Data-driven Approach for Optimizing Foodbank Operation

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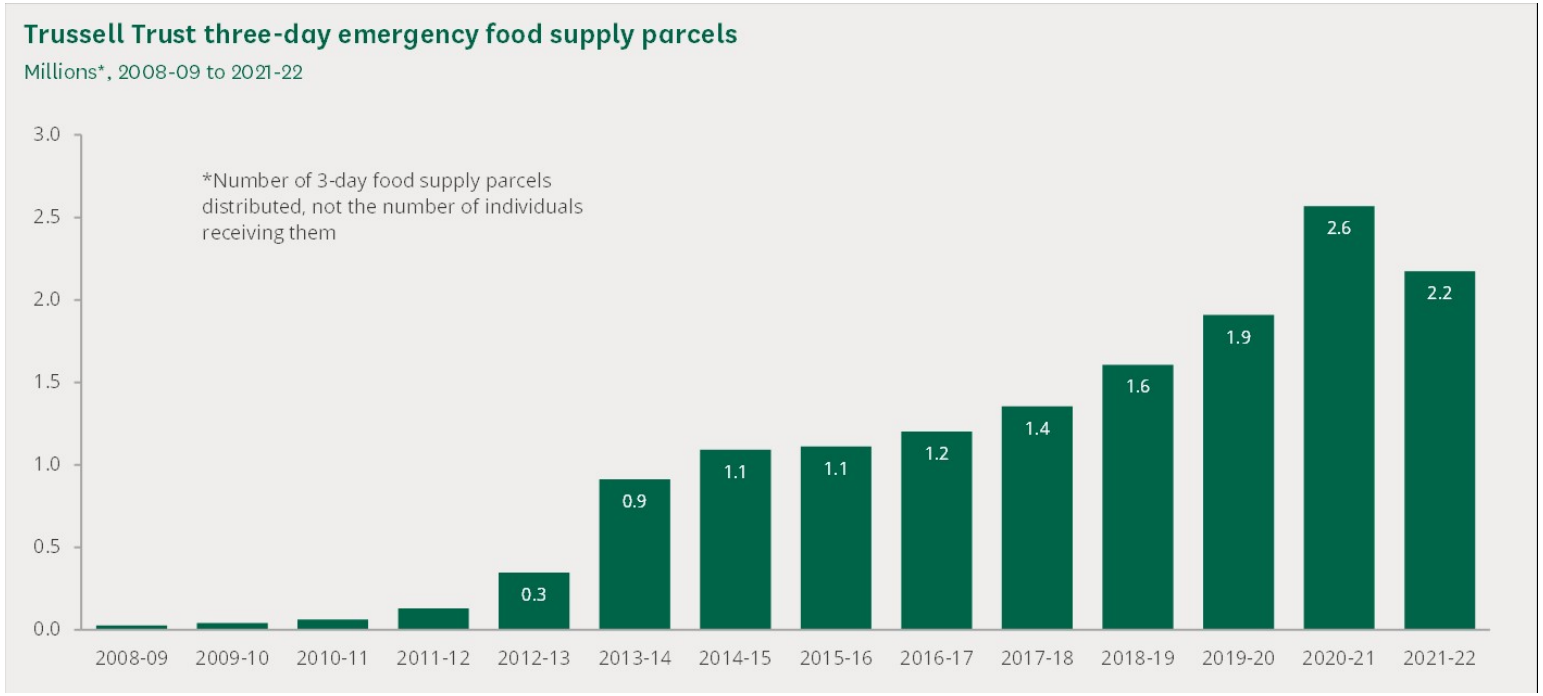
Food Bank Issues

“Increasing demand of Food Banks”

[Decade-long rise food bank use]



(UK-Parliament, 2022)

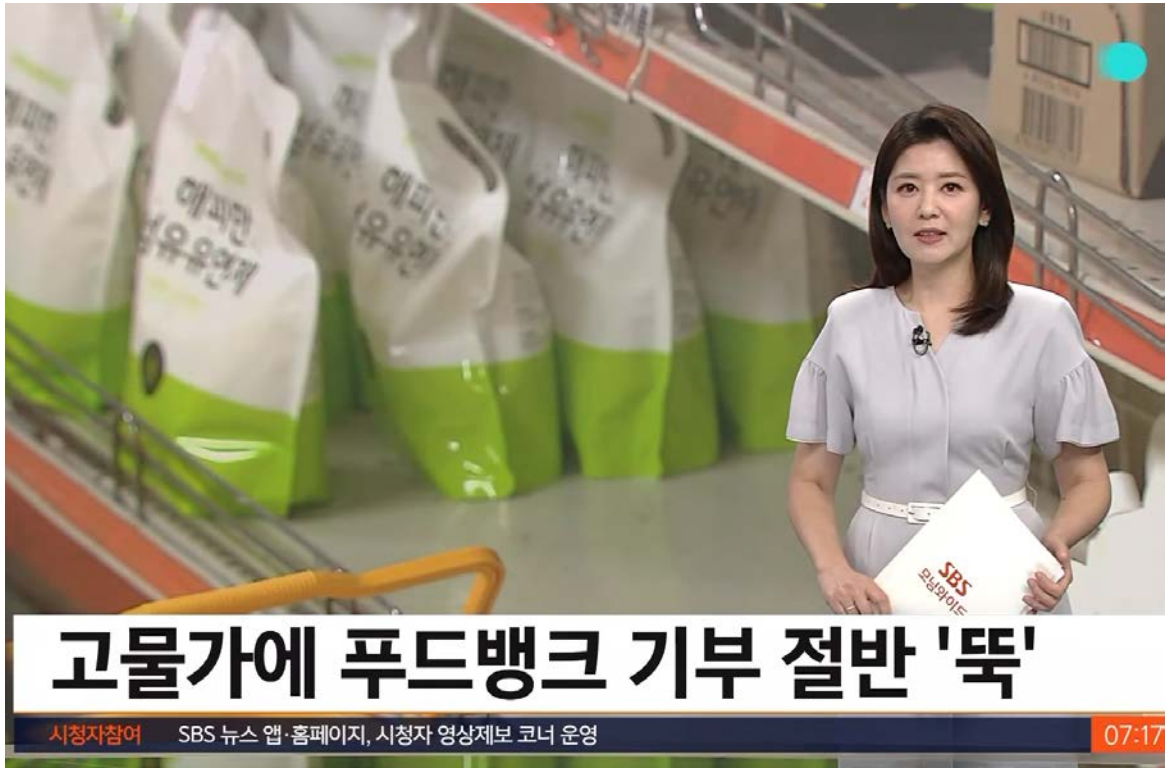
[Line up for food assistance]

