Enhancing Food Resource Allocation in India: A Fuzzy Logic Approach Integrated with Julia and Python

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Abstract

Exploring the intricate network of food resource distribution, especially in the Indian context, this research delves into the multifaceted challenges stemming from poverty and food insecurity. It offers a comprehensive analysis that includes historical perspectives, socio-economic conditions, government policies, and their impact on vulnerable communities. Using innovative methods such as fuzzy logic-based models, Lagrangian optimization, and the Graded Mean Integration (GMI) representation technique, the study provides a systematic approach to allocate resources effectively in food distribution inventory management. By employing the Julia programming language to define and illustrate data for three distinct regions, the research sheds light on critical factors like food poverty levels, budget constraints, demand, supply, inventory, and resource allocation. Additionally, the use of Python libraries for visual representation enhances our understanding of these crucial parameters. Ultimately, this research contributes to the ongoing effort to establish a more equitable and sustainable food distribution system, ensuring access to nutritious food for all individuals, thereby fostering both individual well-being and national prosperity.

Keywords: Food Resource Allocation, Fuzzy Logic Modelling, Lagrangian Optimization, Graded Mean Integration, Data Visualization, India's Food Distribution System.

1.INTRODUCTION

India, with its vast and diverse population, presents a tapestry of stark contrasts. While it stands as a nation with a thriving economy and a burgeoning middle class, it also grapples with deeply entrenched issues of poverty and food insecurity. The allocation of food resources in India has long been a topic of concern and heated debate, as millions of its citizens continue to grapple with inadequate access to nutritious meals. This multifaceted challenge transcends mere economic dimensions; it is intricately interwoven with social, cultural, and political factors. The disparity in food resource allocation reverberates across the nation, impacting the health, well-being, and potential of a significant portion of the Indian population. This discourse endeavours to dissect the multifaceted dimensions of poverty in food resource allocation within India. It takes a historical perspective to unravel the roots of this challenge, examines the existing socio-economic conditions, scrutinizes government policies, and delves into the repercussions on vulnerable communities. Furthermore, it embarks on an exploration of the various efforts and initiatives aimed at alleviating this issue, while also contemplating potential strategies to forge a more equitable and sustainable food distribution system. By addressing this intricate web of factors that contribute to food insecurity in India, we aim to pave the way for a future where every individual has the fundamental right to access nutritious food. This not only ensures individual well-being but also lays the foundation for a healthier, more prosperous nation as a whole.

People suffer from poverty in various ways, and one critical aspect is the allocation of food resources. Poverty affects individuals and communities on multiple levels, with food insecurity being a significant concern. Here are some key aspects of how poverty impacts food resource allocation. People living in poverty often have restricted access to a variety of nutritious foods. This can be due to financial constraints, limited availability of fresh produce in their area, or lack of transportation to reach grocery stores or markets. In many cases, individuals facing poverty may resort to low-cost, energy-dense foods that are often high in sugar, salt, and unhealthy fats. These options may be more readily available and affordable, but they can lead to poor nutrition and health outcomes. Limited financial resources may result in a monotonous diet, lacking in the variety of nutrients necessary for optimal health. This can lead to nutrient deficiencies and related health issues. Poverty can contribute to the existence of "food deserts" – areas where access to affordable, fresh, and nutritious food is severely limited. In such areas, people may rely on convenience stores or fast-food outlets, which often offer limited healthy options. Poverty exacerbates existing inequalities. Vulnerable populations, such as children, the elderly, and those with chronic illnesses, are particularly affected by food insecurity. They may face even greater challenges in accessing adequate and nutritious meals. Inadequate access to nutritious food can lead to a range of health problems, including malnutrition, stunted growth (especially in children), obesity, and diet-related chronic diseases like diabetes and heart disease. Food insecurity can have a profound impact on mental and emotional well-being. The stress and anxiety associated with not knowing where the next meal will come from can lead to depression and other mental health issues.

