

Food Bank Responsiveness During Disasters

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Abstract

The unpredictable nature of disasters (caused by natural phenomena or human activity) often leads to supply chain disruptions. In the aftermath of a disaster, disruptions in food supply specifically affect the role of food banks. The increase in number of food insecure people during and after a disaster causes a surge in demand to food banks in the affected areas. Prepositioning relief items to mitigate the effect of disasters has proven to be a viable approach to curb this problem. In this work, we incorporate this concept in building a resilient network system for a non-profit organization while accounting for the distribution of food items. The state of the network, such as road and facility availability post disaster is crucial in managing the flow within the network and estimates based on weather characteristics, operational policies, etc. are made beforehand to enhance preparations. Pop-up delivery options such as mobile pantries or self-accessible food lockers for both frozen and dry food items, are also considered in an attempt to strengthen the relief response. A mixed integer linear programming model is used to propose a robust network structure for the Food Bank of Central and Eastern North Carolina (FBCENC) using the events around hurricane Florence as a case study. Findings from this study can be applied to other food banks or organizations with similar network structure as well as various disaster types.

Keywords: Humanitarian logistics, Hunger relief, Disaster, Non-profit organization, Supply chain disruptions.

1. Introduction

Disasters caused by natural phenomena such as hurricanes, tornadoes and earthquakes have occurred on average 18 times per year in the United States over the last 5 years (2018-2022) [1]. In the aftermath of these events, people are often seen looking for water, food, health supplies, and shelter. Disaster response as it relates to food banks can be described as the process of planning, coordinating, and distributing food and other relief items to people in need effectively and efficiently after a disaster [2]. Humanitarian relief activities typically encompass the mitigation of food insecurity levels. Tirivangasi [3] postulates that there is a direct connection between disasters and food insecurity. It is believed that disasters induce poverty, which in turn leads to food insecurity and malnutrition. According to Zeuli and Nijhuis [4], an increase in food demand from pantries post disaster results in incremental burden on the food banks. However, both food pantries and food banks may not be adequately prepared or have the means to meet this surge. Additionally, the operational characteristics of the food bank especially its operation hours and reliance on volunteers can limit food accessibility at such times [5].

2. Problem description

Hurricane Florence made landfall in North Carolina in the early hours of September 14, 2018: the storm progressed with heavy rainfall leaving record breaking flood levels in its wake [6]. The aftermath of this storm left the Food bank of Central and Eastern North Carolina (FBCENC) catering for an increased number of food insecure people. Hurricane Florence affected 22 out of 34 counties served by FBCENC. Some partner agencies who work with the food bank in distributing food items became inoperable, and the road infrastructure was also flooded and hence unavailable. This caused a disruption in the network and impaired the efforts of the food bank. These challenges inspired this work where we aim to build a resilient network structure for food banks to enhance emergency preparedness and response. This work aims to answer the following research questions:

1. In what ways can nonprofit food distribution systems effectively respond to surges in demand due to a disaster?

2. What impact do uncertainties caused by disasters have on food availability/food insecurity?
3. To what extent does prepositioning supplies and/or pop-up facilities (mobile pantries and food lockers) affect food insecurity levels post disaster?
4. How well does prepositioning and/or pop-up facilities encourage the distribution of fresh, healthy, and nutritious meals to food insecure people after a disaster?

3. Related Research

Recently, more attention has been drawn towards food insecurity levels in the aftermath of a disaster. Fitzpatrick, et al. [7] conducted a study that shows how social vulnerabilities, circumstantial risks, and social/physiological factors significantly determine the probability of food insecurity occurrence after a disaster. Nevertheless, factors such as organization and coordination, process and resource management tend to impair these efforts [8]. Limitations on food access during a crisis has been especially re-emphasized in recent years due to the coronavirus pandemic. One way of improving preparedness for natural disasters is through prepositioning emergency relief items [9]. In assessing the effect of supply prepositioning on food banks, Marthak, et al. [2] creates scenarios that vary the number of food banks open/closed in a region after a disaster using a stochastic programming model. Results show a significant reduction in unmet demand. Despite prepositioning being vital, organization of resources to be prepositioned is also as important. Davis, et al. [10] shows this in the coordination of supplies in response to a disaster using key information to make decisions.

