Proceedings of the IISE Annual Conference & Expo 2024
A. Brown Greer, C. Contardo, J.-M. Frayret, eds.

Exploring Nutritional Equity In Food Bank Supply Chains

Nowshin Sharmile and Lauren Davis

Department of Industrial & Systems Engineering, North Carolina A&T State University

Greensboro, NC USA

Abstract

Food insecurity, defined as insufficient access to food for a healthy and active life, affected approximately 12.8% of U.S. households in 2022. A concerted effort from both the government and non-government organizations is underway to address this challenge in the United States. This study centers on the Foodbank of Central and Eastern North Carolina (FBCENC), a nonprofit hunger relief organization pivotal in collecting and distributing food donations to local agencies serving individuals in need. However, despite the critical role of food banks, nutritional considerations are often overlooked. To address this gap, the study employs the Healthy Eating Research (HER) Nutrition Guideline, categorizing nutrition types (Red, Yellow, and Green) to assess and enhance the nutritional equity of the current distribution system. A linear programming model is proposed, and equity is adopted as the performance measure. The study aims to develop a model that strategically reduces nutritional disparities across the network. By incorporating HER guidelines and emphasizing equity in distribution, this research contributes to the broader objective of creating a more nutritionally equitable response to food insecurity within the non-profit sector.

Keywords

Humanitarian logistics, Non-profit organization, Nutrition, Hunger Relief.

1. Introduction

Food insecurity can be defined as the lack of consistent access to enough food for every person in a household to live a healthy and active life [1]. In 2022, food insecurity affected around 12.8% of households in the USA. A staggering 49 million individuals sought food assistance for additional support [2]. The economic crises and reduced access to food due to the coronavirus pandemic have made the lives of food-insecure people even harder [3]. Food insecurity has been linked to a lack of access to adequate fresh food and barriers to providing much-needed nutrition, which in turn exacerbate existing health and social problems [4]. Food banks and non-profits are essential for gathering and distributing donated food, providing crucial support to those facing food insecurity. Food banks, pantries, and community groups unite to help millions access affordable food for themselves and their families [5].

In general, the performance of a food bank is typically measured in total pounds of food distributed, and in equitability of the distribution. However, in recent years food banks have started to consider the nutritional quality of the food they offer. A recent study found that the food distributed by the food banks was inconsistent in meeting nutritional requirements and often failed to meet the cultural and personal needs of the customers. Overall, the study found that the food bank clients have limited food options available to them [6]. In 2019, the Healthy Eating Research (HER) program brought together researchers and charitable food agency leaders to create evidence-based standards for uniform application in the charitable food system. The "Healthy Eating Research Nutrition Guidelines for the Charitable Food System" (HER Guidelines) were released in March 2020 [7].

2. Problem Description

In recent years food banks across the country started to take HER guidelines into consideration. With the help of the guidelines, the goal of this work is to answer the following research questions:

1. How equitable is the current food distribution?
2. How can serving capacity and nutritional preference impact overall equity in the supply chain?

We explore nutritional equity using data from The Food Bank of Central and Eastern North Carolina (FBCENC) as a case study. FBCENC serves 34 counties in North Carolina and is one of the seven Feeding America food banks in North Carolina. It ensures the distribution of food and essential services to individuals in need.

3. Related Research

Optimizing humanitarian supply chain operations while considering the nutritional needs of the recipients is a growing area of research. Numerous studies have investigated how food-aid quality influences nutrition and health in food pantries. The results found that better quality of food correlates with recipients adopting healthier diets [8]. The World Food Programme (WFP) developed a mixed integer linear programming model that simultaneously optimizes traditional supply chain elements along with the nutritional requirements of its recipients' tools to assist decision-makers. The application of the deployed model resulted in a lower nutrient gap and an overall reduction in cost [9]. In another study, a mathematical optimization model was proposed where the food collection for the food bank was maximized based on the dietary guidelines of the food bank recipients, subjected to transportation and warehouse capacity constraints [10]. In a study based on the Foodbanks of Madrid, the objective is to identify the optimal weekly choices that fulfill the macro-nutritional needs of the recipients of this social service, while minimizing the overall cost, taking into account contributions from third parties [11]. Researchers in Mexico proposed an optimization model for resource allocation that simultaneously accounts for inventory management, product-beneficiary compatibilities, balanced nutrition, and priority of beneficiaries [12]. Another recent article proposes a multi-objective mathematical programming model and a fuzzy counterpart for designing a food bank network to optimize cost, food freshness, and nutritional value. Applying the model in a case study leads to a supply network featuring reduced costs, a smaller fleet size, and improved food quality, albeit with a minor decrease in freshness compared to the benchmark network [13]. Alkaabneh, et al. [14] proposed a framework measuring efficiency and effectiveness, with nutritional value determining effectiveness and equity implicitly considered as a performance measure. However, none of the recent literature takes HER guidelines into account for nutrition in hunger relief supply chain. This study aims to minimize inequity in food bank supply chains with the help of HER guidelines.