(CNN, 2020)

Food Bank Issues

“Shortfall in Donations”

[Decreasing Number of Donations]



(SBS news, 2022)

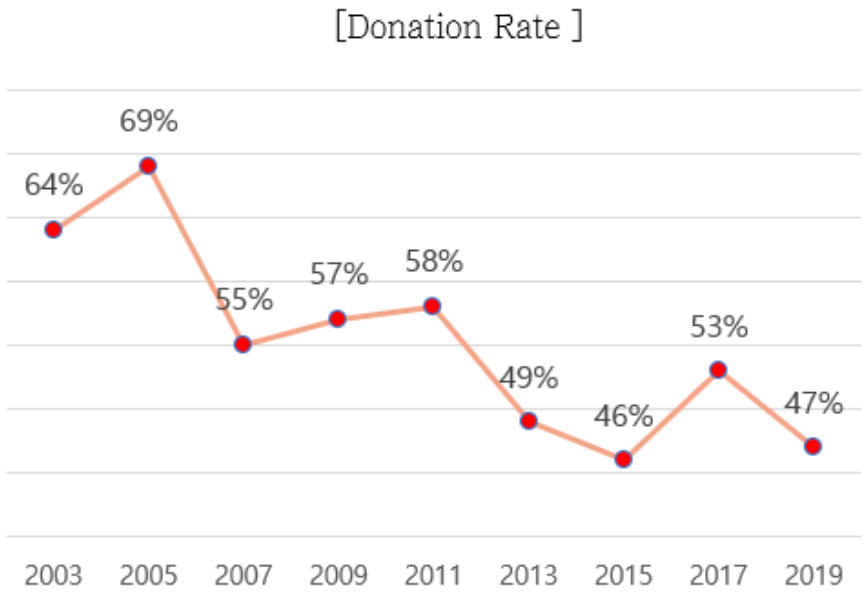
[Food Bank Inventory Shortage]

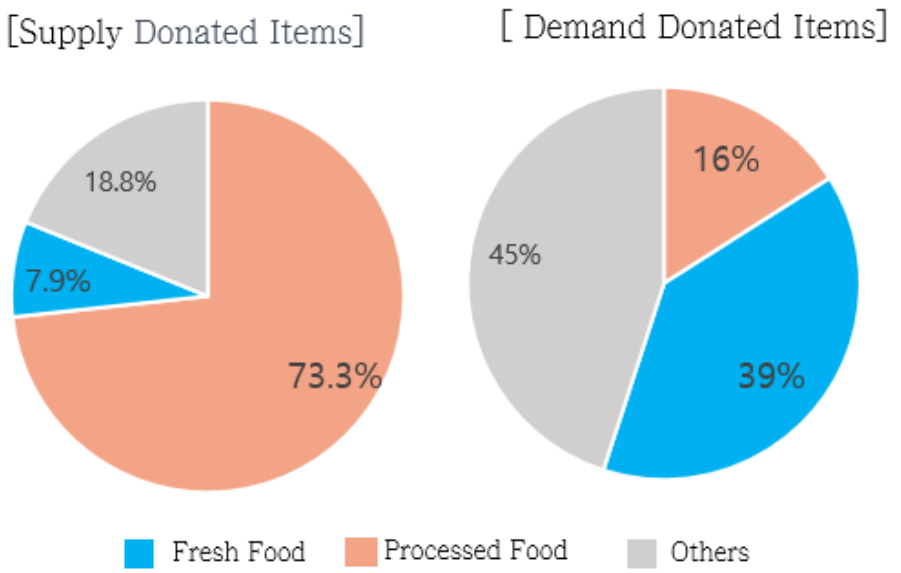
(WHAS11, 2022)

Challenges of Food Bank Operations

1) Perspectives on Demand and Supply

- **Shortages in Supply Due to Decreased Donations**
- **Inconsistencies Among Required and Offered Items**





Challenges of Food Bank Operations

2) Perspectives on logistics

- **Wide variety of donated item types**
- **Unstable supply**
- **Limited delivery capacity**

3) Perspective on Social Values

- **Diversity in Value**
- **Past: Minimizing Costs, Maximizing Beneficiary Benefit**
- **Present: Equity Among Beneficiaries**