Asides prepositioning food items, mobile pantries can be used to enhance food distribution activities post disaster. These are normally employed as a means of eliminating location as an impediment to food access [11]. It can also be inferred that this novel food distribution system enhances fast and flexible distribution of fresh produce such as meat, pastries and dairy. Stauffer, et al. [12] compared the effects of the use of mobile pantries for the food banks and agencies' food distribution. They concluded that the use of mobile pantries is an effective tactic in achieving elevated equity levels particularly when fresh food items are involved. Furthermore, an alternative option to enhance food delivery post disaster is the use of food lockers. Community fridges are quite significant in areas where conventional methods of food aid are difficult to access [13]. Interestingly, these fridges have seen substantial growth in recent years. The Freedgedatabase shows the existence of over 250 community fridges in the United States as of February 2023 [14]. These are always self-accessible and open to users and encourages people who are new to food insecurity perhaps due to a disaster to pick up food at their convenience [15].

4. Methodology

We develop a mixed integer linear programming model over two time periods (pre and post disaster) in creating a structure for the food bank that optimally reconfigures the network in a manner that keeps unmet demand at a minimum based on predictions around the state of the network. Asides the traditional method of using a neighboring agency to meet unmet demand from an affected agency, pop up options such as the use of mobile pantries and food lockers are provided to make our model more robust. The food lockers are sent to the demand zones before the disaster if there is an anticipated road closure while the mobile pantries are used after the disaster to serve demand zones whose roads are still accessible.

4.1 Model assumptions and notation

We consider a supply chain network consisting of the following nodes: demand zones (denoted by the set J), agencies (denoted by the set I), and food bank locations (denoted by the set H). The pounds of available supply (S_h^F) at each food bank $h \in H$ is known a priori. Similarly, the demand for food (in pounds) at each demand zone (D_j) is known a priori. Nodes in the network are fully connected and the distance in miles along with the maximum allowable food flow are specified between the food bank and agencies (d_{hi}^A, C_{hip}^A) and agencies and demand zones (d_{ij}^B, C_{ijp}^B). It should be noted that arc capacities (C_{hip}^A, C_{hip}^B) are specified for both pre-and post-disaster periods p to reflect potential damage to the transportation network caused by the disaster. To mitigate the negative effects of a disaster, pop-up options are readily available at the supply nodes in terms of mobile pantries and lockers. A locker, if activated (binary variable w_j^L), holds a fixed amount of food (K^L) and is physically located at demand zone j which is d_{hj}^L miles from the food bank. The amount of food sent to the locker (variable x_{hjp}^L) in the pre-disaster stage comes directly from the food bank. The lockers are used to preposition food items pre-disaster while considering the arc capacities (C_{hjp}^L) for the lockers in period p .

Similarly in the post disaster stage, the food bank can directly send food (in pounds) to demand zone j (variable x_{hjp}^B) which is d_{hj}^B miles away using a mobile pantry. The mobile pantry, if activated (binary variable w_{hj}^B) holds a fixed amount of food (K_j^{MP}) and is placed on available trucks (T_h) at each food bank $h \in H$. Each truck holding a fixed amount of food (K^T assuming that all trucks are homogeneous) is then sent to each demand zone $j \in J$ using the specified network connection (d_{hj}^B, C_{hjp}^B). Facility vulnerability predictions on open/closed agencies (o_i^A) and food bank locations (o_h^F) based on the characteristics of the disaster are external inputs to the model. These predictions inform supply allocations within the network. For instance, a food bank can only send food (variable x_{hip}^A in pounds) to an agency if the agency is open (o_i^A). Similarly, an agency can only send food (in pounds) to demand zone j (variable y_{ijp}) if it is open (o_i^A) and assigned to demand zone j (binary variable w_{ij}^A). There is a fixed shipping cost per mile (F^M) for every pound of food sent within the network and an additional fixed cost for activating a mobile pantry (F^B) or locker (F^L). Since food banks are non-profit organizations, these operational costs are constrained by the food bank's available budget (B). To augment our binary variables, a suitable large number (M) is used in some of our constraints.

