Scheduling Food Bank Collections and Deliveries to Ensure Food Safety And Improve Access

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Agenda

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2. Research Methodology
3. Mathematical Formulation
4. Alteration on Constraints
5. Case Study
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Introduction

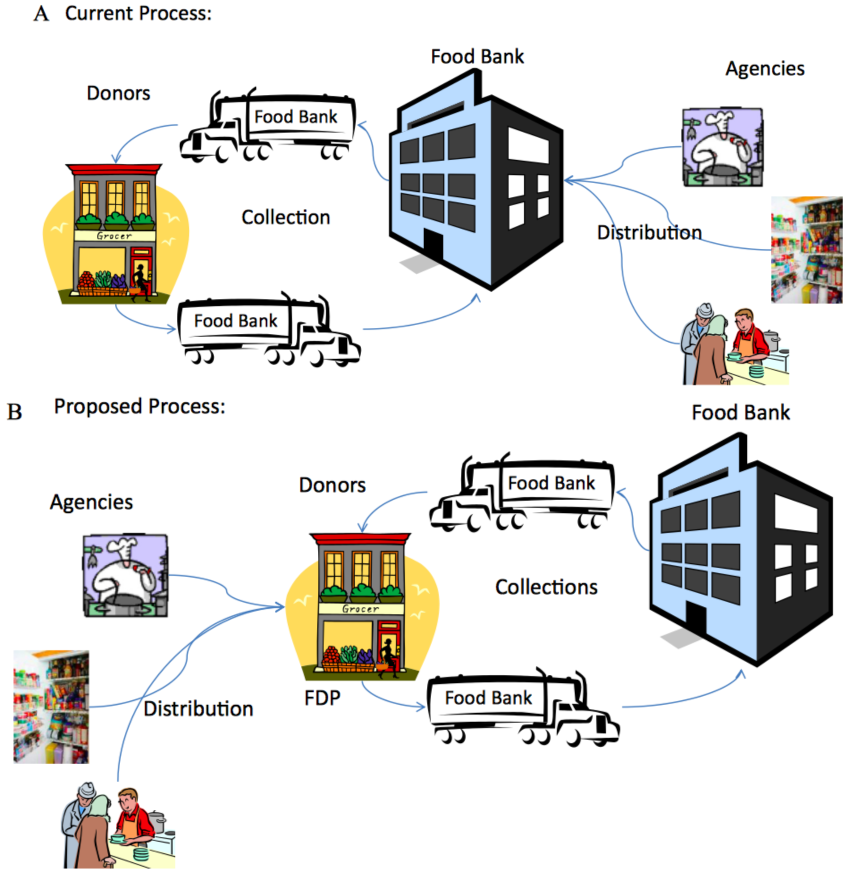
★ Food Banks are privately-owned non-profit organizations.

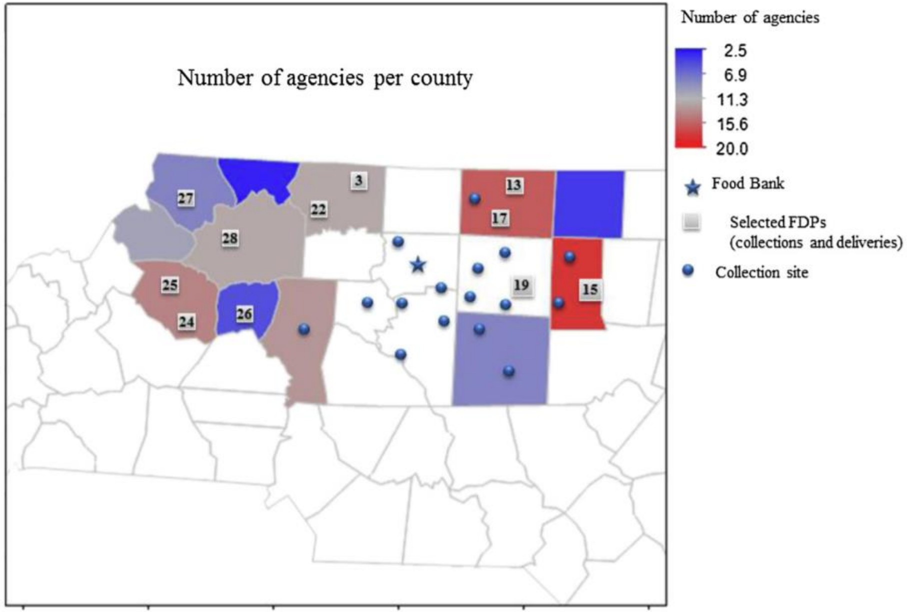
★ Distributes food to individuals at risk of hunger.