Research Objectives

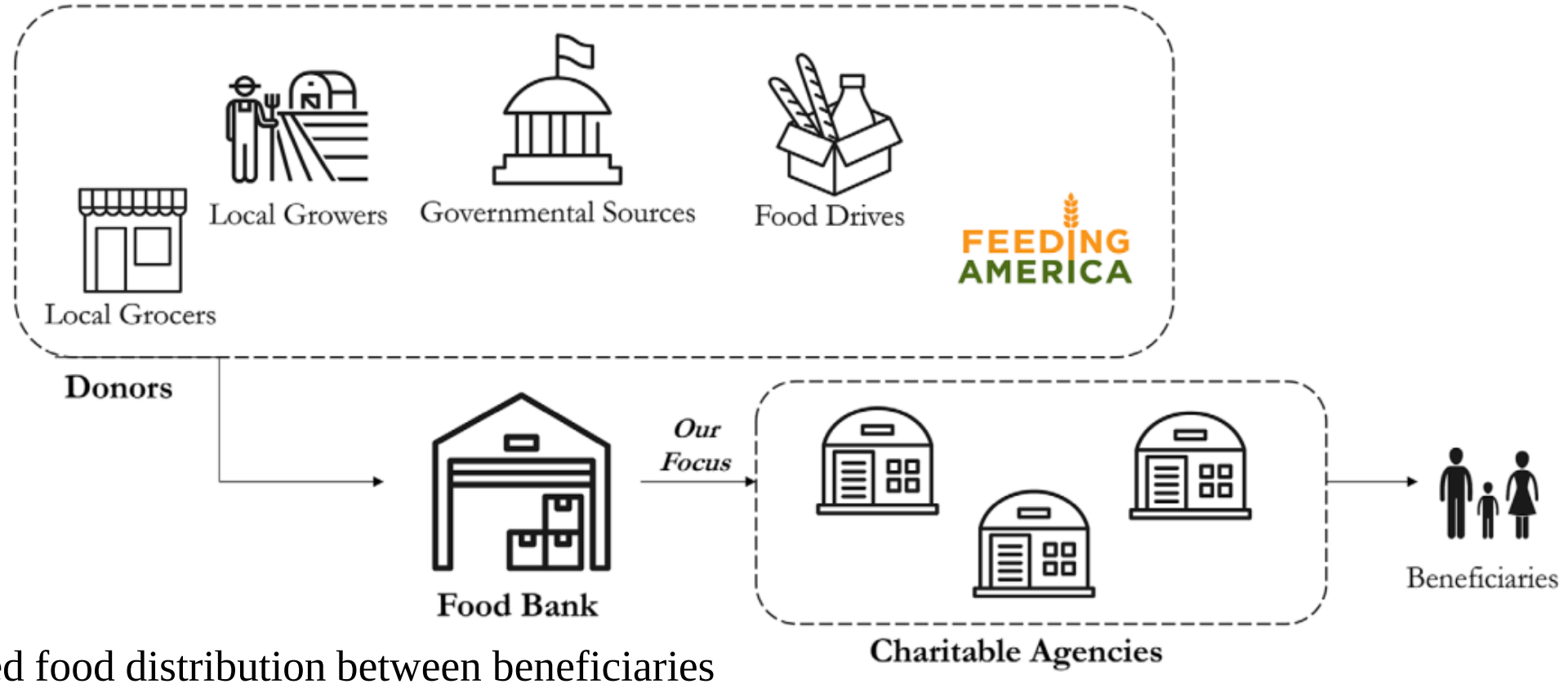
- Formulate a model that effectively solve the food bank’s challenges
- Propose a machine learning techniques using big data to implement solutions
- Case Study with Korean food bank to solve problems and derive useful implications

Literature Review

- Incorporate multiple criteria into single objective function
  - Firouz et al. (2022): Equity & Efficiency trade-off
  - Islam and Ivy (2018, 2021): Consider all Equity / Effectiveness / Efficiency
  - ➢ Incorporate Equity, Effectiveness and Efficiency costs into single objective function
- Various solving methods for foodbank logistics
  - Nair et al. (2018): Cutting-plane algorithm (Exact algorithm)
  - Eisenhandler et al. (2018): Large Neighborhood Search algorithm (Heuristic Algorithm)
  - ➢ Novel 2-stage machine learning approach for solving Foodbank Logistics
- Applicability in current foodbanks
  - Rancourt et al. (2015): Case study in Kenya
  - Hasnain et al. (2021): Case study with Feeding America, North Carolina
  - ➢ Case study with Korean Foodbank

Overview: Food Bank Operations

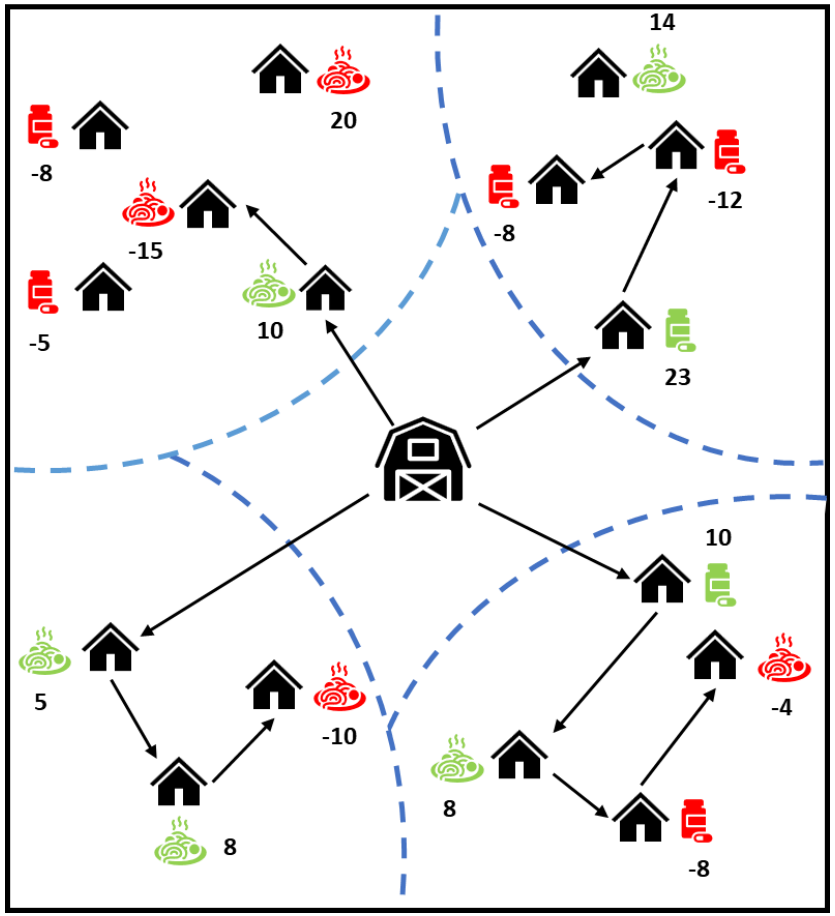
(Sengul Orgut & Lodree, 2023)