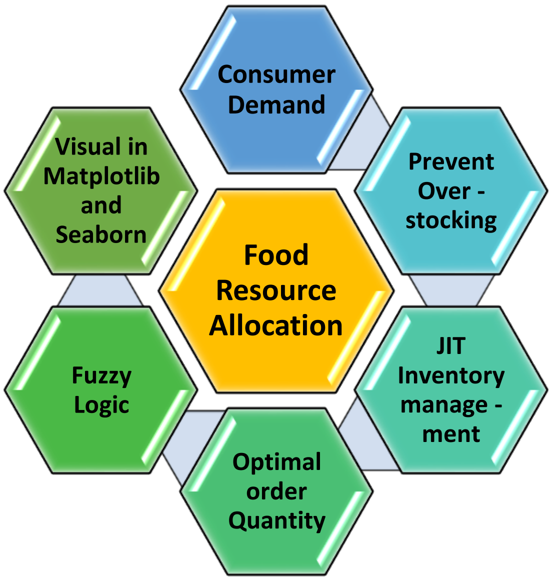
Poverty often coexists with other social issues, such as inadequate housing, lack of access to healthcare, and limited educational opportunities. These factors further compound the challenges associated with food resource allocation. Addressing poverty and its impact on food resource allocation requires a multi-faceted approach that encompasses social, economic, and policy interventions. By understanding the complex dynamics at play, policymakers and stakeholders can work towards more equitable and sustainable solutions to ensure that all individuals have access to nutritious and culturally appropriate food. Fuzzy resource allocation in inventory management for food involves the application of fuzzy logic, an advanced mathematical framework for handling uncertainty and imprecision. This approach is particularly valuable in addressing the inherent variability and uncertainty present in food supply chains. Unlike traditional methods that rely on fixed inventory levels and deterministic demand forecasts, fuzzy logic provides a more flexible and adaptive approach. In a fuzzy logic-based model, various factors related to inventory management, such as demand forecasts, shelf life, storage capacity, and supplier relationships, are represented using linguistic variables and fuzzy sets. This allows for a nuanced and graded representation of these factors, acknowledging the uncertainty associated with them. Membership functions are defined to describe the degree of belongingness of an element to a particular set (e.g., low, medium, high inventory levels). These functions capture the imprecision and variability in the data, allowing for a more realistic representation of real-world scenarios.

Julia is a high-level, high-performance programming language specifically designed for numerical computing. Julia is known for its just-in-time (JIT) compilation, which allows it to achieve performance similar to statically-typed languages while maintaining the flexibility and dynamic nature of a scripting language. The Julia programming language provides powerful tools and libraries for data manipulation, making it an excellent choice for numerical computations and data analysis. Its syntax is intuitive, and its performance rivals that of lower-level languages. This makes Julia a preferred language for scientific computing, machine learning, and other numerical tasks. Unlike some other high-level languages, Julia often produces highly optimized code without manual intervention. This reduces the need for low-level optimization, saving time and effort. Julia is designed to handle large-scale computations. It's suitable for both small-scale data analysis tasks and large-scale scientific simulations. Julia's combination of high performance, ease of use, and a robust ecosystem of packages makes it an excellent choice for numerical computing and data analysis tasks. It's particularly well-suited for applications where speed and efficiency are paramount.

Matplotlib and Seaborn are powerful Python libraries used for data visualization. In the context of fuzzy inventory and food resource allocation, these libraries play a crucial role in creating visual representations of data, making it easier to understand and analyse complex information. Matplotlib provides a comprehensive set of tools for creating static, animated, and interactive visualizations in Python. It offers a high level of customization, allowing users to create a wide range of plots and charts. Seaborn, on the other hand, is built on top of Matplotlib and provides a higher-level interface for creating aesthetically pleasing and informative statistical graphics. In the realm of fuzzy inventory and food resource allocation, these libraries can be utilized to visually represent various aspects of the allocation process. By leveraging Matplotlib and Seaborn in a Jupyter notebook, researchers and practitioners can enhance their understanding of fuzzy inventory and food resource allocation. The visualizations generated through these libraries provide valuable insights, enabling more informed and effective decision-making in the allocation process.

2. OBJECTIVES

- Ensuring products are available when and where they are needed contributes to customer satisfaction.
- Efficient allocation helps minimize costs associated with excess inventory and storage.
- Responsible allocation practices contribute to sustainable practices in the food industry.
- With a growing population and unpredictable environmental conditions, adaptive and intelligent allocation strategies are crucial.



3.PRELIMINARIES

3.1 Food Resource Allocation in Inventory Management

Efficient allocation of food resources is crucial for the operation of food-related businesses. It involves strategic distribution while minimizing waste and maintaining profitability. This process considers factors like demand forecasts, shelf life, and supplier relationships. Various methodologies like JIT, EOQ models, and software systems are employed to balance supply and demand.

3.2 Fuzzy Logic in Food Resource Allocation

Traditional approaches to food distribution often fall short due to the dynamic nature of supply chains. Fuzzy logic, a mathematical framework for handling uncertainty, offers a flexible and responsive solution. It addresses inherent variability in supply chains, reducing inefficiencies, overstocking, and waste.

