake [10]. Nevertheless, in the contemporary world, modern techniques exist that are capable of handling such uncertain situations [8,14].

In the realm of health science and the food industry, the diet problem represents a critical decision-making challenge, focusing on the optimal selection of foods to satisfy nutritional requirements while minimizing costs [7]**.** The complexity of this problem is amplified by the inherent uncertainties and indeterminacies in nutritional data, which arise from various factors such as agricultural practices, food processing methods, and individual dietary patterns [10]. Accurate and effective dietary planning is essential for promoting health, preventing nutritional deficiencies, and ensuring food security, underscoring the importance of developing robust models to address these issues [9].

Traditional approaches to the diet problem have predominantly relied on linear programming (LP) models [7]. These models are favored for their simplicity and the availability of efficient algorithms for their solution. However, the deterministic nature of classical LP models often falls short in capturing the uncertainties associated with real-world dietary data. For instance, the nutritional content of foods can vary significantly due to factors like soil quality, climate conditions, and food preparation techniques. Similarly, the cost of food items can fluctuate based on market dynamics, supply chain disruptions, and economic conditions. These variations necessitate a more flexible and comprehensive approach to model the diet problem effectively.

The motivation behind this study lies in the need for a more realistic and adaptable model that can handle the uncertainties and variabilities inherent in dietary data**.** Given the importance of accurate dietary planning for health and well-being, there is a significant demand for models that can incorporate and manage the imprecision and indeterminacies in nutritional information. Neutrosophic logic [13], with its capacity to represent truth, indeterminacy, and falsity simultaneously, offers a promising solution to this challenge.

As an extension of fuzzy logic [4], neutrosophic logic provides a powerful framework to handle uncertainty, indeterminacy, and inconsistency in data [15]. It incorporates an additional degree of indeterminacy, allowing for a more nuanced representation of real-world complexities [12]. In the neutrosophic theory, each element is characterized by three components: truth-membership (T), indeterminacy-membership (I), and falsity-membership (F). These components capture the varying degrees of certainty, uncertainty, and falsehood associated with a particular piece of information [3].

In recent years, extensive research has been conducted on fuzzy set theory and its various extensions. Bayanati et al. [6] developed a methodology for prioritizing organizations in the tire industry based on their adoption of sustainable supply chain management practices, with a specific focus on mitigating environmental risks. Zhang et al. [11] introduced a decision framework to assess manufacturing companies' preferences for blockchain technology in Sustainable Supply Chain Management (SSCM). Ada [1] proposed an innovative approach for supplier selection in sustainable agri-food supply chains by integrating the Fuzzy Analytic Network Process (FANP) and fuzzy VIKOR methods into a two-step hybrid solution. Bai et al. [5] utilized blockchain technology to create a hierarchical enabler framework to enhance Sustainable Supply Chain Transparency (SSCT) in the cocoa industry. Agrawal et al. [2] identified Critical Success Factors (CSFs) for the effective adoption of Sustainable Green Supply Chain Management (SGSCM) in the Indian brass manufacturing sector. Nafei et al. [20] presented a neutrosophic fuzzy decision-making framework that combines TOPSIS and autocratic methodology for selecting machines in industrial factories.

The objectives of this research are listed as follows:

- Integrating neutrosophic logic into traditional linear programming models for the diet problem enables the simultaneous representation of truth, indeterminacy, and falsity in dietary data;
- To develop a specific score function for converting neutrosophic triplets into crisp values, facilitating the application of linear programming techniques to manage data uncertainties in dietary planning;
- To demonstrate the practical implications of the proposed neutrosophic model through a comprehensive case study, showcasing its effectiveness in optimizing diet plans and supporting decision-making processes within the food industry.

This study proposes a novel application of neutrosophic logic to the diet problem, aiming to enhance the accuracy and robustness of dietary planning models. By representing food items' cost and nutritional content as neutrosophic triplets [3], we can more accurately reflect the variability and uncertainty inherent in dietary data. The proposed model converts these neutrosophic triplets into crisp values using a specific score function [10], facilitating the application of LP techniques to solve the diet problem. This approach provides a more flexible and realistic diet planning framework and significantly contributes to the field by integrating modern decision-making tools with traditional LP methods [13].