★ Local sources ensure vehicles for collection

★ Food Banks function as aggregators and distributors of donated food supply.

Introduction





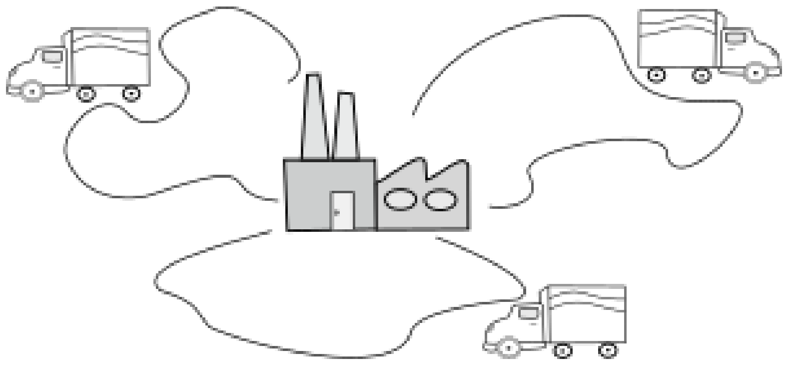
Research Methodology

Vehicle Routing

- Vehicle Routing Problem (VRP)
  - All customers require demand,
  - Demands met by only one vehicle,
  - Vehicles start and end their routes,
  - Vehicles have adequate capacity.

- Traveling Salesperson Problem (TSP)
  - Resource capacity is negligible.

- Vehicle Routing Problem with Backhauls (VRPB)
  - Two sets of customers,
  - Vehicles originate tours at the depot.
  - Demands are met by only one vehicle,
  - Linehaul customers have a priority against backhaul customers,
  - Resource capacity is negligible.



Research Methodology

Research Contribution

- The problem is most similar to VRPB.
    - Two distinct customer classes: whom food is collected (backhauls) and whom food is delivered (linehauls),
    - FDPs are delivery nodes,
    - Linehaul and backhaul customers are co-located,
    - Due to safety constraints, linehauls must occur before backhauls.

- Yildiz et. al
    - Using the constraints on pre-cooked and highly perishable food items.

Mathematical Formulation

Potential FDP Identification

-Agency Locations

-Collection Site Locations

Model 1: FDP Selection

-Candidacy Matrix

-Agency Demand

Model 2: Work - Week Vehicle

-Delivery and Pickup Schedule

-Vehicle Routing Schedule

Mathematical Formulation - Model 1

Index sets:

N, the set of collection sites $N = \{1, \ldots, n\}$.
M, the set of all charitable agencies $M = \{1, \ldots, m\}$.

Decision variables:

$a_{mi} \in \{0, 1\}$, where 1 indicates agency $m \in M$ is assigned to site $i \in N$.
$f_i \in \{0, 1\}$, where 1 indicates site $i \in N$ is selected as an FDP.

Parameters:

q_m, delivery quantity
t_{mi}, travel time to site i for agency m.
$\gamma_{mi} \in \{0, 1\}$, where 1 indicates $t_{mi} \leq T_{\max}$
K, delivery capacity of the truck.