3.3 Lagrangian Method for Resource Optimization

Integrates the Lagrangian method with the fuzzy logic-based model to enhance resource allocation. Lagrange multipliers allow for constraint inclusion. This method addresses factors like budget limitations or capacity restrictions.

3.4 Graded Mean Integration (GMI) Representation Method

The Graded Mean Integration (GMI) representation method is a technique used in fuzzy logic to convert fuzzy sets into crisp values. It offers an alternative approach to defuzzification, which is the process of converting fuzzy output into a single, definite value. GMI is particularly useful in situations where the output of a fuzzy system needs to be interpreted in a more nuanced or graded manner.

3. FOOD RESOURCE ALLOCATION IN FUZZY INVENTORY

Aspect	Description
Purpose	Strategic distribution and utilization of food resources to meet consumer demands, minimize waste, and ensure profitability
Importance	Critical for efficient operation of any food-related business or organization.
Consumer Demand Prediction	Understanding and predicting consumer demand for various food items is essential for effective allocation.
Perishable Goods Consideration	Taking into account expiry dates of perishable goods to ensure timely distribution before becoming unsuitable for consumption
Storage Space Assessment	Assessing available storage space to prevent overstocking or understocking of inventory.
Supplier Relationships	Building strong relationships with suppliers to ensure a reliable and timely supply chain.
Just In Time (JIT) Inventory Management	Ordering and receiving inventory only when needed to minimize excess stock
EOQ Models	Determining the optimal order quantity that minimizes total inventory costs
Extension to Non-Perishable Items	Involves allocation of resources for non-perishable items, packaging materials, and related supplies
Balancing Supply and Demand	Striking the right balance to prevent overstocking (which leads to waste) or understocking (resulting in lost sales and dissatisfied customers).
Fuzzy Logic for Uncertainty Handling	Fuzzy logic allows representation of uncertain variables and imprecise information, which is crucial in food resource allocation
Membership Functions for Inventory, Demand, and Supply	Categorizing levels (Low, Medium, High) using fuzzy logic to capture uncertainty in consumer demand and available supply

Integration with Lagrangian Method	Enhancing fuzzy inventory models by integrating the Lagrangian method to incorporate constraints (e.g., budget limitations, capacity restrictions) into the allocation process
Graded Mean Integration (GMI) Method	Providing an alternative approach to converting fuzzy logic outputs into crisp values by calculating the mean value of membership functions weighted by their degrees of membership.
Flexible Decision-Making	Fuzzy inventory models enable more adaptive and flexible decisions in allocating food resources, considering the inherent uncertainty in supply chain dynamics
Contribution to Efficiency and Sustainability	Application of fuzzy inventory models contributes to more efficient, sustainable, and equitable food distribution systems.

This table provides a structured summary of the key aspects and strategies involved in food resource allocation, including the application of fuzzy inventory models for uncertainty handling.

4. MATHEMATICAL MODEL - INVENTORY LEVEL, DEMAND, SUPPLY, RESOURCE ALLOCATION

Defines membership functions for different levels (Low, Medium, High) for Inventory, Demand, Supply, and Resource Allocation. These functions describe the degree of belongingness of an element to a set.

4.1 Inventory level (I)

The inventory level (I) is divided into three categories: Low (IL(x)), Medium (IM(x)), and High (IH(x)). These categories are defined by their respective membership functions as follows:

- Low ($I_L(x)$)

For Low inventory level (IL(x)), the membership function is defined as follows:

$$\mu_{I_L}(x) = \begin{cases} 1 & if\ x \le 0.3 \\ \dfrac{0.6 - x}{0.3} & if\ 0.3 < x < 0.6 \\ 0 & if\ x \ge 0.6 \end{cases}$$

- Medium ($I_M(x)$)

For Medium inventory level (IM(x)), the membership function is defined as follows

$$\mu_{I_M}(x) = \begin{cases} 0 & if\ x \le 0.3\ or\ x \ge 0.8 \\ \dfrac{x - 0.3}{0.5} & if\ 0.3 < x < 0.8 \\ \dfrac{0.8 - x}{0.2} & if\ 0.6 \le x < 0.8 \end{cases}$$

- High ($I_H(x)$)

For High inventory level (IH(x)), the membership function is defined as follows

$$\mu_{I_H}(x) = \begin{cases} 0 & if\ x \le 0.6 \\ \dfrac{x - 0.6}{0.4} & if\ 0.6 < x < 1 \\ 1 & if\ x \ge 1 \end{cases}$$

