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Mathematical Optimization for Nutritional Equity: A Decision-Making and Transportation Model for Implementing SDG-10

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Abstract:

The Sustainable Development Goal 10 (SDG-10) aims to diminish inequalities within and among countries, including discrepancies in healthcare and nutrition. This study focuses on developing a mathematical model to assist in selecting the most nutritious food based on key health criteria—calcium, vitamins, carbohydrates, and proteins. With the application of multi-criteria decision-making (MCDM) techniques, the optimal food choice is determined to enhance health equity. Furthermore, the transportation problem is used to minimize the cost of distributing this nutritional knowledge and resources to a larger population. The integration of these mathematical approaches ensures that nutritious food choices are both effective and accessible, contributing to a reduction in health-related inequalities.

Keywords: Sustainable Development Goal 10 (SDG-10), Health Inequality, Nutrition Optimization.

Introduction:

In decision-making, individuals assess different alternatives and select the most suitable option based on evaluation most effective one to achieve specific goals and objectives. According to Haddad.M, Sanders.D, decision-making is influenced by various factors, such as available resources, constraints, preferences, and expected outcomes [1]. Because decision-making is a daily task in both professional and personal settings, the use of structured analytical tools is essential for improving decision quality.

One such structured approach is **Multi-Criteria Decision Making (MCDM)**, a multidimensional process designed to address decision-making problems across various disciplines. As noted by Pohekar S.D, Ramachandran M, MCDM enables decision-makers to evaluate complex scenarios systematically and select the most attractive alternative while considering multiple criteria [2]. This method enhances decision-making quality by making it more rational, structured, and efficient.

Several methods have been developed to apply MCDM principles in different fields. In recent years, MCDM has seen significant growth and has been applied in:

- **Sustainable Energy** [2,3]
- **Maintenance Management** [4,5]
- **Construction Management** [6]
- **Tourism Management** [7]
- **Machine Selection** [8]
- **Material Selection** [9]
- **Supply Chain Management** [10]
- **Aviation** [11,12]
- **Risk Management** [13]

These applications highlight the adaptability of MCDM in solving complex problems across multiple domains.

Nutritional Science: Macronutrients and Micronutrients

Nutritional science categorizes nutrients into two primary groups: **macronutrients** and **micronutrients**. According to EFSA, macronutrients are essential for building body tissues and providing energy, while micronutrients support vital biological functions [14].

Nutritional Deficiencies and Public Health Concerns

Malnutrition is a significant public health issue, particularly in low-income communities. Common deficiencies include:

- **Protein Energy Malnutrition (PEM)**
- **Vitamin A Deficiency (VAD)**
- **Iron Deficiency Anemia (IDA)**
- **Iodine Deficiency Disorders (IDD)**
- **Vitamin B Complex Deficiencies** [15]

To ensure balanced nutrition, U.S. Department of Health and Human Services and U.S. Department of Agriculture recommends the following macronutrient distribution for adults:

- **10% to 35%** of total Calories from Protein
- **45% to 65%** from Carbohydrates

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- **20% to 35%** from Fats
- **Less than 10%** of total Calories from Saturated Fat [16]

These guidelines help individuals maintain optimal health and prevent nutrition-related diseases.

Sustainable Development Goal 10 (SDG 10) focuses on **reducing inequalities** within and among countries by addressing disparities in income, opportunities, and access to essential services, including education and healthcare. One of the key challenges in rural communities is the **unequal access to nutritional knowledge**, which leads to malnutrition, poor health outcomes, and long-term socio-economic disadvantages [17]. Ensuring that all individuals, regardless of location or socio-economic status, have access to accurate and practical dietary knowledge is critical to achieving SDG 10.

In many rural areas, a lack of awareness about **nutrient-rich foods** and the importance of a balanced diet results in **higher rates of under nutrition, stunting, and non-communicable diseases**. Despite the availability of various food options, people often make uninformed dietary choices due to limited knowledge. This **knowledge gap exacerbates health inequalities**, particularly affecting vulnerable populations such as children, pregnant women, and the elderly people[18].