4. Methodology and Results

4.1 Data Processing

We started by analyzing the data from FBCENC for the fiscal year 2021-2022 and ranking against the Healthy Eating Research (HER) Guideline. This Guideline employs a system categorizing individual food items into three tiers (green for "choose often," yellow for "choose sometimes," and red for "choose rarely"). Emphasizing key nutrients such as saturated fat, sodium, and added sugar, the guidelines organize foods into 11 categories with specific nutrient thresholds[7]. An example is given below.

Table 1: Nutrition content comparison of Pinto Beans vs Canned Pinto Beans

Product	Category	Content	Amount per Serving	Rank	Final Rank
Pinto Beans	Fruits and Vegetables	Saturated Fat	0.2g	Green	Green
		Sodium	1.7mg	Green	
		Added Sugar	0.6g	Green	
Canned Pinto Beans	Fruits and Vegetables	Saturated Fat	0.5g	Green	Yellow ☆
		Sodium	420mg	Yellow☆	
		Added Sugar	2g	Green	

In this table, we show two examples of pinto beans, one is canned, and the other is not. The canned pinto beans have a higher sodium content, so they have a longer shelf life. However, the higher sodium content puts the threshold for sodium into the yellow or "choose sometimes" tier. As a result, even if the saturated fat and added sugar values are in the green or "choose often" tier, the whole ranking of canned beans falls into the yellow tier.

Not all food types can be ranked according to the guidelines. It puts baby food items and condiments in a separate "unranked" tier. Food items that do not have any information available to rank properly are put in the "assorted" tier.

4.2 Data Explorations and Observations

After ranking the distributed food in FY 2021-2022 against HER guidelines, we explore the current distribution in each county served by FBCENC. For ease of visualization, we group green and yellow-tiered food together. We can see from the data that Johnston County receives a little more green and yellow food (Figure 1(a)). However, Wake County receives more red food than Johnston County (Figure 1(b)). These two counties receive the highest amount of food among FBCENC counties.