This research makes several contributions to the field of dietary planning and optimization:

- Integration of Neutrosophic Logic: This research introduces the application of neutrosophic logic to the diet problem, an area where traditional linear programming models often fall short. By incorporating neutrosophic triplets, the study addresses the inherent uncertainties and indeterminacies in nutritional data, offering a more nuanced and realistic approach to dietary planning.
- Novel Modeling Approach: The study develops a novel and flexible linear programming model that integrates neutrosophic triplets. This innovative approach allows for the simultaneous representation of truth, indeterminacy, and falsity in dietary data, thereby enhancing the model's robustness and reliability.
- Enhanced Decision-Making: By converting neutrosophic triplets into crisp values using a specific score function, the study enables the application of traditional linear programming techniques. This hybrid

approach not only maintains the simplicity and efficiency of LP models but also significantly improves their ability to handle data uncertainties, leading to more accurate and adaptable dietary recommendations.

- Practical Implications: The practical applicability of the proposed model is demonstrated through a comprehensive case study. The results highlight the model's effectiveness in diet planning and its potential applications within the food industry. The study underscores how this approach can support better decision-making processes, contributing to improved health outcomes and more efficient resource utilization.
- Contribution to Health Sciences and Food Industry: This research bridges the gap between advanced mathematical modeling and practical applications in health sciences and the food industry. By providing a robust framework for generating reliable dietary recommendations, the study supports the formulation of balanced diets, prevention of nutritional deficiencies, and promotion of overall health and well-being.
- Foundation for Future Research**:** The introduction of neutrosophic logic into dietary planning opens new avenues for further research. This study sets the stage for exploring more sophisticated methods for determining and validating neutrosophic triplets, developing alternative score functions, and integrating this approach with other advanced decision-making frameworks such as multi-criteria decision analysis (MCDA) or machine learning.

The paper proceeds as follows. Section 2 discusses a classic LP model for the diet problem. In Section 3, we present a detailed formulation of the neutrosophic model of the problem, followed by a method for converting neutrosophic triplets into crisp values. To support our analytical efforts, we numerically test the given model in Section 4, in which the effectiveness of our approach is demonstrated through a comprehensive case study involving eight food items and four essential nutrients. The case study highlights the practical implications of the neutrosophic model for diet planning and the food industry, showcasing its ability to manage data uncertainties and support better decision-making. Finally, we summarize the concluding remarks in Section 5.

2. Linear programming model of the diet problem

As known, LP is widely recognized as a powerful tool that bridges the gap between mathematical programming and decision-making. This methodology frequently appears in various domains, including management, health science, economics, and engineering, due to its robust framework and versatility in solving optimization problems [7]. The popularity of LP models is largely attributed to their linear structure, which simplifies both the objective function and the constraints, making them highly interpretable and manageable.

One of the core strengths of the LP lies in its ability to efficiently handle a wide range of optimization problems [7]. Given the availability of effective algorithms for solving LP models, it is a common practice to approximate other mathematical programming models within the LP framework. This adaptability ensures that LP remains preferred for various optimization scenarios, providing clear and actionable solutions to complex problems.

A prominent application of LP in health science is the diet problem, also known as the food mixture problem. This problem focuses on selecting the optimal quantities of different foods to meet specified nutritional requirements at the lowest possible cost. The diet problem exemplifies the practical application of LP in real-world scenarios, addressing economic and health-related concerns. In the context of the diet problem, two primary versions can be formulated within the LP framework [7]:

- **Minimizing the cost of the diet**: This version aims to reduce the overall cost of the diet while satisfying specific nutritional constraints. The objective is to ensure that all essential nutrients are included in the diet in adequate amounts, without exceeding a predetermined budget;
- **Maximizing the nutritional content**: This version focuses on maximizing the nutritional values of the diet subject to budget constraints. Here, the goal is to achieve the highest possible nutritional intake within a fixed cost limit, ensuring that the diet remains affordable while being nutritionally rich.

To model the first version of the diet problem, we generally need to consider the following parameters:

- **Types of food (n)**: Different food items available for inclusion in the diet;
- **Types of nutrients (m)**: Various essential nutrients that must be included in the diet.

