Optimization of municipal solid waste transportation by integrating GIS analysis, equation-based, and agent-based model

Khanh Nguyen-Trong, Anh Nguyen-Thi-Ngoc, Doanh Nguyen-Ngoc, Van Dinh-Thi-Hai

Optimization of municipal solid waste (MSW) collection and transportation becomes one of the major concerns in the MSW management system design, because the existing MSW management systems have high cost of collection and transportation approximately 80–90% and 50–80% in low income and middle income countries respectively (Das and Bhattacharyya, 2015). Generally, in urban areas different waste sources scatter throughout the areas in unorganized way that increases the cost of waste collection and transportation (Medina, 2008). Therefore, an effective strategy for waste collection and transportation can significantly reduce the cost of waste collection and transportation.

Recently, many models have been proposed in order to optimize the collection and transportation on the whole garbage truck network. Geographical Information System (GIS) to search the best path is used. GIS is a suitable tool for these kinds of study as it is capable of storing, retrieving, analyzing and applying to a large amount of data as well as output visualization with response time (Malakahmad et al., 2014).

For instance, Ebistu and Minale (2013) presented a study to select potential locations for suitable solid waste dumping sites for Bahir Dar Town. Firstly, the main data is collected from different sources, including field surveys, observation, the Internet, reports, books, journals, governmental institutions and other documents. Secondly, the data is integrated into ArcMap tool to create the map of the study area. The map was prepared by overlay and suitability analysis of GIS, remote sensing techniques and multi criteria analysis methods.

In the work of Hareesh et al. (2015), a solid waste management assessment model, using GIS analysis tool (QGIS), is proposed and used as a decision support tool by municipal solid waste management authorities for daily operations such as collection/transport and fuel consumption planning.

However, these proposed approaches do not consider dynamic and temporal issues of urban habitants and traffic. They only introduce solutions based on static states (the fixed traffic flow). However, the traffic flow changes dynamically and is affected by many factors such as timing, behavior of traffic participants, and weather conditions (Das and Bhattacharyya, 2015). To overcome the weakness of GIS, the agent-based model (ABM) is proposed.

Recently, there have been many models and tools proposed to deal with this problem. Many of them are agent-based models.
In which, intelligent agent and multi-agent system seem to be suitable for simulate transportation network at micro level. Each traffic participant is thus modelled as an intelligent agent. It can observe the other and obstacles to change its own speed as well as direction to go to its destination as fast as possible. The transportation network therefore could be modelled as a multi-agent system in which each agent has its own personal goal (the destination) and they have to coordinate and/or interact with each other in order to prevent accidents from happening.

The problem of the MSW collection and transportation can be considered as a conventional vehicle routing problem in which the shortest path used by the vehicle from the waste sources to disposal sites will be found (Maimoun et al., 2013; Mes et al., 2014; Das and Bhattacharyya, 2015; Haghshenas et al., 2015; Buenrostro-Delgado et al., 2015; Son and Louati, 2016). However, it has some properties that is different from the conventional one: (i) the vehicles that are used to collect the waste has a limited capacity; and (ii) the quantity of waste at each collecting point is unpredictable (Nambiar and Idicula, 2013).

Harie, Dolney (2014) presented a study that models the freedom of residents in choosing the collection companies, in order to demonstrate the inefficiency of the actual system and also propose the solution to ameliorate the system. The model based on two component of ArcGIS: (i) the GIS spatial analyst Vehicle Routing problem (VRP) function through ESRI’s ArcGIS network analyst; and (ii) StreetMap Premium for ArcGIS to model traffic flow.

For example, Karadimas et al. (2006) presented a model to deal with the complexity of the field. The authors based on the integration of GIS data and Multi-Agent Simulation to create an intelligent decision support system. The garbage truck, the most important one, is modelled as an agent that has four important characteristics and behaviors: limited waste capacity, limited time on the field, collection of waste bins, and assigned paths.

In the work of Nambiar and Idicula (2013), a real-time and dynamic agent-based system is proposed in order to find an optimized travel plan for waste collection. The agents in this model collect and send real-time data on the capacity utilized and remaining capacity of the vehicle to the system. This information combining with GIS data allows finding suitable travel plans for each vehicle.

In general, the combination of GIS and Multi-agent modelling and simulation complements and enriches the optimized solution of the MSW collection and transportation in urban areas. It allows us not only to capture the situation of waste collection, but also to test in different scenarios of waste management, including the routing, the position of landfills and so on (Huang and Lin, 2015).

In Vietnam, there are also some researches on modelling and simulation of urban transportation network. For instance, Nguyen et al. (2013) proposed an algorithm to optimize the routing at system level of a transportation network. Each individual follows a recommended path that depends on the current traffic capacity and participant preferences such that the overall throughput of the traffic network is maximized and the participants’ preferences are respected.

Nguyen et al. (2015) also proposed an agent-based model for simulation of landslide collection in the National Road No. 6 of Vietnam. However, in contrast with the previous algorithm, there are two different kinds of the vehicle in this model. The first one relates to the conventional vehicles (cars, trucks, and buses, etc.). They act as each individual in the previous algorithm. While the second one is the rescue vehicle, which is responsible for cleaning and repairing roads, where the landslide occurs. The algorithm in this model is not too complex because of the simple road network.