The objective is to determine a network configuration that minimizes the total unmet demand (u_j) in the food bank network given disruptions caused by the disaster and available options. We assume there is adequate exchange of information and cooperation within the food bank network to facilitate this.

4.2 Model formulation

We first develop a deterministic version of the model to enhance our understanding of the base model before adding complexities such as randomness. The Food bank of Central and Eastern North Carolina (FBCENC) has a large network which consists of over 800 partner agencies. As such, we start off with a reduced sample network structure that is representative of the larger network and can be expanded to fit large scale networks. Food banks are typically established in a bid to reduce the number of food insecure people. As a result, the objective function aims to minimize the number of food insecure people who remain hungry during or after a disaster. The proposed model incorporates demand, capacity, assignment, and cost constraints. The base model is run on AMPL software using the CPLEX solver. Findings from the base model are presented in section 5.

Objective function 1 (Unmet demand):

$$\min \sum_{j \in J} u_j \quad (1)$$

Subject to:

a) Demand constraint

$$\sum_{i \in I} \sum_{p \in P} y_{ijp} + \sum_{h \in H} \sum_{p \in P} x_{hjp}^B + \sum_{h \in H} \sum_{p \in P} x_{hjp}^L + u_j = D_j \quad \forall j \in J \quad (2)$$

b) Facility specific supply constraints

$$\sum_{i \in I} \sum_{p \in P} x_{hip}^A + \sum_{j \in J} \sum_{p \in P} x_{hjp}^B + \sum_{j \in J} \sum_{p \in P} x_{hjp}^L \leq S_h^F o_h^F \quad \forall h \in H \quad (3)$$

$$\sum_{j \in J} K_j^{MP} w_{hj}^B \leq T_h K^T \quad \forall h \in H \quad (4)$$

c) Demand satisfaction constraint

$$\sum_{j \in J} y_{ijp} \leq \sum_{h \in H} x_{hip}^A \quad \forall i \in I, p \in P \quad (5)$$

$$y_{ijp} \leq M w_{ij}^A \quad \forall i \in I, j \in J, p \in P \quad (6)$$

$$x_{hjp}^B \leq K_j^{MP} w_{hj}^B \quad \forall h \in H, j \in J, p \in P \quad (7)$$

$$x_{hjp}^L \leq K^L w_{hj}^L \quad \forall h \in H, j \in J, p \in P \quad (8)$$

d) Arc availability constraints

$$x_{hip}^A \leq C_{hip}^A M \quad \forall h \in H, i \in I, p \in P \quad (9)$$

$$y_{ijp} \leq C_{ijp}^B M \quad \forall i \in I, j \in J, p \in P \quad (10)$$

$$x_{hjp}^L \leq C_{hjp}^L M \quad \forall h \in H, j \in J, p \in P \quad (11)$$

$$x_{hjp}^B \leq C_{hjp}^B M \quad \forall h \in H, j \in J, p \in P \quad (12)$$

e) Demand allocation constraints

$$\sum_{i \in I} w_{ij}^A + \sum_{h \in H} w_{hj}^B + w_j^L = 1 \quad \forall j \in J \quad (13)$$

