# Clustered Vehicle Routing Problem for Waste Collection Using K-means-Ant Colony Optimization

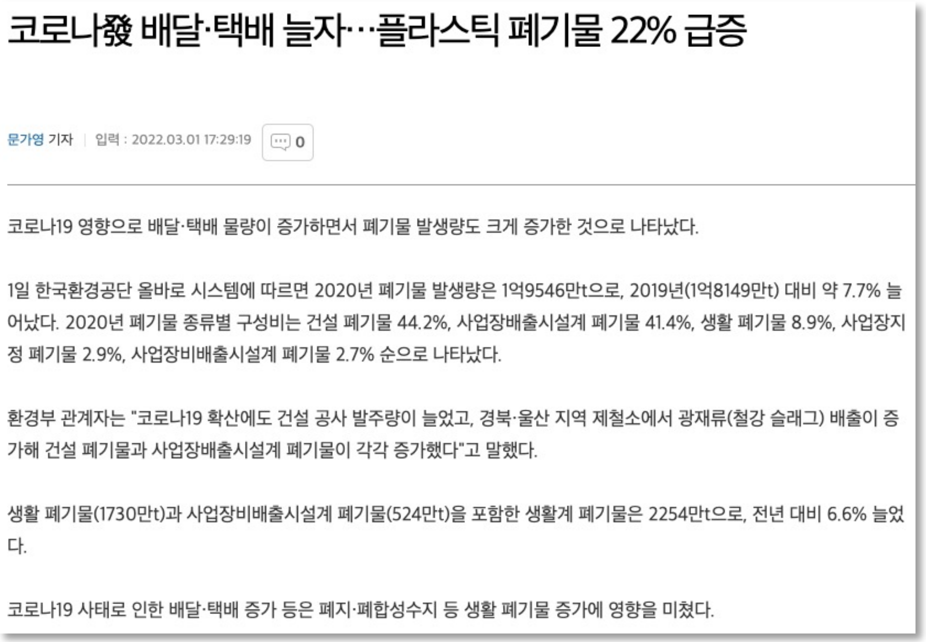
Jungmin Kim[1], Changseong Ko[2], Ilkyeong Moon[1]

[1]Supply Chain Management Lab
Department of Industrial Engineering
Seoul National University
[2]Department of Industrial and Management Engineering
Kyungsung University

April 29, 2022

# Contents

# 1. Introduction



코로나發 배달·택배 늘자…플라스틱 폐기물 22% 급증

문가영 기자 | 입력 : 2022.03.01 17:29:19 | 0

코로나19 영향으로 배달·택배 물량이 증가하면서 폐기물 발생량도 크게 증가한 것으로 나타났다.

1일 한국환경공단 올바로 시스템에 따르면 2020년 폐기물 발생량은 1억9546만t으로, 2019년(1억8149만t) 대비 약 7.7% 늘어났다. 2020년 폐기물 종류별 구성비는 건설 폐기물 44.2%, 사업장배출시설계 폐기물 41.4%, 생활 폐기물 8.9%, 사업장지정 폐기물 2.9%, 사업장비배출시설계 폐기물 2.7% 순으로 나타났다.

환경부 관계자는 "코로나19 확산에도 건설 공사 발주량이 늘었고, 경북·울산 지역 제철소에서 광재류(철강 슬래그) 배출이 증가해 건설 폐기물과 사업장배출시설계 폐기물이 각각 증가했다"고 말했다.

생활 폐기물(1730만t)과 사업장비배출시설계 폐기물(524만t)을 포함한 생활계 폐기물은 2254만t으로, 전년 대비 6.6% 늘었다.

코로나19 사태로 인한 배달·택배 증가 등은 폐지·폐합성수지 등 생활 폐기물 증가에 영향을 미쳤다.

Source : Maeil Business (2022)


Source : The Korea Herald (2021)


Apartment dump (2022)

## Increasing & Overflowing waste

## Smart bin & Waste management


Source : RFID food bin (2010)

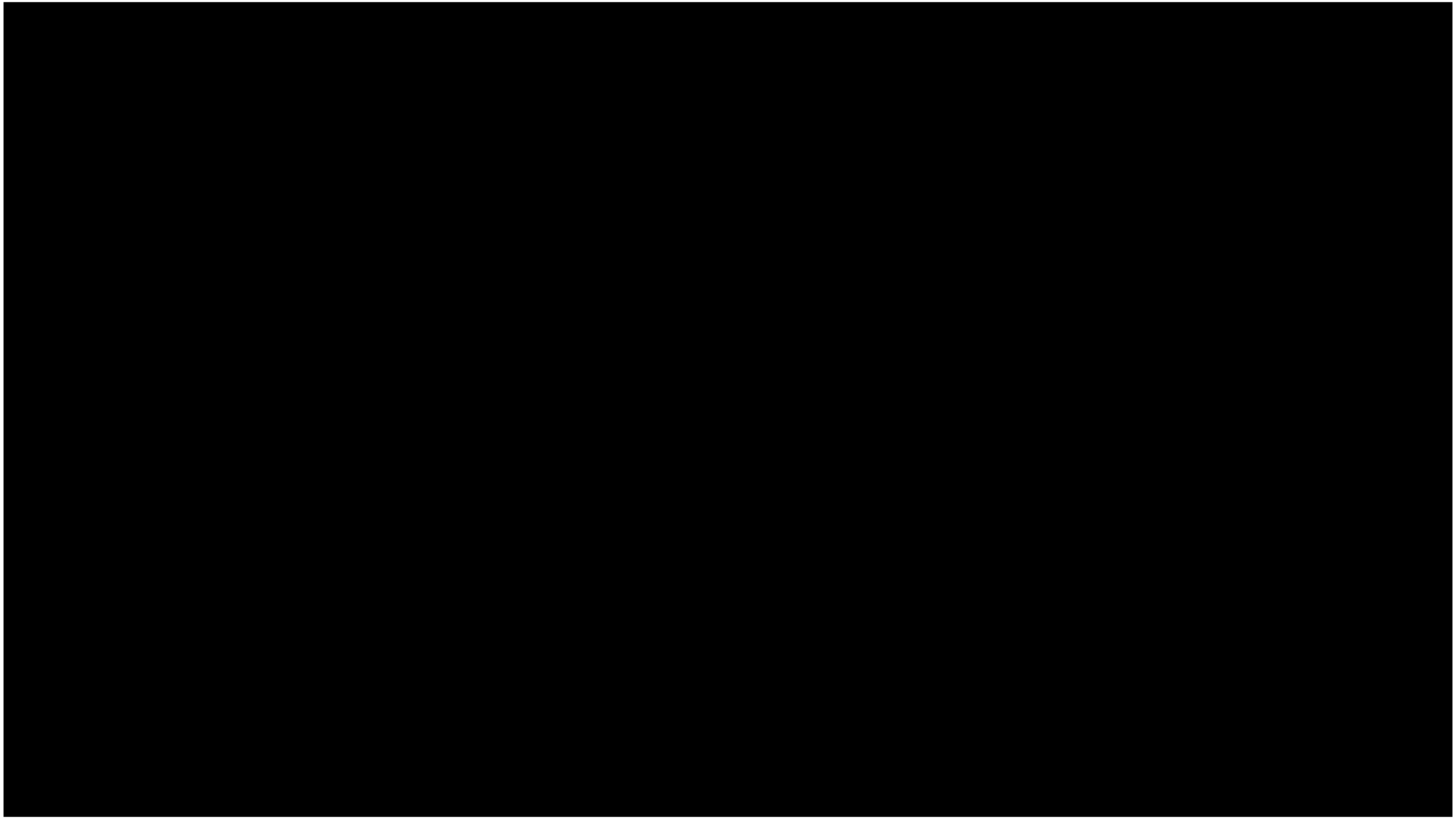

Source : Big Belly (2016)