Mathematical Formulation - Model 1

$$\min \sum_{i \in N} f_i$$

Subject to

$$\sum_{i \in N} \gamma_{mi} a_{mi} = 1 \quad \forall m \in M$$

$$\sum_{m \in M} q_m \gamma_{mi} a_{mi} \leq K f_i \quad \forall i \in N$$

$$a_{mi} \in \{0, 1\} \quad \forall m \in M, \quad i \in N$$

$$f_i \in \{0, 1\} \quad \forall i \in N$$

Phase 1 results: agency allocation and FDP selection

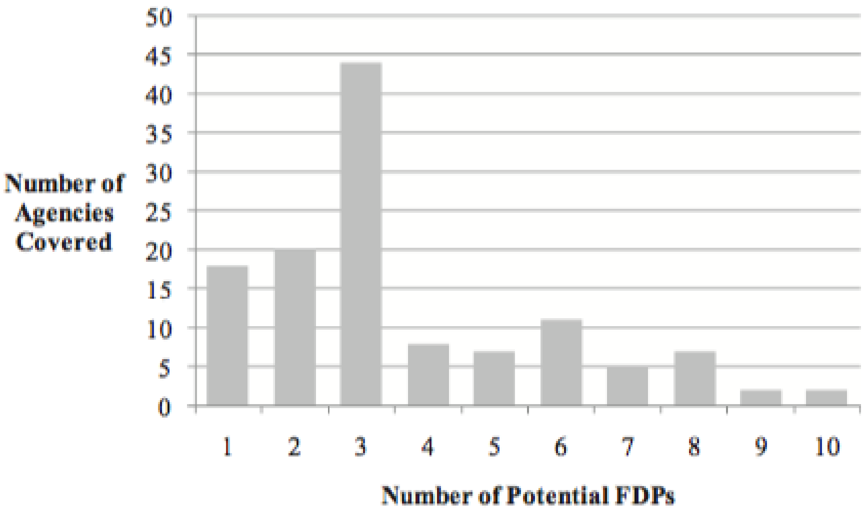


Fig. 4. Distribution of covering matrix.

Table 4
Selected FDP sites.

Site #	Poundage distributed (weekly)	# of assigned agencies
3	5354	3
13	5884	1
15	7466	19
17	8741	9
19	7981	18
22	8562	17
24	9297	11
25	8599	5
26	9985	19
27	9955	13
28	9630	9
Grand total	91,453	124

Alteration on Constraints

- New constraint can be added to Model 1:

$$\sum_{m} a_{mi} \geq 3 \qquad\qquad for\ \forall i$$

- Food types are not suit some travel distances
  - T_{max} can be increased
  - Ex: Frozen meats spoil in 50 minutes

Mathematical Formulation - Model 2

Index sets:

N, the set of collection sites $N = \{1, \dots, n\}$ with the depot denoted as $N_0 = \{0\}$.
N_{fdp}, the set of all collection sites that also serve as food delivery points. $N_{\text{fdp}} \subset N$.
P, the set of operator workdays; $p = \{1, \dots, P_{\max}\}$.

Decision variables:

$x_{ijp} \in \{0, 1\}$, where 1 indicates vehicle travel on day $p \in P$ between sites i and j where $i, j \in N \cup N_0$.
$y_{ip} \in \{0, 1\}$, where 1 indicates site $i \in N$ is scheduled for collections on day $p \in P$.
$z_{ip} \in \{0, 1\}$, where 1 indicates site $i \in N_{\text{fdp}}$ is scheduled for delivery on day $p \in P$
u_{ip}, accumulated departure time on day $p \in P$ given site $i \in N \cup N_0$ is visited.
s_{ip}, accumulated departure load on day $p \in P$ given site $i \in N \cup N_0$ is visited.

Mathematical Formulation - Model 2

Parameters:

W_{max}, maximum operating time per period per driver.
Q_i, amount collected at site $i \in N$.
β, the maximum number of consecutive periods a site can be visited for collections.
δ, the maximum number of FDP visits per period.
V, the number of vehicles available per period.
R_i, required number of collections at site $i \in N$ during the planning horizon.
d_{ij}, travel distance between sites i and j; $i, j \in N \cup N_0$.
t_{ij}, travel time (inclusive of collection time at site j) between sites i and j; $i, j \in N \cup N_0$.
T_j^D, service time allotted for agency pickup at FDP j; $j \in N_{fdp}$.
T^C, service time allotted for collection.
K, delivery capacity of the truck.

Mathematical Formulation - Model 2

$$\min Z = \sum_{p \in P} \left[\sum_{i \in N \cup N_0} \sum_{j \neq i} d_{ij} x_{ijp} \right]$$

Subject to

$$\sum_{j \in N - \{i\}} x_{ijp} = y_{ip} \quad \forall i \in N; \;\; p \in P$$

$$\sum_{j \in N - \{i\}} x_{jip} = y_{ip} \quad \forall i \in N; \;\; p \in P$$

$$\sum_{j \in N} x_{0jp} \leq V \quad \forall p \in P$$

Mathematical Formulation - Model 2

$$\sum_{p \in P} y_{ip} = R_i \quad \forall i \in N$$

$$\sum_{p=p'}^{\beta+p'} y_{ip} \leq \beta \quad \forall i \in N; \;\; p' \in \{1 \ldots P_{\max} - \beta\}$$