$$w_{ij}^A \leq o_i^A \quad \forall i \in I, j \in J \quad (14)$$

f) Cost constraint

$$\begin{aligned} & \sum_{h \in H} \sum_{i \in I} \sum_{p \in P} F^M d_{hi}^A x_{hip}^A + \sum_{i \in I} \sum_{j \in J} \sum_{p \in P} F^M d_{ij}^B y_{ijp}^B + \left(\sum_{h \in H} \sum_{j \in J} \sum_{p \in P} F^M d_{hj}^B x_{hjp}^B + F^B \sum_{h \in H} \sum_{j \in J} w_{hj}^B \right) \\ & + \left(\sum_{h \in H} \sum_{j \in J} \sum_{p \in P} F^M d_{hj}^L x_{hjp}^L + F^L \sum_{j \in J} w_j^L \right) \leq B \end{aligned} \quad (15)$$

g) Sign restrictions

$$x_{hip}^A, x_{hjp}^B, x_{hjp}^L, y_{ijp}^B, u_j \geq 0 \quad \forall h \in H, i \in I, j \in J, p \in P \quad (16)$$

$$w_{ij}^A, w_{hj}^B, w_j^L \in \{0,1\} \quad \forall i \in I, h \in H, j \in J \quad (17)$$

The objective function (1) minimizes the unmet demand at all demand zones. Constraints (2) will ensure that we meet as much demand as possible using the available options. Constraints (3) and (5) control the supply capacity and ensure that only available supplies are used to meet demand. The number of mobile pantries placed on a truck is restricted by constraints (4). Constraints (6) – (8) stop the model from satisfying demand from an agency, mobile pantry or locker that is unavailable. Constraints (9) - (12) eliminate the use of inoperable roads for food distribution. Constraints (13) ensures that only one option is used to satisfy demand in each zone while (14) allocates distribution to only agencies that are open. Total operational costs are confined to the available resources by constraints (15). Constraints (16) and (17) are the non-negativity and binary restrictions on the decision variables.

5. Results

The mathematical model is tested using synthetic data and agency vulnerability predictions. The sample network structure consists of 2 food banks, 4 agencies and 6 demand zones (Figure 2a). Each agency is assigned to serve specific demand zones. Our testing scenario is based on the closure of agency 2 which serves demand zones 2 and 3, and an inoperable link between agency 4 and demand zone 6 after the disaster. This disruption leaves demand zones 2, 3 and 6 unserved and are classified as unmet demand. The affected demand zones constitute 50% of the demand in the network. This scenario was specified in the model and the results show significant network reconfiguration to account for the disruption.

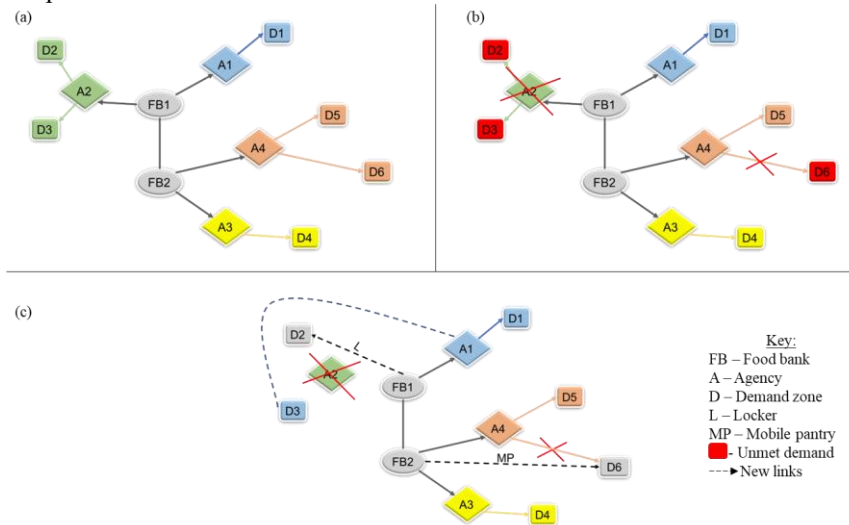


Figure 2: Figure showing sample network structure (a) and predictions around facility vulnerabilities (b) as well as the network reconfiguration suggested by the model (c).

