Optimal transportation planning of classified domestic garbage based on map distance

Optimal Transportation Planning of Classified Domestic Garbage Based on Map Distance

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Abstract

Domestic garbage classification is required in many cities, however, optimal transportation of classified garbage has not been widely studied. Here, the optimal transportation of the classified domestic garbage from the waste transfer center to the garbage disposal station is considered. The locations of waste transfer centers, map distances between these waste transfer centers, different types of garbage disposal stations and the quantity of waste in different areas are used as key factors for constructing a weighted graph model. This study considers Nanshan District in Shenzhen, China as a case study. Solutions were obtained by applying the proposed model to the area using data from 2011. To achieve the decision goal of identifying feasible traveling distance and time for each trash truck, the number of routes considered for recyclable waste transportation was no less than 5; for non-recyclable waste transportation was no less than 2; and for harmful waste transportation was 4. The study provides an auxiliary management tool for optimal municipal solid waste disposal that improves the sustainability of the system.

Keywords: Classified garbage transportation; Optimal transportation scheme; Traveling Salesman Problem; Waste disposal; Environmental management.

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1. Introduction

Municipalities have increased their interest in waste management in recent years to improve environmental outcomes by recycling waste (Thi et al., 2015). A common waste management scheme consists of two stages (Zhang et al., 2010). The first stage is the collection of garbage from residential houses for transport to the nearest Waste Transfer Center (WTC). Commonly, domestic garbage is classified into corresponding garbage bins in front of houses by residents, which is then collected by truck for transfer to the WTC. The second stage is that transferring the garbage from WTC to the nearest garbage Disposal Station (landfill station, recycling center and harmful waste management center) based on their classification.

This process links to complex tasks such as the route and timing on transportation networks, and may involve different options. This has led to research in exploring the optimal location of collection centers (Yan, 2013), analyzing the capacities of the bins in each collection center (Ghiani et al., 2012) and on waste storage at WTC (Erfani et al., 2019). Another key issue is to find the optimal transportation route for domestic garbage from each WTC to the garbage disposal station. This paper focuses on this optimal transportation issue, where an optimal waste collection and transportation scheme can minimize the length of each route, and effectively reduces cost (Das and Bhattacharyya, 2015) by reducing fuel consumption.

Previous literature has explored this issue and proposed related solutions (Dai et al., 2011; Periet al., 2018). However, some reviews indicate that there are two main problems that require further research (Belien et al., 2011; Lu et al., 2017). The first problem is that little attention has been paid to differentiating the transportation for classified garbage. It is important that different types of garbage should not be transported by the same truck. The reasons include:

- Toxic, inflammable and explosive waste should be transported by special truck by expert services; and
- Different types of garbage go to different disposal sites.

The second problem is the lack of discussion on trucks schedules. The activities of urban garbage collection, transportation and storage accounts for 60% - 80% of the total cost of the waste treatment system. Based on the principles of minimum cost and maintaining hygiene standards, it is of great significance to design efficient and simple transportation routes for collection and recovery systems (including distribution points and processing capacity of recycling stations, times of clearance and transportation, staff arrangement, etc.). Particularly, when the collecting route distance is long or the waste to be transported is large, the evaluation of the workload of the garbage transportation and the estimation of how many trucks with the corresponding hours that should be assigned are important issue to achieve cost efficiency.

This paper aims to construct and test a model which generates optimal transportation planning of classified domestic garbage. The specific objectives of this work are to:

(1) establish an optimal transportation model for classified domestic garbage. The model uses practical factors including the number of garbage disposal stations, locations of WTCs, map distance and the quantity of waste in each WTC;

(2) suggest an optimal transportation plan for classified domestic garbage. In the solution, each WTC should be visited one or more times; and

(3) evaluate the workload of each route.

2. Literature review

Waste transportation has been a popular research topic in the past few decades (Belien et al., 2011; Ghiani et al., 2012; Lu et al., 2017). In general, an optimal waste collection and transportation scheme effectively reduces the cost for waste collection and transportation, and tends to focus on minimizing the length of each waste collection and transportation route. Studies related to this topic can be mainly divided into three categories in respect of the number of disposal sites (i.e. the number of start vertices) and optimal closed routes (i.e. the number of salesman in Traveling Salesman Problem (TSP)):

(1) single-disposal station, single-route;

(2) single-disposal station, multiple-routes;

(3) multiple-disposal stations, multiple-routes.