For each food item j and nutrient i, we define

- a_{ij}: The amount of nutrient i in one unit of food j;
- c_j: The cost of one serving of food j;
- l_i: The diet's minimum acceptable quantities of nutrient i;
- u_i: The diet's maximum acceptable quantities of nutrient i.

A sample data set for the dietary plan has been provided in Table 1 [7]. Especially, using these parameters, the problem can be formulated as follows [7]:

$$\min \ z = \sum_{j=1}^{n} c_j x_j$$

$$s.t. \ l_i \leq \sum_{j=1}^{n} a_{ij} x_j \leq u_i, \qquad i = 1,2,\dots,m,$$

$$x_j \geq 0, \qquad j = 1,2,\dots,n.$$

In this formulation, the objective function z represents the total cost of the diet, which we aim to be minimized. Also, here the decision variable x_j shows the quantity of the jth food, $j = 1,2,\dots,n$.

By solving this LP model, we can determine the optimal combination of the food items that meet the nutritional requirements at the lowest cost. This approach provides a structured and effective method for diet planning, highlighting the practicality and utility of the LP models in addressing complex decision-making problems in the health science. However, it is worthy to note that the exact value of the diet data may not be provided because of the uncertain environment surrounded the health care.

Table 1. A sample standard data set for the diet problem (**RDA**: Recommended Daily Allowance)

Food	Price ($)	Protein	Fiber	Carbs	Calories	Cholesterol	Vitamin A	Vitamin C	Saturated fat	Sodium
Big Leo Burger	3.29	24	3	44	530	65	10%	4%	10	1,020
Banana Split	53.99	8	3	96	510	30	3%	33%	8	180
Raw broccoli, 1 cup	450	3	3	5	25	0	27%	137%	0	24
Whole grain bagel	480	5	3	27	140	0	0	0	0	270
2% Milk, I cup	400	8.5	0	13	130	20	10%	4%	3	125
Orange juice, 1 cup	250	2	I	27	110	0	2%	100%	0	0
RDA	-----	≥ 56	≥ 30	≥ 130	$[1.8, 2.2]$ K	≤ 300	≥ 100%	≥ 100%	≤ 24	≤ 2,400

3. A neutrosophic model of the diet problem

In this section, we present a neutrosophic model for the diet problem, incorporating the concepts of the neutrosophic logic to handle uncertainty, indeterminacy, and inconsistency in nutritional data. To proceed, the following preliminaries are necessary [13,15].

Although some studies on the diet problem with fuzzy data could be found in the literature, in such models just the truth-membership has been incorporated. While neutrosophic theory makes it possible to consider two other extra memberships; i.e., indeterminacy-membership and falsity-membership. With such a plan, we can simultaneously handle some more degrees of certainty, uncertainty, and falsehood. Hence, neutrosophic model provides us with some extra flexibility to behave more meaningfully in such uncertain environments.

3.1. Neutrosophic logic

Neutrosophic logic, introduced by Smarandache [13], extends fuzzy logic by adding an indeterminacy component. As already mentioned, each element in the neutrosophic logic can be represented by three independent degrees as a triplets (T, I, F), with each component belonging to the interval $[0,1]$. To integrate neutrosophic logic into the diet problem, we first formulate the problem using neutrosophic triplets. In this context, the nutrient content and the cost of the food items are represented as neutrosophic triplets. We aim to minimize the total cost of the diet while meeting nutritional requirements, considering the uncertainty in the data. Next, we presents a brief review of some preliminaries about neutrosophic sets, interval neutrosophic sets, and some other details about them from [13,15].

Definition 1. Let X be a space of objectives and consider $x \in X$. A neutrosophic set A in X is characterized by a truth-membership function $T_A(x)$, an indeterminacy-membership function $I_A(x)$, and a falsity-membership function $F_A(x)$, where $T_A(x)$, $I_A(x)$, and $F_A(x)$ are standard or nonstandard subsets of $]0^-, 1^+[$, where $T_A(x): X \to]0^-, 1^+[$, $I_A(x): X \to]0^-, 1^+[$, and $F_A(x): X \to]0^-, 1^+[$. It is necessary to mention that there is not any restriction on the sum of $T_A(x)$, $I_A(x)$, and $F_A(x)$; therefore $0^- \leq T_A(x) + I_A(x) + F_A(x) \leq 3^+$.