Source : Superbin (2020)

# Introduction

## Smart bin in a smart city





Source : LOGICTRONS, Techno India University (2018)

**RQ1 :** Advantages of using a smart bin → 
- Tackle uncertainty of fill level
- Penalty for overflowing bin

**RQ2 :** Why are clusters needed for waste collection? → 
- Total cost
- Waste collection rate

**RQ3 :** Why suggest a heuristic? → 
- Efficient and fast solution

# 2. Mathematical model

# Mathematical model

## Assumptions



Bin : Identical with the same capacity

Vehicle : Homogeneous with the same capacity

Waste : Single type

# Mathematical model

## Assumptions



(4) Every bin in each cluster will be visited by the same vehicle.

(5) If the fill level reaches the TFL, then an alert message is transmitted to the cleaning authority so that the waste can be collected.

(6) All the empty vehicles start from a depot and visit the filled bins (above TFL) and their neighboring bins in each cluster.

(7) All filled bins must be visited.

(8) After visiting the filled bins and neighboring bins, the vehicle will return to the depot to unload waste.

(9) During routing, a vehicle can receive fill level information within a neighboring bound from its current location.

- TFL : Threshold fill level (e.g. 80%)

✓ Clustering part

→ Generate clusters : K-means algorithm

→ Decide the number of clusters : Elbow method

✓ Routing part

→ Use ant colony optimization

→ **Minimize** Routing cost + Penalty cost

# Mathematical model

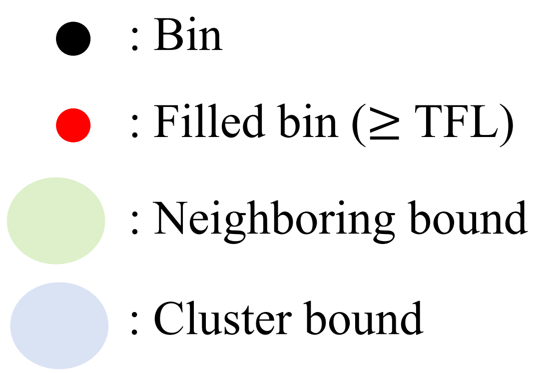
## Routing part

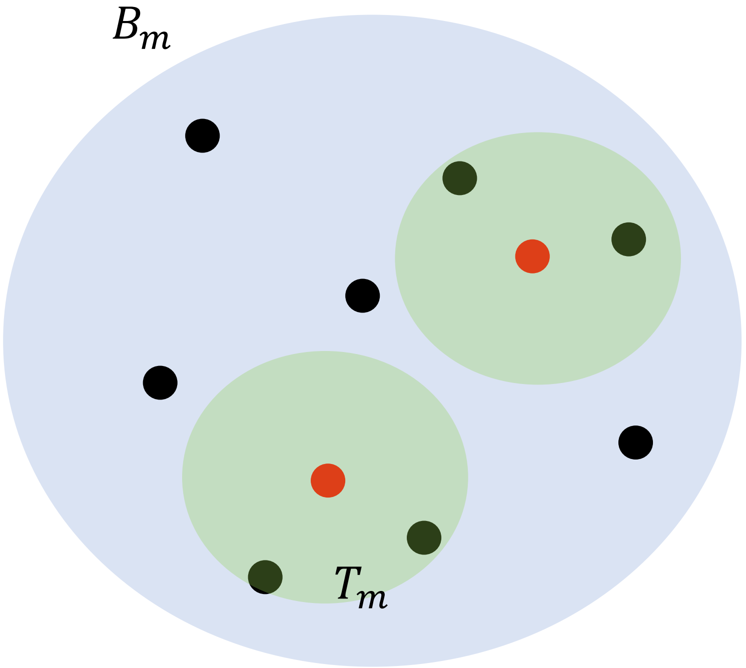


✓ Indices and sets

| | |
|---|---|
| $M$ | Set of $m$ clusters, $M = \{1, 2, \cdots, m\}$ |
| $B_m$ | Set of bins in cluster $m$, $b_{mi} \in B_m$, $b_{mi}$ = bin $i$ in cluster $m$, $\forall m \in M$ |
| $\{0\}$ | Depot |
| $B$ | Set of depot and all bins, $B = \{0\} \cup B_1 \cup B_2 \cup \cdots \cup B_m$ |
| $B_{mf}$ | Set of the filled bins in cluster $m$, fill level$\geq TFL$, $B_{mf} \subseteq B_m$, $\forall m \in M$ |
| $B_f$ | Set of all filled bins, $B_f = B_{1f} \cup B_{2f} \cup \cdots \cup B_{mf}$ |
| $B_{mp}$ | Set of penalty bins in cluster $m$, fill level$\geq 100\%$, $B_{mp} \subseteq B_{mf}$, $\forall m \in M$ |
| $B_p$ | Set of all penalty bins, $B_p = B_{1p} \cup B_{2p} \cup \cdots \cup B_{mp}$ |
| $N[b_{mi}]$ | Neighbor of $b_{mi}$, $N[b_{mi}] = \{b_{mi}\} \cup \{b_{mx} : b_{mx} \in B_m \ ; i \neq x, \ \forall\ m \in M, \ \forall\ i, x = 1, 2, \cdots, \lvert B_m \rvert$ and $d(b_{mx}, b_{mi}) \leq R$, $d$ denotes the euclidean distance$\}$ |
| $K$ | Set of vehicles, $\lvert K \rvert \leq m$ |
| $T_m$ | $B_{mf} \cup N[b_{ml}]$, $b_{ml} \in B_{mf}$ |
| $T_0$ | $\{0\} \cup T_1 \cup T_2 \cup \cdots \cup T_m$ |
| $\delta^+(Z)$ | Set of edges $(i, j) \in Z \times B \backslash Z$ |
| $\delta^-(Z)$ | Set of edges $(i, j) \in B \backslash Z \times Z$ |