2.1. Single-disposal station, single-route

Most literatures focus on this category. The problem of minimizing the length of each waste collection and transportation route is often transformed to TSP), which is a classical combination optimization problem (Černý, 1985). It is proven that TSP is a Non-deterministic Polynomial (NP) completion problem, and there is no polynomial time algorithm for obtaining its exact solution (Helsgaun, 2000). However, a small scale TSP that includes thousands of vertices can be solved in an acceptable computing time using modern computers. For example, the Branch-and-Cut algorithm was introduced to solve a symmetric TSP which had up to 2392 nodes (Padberg and Rinaldi, 1991).

To solve the TSP efficiently, approximate algorithms (including heuristic) were proposed (Lu et al., 2017). These algorithms are generally simple and fast to converge, and include the Monte Carlo algorithm (Černý, 1985), the guided variable neighborhood thresholds metaheuristic (Nuortio et al., 2006), the Lin-Kernighan algorithm (Lin and Kernighan, 1973; Helsgaun, 2000), the membrane-inspired algorithm (He et al., 2015), and the Tabu search algorithm (Vogt et al., 2007; Chaerul and Mulananda, 2018).

2.2. Single-disposal station, multiple-routes

For a big city, there may be a large number of WTCs but only one garbage disposal station. A feasible solution is that several garbage trucks start from the disposal station and end at the station, with each waste collection center visited by at least one truck. This problem is similar to a traditional single depot, multiple traveling salesmen problem (SDMTSP). In the early days, SDMTSP was transformed to standard TSP (Hong and Padberg, 1977; Jonker and Volgenant, 1988). For a small scale TSP, there are exact search schemes for the Min-max version of SDMTSP in which the objective is to minimize the length of the longest route (Frana et al., 1995).

Since the truck scheduling problem is Non-deterministic polynomial – hard problem (Li et al., 2008), heuristic algorithms were proposed in recent years, such as the Tabu search heuristic (Frana et al., 1995), Genetic Algorithms (Carter and Ragsdale, 2006) and the Ant Colony algorithm (Karadimas et al., 2008). This idea was suggested for optimising garbage collection routes in Chicago (Eisenstein and Iyer, 1997). As an optimization problem, it can be formulated as a mathematical programming model which is illustrated in some studies (Martinez-Sykora and Bekta, 2015; Sarin et al., 2014).

2.3. Multiple-disposal stations, multiple-routes

If there are several disposal stations, the solution is to find multiple routes. This type of problem is similar to a traditional multiple depots, multiple traveling salesmen problem (MDMTSP) which can be transformed to a single, asymmetric TSP (Oberlin et al., 2009) and solved with LKH heuristic algorithm (Helsgaun, 2000). Other solutions include transforming a complicated graph into a simplified one (Hou and Liu, 2012), swarm intelligence approaches (Pandiri and Singh, 2016), Genetic Algorithms (Zhou et al., 2018), the ArcGIS Network Analyst and the Ant Colony System (Karadimas et al., 2008).

Some methods use a Geographic Information System (GIS) to get real-time data from the road (Karadimas et al., 2008; Nguyen-Trong et al., 2017; Singh, 2019), so the practical application prospect of these methods is enhanced. For instance, the Science and Technology Commission of Shanghai Municipality funded a project to establish a dynamic intelligent logistics system by integrating key Internet of Things (IoT) technologies and information technologies developed in recent years, including RFID precise position and automatic identification, on-car dynamic transduction and measurement, GPS position, and GPRS mobile transmission (Shuang et al., 2015).

The above methods inspired this study to find an optimised solution for the classified waste transportation. Most of the above methods have the following assumptions in common: the graphical model for TSP is a complete graph; garbage in WTCs is not classified; each WTC is visited exactly once by one and only one truck. However, these assumptions do not reflect the practical situation. This paper does not have the above assumptions. Instead, this study establishes different graphical models for transporting different types of waste for various scenarios.

3. Material and method

3.1. Statement of problem and research approach

In some cities, classified domestic garbage is sorted by residents and collected by trucks for transportation to the nearest WTC (Li et al., 2019). Then the classified garbage is transported to disposal stations. In this section, graphical models are proposed that apply to the Nanshan district in Shenzhen, China, where garbage is classified into three categories (recyclable waste, harmful waste and landfill waste). Considering that the number of disposal stations and positions for each category of waste are different, this paper establishes separate optimal transportation models for each waste category.