The adjustments made to the network deploy a food locker to demand zone 2 in the pre-disaster stage while demand zone 3 is served by agency 1. A mobile pantry is used to serve demand zone 6 (Figure 2c) in the post disaster stage. Although all unmet demand zones were served, only 27.57% of demand at demand zone 6 was met while demand zones 2 and 3 were fully served at 100%. We observed that the base model follows a greedy algorithm and as a result given the budget constraint, demand zone 6 was not fully served as it had the farthest distance in the network configuration. Nevertheless, the results show a significant reduction in unmet demand by *approximately 76%* due to the interventions suggested by the model.

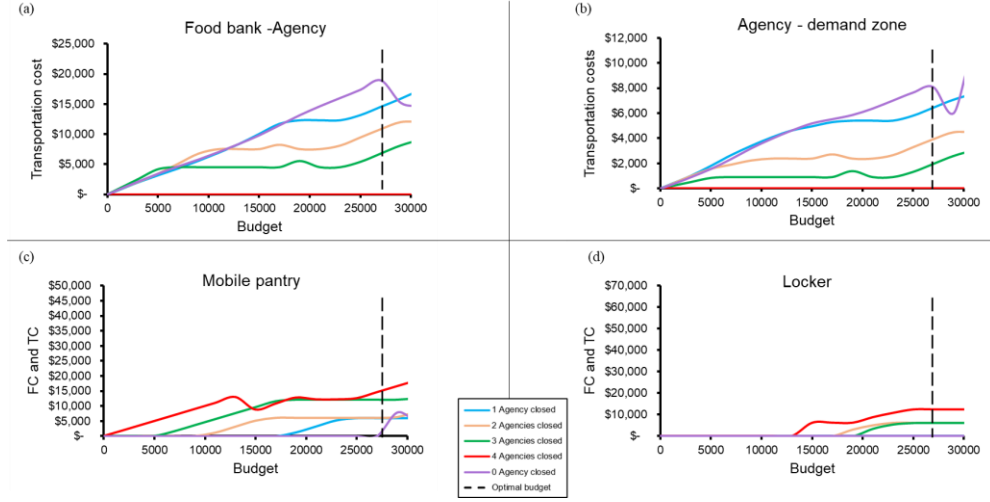


Figure 3: Cost trends in food bank and agency related costs (a) and (b) and pop-up options cost (c) and (d) showing a decline in food bank to agency activities and increase in the use of pop-up options as disruptions become severe.

Further analysis indicates that the budget for operational costs has a significant effect on percentage unmet demand. With a high budget, the unmet demand percentage reduces while a low budget incurs more unmet demand given a network disruption. However, when the network disruption is severe, food bank to agency related activities declines (measured as a function of cost) while that of the pop-up options increases (Figure 3). Our observations from the analysis suggest a negative correlation between food bank and agency related activities and the severity of the disruption to the network. As the network disruption increases, the movement of food to demand zones from the food bank through agencies decreases. On the other hand, there is a positive correlation between the use of pop-up options and the severity of the disruption to the network. As network disruption increases, the use of mobile pantries and lockers increases. This is because more agencies are closed, which necessitates the activation of additional pop-up options to meet the demand. In addition, given a disruption in the network and cost constraints, mobile pantries are seen to be activated earlier than food lockers. However, when the arc capacities are further considered, the lockers could be activated earlier depending on the scenario.

6. Conclusions

Disasters often cause supply chain disruptions which impedes the efforts of food banks to cater for the increased food insecure people due to a disaster. We propose a resilient network structure for food banks given these disruptions using a mixed integer linear programming model. Our model reallocates supplies through unaffected agencies to meet demand in affected zones with pop-up options readily available for support. Preliminary findings show that the model can adjust the network optimally to reduce unmet demand. With an increased overall network disruption, food bank through agency distribution is observed to gradually decrease as the pop-up options cover up for severe network disruption. While our base model is deterministic, we will extend this model to consider uncertainty in supply, demand, and network vulnerability. In addition, the greedy heuristic observed in our base model serves as a foundation for future extensions in solving this problem on large scale food bank networks.