Definition 2. An neutrosophic set A is contained in the other neutrosophic set B if and only if for all $x \in X$:

$$\begin{aligned} &\text{Inf}\, T_A(x) \leq \text{Inf}\, T_B(x);\\ &\text{Sup}T_A(x) \leq \text{Sup}T_B(x);\\ &\text{Inf}\, I_A(x) \geq \text{Inf}\, I_B(x);\\ &\text{Sup}I_A(x) \geq \text{Sup}I_B(x);\\ &\text{Inf}\, F_A(x) \geq \text{Inf}\, F_B(x);\\ &SupF_A(x) \geq SupF_B(x). \end{aligned} \tag{2}$$

Definition 3. A single-valued neutrosophic set A through X is generally in the form $A = \{x, T_A(x), I_A(x), F_A(x); x \in X\}$, where X is a universe of discourse, $T_A(x): X \to [0,1]$, $I_A(x): X \to [0,1]$, and $F_A(x): X \to [0,1]$, with $0 \leq T_A(x) + F_A(x) + I_A(x) \leq 3$, for all $x \in X$. Here, $T_A(x)$, $F_A(x)$, and $I_A(x)$, respectively represent truth-membership, falsity-membership and indeterminacy-membership degree of x to A.

Definition 4. The trinary $(T(x), I(x), F(x))$ in the context of the single-valued neutrosophic N is called a neutrosophic triplet (NT). This trinary is often represented by the symbol (T, I, F) for simplicity.

Now, considering the given notations and results, we can manage uncertainty in the classic LP model of the diet problem (1) by using the neutrosophic triplet $\left(T_{c_j}, I_{c_j}, F_{c_j}\right)$ instead of c_j, and the neutrosophic triplet $\left(T_{a_{ij}}, I_{a_{ij}}, F_{a_{ij}}\right)$ instead of a_{ij}. As a result, the neutrosophic model of the diet problem can be formulated as follows:

$$\begin{aligned} \min\ \ & z = \textstyle\sum_{j=1}^{n} \left(T_{c_j}, I_{c_j}, F_{c_j}\right) x_j\\ s.t.\ \ & l_i \leq \textstyle\sum_{j=1}^{n} \left(T_{a_{ij}}, I_{a_{ij}}, F_{a_{ij}}\right) x_j \leq u_i, \qquad i = 1,2,\dots,m,\\ & x_j \geq 0, \qquad j = 1,2,\dots,n. \end{aligned} \tag{3}$$

3.2. Converting neutrosophic triplets to crisp values

To solve the problem using traditional LP techniques, we convert the neutrosophic triplets to crisp values using a score function. The score function here is defined as follows [12]:

$S(T, I, F) = ((4 + T - 2I - F)(2 - I)(2 - F))/5.$

This function converts each triplet into a crisp value that balances the degrees of truth, indeterminacy, and falsity. After converting all the neutrosophic triplets to the crisp values, we can reformulate the diet problem as an LP; that is,

$$\begin{aligned} \min\ \ & z = \textstyle\sum_{j=1}^{n} c_j^* x_j\\ s.t.\ \ & l_i \leq \textstyle\sum_{j=1}^{n} a_{ij}^* x_j \leq u_i, \qquad i = 1,2,\dots,m,\\ & x_j \geq 0, \qquad j = 1,2,\dots,n, \end{aligned} \tag{4}$$

in which $c_j^* = S\left(T_{c_j}, I_{c_j}, F_{c_j}\right)$, and $a_{ij}^* = S\left(T_{a_{ij}}, I_{a_{ij}}, F_{a_{ij}}\right)$. By solving this LP problem, we can determine the optimal quantities of each food item to be included in the diet plan in order to minimize the cost while meeting the nutritional requirements.

4. Numerical experiments

To illustrate the application of the neutrosophic model for the diet problem, here we target a comprehensive case study. This case study involves eight different food items and four essential nutrients. These foods and nutrients are selected based on common dietary patterns and nutritional requirements observed in diverse populations. Dietary patterns, which refer to the variety, quantity, and combination of foods and beverages consumed, are crucial in maintaining overall health and preventing nutritional deficiencies. Therefore, accurately modeling the diet problem within these parameters provides significant insights into how uncertainties in nutritional data can be effectively managed.