For each waste category, a corresponding optimal transportation plan based on an integrated approach and describes with a graphical model is proposed. Then it is solved with a heuristic algorithm by solving a Revised Traveling Salesman Problem (RTSP). The road distance between any two WTCs is measured using GPS information. A graphical model is used to represent WTC positions and the related neighbor relationship. The optimal transportation scheme for classified domestic garbage is presented by solving the RTSP, followed with the corresponding decision analysis. This study assumes that there is no limitation on the number of trucks.

3.2. Data collection

Nanshan District in Shenzhen is taken as the case study for demonstrating the model. Data used in the proposed graphical models include road distances between WTCs, the quantity of waste in each WTC, the positions of each WTC and each garbage disposal station. The positions of WTCs were obtained from Google map. Thirty-eight WTCs were found in Nanshan district, and were used in the graphical models. The road distance between any two WTCs was measured by Google map and this distance is used as the weighted edge in the graph as shown in Figure 1.

The data for the quantity of waste in each WTC was obtained from 2011 Shenzhen Cup (National University Student) Mathematical Modeling Summer Camp[†]. This paper visualizes the information with a bubble graph. As shown in Figure 2, the bigger disc represents a larger amount of garbage. The number near the vertex is the amount of the waste that should be transported to the disposal station from the transfer station. The total amount of waste was 769 ton, comprised of 60% recyclable waste, 10% harmful waste and 30% landfill waste.

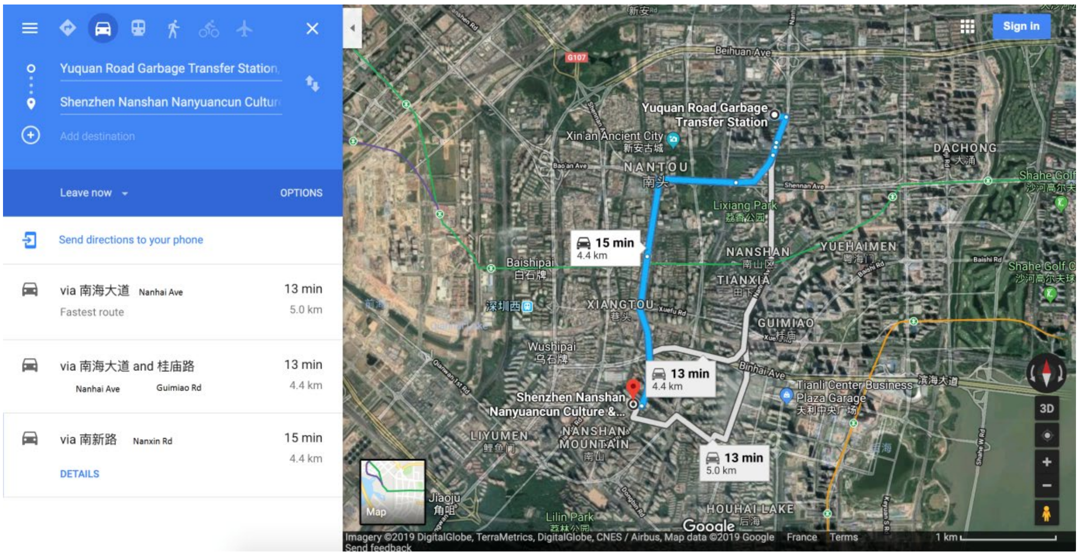


Figure 1: Distance between two WTCs was measured by Google map.