✓ Indices and sets



# Mathematical model

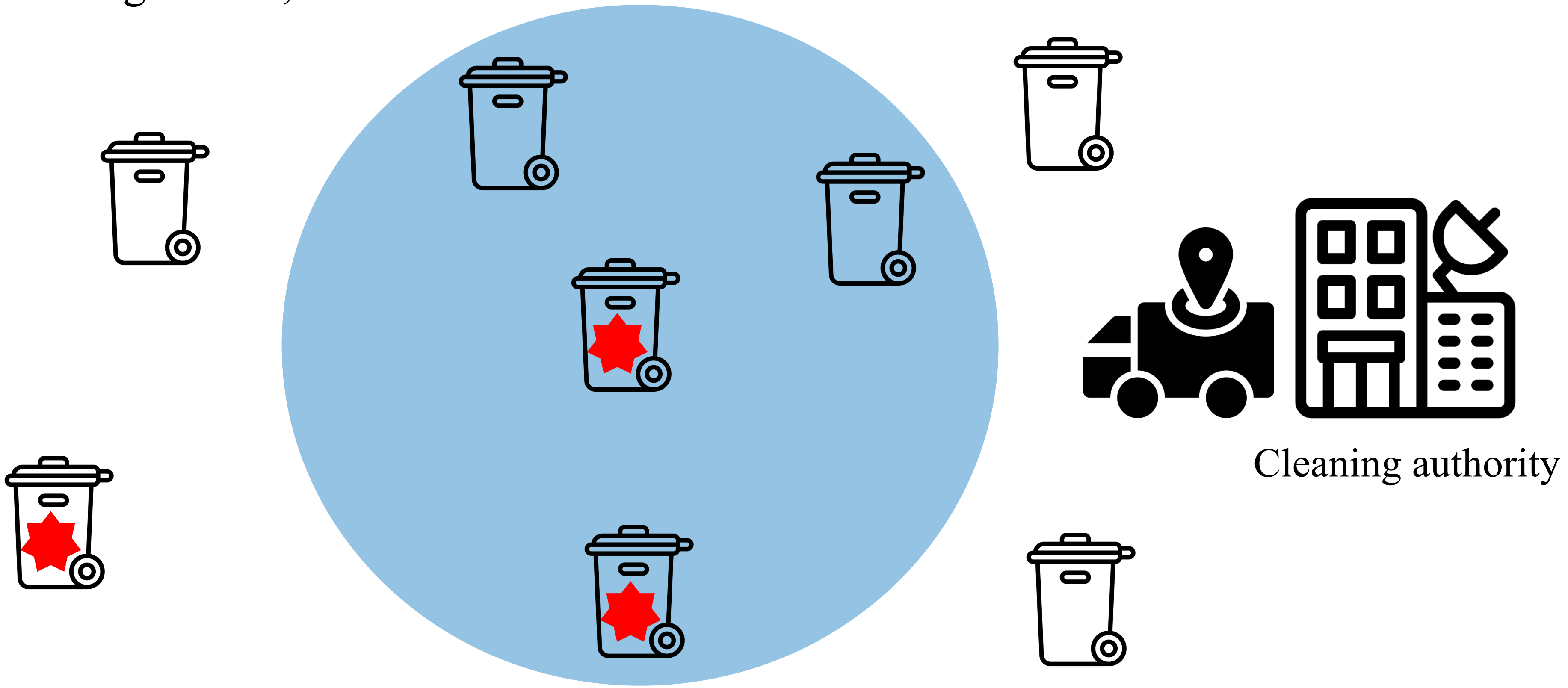
## Routing part : Motivation for a neighboring bin



✓ IoT sensor

- Short range : Bluetooth, NFC, RFID, Wi-Fi (10~20m)

- Medium range : LTE, 5G



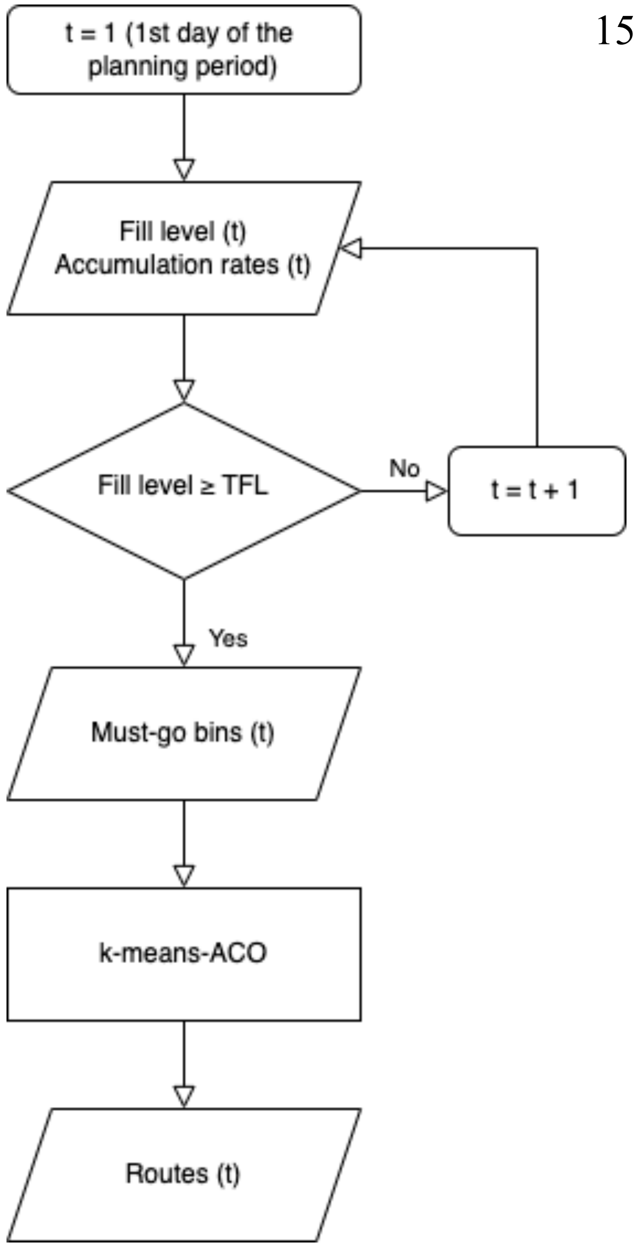

Kim, J. S. (2015). The introduction of IoT (Internet of Things) technologies and Policy Directions. *Review of Korea Contents Association*, *13*(1), 18-24.