Equity: Fair donated food distribution between beneficiaries
Effectiveness: Maximization of food distribution
Efficiency: Minimization of the distribution costs.

Problem Overview

- **Situation**
  - Foodbanks with different stock and request level of items
- **Problems**
  - Need to reduce the costs and waste associated with excess inventory
  - Lower the budgetary spending of the food banks.
  - Reallocation of items for foodbanks' beneficiaries
- **Goal**
  - Minimize the operational costs of redistribution process
  - Consider appropriate level of budget for each foodbank
  - Trade-off between transportation cost and effectiveness



Problem Formulation

Sets and indices

- P : Set of nodes having pickup request (varies by item m), $P = \{1, 2, \dots, p\}$
- D : Set of nodes having delivery request (varies by item m), $D = \{p + 1, p + 2, \dots d\}$
- N : Set of pickup and delivery node, $N = P \cup D$
- V : Set of vehicles available, $V = \{1, 2, \dots, k\}$
- H : Set of commodities to be transported to customers $H = \{1, 2, \dots, m\}$

Parameters

- c_{ij} : Travel costs from node i directly to node j
- S_m : Product cost for each item m
- f_{im} : Arbitrary variable; 1 If foodbank i supplies item m; -1 if foodbank i demands item m; 0 otherwise;
- Q : Maximum capacity for vehicle (Homogeneous Truck)

Multi-Objective function

Decision Variables

- x_{ij}^k = equal to 1 if vehicle k travels from node i directly to node j, and 0 otherwise
- L_{ijm}^k = load quantity of item m on vehicle k when it travels from node i directly to node j
- q_{im}^k : pickup/delivery quantity of item m at node i when it is visited by vehicle k

Multi-Objective function

- $Minimize$

$$\underbrace{\sum_{i=0}^{n}\sum_{j=0}^{n}\sum_{k=0}^{v} c_{ij}^k x_{ij}^k}_{\text{Efficiency Cost}} + \underbrace{\sum_{i=0}^{n}\sum_{k=0}^{v}\sum_{m=0}^{h} S_m(D_{im}^k - q_{im}^k)}_{\text{Effectiveness Cost}} + \underbrace{\sum_{k=0}^{v}(E_{max}^k - E_{min}^k)}_{\text{Equity Cost}}$$

Problem Formulation

Constraints

- $\sum_{j=0}^{n} x_{0j}^{k} = 1, \sum_{j=0}^{n} x_{j0}^{k} = 1, \ \forall k \in V$
- $\sum_{i=0}^{n} \sum_{k=0}^{v} x_{ij}^{k} \leq 1, \forall j \in N$
- $\sum_{i=1}^{n} x_{ij}^{k} - \sum_{i=1}^{n} x_{ji}^{k}, \forall j \in N, \ k \in V$
- $\sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=0}^{v} x_{ij}^{k} \leq |R| - 1, \forall R \in N$

Flow constraints for Vehicle routing problems

- $\sum_{i=1}^{n} L_{ijm}^{k} + q_{jm}^{k} f_{jm} - \sum_{i=1}^{n} L_{jim}^{k} = 0, \ \forall j \in N, m \in H, \ k \in V$
- $L_{0jm}^{k} = 0, \ L_{j0m}^{k} = 0, \forall j \in N, m \in H, k \in V$
- $q_{ijm}^{k} \leq \ \mathrm{Q} \sum_{j=0}^{n} x_{ij}^{k}, \forall j \in N, m \in H, k \in V$
- $\sum_{m=0}^{h} L_{ijm}^{k} \leqslant Q x_{ij}^{k}, \ \forall i \in N, j \in N, k \in V$