[†]http://mcm.edu.cn/html_cn/node/cc3aa1fc07fe689c77198eaba613678d.html

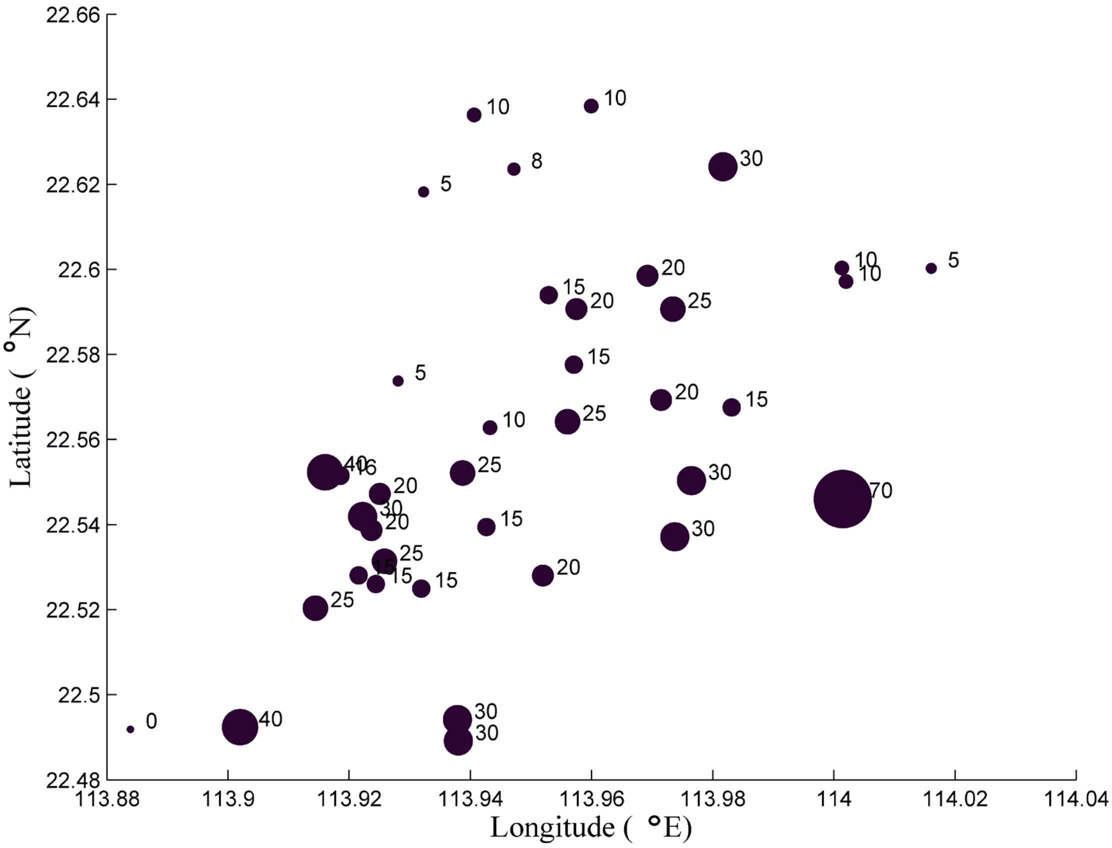


Figure 2: The quantity (ton) of waste received at each WTC. The number by the vertex is the annual amount of waste in the WTC while the size of the circle corresponds to the quantity of waste received. The values on the *x*-axis relate to longitude and *y*-axis to latitude.

From the data, it can be found that garbage disposal stations in Nanshan include: one Recycling Center (RC) for recyclable waste which accompanies the vertex 38, two Landfill stations (LF) for non-recoverable waste which are located at vertices 17 and 37 respectively, and four Harmful Waste Management Centers (HWMC) for harmful waste which are located at vertices 3, 16, 24 and 29 respectively, as shown in Figure 3. Garbage is transported to the disposal stations (RC, LF or HWMC) according to their classification.