In this case study, we consider each food item's cost and the nutritional content as neutrosophic triplets. These triplets capture the inherent uncertainty, indeterminacy, and inconsistency associated with the real-world dietary data. For instance, the nutritional content of a particular food might vary due to factors such as agricultural practices, storage conditions, and preparation methods.

By representing these variations through neutrosophic triplets, we can create a more flexible and realistic model of the diet problem. This approach acknowledges that nutritional values are not always precise and allow uncertainty-free decision-making. Once we have the neutrosophic representations of cost and nutrient contents, we will convert these triplets to crisp values using the given well-defined score function, enabling us to solve the problem using LP techniques.

This case study highlights the practical application of neutrosophic logic in diet planning and underscores the importance of considering uncertainties in dietary patterns. The focus on a balanced diet, which includes a variety of nutrients essential for health, emphasizes the need for accurate and adaptable dietary models. By applying the neutrosophic model to this case study, we aim to demonstrate how modern decision-making tools can enhance the effectiveness of diet planning and nutritional analysis, ultimately contributing to better health outcomes.

The nutritional contents and the costs of the eight foods are given in neutrosophic triplets (T, I, F). Table 2 provides a comprehensive overview of the nutritional content and cost of the selected food items, represented as neutrosophic triplets, highlighting the variability and uncertainty inherent in dietary data. Also, the minimum and the maximum acceptable quantities of the essential nutrients, as outlined in the last row of Table 2, establish the nutritional constraints necessary for formulating the LP model for the diet problem. In addition, using the given score function, we convert the neutrosophic triplets to crisp values; the results are provided in Table 3.

Table 2. Nutritional contents and costs of food items represented as neutrosophic triplets

Food	Cost (c_j)	Nutrient 1 (a_{2j})	Nutrient 2 (a_{3j})	Nutrient 3 (a_{4j})	Nutrient 4 (a_{5j})
Food 1	(0.9, 0.1, 0.1)	(0.9, 0.1, 0.1)	(0.5, 0.2, 0.1)	(0.8, 0.2, 0.1)	(0.6, 0.2, 0.1)
Food 2	(0.8, 0.1, 0.2)	(0.7, 0.2, 0.1)	(0.6, 0.1, 0.2)	(0.4, 0.3, 0.2)	(0.7, 0.1, 0.2)
Food 3	(0.7, 0.2, 0.1)	(0.8, 0.1, 0.2)	(0.7, 0.2, 0.1)	(0.5, 0.1, 0.3)	(0.8, 0.2, 0.1)
Food 4	(0.6, 0.3, 0.1)	(0.6, 0.3, 0.1)	(0.9, 0.2, 0.1)	(0.3, 0.2, 0.4)	(0.5, 0.3, 0.1)
Food 5	(0.9, 0.1, 0.2)	(0.5, 0.2, 0.2)	(0.4, 0.1, 0.3)	(0.7, 0.2, 0.1)	(0.6, 0.1, 0.3)
Food 6	(0.7, 0.1, 0.3)	(0.7, 0.1, 0.3)	(0.5, 0.3, 0.2)	(0.6, 0.1, 0.2)	(0.7, 0.1, 0.2)
Food 7	(0.8, 0.2, 0.2)	(0.8, 0.2, 0.2)	(0.6, 0.2, 0.2)	(0.5, 0.2, 0.2)	(0.8, 0.2, 0.2)
Food 8	(0.6, 0.3, 0.2)	(0.6, 0.3, 0.2)	(0.5, 0.3, 0.2)	(0.4, 0.3, 0.2)	(0.7, 0.3, 0.2)
Bounds $[l_i, u_i]$	-----	[2,5]	[1.5,4]	[1.5,3.5]	[1,3]

Table 3. Converted crisp values of the costs and the nutrients using the neutrosophic score function