$$\sum_{j \in N_{\text{fdp}}} z_{jp} \leq \delta \quad \forall p \in P$$

$$\sum_{p \in P} z_{jp} = 1 \quad \forall j \in N_{\text{fdp}}$$

$$x_{0jp} \geq z_{jp} \quad \forall j \in N_{\text{fdp}}, \;\; p \in P$$

Mathematical Formulation - Model 2

$$u_{ip} - u_{jp} + W_{\max} x_{ijp} + (W_{\max} - t_{ij} - t_{ji}) x_{jip} \leq W_{\max} - t_{ij} \quad \forall i, j \in N, \ \ p \in P$$

$$u_{jp} \geq t_{0j} x_{0jp} + T_j^{\mathrm{D}} z_{jp} \quad \forall j \in N_{\mathrm{fdp}}, \ \ p \in P$$

$$u_{jp} \leq W_{\max} - (W_{\max} - t_{0j}) x_{0jp} + T_j^{\mathrm{D}} z_{jp} \quad \forall j \in N_{\mathrm{fdp}}, \ \ p \in P$$

$$u_{jp} \leq W_{\max} - \left(t_{j0} - T^{\mathrm{C}} \right) x_{j0p} \quad \forall j \in N, \ \ p \in P$$

$$s_{ip} - s_{jp} + K x_{ijp} + (K - Q_i - Q_j) x_{jip} \leq K - Q_i \quad \forall i, j \in N, \ \ p \in P$$

Mathematical Formulation - Model 2

$$s_{jp} \leq K - (K - Q_j)x_{0jp} \quad \forall j \in N, \;\; p \in P$$

$$s_{jp} \geq Q_j + \sum_{i \in N - \{j\}} Q_i x_{ijp} \quad \forall i \in N; \;\; p \in P$$

$$x_{iip} = 0 \quad \forall i, j \in N \cup N_0; \;\; i \neq j; \;\; p \in P$$

Mathematical Formulation - Model 2

$$x_{ijp} \in \{0, 1\} \quad \forall i \in N; \quad p \in P$$

$$y_{ip} \in \{0, 1\} \quad \forall i \in N; \quad p \in P$$

$$z_{ip} \in \{0, 1\} \quad \forall i \in N_{\mathrm{fdp}}; \quad p \in P$$

$$u_{ip} \geq 0 \quad \forall i \in N \cup N_0; \quad p \in P$$

$$s_{ip} \geq Q_i y_{i,p} \quad \forall i \in N \cup N_0; \quad p \in P$$

$$s_{ip} \leq K \quad \forall i \in N \cup N_0; \quad p \in P$$

Phase 2 results: collection and FDP delivery schedule

Total number of collection sites visited per tour (distance traveled) by operating window and weekday.

Operating window (h)	Weekday	T1	T2	T3	T4	T5	T6
12	Monday	6 (104)	10 (209)	3 (113)	9 (266)		
	Tuesday	10 (226)	9 (214)	5 (229)			
	Wednesday						
	Thursday	2 (84)	8 (140)	7 (209)			
	Friday	8 (201)	7 (263)				

Total number of tours per day by day of week.

Operating window (h)	Weekday					Total distance traveled (mi.)	Route efficiency (lbs/mi.)
	Monday	Tuesday	Wednesday	Thursday	Friday		
6	6	2	2	6	5	2841	36.63
7	4	4	2	2	6	2612	39.84
8	5	1	4	4	2	2399	43.37
9	3	3	1	2	4	2304	45.16
10	4	3	0	3	4	2302	45.20
11	3	3	1	2	4	2287	45.50
12	4	3	0	3	2	2258	46.08

Phase 2 results: collection and FDP delivery schedule

Table 6
Total number of collection sites visited per tour (distance traveled) by operating window and weekday.