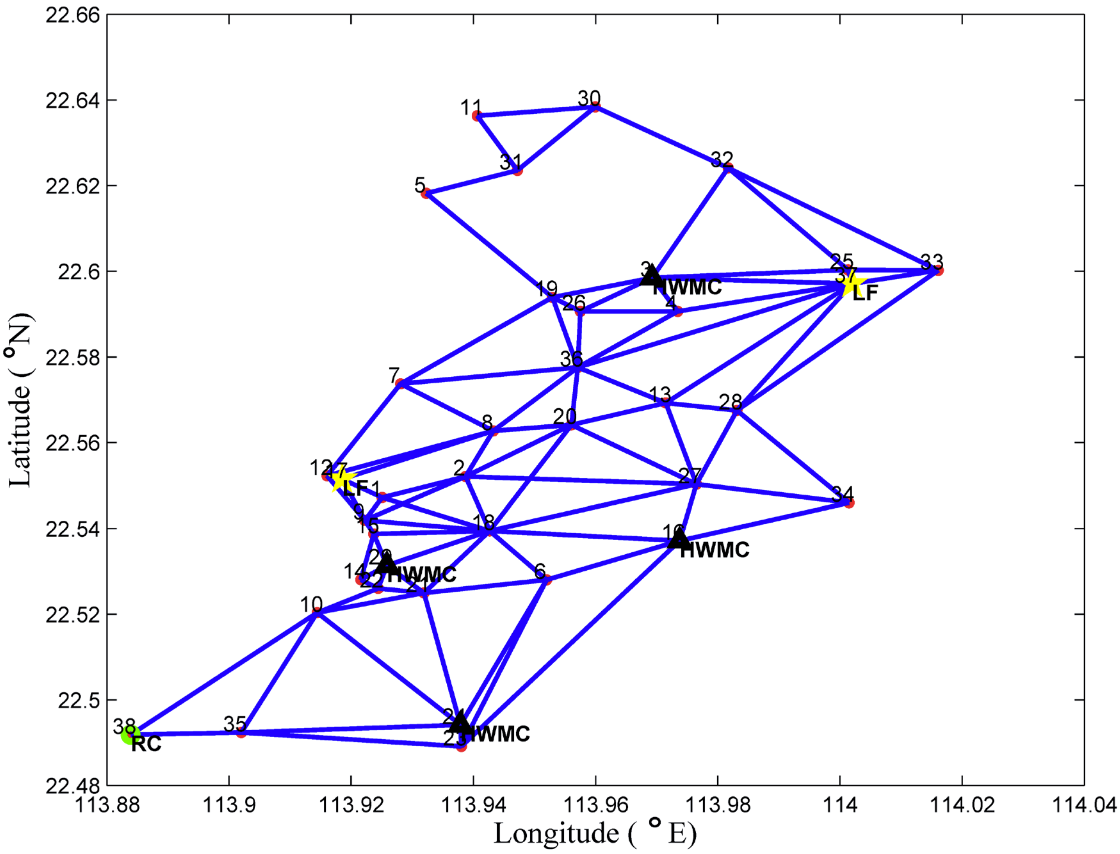


Figure 3: A graphical model. The number by the vertex is the ID for the WTC.

3.3. Graphical model

The graphical model is denoted by $G = \langle V, E \rangle$, where V is the set of vertices. Each vertex in the graph is a WTC. Let n be the number of WTCs, i.e. $V = \{v_1, v_2, ..., v_n\}$ and v_i be the i[th] WTC. In the graphical model, E is the set of all edges and the number of edges in the set is denoted as $|E|$ or m. An edge e_{ij} is built between vertex v_i and v_j if there is a truck road in the map between two WTCs corresponding to v_i and v_j, and no other WTC located in the road between them. All vertices and edges consist of a graphical model G (Figure 3). In Nanshan case, there are 38 (n=38) vertices and 89 (m=89) edges.

The graphical model is a weighted graphical model, and the weight w_{ij} of an edge e_{ij} is the distance d_{ij} between vertex v_i and v_j. Therefore, the graphical model can be represented as $G = \langle V, E, W \rangle$, where W denotes the set of the weights of edges.

3.4. Transportation route of recyclable waste

When there is only one RC in the transportation network, all recyclable waste is transported to the same *RC*. This optimal problem belongs to the case 1: *Single-disposal* *station, single-route*. In order to find the optimal transportation route, the municipal domestic garbage transfer question is transformed to a RTSP, which can be solved with a Tabu search algorithm (Vogt et al., 2007) and Genetic Algorithm (Carter and Ragsdale, 2006). This is a single source (i.e. the vertex 38, labeled RC) modified TSP. The mathematical programming model can be presented as follows,

$$\begin{cases} \min \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij} x_{ij} \\ \text{s.t.} \quad \frac{1}{2}\sum_{j=1}^{n} x_{ij} - v_i = 0, \quad i = 1,2,\cdots,n \\ v_i > 0, i = 1,2,\cdots,n \\ v_i \text{ connecting to RC}, i = 1,2,\cdots,n \\ x_{ij} \in N, v_i \in N, \forall i,j \in \{1,2,\cdots,n\} \end{cases} \tag{1}$$

In the objective function of equation (1), the number of d_{ij} is n^2 although the undirected graph (Figure 3) has only m ($m < n^2$) edges. If there is no edge between vertex v_i and v_j, $d_{ij} = \infty$, the number of unknown integer variables x_{ij} is also n^2. After solving the mathematical programming model as built in equation (1), the values of all x_{ij} can be obtained, which is the number of times the road has been visited by a garbage truck. If $x_{ij} = 0$, the edge e_{ij} does not belong to the optimal route, so a garbage truck does not visit the road between the ith WTC and the jth WTC.