To bridge this gap, an **efficient and structured approach** is required to disseminate nutritional knowledge to rural populations. This study proposes a **transportation model** that optimizes the delivery of **nutrition awareness programs** across multiple villages in the least amount of time. The model ensures that trainers and resources are distributed equitably, addressing the **disparity in knowledge access** and aligning with the objectives of SDG 10.

Using the **transportation problem**, a special case of **Linear Programming (LP)**, this study develops an **optimized allocation strategy** for deploying nutrition trainers to different rural locations. By minimizing transportation time and ensuring **maximum outreach**, the model contributes to reducing knowledge inequality, promoting **sustainable health improvements**, and supporting the broader vision of SDG 10[22]. A numerical example is provided to illustrate the effectiveness of this method in ensuring **fair and efficient dissemination of nutritional awareness**.

2. Preliminaries:

2.1. Alternatives:

Alternatives are the "different possible courses of action".

2.2. Criteria:

Criteria are defined as "tools for evaluating and comparing alternatives from the view point of the consequences of their selection"

2.3. Decisions:

Decision-making differs according to the problem type, which can encompass choice, ranking, and sorting issues

2.4 Survey Method:

Survey Research is a quantitative research method used for collecting data from a set of respondents. It has been among the most frequently utilized techniques in the industry for several years due to the multiple benefits and advantages it offers when collecting and analyzing data.

2.5 Macronutrient:

Macronutrients constitute the primary energy source for the human body and include:

- Carbohydrates
- Proteins
- Lipids (Fats)

These nutrients form the basis of caloric intake and are crucial for maintaining overall health [19].

2.6. Micronutrients:

Micronutrients are essential in small amounts. They include vitamins and minerals Micronutrients, though required in smaller amounts, are vital for biochemical processes and include:

- Vitamins (fat-soluble and water-soluble)
- Minerals

While they do not contribute significantly to caloric intake, micronutrients are essential for immune function, growth, and disease prevention [20].

2.7 Transportation Problem

The transportation problem is an optimization model used to minimize transportation costs or time by allocating resources efficiently from

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multiple supply points to multiple demand points.

2.8. Supply Points (Origins)

Supply points refer to locations where resources are available. In this study, supply points represent training centers from which trainers are dispatched to rural areas.

2.9. Demand Points (Destinations) [23]

Demand points are locations where resources are needed. In this study, they represent villages requiring nutrition awareness programs.

2.10. Cost (or Time) Matrix

A cost (or time) matrix represents the transportation cost (or time) from connecting supply points to demand points while minimizing the total cost or time involved in transportation.

3. Proposed Method:

In this section, an advanced decision-making approach is used, with its structure illustrated in Table 4.1. For a particular MCDM problem, 'm' alternatives (F1, F2, F3, ..., Fm) are involved, each being distinct."

In this section advanced decision making approach is used, with its structure illustrated in Table 4.1. For a given MCDM problem there are 'm' alternatives (F_1, F_2, F_3,…F_m), are involved, each being distinct which contains Carbs, Proteins, calcium& Vitamins and 'n' criteria (C_1, C_2, C_3, …C_n). Here we applied the advanced proposed method to find the best daily Nutrition intake for our healthy life.

Mathematical form of MCDM problem:

In a mathematical form, an MCDM problem is defined as follows A $=\{B_i \mid i = 1,2,3, \dots \dots . . m\}$where B is a distinct and finite set of alternatives, and m represents the number of them C $=\{C_j \mid j = 1,2,3, \dots \dots . . n\}$ where C represents a set of specific criteria used to evaluate B, and n denotes their number. The alternatives are generally homogeneous; however, this is not a strict requirement for the criteria. In other words, the criteria may have different units, lack direct relationships, and pursue different, often conflicting, objectives — with some requiring minimization and others maximization

W $=\{W_j \mid j = 1,2,3, \dots \dots . . n\}$ where W is a set of normalized weights assigning to each criterion based on their importance.

3.2. Matrix form of MCDM:

Alternatives/ Criteria	C_1	C_2	……	C_n
B_1	x_{11}	x_{12}	……	x_{1n}
B_2	x_{21}	x_{22}	……	x_{2n}
….	…	…	……	…
B_m	x_{m1}	x_{m2}	……	x_{mn}

Table 3.1-Matrix Form

In this matrix, x_{ij} represents the value of B_i related to Cj, and the matrix (M) and the weights' vector W = {w_1, w_2, . . . , w_n} are the basic inputs for the MCDM problems.