Capacity constraints for Pickup & Delivery

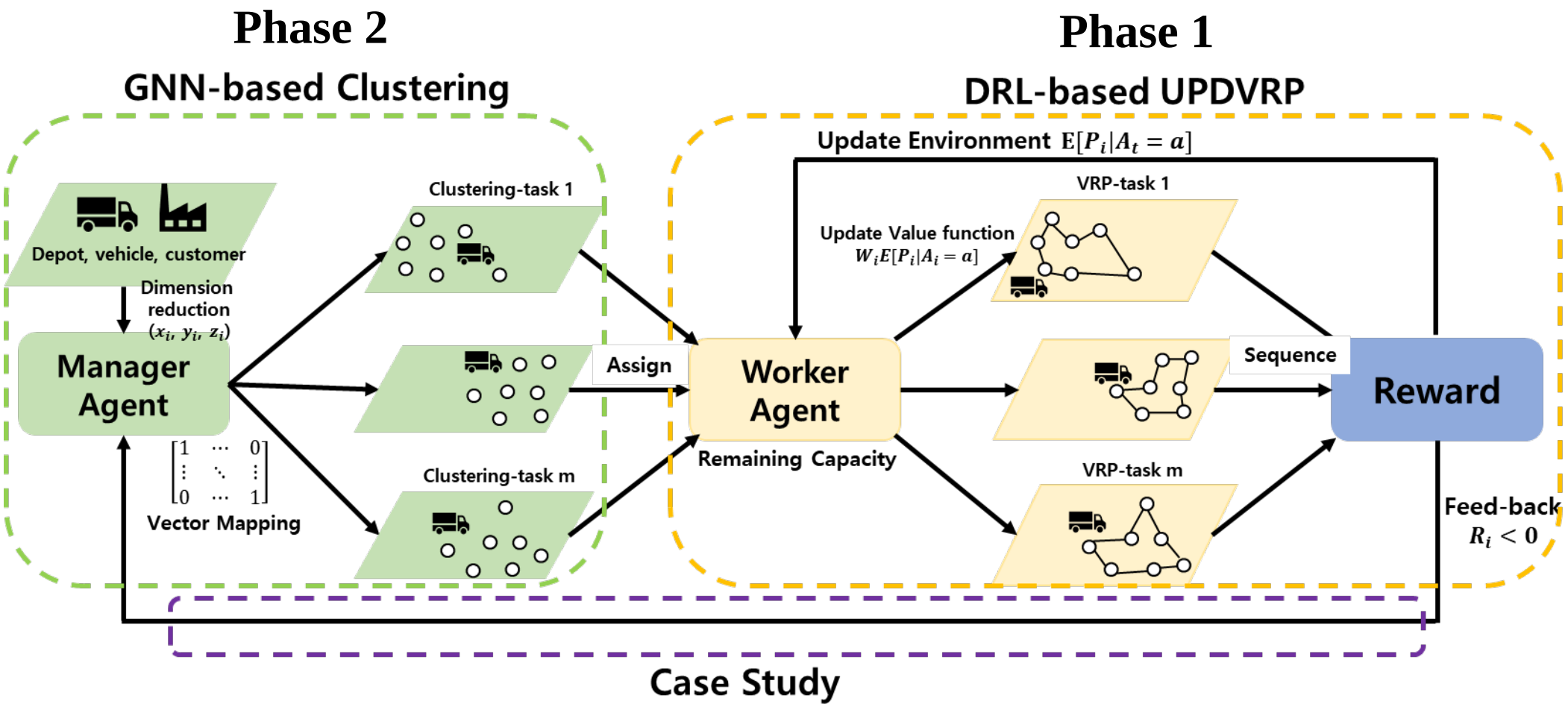
- $E_{max}^{k} \geq \ \sum_{k=0}^{v} \sum_{m=0}^{h} S_m (D_{im}^{k} - q_{im}^{k}), \forall k \in V$
- $E_{min}^{k} \leq \ \sum_{k=0}^{v} \sum_{m=0}^{h} S_m (D_{im}^{k} - q_{im}^{k}), \ \forall k \in V$