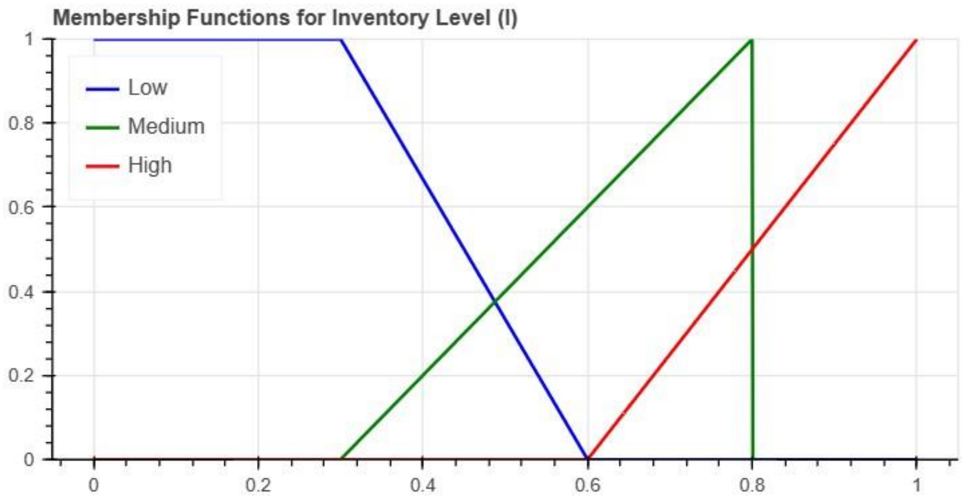


Figure 4.1 Membership function of Inventory level

4.2 Demand (D)

The demand (D) is categorized into three levels: Low (DL(x)), Medium (DM(x)), and High (DH(x)), each with their respective membership functions defined as follows:

- Low (D_L (x))

For Low demand (DL(x)), the membership function is defined as follows:

$$\mu_{D_L}(x) = \begin{cases} 1 & if\ x \leq 0.3 \\ \dfrac{0.6 - x}{0.3} & if\ 0.3 < x < 0.6 \\ 0 & if\ x \geq 0.6 \end{cases}$$

- Medium (D_M (x))

For Medium demand (DM(x)), the membership function is defined as follows:

$$\mu_{D_M}(x) = \begin{cases} 0 & if\ x \leq 0.3\ or\ x \geq 0.8 \\ \dfrac{x - 0.3}{0.5} & if\ 0.3 < x < 0.8 \\ \dfrac{0.8 - x}{0.2} & if\ 0.6 \leq x < 0.8 \end{cases}$$

- High (D_H (x))

For High demand (DH(x)), the membership function is defined as follows:

$$\mu_{D_H}(x) = \begin{cases} 0 & if\ x \leq 0.6 \\ \dfrac{x - 0.6}{0.4} & if\ 0.6 < x < 1 \\ 1 & if\ x \geq 1 \end{cases}$$

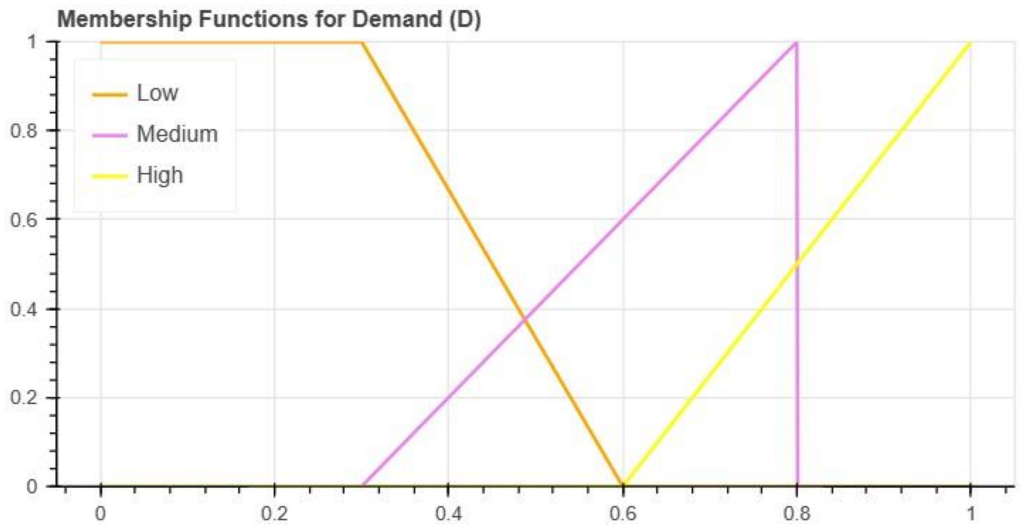


Figure 4.2 Membership function of Demand

4.3 Supply (S)

The supply (S) is categorized into three levels: Low (SL(x)), Medium (SM(x)), and High (SH(x)), with corresponding membership functions defined as follows:

- Low (S_L (x))

For Low supply (SL(x)), the membership function is defined as

$$\mu_{S_L}(x) = \begin{cases} 1 & if\ x \leq 0.3 \\ \dfrac{0.6 - x}{0.3} & if\ 0.3 < x < 0.6 \\ 0 & if\ x \geq 0.6 \end{cases}$$

- Medium (S_M (x))

For Medium supply (SM(x)), the membership function is defined as

$$\mu_{S_M}(x) = \begin{cases} 0 & if\ x \leq 0.3\ or\ x \geq 0.8 \\ \dfrac{x - 0.3}{0.5} & if\ 0.3 < x < 0.8 \\ \dfrac{0.8 - x}{0.2} & if\ 0.6 \leq x < 0.8 \end{cases}$$

- High (S_H (x))

For High supply (SH(x)), the membership function is defined as

$$\mu_{S_H}(x) = \begin{cases} 0 & if\ x \leq 0.6 \\ \dfrac{x - 0.6}{0.4} & if\ 0.6 < x < 1 \\ 1 & if\ x \geq 1 \end{cases}$$

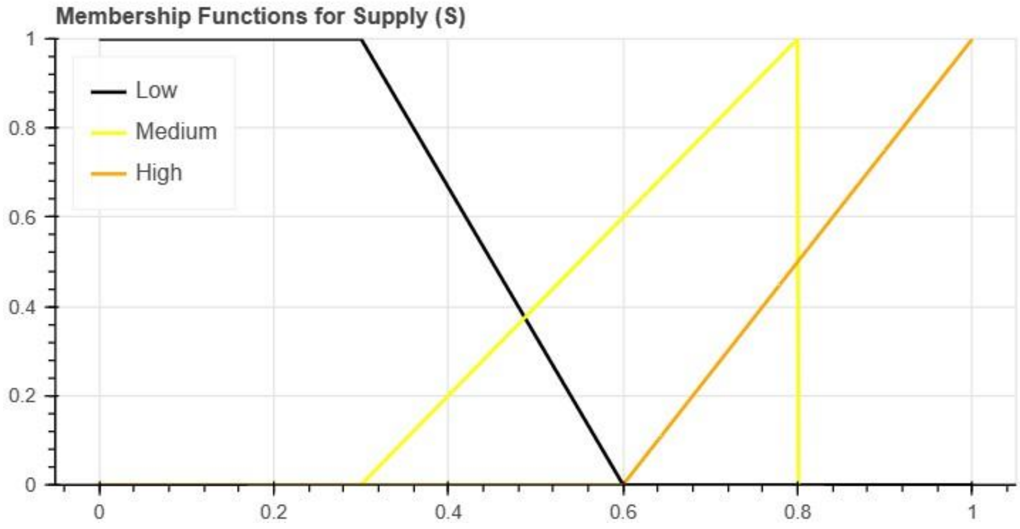


Figure 4.3 Membership function of Supply

4.4 Resource Allocation (R)

The resource allocation (R) is categorized into three levels: Low (RL(x)), Medium (RM(x)), and High (RH(x)), with corresponding membership functions defined as follows:

- Low (R_L (x))

  For Low resource allocation (RL(x)), the membership function is defined as:

$$\mu_{R_L}(x) = \begin{cases} 1 & if\ x \leq 0.3 \\ \dfrac{0.6 - x}{0.3} & if\ 0.3 < x < 0.6 \\ 0 & if\ x \geq 0.6 \end{cases}$$

- Medium (R_M (x))

  For Medium resource allocation (RM(x)), the membership function is defined as

$$\mu_{R_M}(x) = \begin{cases} 0 & if\ x \leq 0.3\ or\ x \geq 0.8 \\ \dfrac{x - 0.3}{0.5} & if\ 0.3 < x < 0.8 \\ \dfrac{0.8 - x}{0.2} & if\ 0.6 \leq x < 0.8 \end{cases}$$

- High (R_H (x))

  For High resource allocation (RH(x)), the membership function is defined as

$$\mu_{R_H}(x) = \begin{cases} 0 & if\ x \leq 0.6 \\ \dfrac{x - 0.6}{0.4} & if\ 0.6 < x < 1 \\ 1 & if\ x \geq 1 \end{cases}$$