Operating window (h)	Weekday	T1	T2	T3	T4	T5	T6	FDP visits per day
6	Monday	3 (131)[a]	4 (128)	5 (98)	4 (75)[a]	4 (138)[a]	4 (194)	3
	Tuesday	5 (131)	3 (181)[a]					1
	Wednesday	6 (134)	2 (185)[a]					1
	Thursday	2 (84)[a]	6 (104)	4 (124)[a]	6 (116)	4 (181)	2 (185)[a]	3
	Friday	6 (104)	4 (114)[a]	3 (113)[a]	3 (181)[a]	4 (140)		3
7	Monday	7 (115)	4 (114)[a]	5 (183)[a]	4 (204)[a]			3
	Tuesday	2 (84)[a]	6 (104)	6 (134)[a]	5 (142)			3
	Wednesday	3 (236)	4 (160)[a]					1
	Thursday	6 (164)	4 (75)[a]					1
	Friday	6 (104)	4 (132)[a]	6 (134)	3 (113)[a]	6 (185)	3 (229)[a]	3
8	Monday	3 (64)	7 (165)[a]	6 (116)	6 (187)[a]	5 (219)[a]		3
	Tuesday	7 (130)						0
	Wednesday	2 (23)	5 (147)[a]	5 (198)[a]	5 (229)[a]			3
	Thursday	2 (84)[a]	8 (183)	4 (194)[a]	6 (190)[a]			3
	Friday	5 (130)[a]	8 (140)[a]					2
9	Monday	8 (187)[a]	7 (176)[a]	6 (228)[a]				3
	Tuesday	4 (132)[a]	7 (118)[a]	7 (194)[a]				3
	Wednesday	6 (240)[a]						1
	Thursday	10 (173)	5 (229)[a]					1
	Friday	4 (114)[a]	10 (191)	3 (113)[a]	7 (209)[a]			3
10	Monday	4 (114)[a]	11 (195)	7 (209)[a]	5 (229)[a]			3
	Tuesday	2 (84)[a]	5 (156)[a]	7 (255)[a]				3
	Wednesday							0
	Thursday	9 (178)	6 (123)[a]	7 (263)[a]				2
	Friday	6 (104)	7 (137)[a]	3 (113)[a]	5 (142)[a]			3
11	Monday	9 (185)	6 (205)[a]	5 (229)[a]				2
	Tuesday	2 (84)[a]	11 (202)[a]	8 (259)[a]				3
	Wednesday	4 (114)[a]						1
	Thursday	8 (151)[a]	3 (95)[a]					2
	Friday	4 (132)[a]	12 (208)	7 (281)[a]	5 (142)[a]			3
12	Monday	6 (104)	10 (209)[a]	3 (113)[a]	9 (266)[a]			3
	Tuesday	10 (226)[a]	9 (214)[a]	5 (229)[a]				3
	Wednesday							0
	Thursday	2 (84)[a]	8 (140)[a]	7 (209)[a]				3
	Friday	8 (201)[a]	7 (263)[a]					2

[a] Denotes first stop in tour is an FDP visit.

Alteration on Constraints

Index Set

$v = \{1, \dots, V\}$ set of the all available trucks

Decision Variable

$V_{ijpk} \in \{0,1\}$, where 1 indicates vehicle is assigned from site i to j, in period p, by driver k.

Parameters

V_c ,Rent cost of one vehicle.

F, fuel cost per distance

Additional Constraints

$$min \sum_{p \in P} [\sum_{i \in N} \sum_{j \neq i} (d_{ij} V_{ijkp} F + V_c * V_{ijpk})]$$

$$\sum_{k \in v} \sum_{j \neq i} V_{ijkp} = y_{ip} \qquad for\ \forall i\ \forall p$$

$$\sum_{k \in v} \sum_{j \neq i} V_{jikp} = y_{ip} \qquad for\ \forall i\ \forall p$$

$$\sum_{i \in N} V_{ijkp} = \sum_{n \in N} V_{jnkp} \qquad for\ \forall j\ \forall k\ \forall p$$

Sensitivity Analysis

1. Policy robustness with respect to delivery durations
2. Policy robustness with respect to collection quantity (Table 2)
3. Policy robustness with respect to transportation resources (Table 3)

Total number of tours per day and total distance traveled by collection amounts.

Collection amounts, Q_i (lbs)	Weekday					Total distance traveled	Run time (s)
	Monday	Tuesday	Wednesday	Thursday	Friday		
1000	3	3	1	2	2	2354	10.53
1250	4	3	2	3	4	2379	15.40
1500	4	5	2	1	4	2388	522.87

Note: the optimality gap is 10%.

Table 2

Comparison of alternative distribution policies.

Operating window (h)	Number of trucks available			
	20 (base case)	5	4	3
6	2841 (6 trucks)	2950 (5 trucks)	No solution	No solution
7	2612 (6 trucks)	2662 (5 trucks)	2542 (4 trucks)	No solution
8	2399 (5 trucks)		2477 (4 trucks)	No solution
9	2304 (4 trucks)			2351 (3 trucks)
10	2302 (4 trucks)			2289 (3 trucks)
11	2287 (4 trucks)			2289 (3 trucks)
12	2258 (4 trucks)			2269 (3 trucks)

Table 3

Quantifying the benefits of FDPs: measuring equity

Ei = the effect of the location decision on a group i
FDP(m) = the pickup location for agency m