# Mathematical model

## Routing part : A smart bin



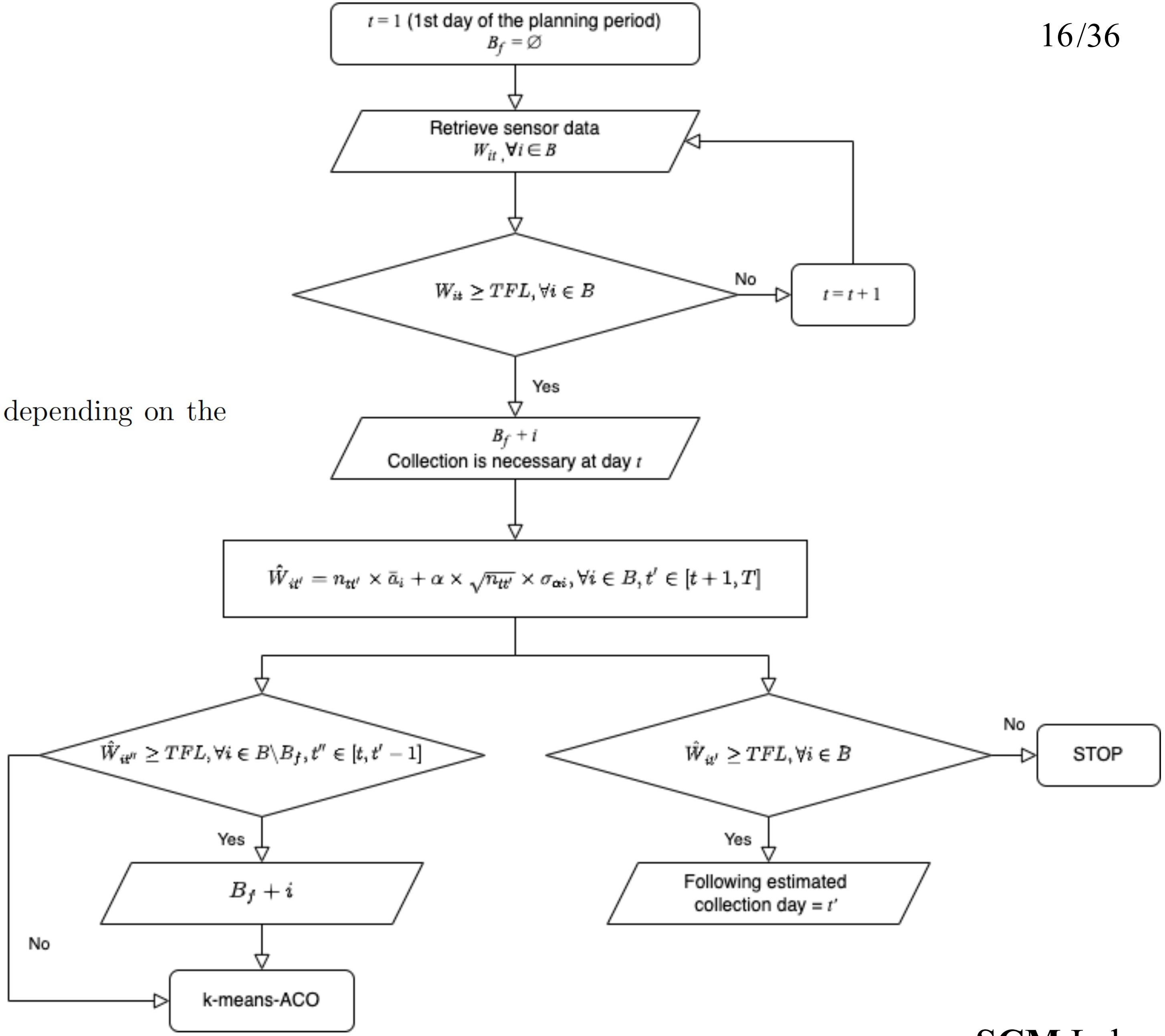
- ✓ Must-go bins : Fill level ≥ TFL
- ✓ Might-go bins : Fill level < TFL
- ✓ Must-go bins include not only above TFL but also expected to above TFL based on accumulation rate
- ✓ Time period
  - Discrete : t starts from 1
  - Check fill level at the beginning of each time period (once in a day)



✓ Fill level estimation

$\hat{W}_{it}$ : estimated waste fill level in bin $i$ at day $t'$
$n_{tt'}$ : number of days between collection day $t$ and day $t'$
$\bar{a}_i$ : average daily accumulation rate of bin $i$
$\alpha$ : value for a probability retrieved from the normal distribution depending on the desired level of confidence for $\hat{W}_{it}$
$\sigma_{ai}$ : standard deviation of the daily accumulation rates of bin $i$

Waters, D. (2008). *Inventory control and management*. John Wiley & Sons.



# Mathematical model

## Routing part : Motivation for a smart bin



✓ Example

| Bin | Expected waste accumulation (%/day) | Day 1 | $\widehat{W}_{it}$ Estimated fill level (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Waste fill level, $W_{it}$ | Day 2 | | Day 3 | | Day 4 | | Day 5 | |
| | | | Before collection | After collection | Before collection | After collection | Before collection | After collection | Before collection | After collection |
| 1 | 40 | 20 | 60 | **20** | $\boxed{100}$ | | 140 | | 180 | |
| 2 | 20 | $\boxed{80}$ | 100 | 20 | 120 | 40 | 140 | 60 | 160 | $\boxed{80}$ |
| 3 | 30 | 40 | $\boxed{70}$ | **30** | 100 | | 130 | | 160 | |
| 4 | 10 | $\boxed{70}$ | 80 | 10 | 90 | 20 | 100 | 30 | 110 | 40 |
| 5 | 5 | 55 | 60 | **60** | 65 | | 70 | | 75 | |

TFL : 70%

First collection day : Day 1 with Bin 1,2,3,4
Following estimated collection day : Day 5

✓ Parameters

| | |
|---|---|
| $TFL$ | Threshold fill level |
| $R$ | Neighboring bound |
| $d_{ij}$ | Travel cost required to move a vehicle from node $i$ to node $j$ |
| $L_i$ | Amount of waste at bin $i$ |
| $P_i$ | Penalty if bin $i$ is not visited by a vehicle |
| $L$ | Maximum capacity of a vehicle |

✓ Variables

$$x_{ijk} = \begin{cases} 1 & \text{if a vehicle } k \text{ traverses from node } i \text{ to node } j \text{ in the undirected graph} \\ 0 & \text{otherwise} \end{cases}$$

$i, j \in B, k \in K$

$$y_i = \begin{cases} 1 & \text{if a bin } i \text{ is visited in the solution} \\ 0 & \text{otherwise} \end{cases}$$

$i \in B \backslash \{0\}$

# Mathematical model

## Routing part



✓ Objective function

$$min \sum_{k\in K}\sum_{i\in T_0}\sum_{j\in T_0} x_{ijk}d_{ij} + \sum_{i\in T_0\setminus\{0\}} (1-y_i)P_i \tag{1}$$