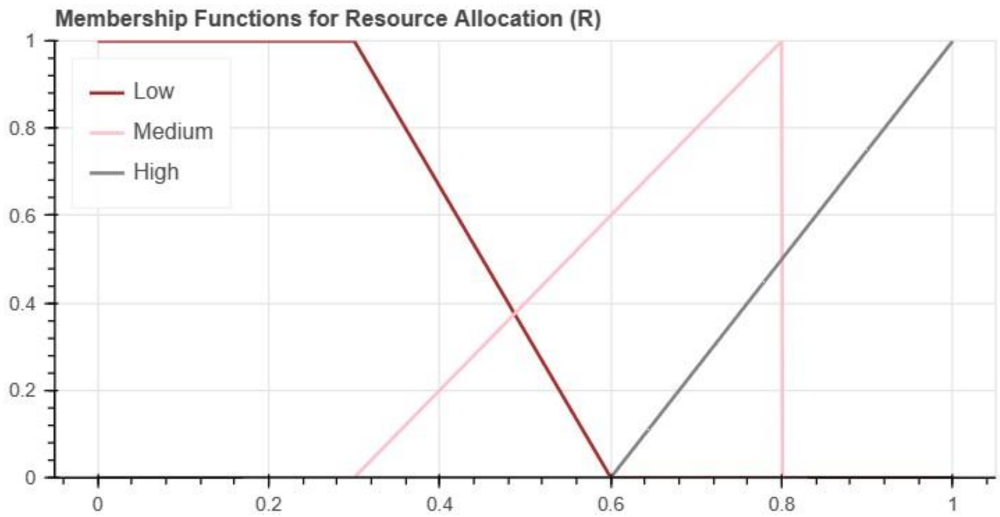


Figure 4.1 Membership function of Resource Allocation

5. Lagrangian Method for Resource Optimization

The Lagrangian method is a powerful optimization technique that can be integrated with the fuzzy logic-based model to further enhance resource allocation in limited supply scenarios. By introducing Lagrange multipliers, this method allows for the inclusion of constraints in the optimization process. In our context, constraints could represent factors such as budget limitations or capacity restrictions.

The Lagrangian function L is defined as

$$L(x,\lambda) = f(x) + \sum_{i} \lambda_i (g_i(x) - b_i)$$

Where

$f(x)$ is the objective function to be maximized / minimized

$g_i(x)$ are the constraint functions

λ_i are the lagrange multipliers associated with each constraint

b_i are the constraint values

By solving for the partial derivatives of L with respect to x and λ_i and setting them to zero, we can obtain the optimal resource allocation that considers both the fuzzy logic-based model and the imposed constraints. This synergistic integration of fuzzy logic and the Lagrangian method provides a comprehensive framework for resource allocation that accounts for uncertainties and constraints, making it particularly well-suited for complex real-world scenarios.

6. GRADED MEAN INTEGRATION (GMI) REPRESENTATION METHOD

In addition to the Signed Distance Method, another noteworthy technique for defuzzification is the Graded Mean Integration (GMI) representation method. GMI provides an alternative approach to converting fuzzy logic outputs into crisp values. This method calculates the mean value of the membership functions weighted by their degrees of membership, effectively offering a representation of the "graded" nature of the fuzzy set.

In GMI, the crisp output R_{crisp} is calculates as follows

$$R_{crisp} = \frac{\int_{x_{min}}^{x_{max}} x.\mu_R(x)dx}{\int_{x_{min}}^{x_{max}} \mu_R\ (x)dx}$$

This approach provides a different perspective on defuzzification and can be employed in tandem with the Signed Distance Method, offering a comprehensive toolkit for optimizing resource allocation.

7. FUZZY RULES FOR RESOURCE ALLOCATION

Fuzzy logic rules for resource allocation based on the levels of inventory (I), demand (D), and supply (S)

Rule 1: If Inventory is High AND Demand is Low AND Supply is High, THEN Allocate a High Proportion of Resources

(IF (I_H AND D_L AND S_H) THEN R_H)

Rule 2: If Inventory is High AND Demand is Medium AND Supply is High, THEN Allocate a Medium Proportion of Resources

(IF (I_H AND D_M AND S_H) THEN R_M)

Rule 3: If Inventory is High AND Demand is High AND Supply is High, THEN Allocate a Low Proportion of Resources

(IF (I_H AND D_N AND S_H) THEN R_L)

Rule 4: If Inventory is Medium AND Demand is Low AND Supply is High, THEN Allocate a Medium Proportion of Resources