Equity constraints for Re-allocations

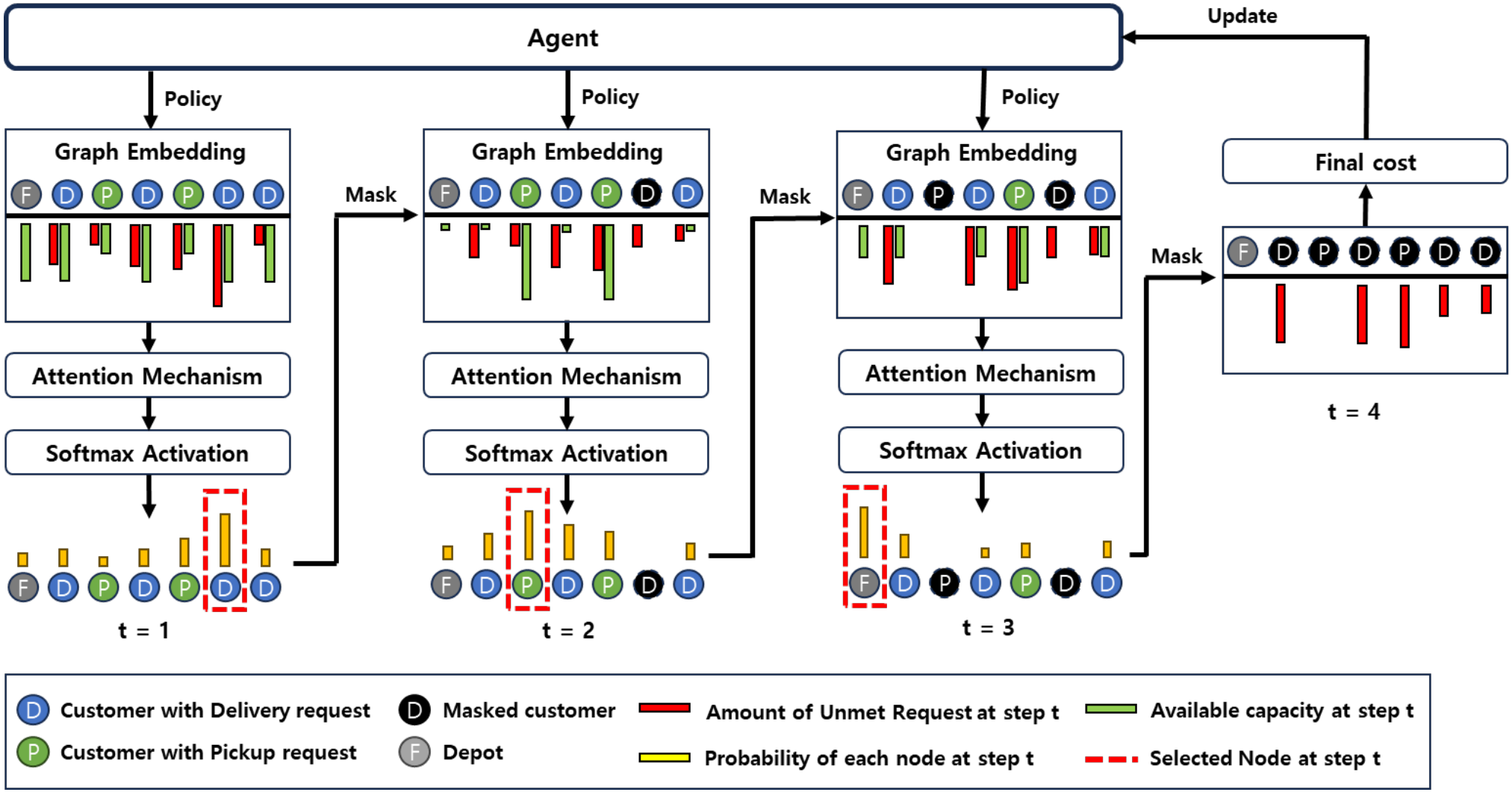
Solution Method: DRL

- Due to complexity of model, hard to solve through MLIP
- **Reinforcement Learning Approach**
  - State
    - Delivery or pickup request quantities for each item by each food bank
    - Previous Route information
    - Current load of vehicle
  - Action
    - Select foodbank to visit
    - When selected, driver will automatically pickup/deliver the item based on the current load
  - Reward
    - Total sum of effective / equity / efficiency cost