✓ Constraints

$$\sum_{i\in B\setminus\{0\}} x_{0ik} = \sum_{j\in B\setminus\{0\}} x_{j0k} = 1, \quad \forall k \in K \tag{2}$$

$$\sum_{k\in K}\sum_{(i,j)\in\delta^+(T_m)} x_{ijk} = \sum_{k\in K}\sum_{(i,j)\in\delta^-(T_m)} x_{ijk} = 1, \quad \forall m \in M \tag{3}$$

$$\sum_{(i,j)\in\delta^+(T_m)} x_{ijk} = \sum_{(i,j)\in\delta^-(T_m)} x_{ijk}, \quad \forall m \in M, \quad \forall k \in K \tag{4}$$

$$\sum_{i\in B\setminus\{0\}}\sum_{j\in B} x_{ijk}L_i \leq L, \quad \forall k \in K, \quad i \neq j \tag{5}$$

✓ Constraints

$$\sum_{k \in K} \sum_{i \in B \setminus \{0\}} x_{ijk} = y_j, \quad \forall j \in B \setminus \{0\}, \quad i \neq j \tag{6}$$

$$\sum_{i \in B \setminus \{0\}} x_{ipk} = \sum_{j \in B \setminus \{0\}} x_{pjk}, \quad \forall k \in K, \quad \forall p \in B \setminus \{0\} \tag{7}$$

$$\sum_{i \in S} \sum_{j \in S} x_{ijk} \leq |S| - 1, \quad \forall k \in K, \quad \forall S \subseteq B \setminus \{0\}, \quad |S| \geq 2 \tag{8}$$

$$\sum_{i \in B_f} y_i = |B_f| \tag{9}$$

$$x_{ijk} \in \{0, 1\}, \ \forall i \in B, \ \forall j \in B, \ \forall k \in K \tag{10}$$

$$y_i \in \{0, 1\}, \ \forall i \in B \tag{11}$$

# 3. K-means-Ant Colony Optimization

**Algorithm 1** k-means clustering algorithm

**Require:** Set of bins $B$ except for a depot, and the number of clusters $|M|$;

**Ensure:** Unique set of bins in each cluster; centroid of each cluster;

Step-1: Start;

Step-2: Initialize a positive integer $c$ ($c = |M|$) using elbow method;

Step-3: Generate bins in each cluster (an initial set) randomly;

Step-4: Determine the centroid of each cluster;

Step-5: Allocate each bin to the cluster where it is nearest to the centroid;

Step-6: Update the centroid in each cluster;

Step-7: Repeat Step 5 and 6 until the centroids no longer move;

Step-8: Stop.

# K-means-Ant Colony Optimization

## Procedures



1. Representation : $$X_i = (\underbrace{\{0\}}_{\text{Depot}}, \underbrace{b_{m1}, b_{m2}, \ldots, b_{mp}}_{\text{Filled bins}}, \underbrace{b_{m,p+1}, .., b_{m,p+l}}_{\text{Neighboring bins}})$$

2. Pheromone initialization : $$\tau_{ij} = \frac{1}{\sqrt{d_{ij}}}$$

3. Path construction : $$p_{ij} = \frac{\tau_{ij}^{\delta_1}}{\sum_{j \in E'} \tau_{ij}^{\delta_1}}$$ ➡ **See Appendix A.**

4. Pheromone evaporation : $$\tau_{i,j} = (1-\rho)\tau_{i,j}$$

5. Pheromone updating : $$\tau_{i,j} = (1-\rho)\tau_{i,j} + \frac{\rho}{n}\sum_{i=1}^{n} \tau_{i,j}^{best}$$

# 4. Computational experiments

# 04 Computational experiments

Small size



1. Dataset : 16 Nodes (Gwanak-gu, Seoul)

   - 1 Depot, 15 Bins

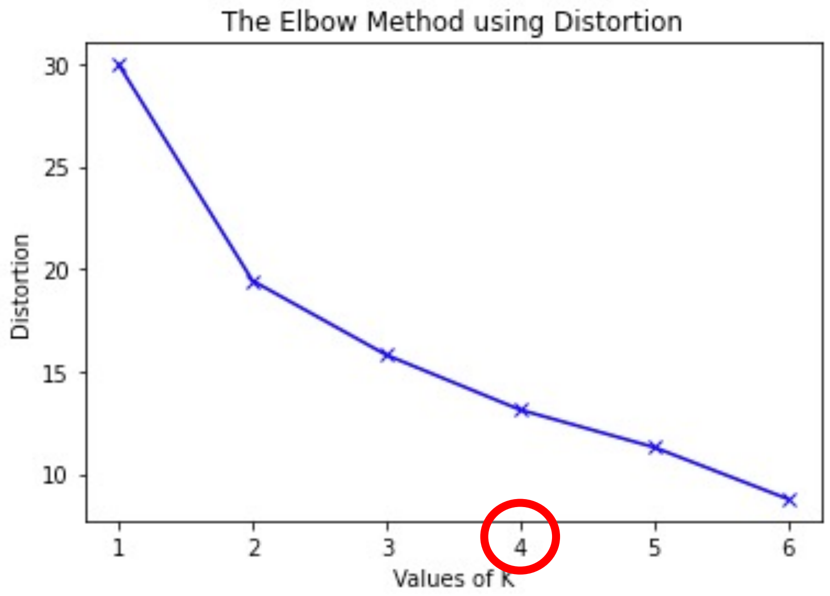
2. 4 Clusters by k-means algorithm + Elbow method

3. Parameter setting

   - TFL : 80, # of vehicles : 2, L : 700, R : 25

   - A week, fill level estimation*

4. Exact method




1 : 29.969884354402602
2 : 19.43334875751521
3 : 15.81346060178041
4 : 13.138845094623909
5 : 11.31554115977245
6 : 8.79368992781059