In the constraints of equation (1), $\frac{1}{2}\sum_{j=1}^{n} x_{ij} - v_i = 0$ means that each vertex can be visited more than once. This is different from traditional TSP (Das and Bhattacharyya, 2015) where the constraint was $\sum_{j=1}^{n} x_{ij} = 2$. v_i connecting to *RC* is a necessary constraint which is used for voiding a broken route.

3.5. Transportation route of non-recoverable waste

In this graphical model, all non-recoverable waste go to the two LFs (labeled *LF* in Figure 3) according to the nearest neighbor principle. As a result, all vertices are clustered into two groups. Garbage is transported to LF_1 (located at vertex 17) if the WTC in the group 1 (G_1), or is transported to LF_2 (located at vertex 37), denoted G_2. For this purpose, firstly the geographic distances from every vertex to LF_1 and LF_2 are calculated respectively. Then all vertices v_i are classified into two groups according to the rule,

$$\begin{cases} v_i \in G_1, d(v_i, LF_1) \le d(v_i, LF_2) \\ v_i \in G_2, d(v_i, LF_1) > d(v_i, LF_2) \end{cases} \tag{2}$$

where $d(v_i, LF_j)$ is the distance from vertex v_i to LF_j(j=1, 2). The solution of each group is obtained with equation (1).

Note that this problem is a *Multiple-disposal stations, Multiple-routes* problem.

3.6. Transportation route of harmful waste

Considering the fact that harmful waste cannot be directly disposed to LFs and it is not good to transport harmful waste long distances, the number of HWMC for harmful waste should be more. In Nanshan, there are four large HWMCs, which are located at four vertices: 3, 16, 24 and 29 (Figure3). Taking nearby transportation and disposal into account, all vertices are clustered into four groups (G_i, i=1, 2, 3, 4) directing to four HWMCs respectively based on the rule of nearest neighbor. That is, the garbage of each WTC is transported to its nearest HWMC. For this purpose, firstly the geographic distance from every vertex v_i(i=1, 2..., n) to each HWMC is calculated. Then all vertices v_i are classed into four groups according to the rule,

$$j^* = \arg\min\{d(v_i, HWMC_j), j=1, 2, 3, 4\} \quad (3)$$

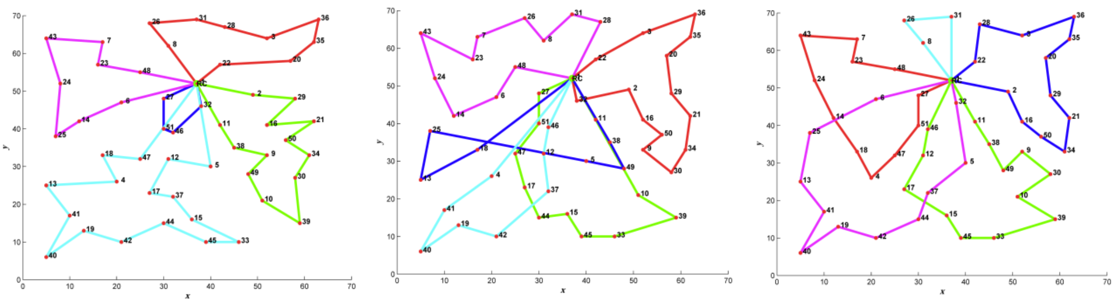
where $d(v_i, HWMC_j)$ is the distance from vertex v_i to $HWMC_j$. With Equation (3), the vertex v_i will be categorized to the group G_{j^*}.

For each group, the RTSP method with equation (1) is employed to obtain the optimal solution. This optimisation problem belongs to the case 3: *Multiple-disposal stations, Multiple-routes*.

3.7. Comparison

In order to evaluate the efficiency of the proposed method, a TSP data, eil51.tsp, from the TSPLIB benchmark [‡] was used for comparison. Two representative methods, Maximum Independent Sets on Massive Graphs (MISoM) (Liu et al., 2015) and an Ant Colony Systems (ACS) (Necula et al., 2015), are tested with this data. The routes obtained by MISoM, ACS and the proposed method are shown respectively in Figure 4. All three methods work well. The sum of the distances of the five routes are 536.565 km, 615.19 km and 539.88 km. In the view of workload balance, the best is ACS because five paths are almost the same length in its result. However, both MISoM and the proposed method are easier to find the approximate optimal solution than ACS.