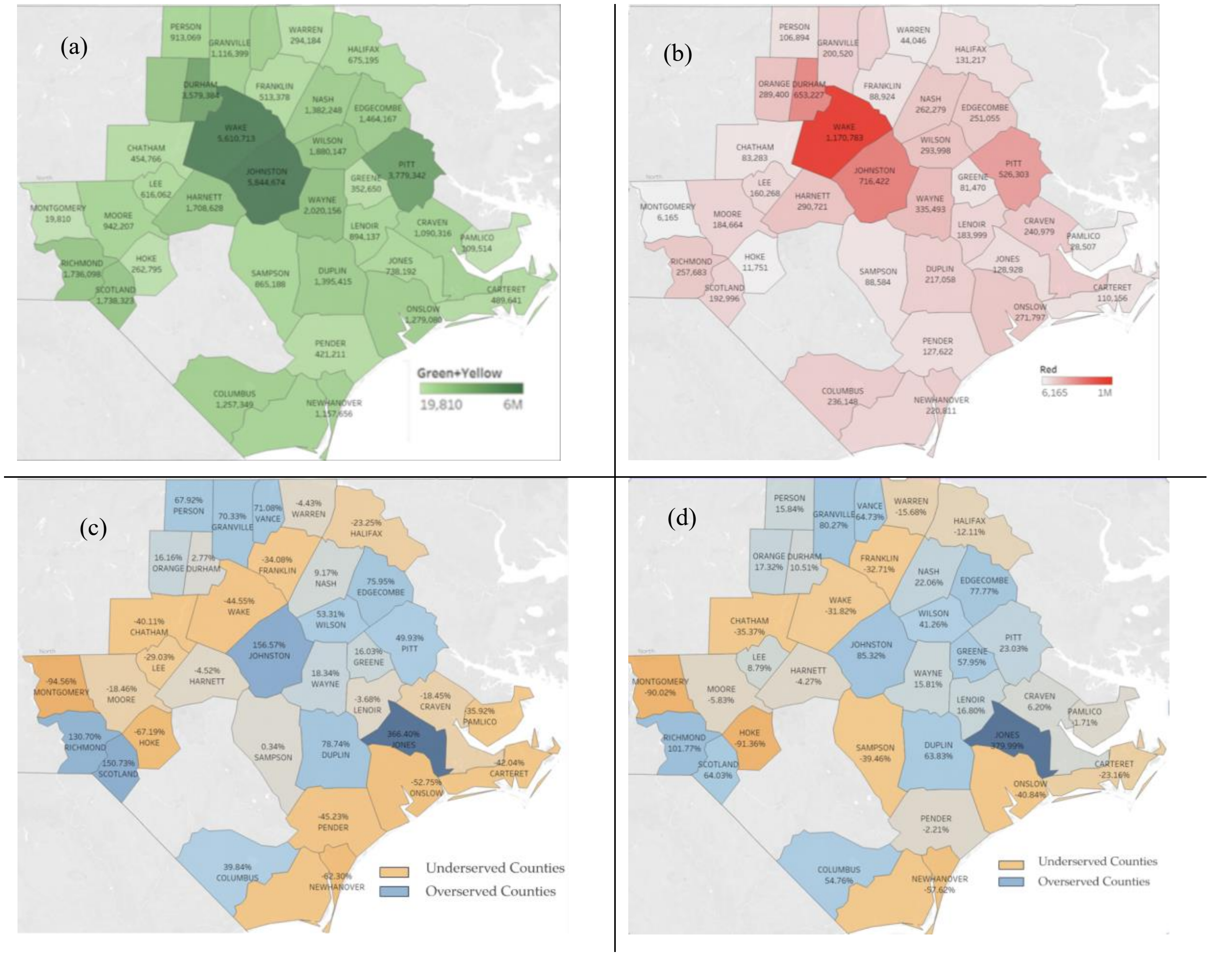

Figure 1: The total pounds of (a) green and yellow food distributed, (b) red food distributed; (c) underserved and overserved counties for green and yellow foods, and (d) underserved and overserved counties for red foods.

When analyzing food insecurity in Wake and Johnston counties, Wake County houses 104,210 food-insecure individuals, compared to Johnston County's 23,460 [15]. Wake County's food-insecure population is four times that of Johnston County. This leads to Wake County receiving approximately 44.55% less than its fair share of green and yellow food (calculated by the total amount of food distributed that year taking the food insecure population into account), while Johnston County receives 156.57% more (Figure 1(c)). Similarly, in red food distribution, Wake County receives more pounds (Figure 1(b) but less than its fair share (Figure 1(d)). Overall, the current distribution strategy fails to achieve equitable distribution.

4.3 Model Formulation

Foodbanks reach the food insecure population through agencies, which receive the food from foodbanks and distribute it among the people in need. Some agencies can be served by multiple branches of a food bank. We consider a supply chain network of 2 branches and a few agencies. We assume that agencies can set their requirement for each nutrition type as a fraction of their capacity. Some agencies can be served by only one branch and others can be served by multiple ones. We define serving capacity as how much food an agency can serve to the food-insecure population. We also assume that agencies, and in case of unavailability of food of a certain nutrition type, agencies can sometimes take on more food of other nutritional requirements, until the total serving capacity of the agency is not met. The supply chain network in consideration has a set of branches (denoted by the set *J*), and a set of agencies (denoted by the set *I*). The set of nutrition tiers or types is denoted by the set *K*.