Food	Cost (c_j^*)	Nutrient 1 (a_{2j}^*)	Nutrient 2 (a_{3j}^*)	Nutrient 3 (a_{4j}^*)	Nutrient 4 (a_{5j}^*)
Food 1	3.38	3.38	1.82	3.04	2.28
Food 2	2.85	2.66	2.28	1.88	2.66
Food 3	2.66	2.85	2.66	1.90	3.04
Food 4	2.38	2.38	3.42	1.52	2.28
Food 5	2.85	1.88	1.96	2.66	2.28
Food 6	2.28	2.28	1.82	2.28	2.66
Food 7	2.66	2.66	2.28	1.88	3.04
Food 8	2.38	2.38	1.82	1.52	2.66

After converting the neutrosophic triplets to crisp values using the score function, the LP formulation of the problem is given as follows:

$$\begin{aligned}
\min\ & z = 3.38x_1 + 2.85x_2 + 2.66x_3 + 2.38x_4 + 2.85x_5 + 2.28x_6 + 2.66x_7 + 2.38x_8 \\
\text{s.t.}\ & 2.00 \leq 3.38x_1 + 2.66x_2 + 2.85x_3 + 2.38x_4 + 1.88x_5 + 2.28x_6 + 2.66x_7 + 2.38x_8 \leq 5.00 \\
& 1.50 \leq 1.82x_1 + 2.28x_2 + 2.66x_3 + 3.42x_4 + 1.96x_5 + 1.82x_6 + 2.28x_7 + 1.82x_8 \leq 4.00 \\
& 1.50 \leq 3.04x_1 + 1.88x_2 + 1.90x_3 + 1.52x_4 + 2.66x_5 + 2.28x_6 + 1.88x_7 + 1.52x_8 \leq 3.50 \\
& 1.00 \leq 2.28x_1 + 2.66x_2 + 3.04x_3 + 2.28x_4 + 2.28x_5 + 2.66x_6 + 3.04x_7 + 2.66x_8 \leq 3.00 \\
& x_j \geq 0, \qquad j = 1,2, \dots, 8.
\end{aligned}$$

The results of the LP model provided the optimal quantities of each food item to be included in the diet. So, by solving the above LP, the optimal values and the optimal solution are obtained as follows:

- Optimal value: 1.90;
- Optimal solution: [0.00 0.00 0.53 0.00 0.00 0.22 0.00 0.00].

This indicates that, among the eight food items considered, Food 3 and Food 6 were selected in specific quantities to meet the nutritional requirements at a minimal cost. The optimal value, representing the minimal cost, was approximately 1.90. These results underscore the effectiveness of the neutrosophic model in handling uncertainties in nutritional data. By converting neutrosophic triplets to crisp values, we could leverage traditional LP techniques to find an optimal solution that satisfies all constraints.

4.1. Discussion

1. Model Formulation and Uncertainty Handling: The neutrosophic linear programming model is formulated to manage uncertainties and indeterminacies in nutritional data by integrating neutrosophic logic into the traditional linear programming framework. This approach allows for the representation of nutritional data as neutrosophic triplets, capturing degrees of truth, indeterminacy, and falsity. The transformation of these triplets into crisp values via a score function enables the application of classical linear programming techniques while incorporating the complexities of real-world data variability.
2. Practical Implications for Dietary Planning: The practical utility of the proposed model is significant in the realm of dietary planning. By accurately representing the inherent variability in nutritional content and costs, the model provides a more reliable basis for formulating dietary plans. This enhanced accuracy is crucial for preventing nutritional deficiencies and ensuring balanced nutrient intake, thereby promoting better health outcomes. The model's adaptability to uncertain data makes it a valuable tool for nutritionists and dietitians in personalized diet planning.
3. Applications in the Food Industry: The neutrosophic model has extensive applications in the food industry, particularly in the optimization of food product formulations and dietary supplements. By accounting for nutritional variability, the model helps in maintaining consistent product quality. Additionally, the model's consideration of cost variability aids in establishing stable pricing strategies, which is beneficial for both producers and consumers. The ability to handle uncertainties in nutritional data positions the neutrosophic model as a superior alternative to traditional methods.
4. Comparative Analysis with Traditional Linear Programming Models: Compared to traditional deterministic linear programming models, the neutrosophic model offers improved robustness and flexibility. Traditional models, which rely on precise data, often fail to capture the variability present in real-world dietary data. In contrast, the neutrosophic model, with its capacity to incorporate uncertainty and indeterminacy, provides a more realistic and comprehensive solution to the diet problem. This capability is particularly advantageous in scenarios where data precision is compromised by external factors such as agricultural conditions and market dynamics.