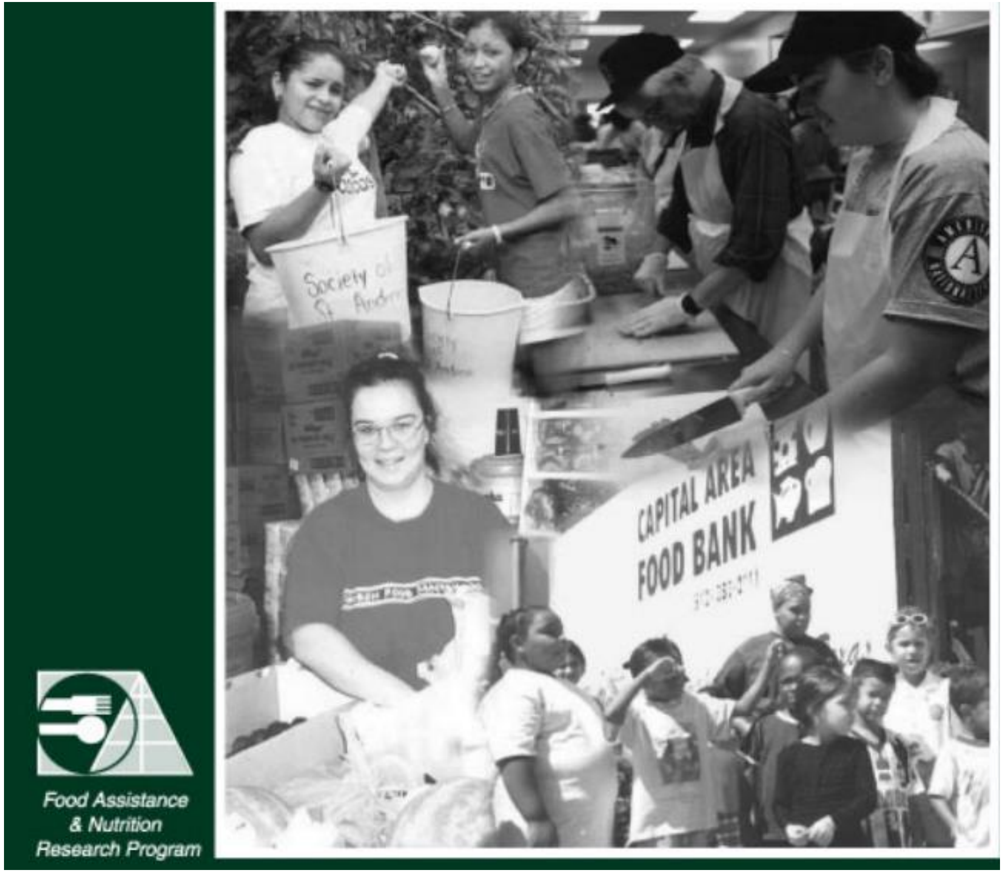
$$\max_i E_i - \min_j E_j$$

where

$$E_i = \sum_{m \in \{\text{Group}i\}} t_{m,\text{FDP}(m)}$$

Emergency Food Assistance System (EFAS)

- Emergency kitchens,
- Food pantries,
- Food banks,
- Food rescue organizations,
- Emergency food organizations



Similar Cases in Turkey

- ❖ Türkiye Yardım Sevenler Derneği (TYSD)
- ❖ Çorbada Tuzun Olsun
- ❖ Yardım eli

References

1. Brenda, et al. “The Emergency Food Assistance System - Findings From The Provider Survey, Volume Ii: Final Report, by Ohls, James; Saleem-Ismail, Fazana; Cohen, Rhoda; Cox, Brenda.” *Food Assistance and Nutrition Research Reports*, United States Department of Agriculture, Economic Research Service, 1 Jan. 1970, ideas.repec.org/p/ags/uersfa/33797.html
2. “Figure 2f from: Irimia R, Gottschling M (2016) Taxonomic Revision of Rochefortia Sw. (Ehretiaceae, Boraginales). Biodiversity Data Journal 4: e7720. Https://Doi.org/10.3897/BDJ.4.e7720.” doi:10.3897/bdj.4.e7720.figure2f.
3. Advanced vehicle routing algorithms for complex operations management problems Irimia R, Gottschling M (2016) Taxonomic Revision of Rochefortia Sw. (Ehretiaceae, Boraginales). Biodiversity Data Journal 4: e7720. Https://Doi.org/10.3897/BDJ.4.e7720.” doi:10.3897/bdj.4.e7720.figure2f.

Thanks for your attention

Any Questions?