We formulate a linear programming model. The food that is available for distribution at each branch for each nutrition type (B_{jk}) is known beforehand. Each agency cannot take food more than its Serving Capacity (s_i) and has its nutrition requirements (N_{ik}), these parameters are also known a priori. Whether an agency is served by a branch is denoted by a_{ij}, 1 would indicate, that the agency receives food from that branch, and 0 indicates otherwise. For decision variables, x_{ijk} indicates pounds of product allocated to agency *i* of nutrition type *k* from branch *j*. The percentage of under-target pounds distributed of each nutrition tier or type is denoted by u_k, and the percentage of over-target pounds received of nutrition type *k* is denoted by o_k. Any excess food of nutrition type *k* at branch *j* is denoted by Z_{jk}.

The objective of this problem is to distribute the food equitably based on the nutritional preferences and serving capacity of the agencies and keep both the maximum fraction of over-target pounds and under-target pounds of food distributed to a minimum. The base model is run on the Gurobi solver using Python. Findings from the model are presented in section 4.4.

Objective function (Minimize the maximum overserved and the underserved fraction of serving capacity)

$$Min \sum_{k=1}^{K} u_k + \sum_{k=1}^{K} o_k \tag{1}$$

Material Flow Constraint

$$x_{ijk} \le B_{jk} * a_{ij}, \qquad \forall i \in I, \qquad j \in J, \qquad k \in K \tag{2}$$

Inventory Balance constraint

$$\sum_{i=1}^{I} x_{ijk} + Z_{jk} = B_{jk}, \qquad \forall j \in J, \qquad k \in K \tag{3}$$

Capacity Constraint

$$\sum_{K=1}^{K} \sum_{j=1}^{J} x_{ijk} \le s_i\,, \qquad \forall\, i \in I \tag{4}$$

Minimizing the fraction of underserved serving capacity

$$u_k * N_{ik} \ge \frac{N_{ik} * s_i - \sum_{j=1}^{J} x_{ijk}}{S_i}\;, \forall\, i \in I, \qquad k \in K \tag{5}$$

Minimizing the fraction of overserved serving capacity

$$o_k * N_{ik} \ge \frac{\sum_{j=1}^{J} x_{ijk} - N_{ik} * s_i}{s_i} \;\forall\, i \in I, \qquad k \in K \tag{6}$$

Non-negativity Constraints

$$x_{ijk}, u_k, o_k, Z_{jk} \ge 0 \qquad \forall i \in I, \qquad j \in J, \qquad k \in K \tag{7}$$

The objective function (1) minimizes the maximum underserved fraction and maximum overserved fraction for all nutrition types. Constraints (2) ensure that an agency receives food from a branch only if it is served by it. Constraints (3) ensure that the total food distributed by a branch of each food type adds up to the total food distributed to the agencies and the excess leftover at the branch for each nutrition type. Constraints (4) limit agency allocation within serving capacity. Constraints (5) and (6) calculate the maximum value of the overserved and underserved percentage of each nutrition type. The sign restrictions (7) ensure the non-negativity of the decision variables.

4.4 Model Results

We test our model for two scenarios using synthetic data and make a comparison of the results. The first case is where no nutritional preference is considered for any agencies. The second case is where we consider agencies having different fractions of nutritional requirements. We test our model by varying the total food available for distribution at the branches from -40% to 40% to observe the model behavior.

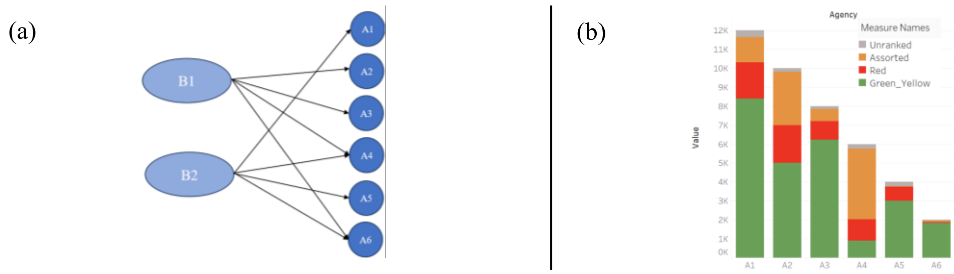

Figure 2: (a) The basic Supply Chain diagram. B1 and B2 represent the branches and A1 to A6 represent the agencies. (b) serving capacity of different agencies with different nutrition requirements.