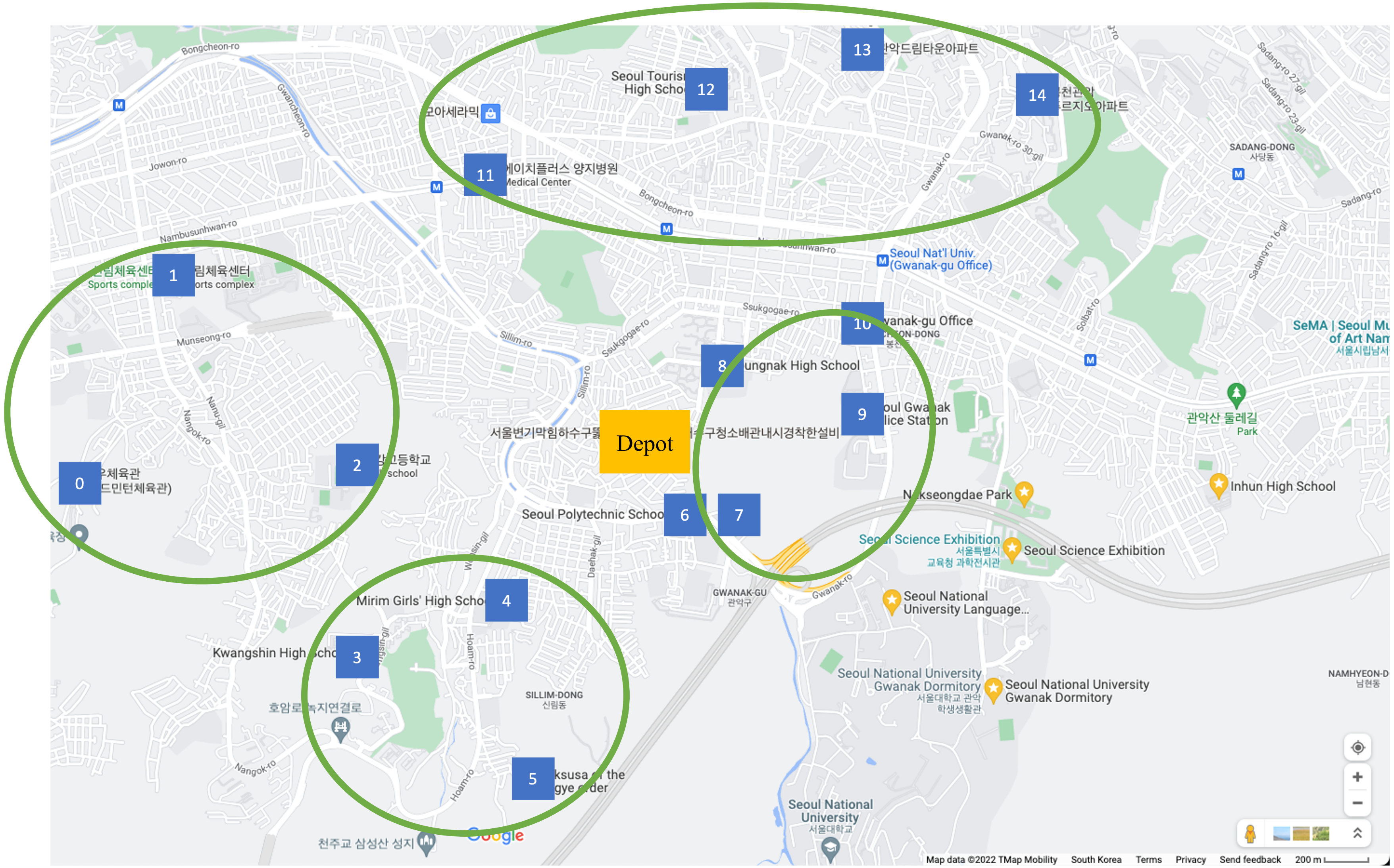
*김채현, 양라영, 이주현, 장희진, 하수빈, & 김응섭. (2020). 최적의 생활 폐기물 수거 경로 탐색과 지역별 폐기물 예측에 대한 연구. *한국정보처리학회 학술대회논문집, 27*(2), 216-219.

# Computational experiments

## Small size



Hospital, School, Sports complex, Apartment..




Google Maps

✓ Exact method (Python-Cplex)

| | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 |
|---|---|---|---|---|---|---|---|
| Must go bins | All bins | Ø | All bins | Ø | 9 bins | Ø | 4 bins |
| Collection rate (%) | 100 | 0 | 100 | 0 | 88.34 | 0 | 53.41 |
| Routing cost | 247.19 | 0 | 247.19 | 0 | 219.394 | 0 | 148.836 |
| Penalty cost | 0 | 0 | 0 | 0 | 10.4 | 0 | 34.8 |

# Computational experiments

## Large size



1. Dataset : 52 Nodes (TSPLIB*)

   - 1 Depot, 51 Bins

2. 5 Clusters by k-means algorithm + Elbow method

3. Parameter setting

   - TFL : 70, # of vehicles : 5, L : 250, R : 20

   - A week, fill level estimation

4. Heuristic (k-means-ACO)

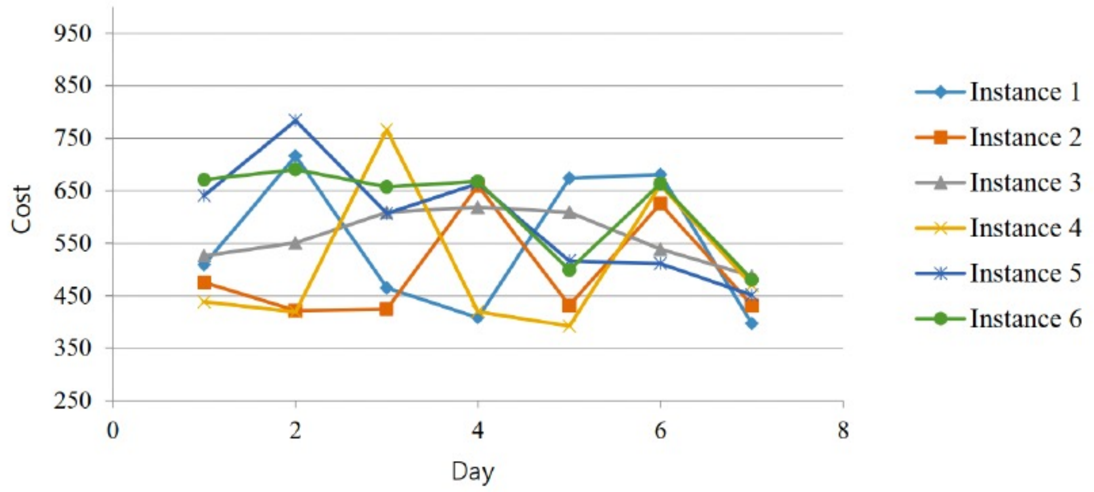
*http://comopt.ifi.uni-heidelberg.de/software/TSPLIB95/

# Computational experiments

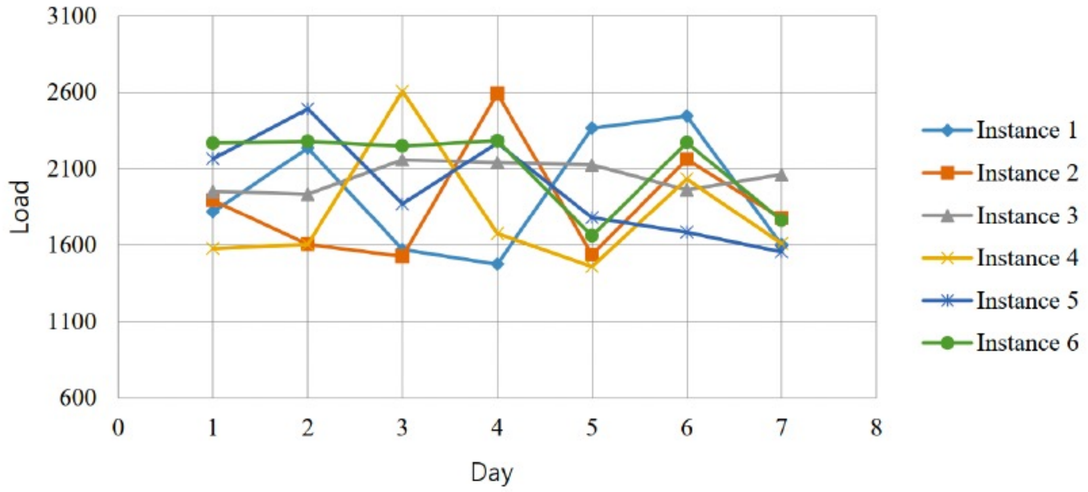
Large size

➡ See Appendix B.