[‡] https://wwwproxy.iwr.uni-heidelberg.de/groups/comopt/software/TSPLIB95/



(a) **MISoM** (b) **ACS** (c) **The proposed method**

Figure 4: Comparison of three algorithms. Both *x*-axis and *y*-axis are coordinates and have no unit.

4. Results

After solving the graphical model, results show that for recyclable waste transportation, it is achievable in one day in Nanshan with no less than five routes; for landfill waste, it is feasible with two landfill stations using two optimal routes; for harmful waste, it is also feasible with existing four HWMC's according to the four optimal routes.

4.1. Solution for recyclable waste transportation

The model for recyclable waste transportation was solved by the Genetic Algorithm (Carter and Ragsdale, 2006) using data from Nanshan district. The solution for one optimal path is as shown in Figure 5. The start and the end of the path is the same point, the vertex 38, labeled *RC*. The length of the optimal path is 122.30 km. The transported waste is 461.40 ton.

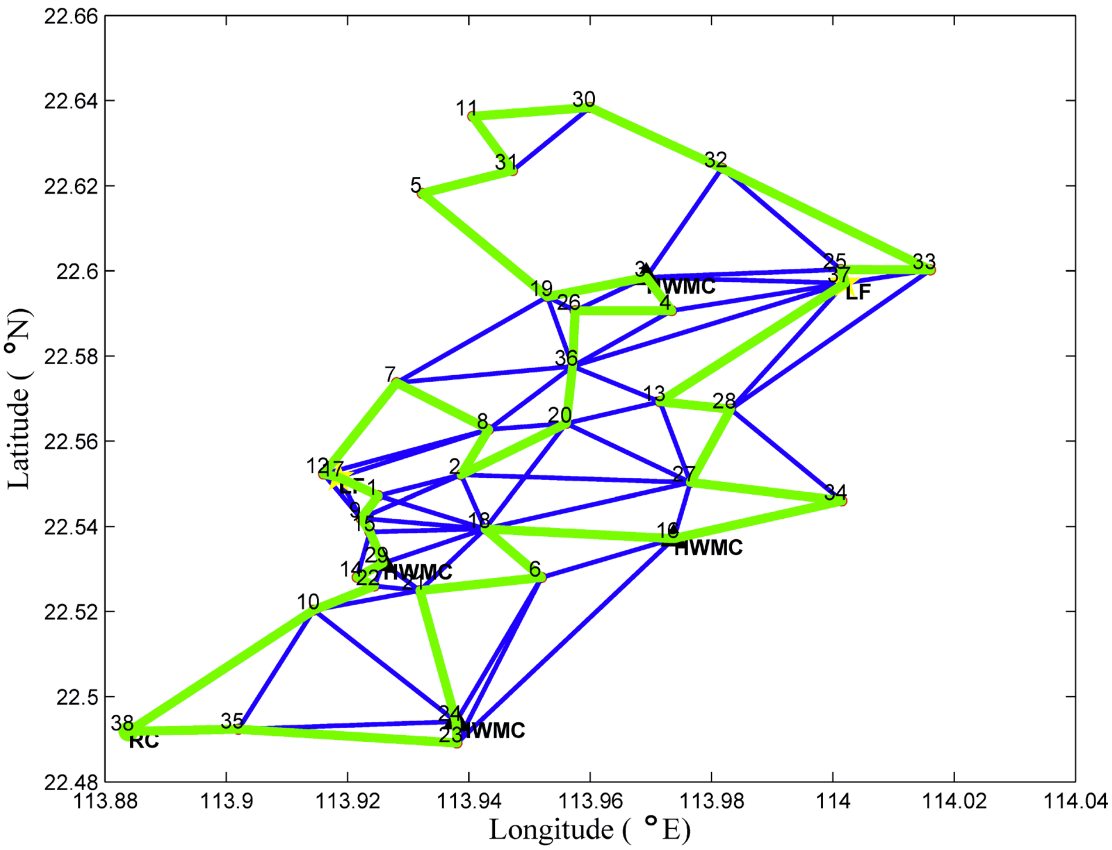


Figure 5: The optimal transportation paths of recyclable waste.