From the model results, we learn that when there is no constraint on the nutrition type, equity is achieved across all agencies, i.e. all agencies receive the same fraction of food with respect to their total serving capacity (Figure 3(a)). However, when we take the nutrition type into account, the results change. If the branches overall have less food than the total serving capacity, equity is achieved across nutrition types i.e. all the agencies receive the same fraction of their desired nutrition type (Figure 3(d)). However, as different agencies have different nutrition requirements, when the total pounds of all foods are summed, the fraction of total serving capacity met varies across agencies (Figure 3(b)).

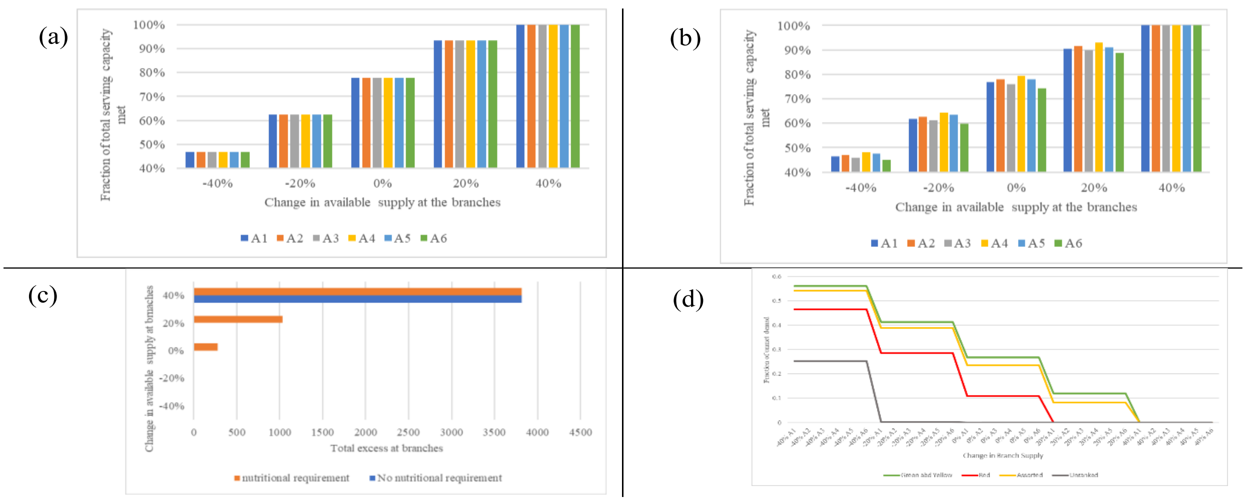

Figure 3: Fraction of total serving capacity met for (a) no nutritional requirement, (b) nutritional requirement. (c) shows the impact of excess capacity at branches for the case with different nutritional requirements for agencies vs no nutritional requirement (d) shows equitable unmet demand fractions for all nutritional needs from all agencies.

Next, we compare the total amount of pounds of undistributed food at the branches. When there is no nutritional requirement, the overall excess food at branches is lower in a few cases than when the nutrition requirement is set by the agencies. This is particularly true if there is a shortage of one food of one nutrition tier and an excess of another. This is intuitive behavior since agencies have certain requirements for certain types of food. As a result, they cannot take more than what they set their requirement for, even if they have an overall unmet serving capacity left (Figure 3(c)). In cases where branches do not have enough capacity to fulfill any nutritional requirement or they can meet all the nutritional requirements (Figure 3(c)), there is no difference in total excess in branches. Another observation is, that this model does not overserve the agencies for any nutrition type, since the primary objective of the model is to not reduce excess but rather achieve equity, which is achieved at the expense of not having effective distribution at the branches.

5. Conclusion

Food insecurity is tied to inadequate fresh food access and barriers to nutrition, exacerbating health and social challenges in communities. We propose a deterministic linear programming model to reduce inequity in terms of nutrition in the existing food bank supply chain. The model reduces inequity in the supply chain across all the nutrition types. The study can encourage food banks to adopt a more nutrition-focused approach in their distribution. However, the model has some limitations. It achieves equity, but it comes at the expense of a little less effective distribution in the supply chain. In the future, we want to extend this model to incorporate effectiveness and efficiency for a more balanced approach. We also aim to incorporate uncertainty that exists in the foodbank supply chain.