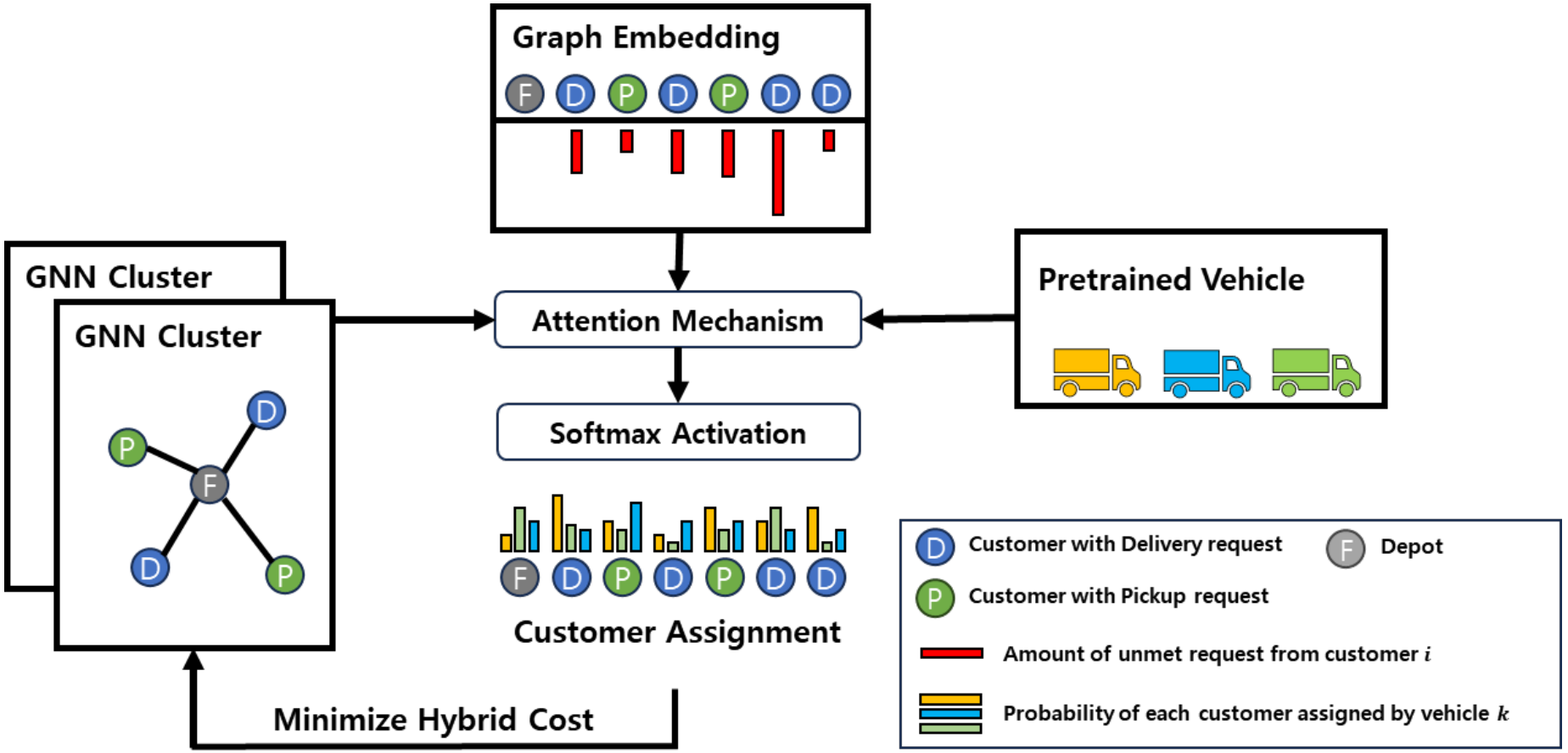
Model Architecture



Phase 1. DRL-Based UPDVRP

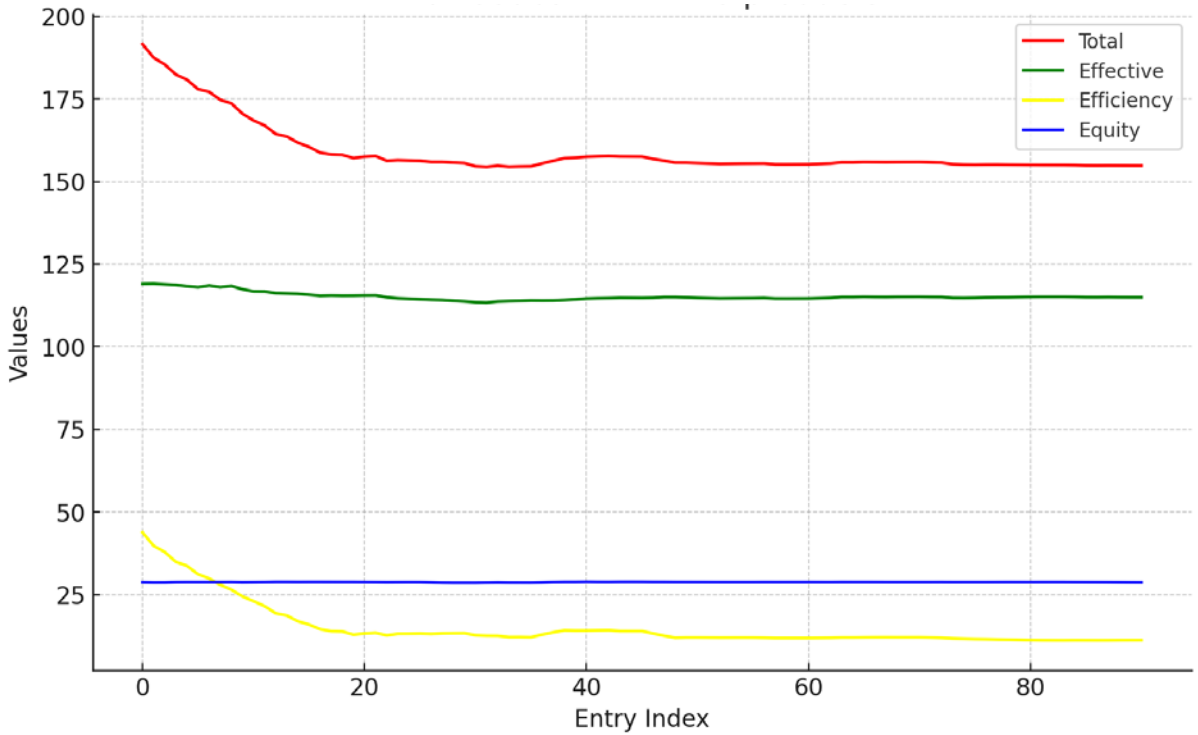


Phase 2. GNN based Clustering

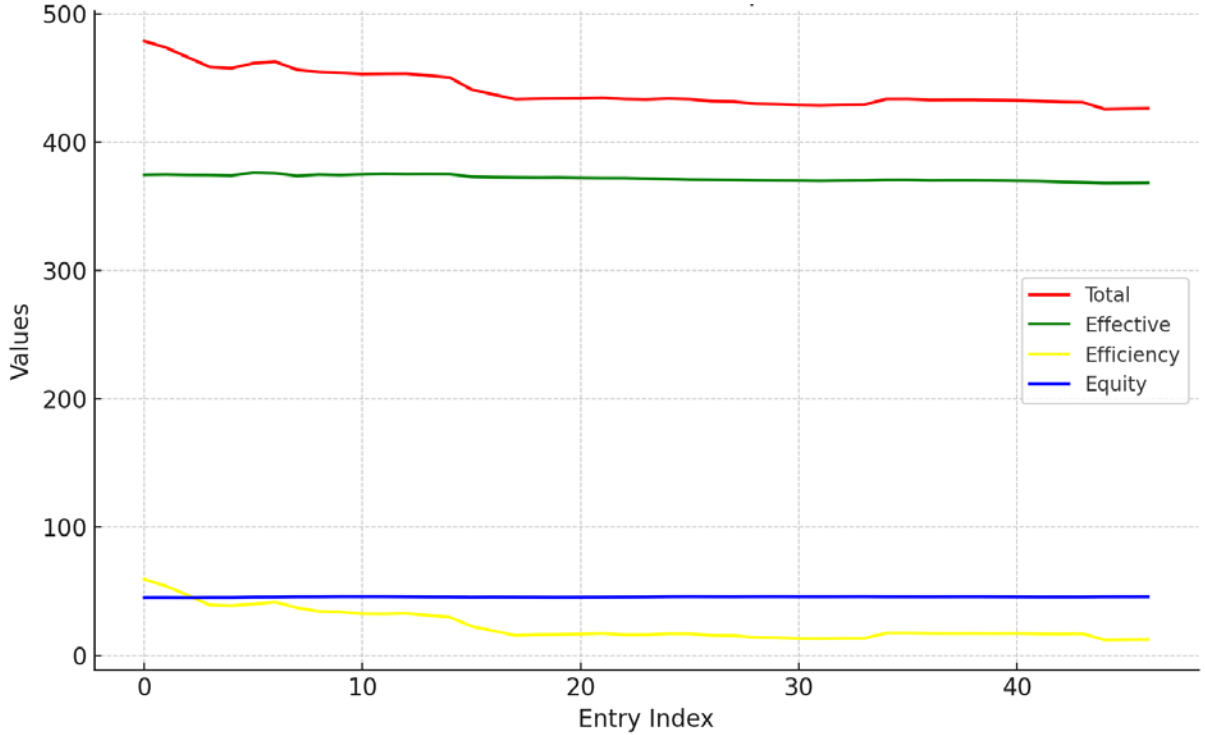


Numerical Experiment (N = 20, M = {10, 20})