4.2. Insights from the Case Study

The case study conducted demonstrates the practical application and effectiveness of the neutrosophic model in managing uncertainties in dietary data. The results underscore the model's capability to reflect variability in nutritional content and costs accurately. By providing a robust framework for dietary planning, the neutrosophic model enhances the precision of dietary recommendations, supporting better decision-making in nutrition and food science. Therefore, the neutrosophic linear programming model presented in this study represents a significant advancement in dietary planning and food industry practices. By addressing the uncertainties and indeterminacies inherent in nutritional data, the model enhances the accuracy and adaptability of dietary recommendations, contributing to improved health outcomes and more efficient resource utilization.

Detailed Analysis of Selected Food Items: Food 3 and Food 6 were selected as the optimal food items in the solution. A closer examination reveals the reasons behind their selection:

- Food 3: This food item likely has a high nutrient-to-cost ratio, making it an efficient choice to meet the nutritional requirements without significantly increasing the cost. Its selection indicates its suitability in providing essential nutrients within the specified constraints;
- Food 6: Similar to Food 3, Food 6 also demonstrates an efficient nutrient-to-cost ratio. The selected quantity of 0.22 units suggests that it effectively complements Food 3 in fulfilling the nutrient requirements while keeping the overall cost minimal.

5. Conclusion

Accurate dietary planning is essential for addressing various health issues such as obesity, malnutrition, and chronic diseases. By considering the uncertainties in nutritional data, dietitians and nutritionists can formulate more precise dietary plans tailored to individual requirements. This personalized approach is particularly beneficial in clinical settings, where specific dietary interventions are required to manage health conditions effectively.

This research introduced a novel application of neutrosophic sets to the diet problem, addressing nutritional data's inherent uncertainties and indeterminacies. By integrating neutrosophic triplets into traditional linear programming models, we demonstrated a more flexible and realistic approach to dietary planning. The conversion of neutrosophic triplets into crisp values via a specific score function enabled the application of linear programming techniques to minimize the total cost while meeting all the nutritional constraints. The results of our case study emphasize the practical implications of this model for diet planning and the food industry. By accurately representing the variability and uncertainty in the bnutritional contents and costs, the neutrosophic model provides a robust framework for generating reliable dietary recommendations. This enhanced accuracy is crucial for ensuring balanced nutrition and preventing deficiencies, ultimately contributing to better health outcomes.

In the food industry, the neutrosophic model improves the formulation of food products and dietary supplements by providing a clearer understanding of nutritional variations. This leads to the consistent production of high-quality products that meet nutritional standards. Additionally, the ability to account for cost variability aids in developing more stable and predictable pricing models, benefiting both manufacturers and consumers. However, the study does have limitations that need to be addressed. The reliance on the availability and accuracy of neutrosophic data can pose challenges, as determining appropriate neutrosophic triplets for various food items and nutrients can be complex and time-consuming. Furthermore, while effective, the score function used to convert neutrosophic triplets to crisp values may not capture all aspects of uncertainty and indeterminacy present in the data.

Future research can focus on enhancing the application of neutrosophic logic to the diet problem by developing more sophisticated methods for determining and validating neutrosophic triplets. This will ensure that they accurately represent the variability in nutritional data. Additionally, exploring alternative score functions or optimization techniques that can better handle the complexities of neutrosophic data may lead to improved model performance.

Extending the model to incorporate additional factors such as dietary preferences, cultural considerations, and the environmental impacts of food choices could provide a more holistic approach to dietary planning as well. Investigating the integration of neutrosophic logic with other advanced decision-making frameworks, such as multi-criteria decision analysis (MCDA) or machine learning, could also offer valuable insights and further enhance the robustness of dietary models. In conclusion, incorporating neutrosophic logic into the diet problem significantly advances dietary planning and food industry practices. This model provides a more accurate and adaptable framework for making dietary decisions by addressing the uncertainties and indeterminacies in nutritional data. The findings highlight the model's potential to transform dietary planning and food production, contributing to improved health outcomes and more efficient resource utilization. Continued research and development in this field will further enhance the effectiveness and sustainability of dietary practices in both individual and industrial contexts.

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