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References

- [1] National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI). "U.S. Billion-Dollar Weather and Climate Disasters." <https://www.ncei.noaa.gov/access/billions/> (accessed February, 2023).
- [2] Y. V. Marthak, E. Pérez, and F. A. Méndez Mediavilla, "A stochastic programming model for tactical product prepositioning at domestic hunger relief organizations impacted by natural hazards," *Natural Hazards*, vol. 107, no. 3, pp. 2263-2291, 2021, doi: 10.1007/s11069-021-04639-3.
- [3] H. M. Tirivangasi, "Regional disaster risk management strategies for food security: Probing Southern African Development Community channels for influencing national policy," *Jamba*, vol. 10, no. 1, p. 468, 2018, doi: 10.4102/jamba.v10i1.468.
- [4] K. Zeuli and A. Nijhuis, "The resilience of America's Urban food systems - Evidence from five cities," 2017. Accessed: July 2022.
- [5] R. Loopstra, H. Lambie-Mumford, and J. Fledderjohann, "Food bank operational characteristics and rates of food bank use across Britain," *BMC Public Health*, vol. 19, no. 1, p. 561, May 14 2019, doi: 10.1186/s12889-019-6951-6.
- [6] National Weather Service. "Hurricane Florence: September 14, 2018." National Oceanic and Atmospheric Administration (NOAA). <https://www.weather.gov/ilm/HurricaneFlorence#:~:text=Hurricane%20Florence%2C%20a%20large%20a%20nd,morning%20of%20September%2014%2C%202018>. (accessed February, 2023).
- [7] K. M. Fitzpatrick, D. E. Willis, M. L. Spialek, and E. English, "Food Insecurity in the Post-Hurricane Harvey Setting: Risks and Resources in the Midst of Uncertainty," *Int J Environ Res Public Health*, vol. 17, no. 22, Nov 13 2020, doi: 10.3390/ijerph17228424.
- [8] S. Ainehvand, P. Raeissi, H. Ravaghi, and M. Maleki, "Natural disasters and challenges toward achieving food security response in Iran," *J Educ Health Promot*, vol. 8, p. 51, 2019, doi: 10.4103/jehp.jehp_256_18.
- [9] C. G. Rawls and M. A. Turnquist, "Pre-positioning of emergency supplies for disaster response," *Transportation Research Part B: Methodological*, vol. 44, no. 4, pp. 521-534, 2010, doi: 10.1016/j.trb.2009.08.003.
- [10] L. B. Davis, F. Samanlioglu, X. Qu, and S. Root, "Inventory planning and coordination in disaster relief efforts," *International Journal of Production Economics*, vol. 141, no. 2, pp. 561-573, 2013, doi: 10.1016/j.ijpe.2012.09.012.
- [11] D. T. Guion Peoples, "Mobile Food Pantries: A Marketing Opportunity," 2019.
- [12] J. M. Stauffer, M. Vanajakumari, S. Kumar, and T. Mangapora, "Achieving equitable food security: How can food bank mobile pantries fill this humanitarian need," *Production and Operations Management*, vol. 31, no. 4, pp. 1802-1821, 2022, doi: 10.1111/poms.13663.
- [13] K. Oung. "Community fridges are lifelines for the neighborhoods they serve." Vox Media LLC <https://www.vox.com/the-goods/22285863/community-fridges-neighborhoods-free-food> (accessed July 20th, 2022).
- [14] "What is freedge." <https://freedge.org/> (accessed February 15th, 2023).
- [15] C. Barrish. "Free, healthy food and some gourmet treats in Wilmington's community fridges." WHYY. <https://whyy.org/articles/free-healthy-food-and-some-gourmet-treats-in-wilmingtons-community-fridges/> (accessed July 20th, 2022).