(IF (I_M AND D_L AND S_H) THEN R_M)

Rule 5: If Inventory is Medium AND Demand is Medium AND Supply is High, THEN Allocate a Medium Proportion of Resources

(IF (I_M AND D_M AND S_H) THEN R_M)

Rule 6: If Inventory is Medium AND Demand is High AND Supply is High, THEN Allocate a Low Proportion of Resources

(IF (I_M AND D_H AND S_H) THEN R_L)

Rule 7: If Inventory is Low AND Demand is Low AND Supply is High, THEN Allocate a Low Proportion of Resources

(IF (I_L AND D_L AND S_H) THEN R_L)

Rule 8: If Inventory is Low AND Demand is Medium AND Supply is High, THEN Allocate a Low Proportion of Resources

(IF (I_L AND D_M AND S_H) THEN R_L)

Rule 9: If Inventory is Low AND Demand is High AND Supply is High, THEN Allocate a Low Proportion of Resources

(IF (I_L AND D_H AND S_H) THEN R_L)

Rule 10: If Inventory is High AND Demand is Low AND Supply is Medium, THEN Allocate a High Proportion of Resources

(IF (I_H AND D_L AND S_M) THEN R_H)

8. NUMERICAL EXAMPLE IN JULIA PROGRAMMING

In Julia programming, defined various data sets and parameters for three regions, namely "Region A," "Region B," and "Region C." Here's a breakdown of the data:

Regions are represented by the names "Region A," "Region B," and "Region C."

"Region A"
"Region B"
"Region C"

Initial food poverty levels are specified for each region. In "Region A," the levels are 70% Low, 30% Medium, and 0% High. In "Region B," they are 40% Low, 60% Medium, and 0% High. Finally, in "Region C," they are 20% Low, 50% Medium, and 30% High.

[0.7, 0.3, 0.0]
[0.4, 0.6, 0.0]
[0.2, 0.5, 0.3]

Budget constraints are set for each region: $10,000 for "Region A," $15,000 for "Region B," and $12,000 for "Region C."

10000,15000, 12000

Demand levels for each region are defined. In "Region A," the levels are 40% Low, 50% Medium, and 10% High. In "Region B," they are 30% Low, 60% Medium, and 10% High. Lastly, in "Region C," they are 20% Low, 70% Medium, and 10% High.

[0.4, 0.5, 0.1]
[0.3, 0.6, 0.1]
[0.2, 0.7, 0.1]

Supply levels are outlined for each region. In "Region A," the levels are 30% Low, 40% Medium, and 30% High. In "Region B," they are 40% Low, 50% Medium, and 10% High. In "Region C," they are 20% Low, 60% Medium, and 20% High.

[0.3, 0.4, 0.3]
[0.4, 0.5, 0.1]
[0.2, 0.6, 0.2]

Inventory levels for each region are specified. In "Region A," the levels are 30% Low, 40% Medium, and 30% High. In "Region B," they are 40% Low, 50% Medium, and 10% High. In "Region C," they are 20% Low, 60% Medium, and 20% High.

[0.3, 0.4, 0.3]
[0.4, 0.5, 0.1]
[0.2, 0.6, 0.2]

Resource allocation percentages are determined for each region. In "Region A," 70% of resources are allocated to Low poverty, 20% to Medium poverty, and 10% to High poverty. In "Region B," 50% go to Low poverty, 30% to Medium poverty, and 20% to High poverty. In "Region C," 60% are allocated to Low poverty, 20% to Medium poverty, and 20% to High poverty.

[0.7, 0.2, 0.1]
[0.5, 0.3, 0.2]

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[0.6, 0.2, 0.2]

This data, generated using Julia programming, provides a structured representation of various factors influencing food resource allocation across the three regions.

9. VISUALIZATION OF FOOD POVERTY AND BUDGET CONSTRAINTS ACROSS REGIONS

In this visual representation of data using Python, depicted various key factors for three regions: "Region A," "Region B," and "Region C." The code imports the necessary Python libraries for data visualization, including `matplotlib.pyplot` as `plt` for basic plotting functionalities, `seaborn` as `sns` to enhance the visual aesthetics of the plots, and `pandas` as `pd` for efficient data manipulation. The first subplot illustrates the initial food poverty levels, highlighting the percentages of individuals classified as Low, Medium, and High in each region. Moving to the second subplot, we delve into the allocated budgets for these regions, with "Region A" having $10,000, "Region B" with $15,000, and "Region C" with $12,000. The third subplot portrays the demand levels, showcasing the proportions of Low, Medium, and High demands across the regions. The fourth subplot gives insights into the supply levels, delineating the distribution of resources in terms of Low, Medium, and High availability. The fifth subplot focuses on inventory levels, providing a breakdown of the percentages of Low, Medium, and High inventories. Lastly, the sixth subplot visualizes resource allocation, indicating the proportions allocated to Low, Medium, and High poverty levels in each region.