In fact, MCDM scores the alternatives and orders them based on the best to the worst.

3.3. Algorithm of Proposed Method:

Step 1: Calculate the Mean:

$\bar{X}=\frac{\sum_{i=1}^{n} x_i}{n}$

Step 2: Calculate:$|x - \bar{x}|$

Step 3: Assign weightage for each criteria using any one of the existing method

Step 4: Allot best rank for the smallest deviation.

Step 5: Calculating weightage: X_{ij} = X_{ij} × corresponding weight.

Step 6: Find the optimal solution

4. The Advanced Best Alternative Technique for the Optimal Solution (BATOS) Method for Multi-Criteria Decision Making (MCDM)

The Advanced Best Alternative Technique for Optimal Solution (BATOS) sounds like a promising method for multi-criteria-based decision-making. Its emphasis on simplicity and accessibility could make it particularly attractive for researchers and decision-makers who prefer straightforward approaches. Using elementary calculations like mean, weight, and ranking systems can indeed streamline the

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decision-making process, making it more manageable and less prone to complications. By focusing on these fundamental calculations, Advanced BATOS provide a clear framework for evaluating alternatives and selecting the best course of action. Overall, the Advanced BATOS method appears to offer a practical and user-friendly approach to decision-making, which could be beneficial across various domains and disciplines.

Weights mean how much a given factor should be taken into consideration (default weight = 1for all factors.

Impact means that a given factor has positive or negative impact. Like we want quality to be great (Beneficial or favorable) as possible but the price to be less (Non-Beneficial) as possible, so I will assign '+' weight to the quality, and '-' weight to the price.

In this paper I have taken four types nutrients in that two from macronutrient (Carbohydrate &Protein) and two from micro nutrient (Calcium &Vitamin A)

Carbohydrates (Carbs):

As a primary energy source, carbohydrates provide fuel for various bodily activities, including physical exercise and cognitive functions. Additionally, carbohydrates play a crucial role in regulating blood glucose levels and insulin metabolism, which are vital for maintaining stable energy levels and preventing conditions like diabetes. Carbohydrates are also involved in cholesterol and triglyceride metabolism, affecting cardiovascular health. Moreover, certain types of carbohydrates, such as dietary fiber, aid in digestion and promote gut health through fermentation by beneficial gut bacteria. Overall, carbohydrates are indispensable for maintaining overall health and well-being.

Proteins:

Proteins are composed of amino acids, which are often referred to as the building blocks of life because they form long chains to create various types of proteins. These proteins play crucial roles in the body, serving as structural components, enzymes, hormones, antibodies, and more. Since the body cannot produce all the necessary amino acids on its own, it relies on dietary sources to obtain them. Hence, proteins are categorized as macronutrients, along with carbohydrates and fats, because they are required in relatively large quantities to support various physiological functions and maintain overall health.

"It is important for individuals to consume protein every day. Daily protein intake plays a role in keeping your cells in good shape and should be part of your daily health maintenance plan."

Calcium:

Calcium is a important mineral for maintaining overall health. Its primary role lies in building and maintaining strong bones and teeth, where the majority of the body's calcium is stored. Beyond skeletal health, calcium is involved in numerous physiological processes. It supports muscle function, including the contraction and relaxation of muscles, and aids in the transmission of nerve impulses throughout the body, facilitating communication between the brain and various body parts. Moreover, calcium plays a role in the movement of blood through blood vessels and contributes to the release of hormones that regulate various bodily functions. Overall, adequate calcium intake is essential for maintaining optimal health and functioning.

Vitamin A:

Vitamin A is indeed crucial for various bodily functions. It plays a vital role in maintaining healthy vision, particularly in low-light conditions. It also supports the immune system, aiding in the body's defense against infections. Additionally, vitamin A is involved in cell growth and differentiation, making it essential for reproduction and development. Furthermore, it contributes to the proper functioning of organs like the heart and lungs, highlighting its significance for overall health.