(a) Routing cost in a week




(b) Waste load in a week

**Figure 2.** Routing cost and waste load in a week

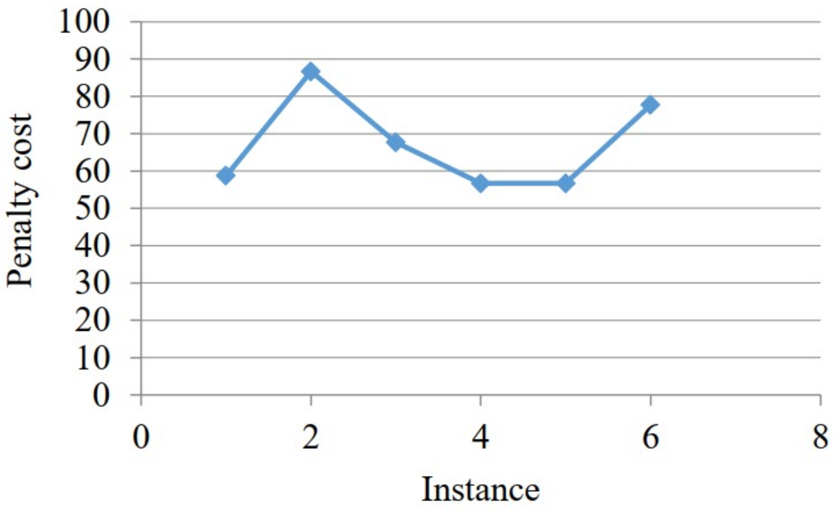



**Table 3.** Statistical measures on different costs

| Item | Routing cost | Penalty cost | Total cost |
|---|---|---|---|
| Mean | 3888.45 | 67.36 | 3955.81 |
| SD | 304.94 | 11.42 | 303.62 |

**Table 4.** Computation times of k-means-ACO

| Instance | Computation times (sec) |
|---|---|
| 1 | 43.986 |
| 2 | 39.147 |
| 3 | 40.308 |
| 4 | 32.904 |
| 5 | 34.924 |
| 6 | 35.364 |

# 5. Conclusions

# Conclusions



✓ Contributions

- Reduce the complexity of the VRP by clustering
- Suggest k-means-ACO for fast and efficient waste collection
- Suggest a set concept for each bin to tackle the uncertainty of a smart bin

✓ Future study

- Consider several types of waste
- Multiple compartments in a vehicle for waste collection

# References




- Adeleke, O. J., and M. M. Ali. 2021. “An Efficient Model for Locating Solid Waste Collection Sites in Urban Residential Areas.” *International Journal of Production Research* 59 (3):798–812.
- Battarra, M., G. Erdogan, and D. Vigo. 2014. “Exact Algorithms for the Clustered Vehicle Routing Problem.” *Operations Research* 62 (1): 58–71.
- Daugherty, P. J., R. G. Richey, S. E. Genchev, and H. Chen. 2005. “Reverse Logistics: Superior Performance Through Focused Resource Commitments to Information Technology.” *Transportation Research Part E: Logistics and Transportation Review* 41 (2): 77–92.
- Defryn, C., and K. Sorensen. 2017. “A Fast Two-level Variable Neighborhood Search for the Clustered Vehicle Routing Problem.” *Computers & Operations Research* 83: 78–94.
- Defryn, C., K. Sorensen, and T. Cornelissens. 2016. “The Selective Vehicle Routing Problem in a Collaborative Environment.” *European Journal of Operational Research* 250 (2): 400–411.
- Exposito-Izquierdo, C., A. Rossi, and M. Sevaux. 2016. “A Two-level Solution Approach to Solve the Clustered Capacitated Vehicle Routing Problem.” *Computers & Industrial Engineering* 91: 274–289.
- Fayoumi, A., and P. Loucopoulos. 2016. “Conceptual Modeling for the Design of Intelligent and Emergent Information Systems.” *Expert Systems with Applications* 59: 174–194.
- Fernandez, E., M. Roca-Riu, and M. G. Speranza. 2018. “The Shared Customer Collaboration Vehicle Routing Problem.” *European Journal of Operational Research* 265 (3): 1078–1093.

- Haque, M. S., S. Uddin, S. M. Sayem, and K. M. Mohib. 2021. "Coronavirus Disease 2019 (COVID-19) Induced Waste Scenario: A Short Overview." *Journal of Environmental Chemical Engineering* 9 (1): 104660.
- Hintsch, T., and S. Irnich. 2018. "Large Multiple Neighborhood Search for the Clustered Vehicle-routing Problem." *European Journal of Operational Research* 270 (1): 118–131.
- Huang, S.-H., and P.-C. Lin. 2015. "Vehicle Routing–scheduling for Municipal Waste Collection System under the Keep Trash Off the Ground Policy." *Omega* 55: 24–37.
- Jorge, D., A. P. Antunes, T. R. P. Ramos, and A. P. Barbosa-Povoa. 2022. "A Hybrid Metaheuristic for Smart Waste Collection Problems with Workload Concerns." *Computers & Operations Research* 137: 105518.
- Pop, P. C., I. Kara, and A. H. Marc. 2012. "New Mathematical Models of the Generalized Vehicle Routing Problem and Extensions." *Applied Mathematical Modelling* 36 (1): 97–107.
- Psaraftis, H. N. 1995. "Dynamic Vehicle Routing: Status and Prospects." *Annals of Operations Research* 61 (1): 143–164.
- Ramos, T. R. P., C. S. de Morais, and A. P. Barbosa-Povoa. 2018. "The Smart Waste Collection Routing Problem: Alternative Operational Management Approaches." *Expert Systems with Applications* 103: 146–158.
- Zhao, J., and F. Zhu. 2016. "A Multi-depot Vehicle-routing Model for the Explosive Waste Recycling." *International Journal of Production Research* 54 (2): 550–563.