Generally, regarding to the traffic network, existing works in the literature just propose solutions in a static context (the fixed traffic flow or not including it) (Anghinolfi et al., 2013; Das and Bhattacharyya, 2015; Kinobe et al., 2015). They have not integrated the GIS analysis, the equation-based, and the agent-based model to form a dynamic solution. This paper will address this integration, as show in Fig. 1. Firstly, the optimized plan is developed in a static context, and then it is integrated into a dynamic context using multi-agent based modelling and simulation.

There are two kinds of individual in our agent-based mode. The first one is like those in the work of Nguyen et al. (2013), the conventional vehicles, where each one will be recommended to follow a path which depends on the current traffic capacity and the participants’ preferences such that the overall throughput of the traffic network is maximized and the participants’ preferences is respected. The second one relates to a specific vehicle, the garbage truck. It respects the optimization conditions of the first one, but also optimizes the cost of transportation.

This algorithm is applied in simulations of the transportation system of Hagiang City (Vietnam). Extensive simulations and real testbed results show that the proposed solution can significantly improve the MSW performance. Results also show that the proposed scheme is an able decision support system for the manager about the optimized strategy of waste collection and transportation (see Fig. 1).

This paper is organized as follow: Section 2 introduces our approaches; Section 3 presents our case study by applying this algorithm on the real traffic network of Hagiang City; Section 4 is our conclusions and future works.

2. Material and methods

2.1. The general system

In general, the collection and transportation of municipal solid waste (MSW) can be divided into 2 steps, as show in Fig. 2. Firstly, the MSW, generated by different sources (S) (households, markets, offices and so on) is collected and conveyed to the nearest collection centre (C). Each centre is composed of a number of bins that have a same capacity (in m³). Then, vehicles that start from depot (D) move through collection centres following a scheduled route, collect MSW and finish at the landfill (L).

We are interested in the collection and transportation at step 2. It means that the optimization of the route of different vehicles from D to L goes through different C: D → C₁ → C₂ → ... → L → D.

For each trip, a vehicle will go to the landfill in two cases: (i) it reaches the last collection centre of the trip; or (ii) it is full of waste, so that it needs to go to the landfill for unloading, then returns to the next centre in the plan. Generally, these cases can be treated as a Open Vehicle Routing Problem (OVRP) (Li et al., 2007) in which the shortest path used by the vehicle to dispose the waste can be considered as the least costly route. OVRP is a variant of the classical Vehicle Routing Problem (VRP) (Laporte, 1992) in which the vehicles are not required to return to the depot after completing their services.

Fig. 1. Integrating GIS analysis, equation-based, and agent-based model to find out the optimized strategy for MSW management.
However, for the most developing countries, the depot and the landfill are the same one. Therefore, we suppose the following assumptions for our system:

- The total volume of waste in a collecting tour is less than or equal to the capacity of the vehicle. So, that, our problem can be transformed into a VRP. In fact, for the complex case with more vehicles and the total volume of waste greater of the total capacity, we can transform into many classic VRPs.
- The depot and the landfill are the same one.
- The position and the quantity (the number of bins) of each collection centre are known.
- The plan of collection of each vehicle is available. It means sequences of the collection centre that the vehicles must pass through.
- The distance between nodes is known.
- The waste generation rate is known. This indication is presented by the ratio of the waste collection into a bin. So that, the volume of waste at a centre depends on the number of bin and this ratio. For simplicity, all collection centres have a same ratio.

### 2.2. The equation-based optimization

For this model, we apply the classical vehicle routing problem using mixed integer linear programming to identify the optimized plan. Let $G=(V,A)$ be the graph that presents the route of a vehicle in which, $V = \{v_0, v_1, \ldots, v_n\}$ is a vertex set, where:

- Consider the depot to be located at $v_0$.
- Let $V’= V \setminus \{v_0\}$ be used as the set of $n$ collection centres, $v_n$ is the landfill.
- $A = \{(v_i, v_j) \mid v_i, v_j \in V; i \neq j\}$ is an arc set.
- $C$ is a matrix of non-negative costs (distances) $c_{ij}$ between collection centres $v_i$ and $v_j$.
- Let $m$ be a number of vehicles.
- Let $S$ be a set of routes that satisfy all constraints of our objectives.
- $X$ is a matrix of $(0,1)$ where:

$$x_{ij} = \begin{cases} 1, & \text{the path goes from node } i \text{ to node } j \\ 0, & \text{otherwise} \end{cases}$$

The goal of our work is to minimize the total cost which is the sum of the tour length and the fixed costs associated with the visited nodes. Our problem relates to the OVRP, but with a particular constrain: the vehicle must terminate at the landfill (the cost to go from the landfill to the depot is constant; we consider that the vehicles stop at the landfill).