In this paper I have taken four different criteria's like Crabs, Proteins, Calcium, Vitamin and four Alternatives like Food 1,Food 2, Food 3, Food 4.Each alternatives contains the Nutrient component of crabs, Proteins, Calcium, Vitamin.

Here I have taken data from Nutritional goals for each age/sex group used in assessing adequacy of USDA Food Patterns at various Calorie levels From the RDA (Recommended Dietary Allowance)

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Age Group	Carbs (g)	Proteins (g)	Calcium (g)	Vitamin (g)	Calorie
Female (31-50)	130	46	1	0.7	1800
Male (31-50)	130	56	1	0.9	2200
Female (51+)	130	46	1.2	0.7	1600
Male (51+)	130	56	1.2	0.9	2000
Average ($\bar{X}$)	130	51	1.1	0.8	1900

Table 4.1-RDA Data

Numerical Analysis:

To solve the problem of selecting the best diet for daily intake for a healthy life from the four varieties of foods based on the daily requirement of calorie intake recommended by RDA (Recommended Dietary Allowance), we need to consider factors such as carbohydrates, proteins, calcium, and minerals. Given data values for a particular factor is to be considered as standard units.

Food	Carbs (g)	Proteins(g)	Calcium(g)	Vitamin A (g)
F_1	120	45	0.7	0.8
F_2	135	50	1.0	0.7
F_3	125	55	0.8	0.4
F_4	130	40	1.3	0.9
Avg From RDA	130	51	1.1	0.8

Table 4.2-Problem

Solution:

Step 1: Survey Method to calculate weightage for each criteria.

Factory/criteria	F_1	F_2	F_3	-	-	F_{30}
Carbs (X_1)	0.55	0.6	0.63	-	-	0.54
Proteins (X_2)	0.15	0.2	0.17	-	-	0.24
Calcium (X_3)	0.2	0.15	0.12	-	-	0.18
Vitamins A (X_4)	0.1	0.5	0.8	-	-	0.4

Table 4.3-Weightage Calculation

Using Arithmetic Mean Calculate the weight.

Weight for Carbs:

$$\overline{X_1} = \frac{\sum_{i=1}^{30} X_i}{n} = \frac{0.55+0.6+0.63+********** +0.54}{30} = 0.6$$

Weight for Proteins:

$$\overline{X_2} = \frac{\sum_{i=1}^{30} X_i}{n} = \frac{0.15+0.2+0.17+********** +0.24}{30} = .2$$

Weight for Calcium

$$\overline{X_3} = \frac{\sum_{i=1}^{30} X_i}{n} = \frac{0.2+0.15+0.12+********** +0.18}{30} = .15$$

Weight for Vitamin A:

$$\overline{X_4} = \frac{\sum_{i=1}^{30} X_i}{n} = \frac{0.1+0.5+0.8+********** +0.4}{30} = .05$$

Step 2: Assigning Weight to Criteria

Food	Carbs (g)	Proteins (g)	Calcium (g)	Vitamin A (g)
Weight	0.6	0.2	0.15	0.05
F_1	120	45	0.7	0.8
F_2	135	50	1.0	0.7
F_3	125	55	0.8	0.4
F_4	130	40	1.3	0.9
Avg From RDA	130	51	1.1	0.8

Table 4.4-MCDM Formulation

Step 3: Deviation from the average $|x - \bar{x}|$:

Food	Carbs (g)	Proteins (g)	Calcium (g)	Vitamin A(g)
Weight	0.6	0.2	0.15	0.05
F_1	10	6	0.4	0
F_2	5	1	0.1	0.1
F_3	5	4	0.3	0.4
F_4	10	11	0.2	0.1

Table 4.5-Deviation Table

Step 4: Assigning Rank for each criteria:

Food	Carbs (g)	Proteins (g)	Calcium (g)	Vitamin A(g)
Weight	0.6	0.2	0.15	0.05
F_1	10-2	6-3	0.4-4	0-1
F_2	5-1	1-1	0.1-1	0.1-2
F_3	5-1	4-2	0.3-3	0.4-3
F_4	10-2	11-4	0.2-2	0.1-2

Table 4.6-Rank Table

(Smallest value should be given the best rank)

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Step 5:Find the optimal solution:

Food	Carbs (g)	Proteins (g)	Calcium (g)	Vitamin (g)	Total	Rank
F_1	1.2	0.6	0.6	0.05	2.45	4
F_2	0.6	0.2	0.15	0.1	1.05	1
F_3	0.6	0.4	0.45	0.15	1.6	2
F_4	1.2	0.8	0.3	0.1	2.4	3

Table 4.7-Optimal Solution

From the mathematical model we can conclude that F_2 contains the best daily required Nutrition Contents since it has the minimum deviation from the daily requirement recommended by RDA (Recommended Dietary Allowance).