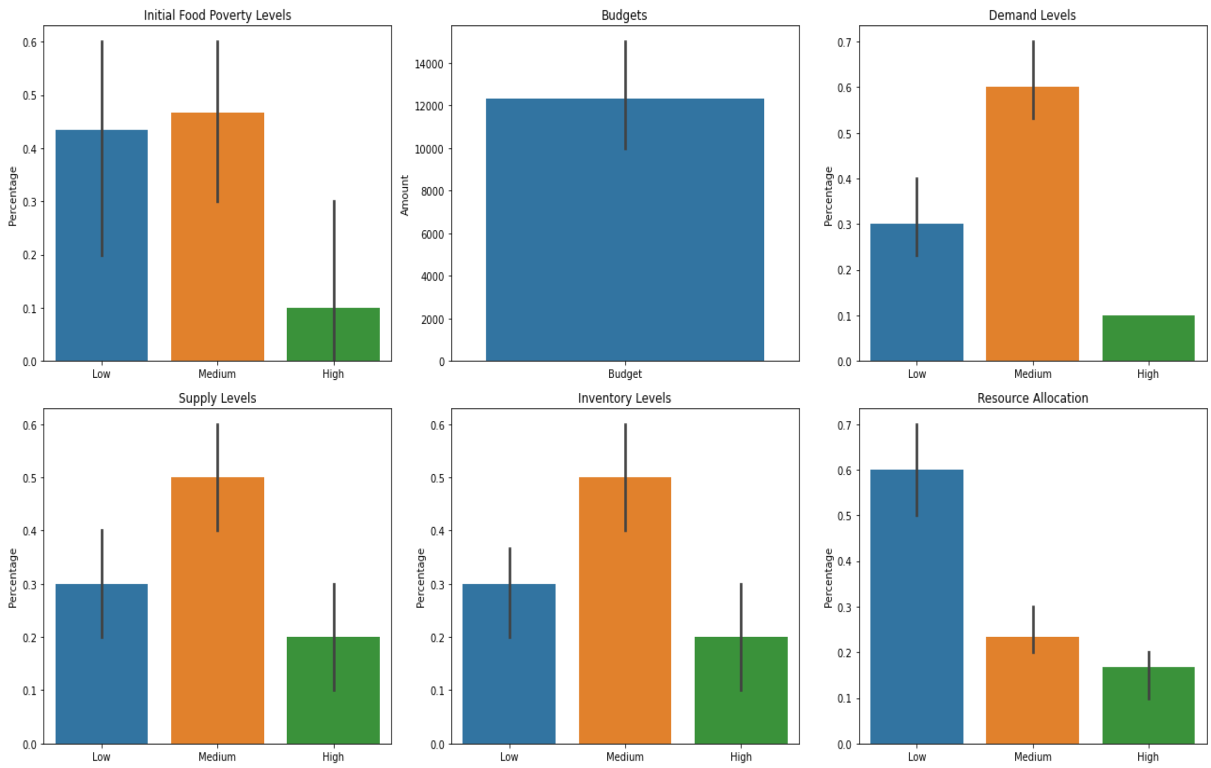

Figure 9.1 Regional Food Resource Allocation Analysis

This comprehensive set of visualizations offers a clear and concise overview of the critical aspects influencing food resource allocation across the specified regions.

10. CONCLUSION

This research offers a comprehensive analysis of food resource allocation in India's complex socio-economic context. It employs innovative methods like fuzzy logic models, Lagrangian optimization, and the Graded Mean Integration approach to systematically manage food distribution inventory. The use of Julia programming provides data for three distinct regions, shedding light on critical factors such as food poverty, budgets, demand, supply, inventory, and resource allocation. Visualizing this data with Python libraries like Matplotlib, Seaborn, and Pandas enhances comprehension of these crucial parameters. By addressing these multifaceted challenges and proposing adaptive allocation strategies, the paper significantly contributes to creating a more equitable and sustainable food distribution system. This is essential for ensuring access to nutritious food for all, promoting individual well-being and national prosperity. The integration of the Lagrangian method and Graded Mean Integration technique further enhances the model's effectiveness in dealing with uncertainties and constraints, making it a powerful tool for real-world applications.

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