20 Foodbank with 10 products



20 Foodbank with 20 products



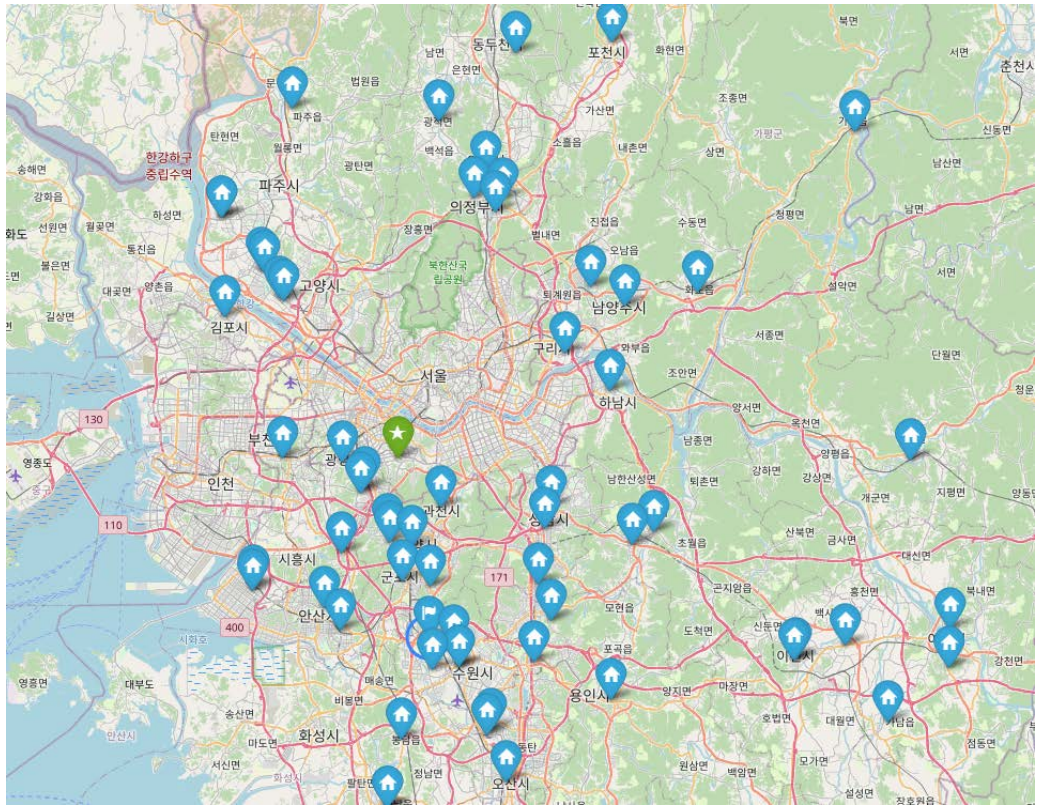
Gyeonggi Metropolitan Foodbank (경기광역푸드뱅크)

- Data Description

- 84 Foodbanks with 5,165 types of product
- Training date: 2022-01-01~ 2022-12-31 (1 year)
- Assumed 63 reallocation happened (5 days)

사업장 명칭	가평군푸드뱅크			
사업장 소재지	가평군 가평읍 달전로 44(달전리)			
모집일자	종류	품목	수량	가액
2022-01-01	대용식(빵)	기타빵	24	126,000
2022-01-02	대용식(빵)	기타빵	92	495,880
2022-01-03	대용식(빵)	기타빵	72	417,600

- Map for Foodbank Center



Data Preprocessing

- **Text classification model: Bert**
  - Bert Classification: Multilingual classification + Pretrained model
  - Standardize inconsistent item names among food banks
  - Convert 5,165 types → 20 types
- **Data Normalization**
  - For pickup request we assume to be products being positive while demand request as negative
  - Applied Hyperbolic Tangent function to normalize data from -1 to 1

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name	1	2	3	4	5
가평군푸드뱅크	0	0	0	0	0
경기도광역푸드뱅크	0	-1	-1	0	0
고양시문촌7푸드뱅크	0	0	0	0	0
고양시문촌9푸드뱅크	0	0	0	-1	0
고양시한아름푸드마켓	1	0	0	0	0
고양시흰돌기초푸드뱅크	-1	0	0	0	0
광명시푸드뱅크마켓센터	-1	-0.69287	0	-1	-1

Conclusion

- **Current Status**
  - Present a mathematical model that considers various evaluation criteria & constraints of food banks
  - Utilize state-of-art machine learning techniques and proposed pretrained model
  - Case study with domestic food bank and derive effective solution method
- **Further plans**
  - Conduct interviews with related employees to build more practical model for field
  - Expand the training data range up to 2016
  - Compare with other solution methods such as Gurobi (OR tools) or other heuristic methods

Thank you

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