Acknowledgments

This project is supported by the NSF grant Excellence in Research: Human Centered Visual Analytics for Evidence Based Decision Making in Hunger Relief (Award No: 2100855). Special thanks to FBCENC for sharing data and information for this project.

References

[1] BMC Medicine, "Food insecurity: a neglected public health issue requiring multisectoral action," *BMC Medicine*, vol. 21, no. 1, p. 130, Apr. 2023, doi: 10.1186/s12916-023-02845-3.

[2] M. P. Rabbitt, "Household Food Security in the United States in 2022," 2022.

[3] B. N. Lauren *et al.*, "Predictors of households at risk for food insecurity in the United States during the COVID-19 pandemic," *Public Health Nutr*, pp. 1–8, 2021, doi: 10.1017/S1368980021000355.

[4] C. Thompson, D. Smith, and S. Cummins, "Understanding the health and wellbeing challenges of the food banking system: A qualitative study of food bank users, providers and referrers in London," *Social Science & Medicine*, vol. 211, pp. 95–101, Aug. 2018, doi: 10.1016/j.socscimed.2018.05.030.

[5] Feeding America, "Hunger in America | Feeding America." Accessed: Jan. 26, 2023. [Online]. Available: https://www.feedingamerica.org/hunger-in-america

[6] L. Oldroyd, F. Eskandari, C. Pratt, and A. A. Lake, "The nutritional quality of food parcels provided by food banks and the effectiveness of food banks at reducing food insecurity in developed countries: a mixed-method systematic review," *J Human Nutrition Diet*, p. jhn.12994, Mar. 2022, doi: 10.1111/jhn.12994.

[7] "Healthy Eating Research Nutrition Guidelines for the Charitable Food System," Healthy Eating Research. Accessed: Nov. 17, 2022. [Online]. Available: https://healthyeatingresearch.org/research/healthy-eating-research-nutrition-guidelines-for-the-charitable-food-system/

[8] D. Efrati Philip, G. Baransi, D. R. Shahar, and A. M. Troen, "Food-Aid Quality Correlates Positively With Diet Quality of Food Pantry Users in the Leket Israel Food Bank Collaborative," *Frontiers in Nutrition*, vol. 5, 2018, Accessed: Jan. 31, 2024. [Online]. Available: https://www.frontiersin.org/articles/10.3389/fnut.2018.00123

[9] K. Peters *et al.*, "The Nutritious Supply Chain: Optimizing Humanitarian Food Assistance," *INFORMS Journal on Optimization*, vol. 3, no. 2, pp. 200–226, Jan. 2021, doi: 10.1287/ijoo.2019.0047.

[10] A. Gharehyakheh and N. Sadeghiamirshahidi, "A SUSTAINABLE APPROACH IN FOOD BANK LOGISTICS," 2018.

[11] R. Castañón, Fco. A. Campos, S. Doménech Martínez, and J. Villar, "The Food Bank of Madrid: A Linear Model for Optimal Nutrition," *IJERPH*, vol. 17, no. 21, p. 8097, Nov. 2020, doi: 10.3390/ijerph17218097.

[12] J. Á. Gómez-Pantoja, M. A. Salazar-Aguilar, and J. L. González-Velarde, "The food bank resource allocation problem," *TOP*, vol. 29, no. 1, pp. 266–286, Apr. 2021, doi: 10.1007/s11750-020-00581-y.

[13] J. Ghahremani-Nahr, A. Ghaderi, and R. Kian, "A food bank network design examining food nutritional value and freshness: A multi objective robust fuzzy model," *Expert Systems with Applications*, vol. 215, p. 119272, Apr. 2023, doi: 10.1016/j.eswa.2022.119272.

[14] F. Alkaabneh, A. Diabat, and H. O. Gao, "A unified framework for efficient, effective, and fair resource allocation by food banks using an Approximate Dynamic Programming approach," *Omega*, vol. 100, p. 102300, Apr. 2021, doi: 10.1016/j.omega.2020.102300.

[15] "Overall (all ages) Hunger & Poverty in the United States | Map the Meal Gap." Accessed: Feb. 10, 2024. [Online]. Available: https://map.feedingamerica.org