**Algorithm 2** Path construction

**Require:** A depot and the set of bins of a cluster;
**Ensure:** The optimum tour for the $r^{th}$ ant of the cluster;

Step-1: Start;
Step-2: Set $E = \{1, 2, ...., N\}$, $l = 1$ and $E' = \{2, 3, ...., N\}$. Node 1 to $N$ in $E$ represent a depot, filled bins, and neighboring bins, respectively;
Step-3: $x_{rl}$= a random element from the set $E'$;
Step-4: $i = x_{rl}$;
Step-5: Set $WL$=0; //$WL$ means waste method
Step-6: while $(((L - WL) >= L_i)$ *and* $(l < N))$
{
$WL = WL + L_i$;
Set $E'$=$E'$-$\{i\}$;
Let bin $i$ be the present position of an ant. Then the next bin $j \in E'$ is selected by the ant, with probability $p_{ij}$ given by the formula

$$p_{ij} = \frac{\tau_{ij}^{\delta_1}}{\sum\limits_{j \in E'} \tau_{ij}^{\delta_1}}$$

where $\delta_1$ is a user-defined parameter that controls the relative importance of pheromone concentration. A roulette-wheel selection process is used for this parameter.
$l = l + 1, i = j$;
}
Step-7: Print the optimal tour of the cluster;
Step-8: End.

**Algorithm 3** k-means-ACO

**Require:** Problem data, ACO parameters, number of clusters ($|M|$)
**Ensure:** The optimum tour in each cluster

Step-1: Start;
Step-2: Initialize a set of bins and the number of clusters ($|M|$);
Step-3: Execute a k-means algorithm (subsection 3.1);
Step-4: Start ACO;
Step-5: Identify the fill level information above $TFL$;
Step-6: Distribute the total number of ants;
Step-7: Determine pheromone initialization (subsection 3.3.2);
Step-8: Execute path construction (subsection 3.3.3);
Step-9: Perform pheromone evaporation (subsection 3.3.4);
Step-10: Execute pheromone updating (subsection 3.3.5);
Step-11: If pheromone updating occurred, go to step-8;
Step-12: Find the optimal tour in each cluster;
Step-13: End.

# Appendix

## B. Computation results of the proposed algorithm



**Table 5.** Optimum routing plan in a week (Instance 2)

| Day | No. of trip | Filled bin location sequence cluster wise | | | | | Total load (kg.) | Routing cost ($) | Penalty cost ($) | Total cost ($) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | cluster-1 | cluster-2 | cluster-3 | cluster-4 | cluster-5 | | | | |
| | 1 | 46, 49, 19, 40 | 48, 1, 13, 31 | 37, 10, 18 | 33, 44, 51, 15 | 45, 23, 27 | 583.31 | 143.00 | | |
| 1 | 2 | 50, 7 | 42, 28, 25 | 6, 39, 36 | 26, 32, 5 | 22, 17, 4, 34, 16 | 512.88 | 118.28 | | 475.38 |
| | 3 | 47, 49, 30, 19, 40 | 48, 13, 21, 29, 2 | 9, 18, 10, 43 | 44, 51, 24, 20, 15, 41 | 45, 38, 8, 27, 35 | 797.79 | 214.10 | | |
| 2 | 1 | 9, 6, 43, 18 | 2, 3, 31 | 24, 47, 14, 30, 40 | 32, 41, 15 | 38, 45, 4, 23, 27, 16, 8 | 705.85 | 220.07 | 18.90 | 450.72 |
| | 2 | 39, 36 | 48, 1, 13, 21, 29 | 51, 46, 50, 49, 11, 7, 19 | 20, 37, 10, 5, 35 | 33, 26, 42, 22, 17, 12, 34, | 900.56 | 201.75 | | |
| 3 | 1 | 13, 25, 16, 4 | 20, 32, 35 | 26, 33, 50, 30, 2, 1, 48 | 9, 37 | 6, 43, 7, 11, 19 | 684.52 | 220.63 | 36.98 | 477.50 |
| | 2 | 45, 22, 28, 23, 12, 34 | 38, 8, 27, 5, 41, 15 | 24, 44, 51, 46, 14, 29, 3 | 18, 10 | 49, 47, 40, 39, 36 | 843.27 | 203.89 | | |
| | 1 | 51, 15, 10, 18 | 33, 22, 45, 4, 12, 34, 25 | 50, 30 | 32, 41, 5, 27 | 6, 39, 36, 40 | 672.97 | 158.8 | | |
| 4 | 2 | 24, 20, 37 | 26, 42, 23, 31 | 14, 2, 21 | 38, 8 | 49, 47, 11, 7, 43(N) | 540.19 | 123.00 | | 659.50 |
| | 3 | 44, 51, 9, 10 | 33, 45, 17, 12, 34, 16, 25 | 50, 30, 1, 29, 3 | 41, 5, 35, 27 | 6, 39, 36, 40 | 768.59 | 218.78 | | |
| | 4 | 24, 20, 15, 18 | 42, 22, 4, 23, 28 | 48, 13, 21, 14 | 32, 38 | 46, 49, 11, 19 | 610.08 | 158.92 | | |
| 5 | 1 | 38, 8, 27, 35, 34 | 6, 39, 7, 49, 19, 30 | 1, 14, 21, 3, 13 | 20, 9, 37, 32 | 42, 23, 4, 25, 31 | 800.85 | 330.36 | 15.90 | 461.60 |
| | 2 | 5, 16 | 24, 44, 51, 47, 11, 40, 36 | 48, 2, 29 | 41, 15, 10, 18 | 26, 33, 22, 45, 17, 12, 28 | 737.27 | 101.34 | | |
| | 1 | 20, 9, 18, 15 | 14, 21 | 44, 47, 7, 43, 19 | 22, 17, 38, 8 | 31, 25 | 547.26 | 147.53 | | |
| 6 | 2 | 33, 26, 32, 10, 37 | 42, 50, 30, 2, 3, 1 | 24, 46, 11, 40, 39, 6, 36 | 45, 4, 12, 23, 16, 27, 35 | 28, 13 | 868.24 | 262.98 | 14.90 | 640.34 |
| | 3 | 20, 9, 18, 15, 41, 5 | 48, 14, 29, 21 | 44, 51, 49, 47, 7, 43, 19 | 22, 17, 34, 38 | 31, 25 | 745.82 | 214.93 | | |
| | 1 | 50, 14, 40 | 45, 17, 12, 34 | 32, 18 | 48, 2, 25 | 26, 24, 43, 39, 36 | 548.30 | 136.49 | | |
| 7 | 2 | 49, 47, 11, 30 | 38, 8, 27 | 15, 10 | 42, 3, 29 | 33, 44, 51, 9 | 517.27 | 124.36 | | 431.64 |
| | 3 | 46, 50, 14 | 22, 45, 23, 12, 34, 16, 35 | 32, 41, 37, 18 | 1, 13, 31, 25, 21 | 26, 20, 6 | 710.82 | 170.79 | | |
| | | | | | | Total | 12512.53 | 3470 .00 | 86.68 | 3556.68 |

# Thank you

# Q & A

ENGINEERING
COLLEGE OF ENGINEERING
SEOUL NATIONAL UNIVERSITY

Supply Chain Management Laboratory