Now I would like to spread this knowledge to the rural people to reduce the inequality in the knowledge of taking nutrient food and how to choose the best food among the different varieties of food. For that I am using the proposed transportation problem to spread this knowledge to most of the villages with minimum time period.

5. Mathematical Structure of the Problem:

The transportation model for optimizing nutrition awareness sessions in rural areas can be formulated as a Linear Programming (LP) problem. The objective is to minimize the total transportation time while ensuring that all villages receive the required number of training sessions.

5.1 Algorithm for the proposed method:

Step 1: Balance the transportation problem
Step 2: For each row in the cost table, subtract the row mean from each element in the row.
Step 3: For each column, subtract the column mean from each element in the column.
Step 4: For minimization: start allocating as much as possible to the least cost value cell.
Step 5: For maximization: start allocating as much as possible to the highest cost value cell.
Step 6: Proceed to step 4/5 until all allocations are complete.

5.2 Problem Formulation:

Decision Variable:

Let x_{ij} represent the number of training sessions transported from training center i to village j, where: i=1,2,3 (Centers: A, B, C j=1,2,3,4 (Villages: V1, V2, V3, V4)

Objective Function:

The goal is to minimize the total transportation time, given by:

$$\text{Min } Z = \sum_{i=1}^{3}\sum_{j=i}^{4} c_{ij}x_{ij} \text{ where}$$

- c_{ij} represent the transportation time in hours from centre i to village j.
- x_{ij} is the number of session transported from centre i to village j

Constraints:

(i)Supply Constraints (Trainers availability at centers)

Each center has a limited number of trainers available, which imposes a supply constraint:

$$\sum_{j=1}^{4} x_{ij} \le s_i, \ \forall \ i = 1,2,3$$

Where, S_i represents the total number of training sessions available at center i.

For the given data:

- Center A: S_1=10
- Center B: S_2=12
- Center C: S_3=8

Thus, the supply constraints are:

$x_{A1}+x_{A2}+x_{A3}+x_{A4} \le 10$
$x_{B1}+x_{B2}+x_{B3}+x_{B4} \le 12$
$x_{C1}+x_{C2}+x_{C3}+x_{C4} \le 08$

Demand Constraints (Sessions required at Villages)

Each village requires a certain number of training sessions, which must be met:

$$\sum_{j=1}^{4} x_{ij} \le s_i, \ \forall \ i = 1,2,3$$

Where, Dj represents the total number of training sessions required at village j.

For the given data:

- Village V1: D_1=6
- Village V2: D_2=5
- Village V3: D_3=7

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- Village V4: D_4=6

Thus, the demand constraints are:

$$x_{A1}+x_{B1}+x_{C1} \leq 6$$
$$x_{A2}+x_{B2}+x_{C2} \leq 5$$
$$x_{A3}+x_{B3}+x_{C3} \leq 7$$
$$x_{A4}+x_{B4}+x_{C4} \leq 6$$

Non negativity constraints:

Since the number of training sessions cannot be negative, we impose:

$X_{ij} \geq 0, \quad \forall\ i,j$

Transportation Cost (Time) Matrix:

The transportation time (in hours) from each centre to each village is given by:

Centre/Village	V 1	V 2	V 3	V 4	Supply
A	4	3	5	6	10
B	2	6	4	5	12
C	3	5	2	4	8
Demand	6	5	7	6	

Table 5.1

Solution:

Step 1: Balance the transportation problem. Since total supply (10+12+8 = 30) is greater than total demand (6+5+7+6 = 24), this is an unbalanced transportation problem. To balance it, a dummy village (V5) can be introduced with demand = 6 sessions and transportation time c_{i5}=0for all centers.