The result shows the total distance of the route is too long and the amount of garbage weight is too large. If the speed of a truck is 20 km/hour, it would take 6 hours for a round trip. Assuming the maximum load of garbage truck is 10.0 ton, 47 round trips are required for taking all the above garbage of WTCs (461.40 tons) to the RC. This is a big challenge for the waste management department of Nanshan district. Therefore, the alternative is to use multiple routes, i.e. *Single-disposal station, Multiple-routes*. Assuming the route number be five, then five routes for recyclable waste transportation are obtained using the proposed method, and the information of routes is listed in Table 1. According to Table 1, the longest distance for the route is 73.9 km (route No.5) which takes a truck less than 4 hours in one round trip. This is feasible in practice according to the research from Nguyen-Trong et al. (2017). Route No.2 takes the heaviest workloads among the five routes. There are 131.08 tons of wastes that need to be transported by this route, which can be finished in one day by several trunks.

Table 1: Information about five routes for the transportation of recyclable waste.

#	Dist. (km)	No. of Stops	Path (nodes)	Waste (ton)
1	37.5	17	38, 10, 21, 22, 14, 29, 15, 9, 12, 17, 1, 9, 15, 29, 22, 10, 38	62.433
2	71.9	21	38, 10, 21, 6, 16, 34, 27, 28, 13, 37, 25, 33, 25, 37, 4, 36, 20, 18, 21, 10, 38	131.08
3	41.8	11	38, 10, 21, 6, 16, 18, 6, 24, 23, 35, 38	82.417
4	52.5	20	38, 10, 22, 29, 15, 9, 2, 8, 20, 36, 26, 19, 7, 12, 9, 15, 29, 22, 10, 38	82.833
5	73.9	21	38, 10, 21, 18, 20, 36, 26, 19, 5, 31, 11, 30, 32, 3, 4, 36, 20, 18, 21, 10, 38	90.633

Note: Dist. = distance.

4.2. Solution for non-recyclable waste transportation

The model for non-recyclable waste transportation was solved using the proposed method with Nanshan Data. The results for each route are listed in Table 2. The result from the table 2 shows the length of round trip is moderate, and the total quantity of waste for the landfill is accorded for each.

Table 2: Information about the two routes for the transportation of non-recyclable waste.

#	Dist. (km)	No. of Stops	Path (nodes)	Waste (ton)
1	66.2	22	17, 12, 7, 8, 20, 2, 18, 16, 6, 24, 23, 35, 38, 10, 21, 22, 14, 29, 15, 9, 1, 17	135.3
2	60.4	18	37, 4, 3, 32, 30, 11, 31, 5, 19, 26, 36, 13, 27, 34, 28, 33, 25, 37	95.4

4.3. Solution for harmful waste transportation

The model for harmful waste transportation was solved using the method with equation (3). Four optimal routes are listed in Table 3. According to the table, the task of waste transportation for each route can be estimated and the schedule of transportation can be well arranged. Compared to the traditional method, the task through this method can be managed more effectively considering the time and distance of each route. As a result, it can reduce fuel consumption for improved environmental performance.

Table 3: Information about four routes for the transportation of harmful waste.

#	Dist. (km)	No. of Stops	Path (nodes)	Waste (ton)
1	53.7	17	3, 4, 26, 36, 20, 8, 7, 19, 5, 31, 11, 30, 32, 33, 25, 37, 3	22.3
2	25.9	8	16, 6, 18, 27, 13, 28, 34, 16	20
3	12.4	5	24, 38, 35, 23, 24	10
4	53.2	12	29, 15, 9, 12, 17, 1, 2, 10, 21, 22, 14, 29	24.6

5. Conclusion

This paper proposed a method to generate optimal transportation planning of classified domestic garbage. The method uses practical factors to construct a weighted graphical model. An optimal transportation plan of classified domestic garbage was found by solving the model with RTSP. The results from applying the model to Nanshan District in Shenzhen China demonstrated that:

- Consideration of the quantity of waste and length of each route, the transportation plan proposed by solving the model is practical and feasible.
- The application of the proposed model to Nanshan District in Shenzhen China has presented more feasible and efficient solution compared to traditional optimization methods.
- Some WTCs should be visited more than one time (rather than only once in traditional methods) because of situation at Nanshan District which are presented in Table 1.
- Different graphical models for different types of waste were established to achieve feasible outcomes.

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