Now Row total and Column total are equal. i.e $\sum_{i=1}^{m} a_{ij} = \sum_{i=1}^{m} b_{ij}$ =30, therefore given problem is Balanced.

	V 1	V 2	V 3	V 4	V 5	Supply
A	4	3	5	6	0	10
B	2	6	4	5	0	12
C	3	5	2	4	0	8
Demand	6	5	7	6	6	

Table 5.2-Balanced data

Step 2: Find the mean for each row $\bar{s_i} = \frac{\sum_{i=1}^{n} C_{ij}}{N}$, Where N is the number of elements of each row.

Step 3: Find the Cost Deviation from the row mean. (i.e) $\widetilde{C_{ij}} = C_{ij}$ - $\bar{s_i}$

	V 1	V 2	V 3	V 4	V 5	Supply
A	0	-1	1	2	-4	10
B	-1	3	1	2	-3	12
C	0	2	-1	1	-3	8
Demand	6	5	7	6	6	

Table 5.3-Row Deviation

Step 4: Find the column mean and Cost Deviation from the Column mean.

(i.e) $\widetilde{C_{ij}} = C_{ij} - \bar{s_i}$ - $\bar{t_j}$

	V1	V 2	V3	V 4	V 5	Supply
A	0	-2	1	0	-1	10
B	-1	2	1	0	0	12
C	0	1	-1	-1	0	8
Demand	6	5	7	6	6	

Table 5.4-Column Deviation

Step 5: If there are multiple cells with the same lowest value in the resultant table, Start the allocation decision by selecting the cell with the maximum allocation is possible

	V1	V 2	V 3	V 4	V 5	Supply
A	0	[5] -2	1	0	[5] -1	~~10~~ 5
B	[6] -1	2	1	[5] 0	[1] 0	~~12~~ ~~6~~ ~~5~~ ~~1~~ 0
C	0	1	[7] -1	[1] -1	0	~~8~~ 0
Demand	~~6~~ 0	~~5~~ 0	~~7~~ 0	~~6~~ ~~5~~ ~~1~~ 0	~~6~~ ~~1~~ 0	

Table 5.5-Optimal Solution

Now there is no allocation left out. Also m+n-1=7=the number of allocation.

i.e. The total minimum transportation time is =(3×5) + (0×5) +(2×6) +(5×5) +(0×1) +(2×7) +(4×1) =70 hours.

Results:

The proposed mathematical model effectively identifies the most nutritious food option based on key criteria—calcium, vitamins, carbohydrates, and proteins—using Multi-

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Criteria Decision-Making (MCDM) techniques such as the Advanced Best Alternative Optimal Solution method. The results indicate that food items with a balanced nutritional profile rank higher in the selection process. This structured approach ensures that dietary decisions prioritize nutrition while minimizing costs.

In the second phase, the transportation model optimizes the cost-effective distribution of nutritional awareness and food supply using minimal resources. By reducing transportation expenses and maximizing outreach to underprivileged populations, the model contributes to reducing health inequalities in alignment with SDG-10.

The findings emphasize the significance of mathematical optimization techniques in addressing health equity. The integration of MCDM for food selection and the transportation model for efficient dissemination offers a robust approach to minimizing nutritional disparities and promoting accessible, cost-effective nutrition solutions.

Future Work:

The model holds promise for applications beyond the health sector, particularly in business management across various industries. Future developments will focus on enhancing the model's adaptability for different fields, such as supply chain management, marketing strategies, and resource allocation. Efforts will also be directed towards improving its scalability for large-scale implementations, refining its decision-making capabilities for both planning and execution. Additionally, real-time data integration and AI-driven optimization techniques will be explored to further enhance the model's accuracy and efficiency.

Conclusion:

This study identifies F2 as the optimal choice for meeting daily nutritional needs based on minimal deviation from RDA recommendations. Additionally, an optimized transportation model was developed to efficiently distribute nutritional awareness sessions across rural villages, ensuring broader outreach with minimal travel time. This approach supports SDG 10 by promoting equal access to nutritional education and reducing knowledge disparities. Future research can enhance efficiency through real-time traffic data, multi-modal transport, different food combinations with nutritional values, and dynamic scheduling

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