#### 2.2.1. MILP model

The objective function for optimal path calculation is formulated as follows:

$$\min \sum_{i=0}^{n} \sum_{j=0}^{n} c_{ij}x_{ij},$$

subject to:

$$\sum_{j=1}^{n} x_{ij} = 1, j = 1, \ldots, n$$

$$\sum_{i=1}^{n} x_{ij} = 1, i = 1, \ldots, n$$

$$\sum_{i=0}^{n} x_{i0} = m,$$

$$\sum_{j=0}^{n} x_{0j} = m,$$

$$\sum_{i \in S} \sum_{j \in S} x_{ij} > r(S), \forall (S) \in V \setminus \{0\}, S \neq 0$$

$$x_{ij} \in \{0, 1\}, \forall (i, j) \in A$$

Constraints (2), (3) are the classical assessment restriction that each source point in the set $v_1, v_2, \ldots, v_n$ to be visited exactly by one vehicle. Constraints (4) and (5) indicate that the number of vehicles leaving the depot is the same as the number entering. Constraint (6) is the capacity cut constraints, which impose that the routes must be connected and that the demand on each route must not exceed the vehicle capacity. Constraint (7) is the logical representation of the decision variables the usual assignment constraints.

#### 2.2.2. The algorithm

Let $o = v_0 = D \in V$ be the depot and also the landfill, $S \in V$ be the set of visited nodes, $V’ \in V$ be the set of unvisited nodes, $D$ be the distance of the shortest path, and $P(i) = j$ means that node $j$ is the node just before node $i$ on the shortest path from original node $o$ to node $j$. For our problem, we apply the Clarke and Wright savings algorithm (Lysgaard, 1997). The idea of the algorithm is follow:

1. Select the o as the central node.
2. Calculate $s_{ij} = c_{0i} + c_{0j} - c_{ij}$ for all pairs of node $i, j (i = 1, 2, \ldots, n; j = 1, 2, \ldots, n; i \neq j)$. 
3. Order $s_{ij}$ from largest to smallest.
4. Starting with the largest $s_{ij}$, do the following:
   4.1. If linking nodes $i$ and $j$ results in a feasible route, then add this link to the route; if not, reject the link.
   4.2. Try the next $s_{ij}$ in the list and repeat (4). Do not break any links formed earlier. Start new routes when necessary. Stop when all cities are on a route.

#### 2.3. The agent-based model

In fact, after applying the previous algorithm, we can obtain the total distance that each vehicle will travel. But, this value is calculated in a static context. So that, we develop an agent-base model (ABM) to situate the optimized plan in a dynamic context. This ABM models the dynamic of the traffic network that has impact on the total distance of the vehicles. In the ABM, we model five types of agent: Road agent, Garbage agent, Transport agent, Garbage agent, and Environmental agent. There is a need to balance the optimality of the solution with the performance of the algorithm.
truck agent, and Depot agent, as shown in Fig. 3. These agents will be described in detail in the following sections.

2.3.1. Road agent

This agent represents the real road. The real data is got from GIS files. So this kind of agent has all geometry attributes: position, length, etc. Each agent represents a short segment of the road. This kind of agent has no behavior. For this agent, we adapt our previous work presented in Nguyen et al. (2015).

2.3.2. Transport agent

A transport could be a truck, a bus, a car (including taxi), a motor. It has some attributes, behaviors and ability to move. The transport has an important impact on the effectiveness of the MSW collection and transportation. So we need to model it as an agent in our system. We consider the whole of a driver and his transport as a unique transport agent. The behavior and attributes of this agent is adapted from our previous work, presented in Nguyen et al. (2015).

2.3.3. Garbage agent

The garbage agent represents collection centres that are generated from GIS data. It has the following attributes and behaviors:

- **Waste generation rate**: the ratio represents the volume of garbage that augments after each second.
- **Position**: the position of this collection centre.
- **Volume**: the amount of waste. The higher the amount is, the longer time the garbage truck agent needs to collect.

This agent has a behavior that represent the increasing of the waste amount in time, as shown in Fig. 4. If it is not in the collection time, the amount of waste will be increased according its ratio.

2.3.4. Garbage truck agent

The garbage truck agent represents vehicles that transfer the garbage from the collection centres to the landfill. This agent is basically the same as transport agents on the attributes and the movement behaviors. Besides, it has some special attributes dedicated to a garbage truck:

- **Full capacity**: an attribute represents the maximum amount of garbage that it can store.
- **Current capacity**: an attribute represents the amount of garbage that it can store, at the current moment.
- **Garbage list**: a list of collection centres that the agent must visit during a trip.

The garbage truck agent has two main behaviors, as shown in Fig. 5.

- **Collection and cleaning**: when arriving the collection centres, it collects and cleans the garbage. If it is full of waste, it will return to the landfill for unloading.
- **Unloading**: when the garbage truck agent is full of waste, it will return to the landfill and unload the waste. Then if there are still collection centres for collection, it will go to the next centre in the plan; if not, it will return to the depot.
The behaviors related the movement of this agent is inherited from the behaviors of the transport agent. These behaviors make our model dynamic and different from the others.

2.3.5. Depot agent
This agent manages a set of garbage and garbage truck agents. At the beginning of a collection trip, it will initiate the plan for each garbage truck agent. This agent has following attributes:

- **Position**: the position where it is situated.
- **Number of garbage trucks**: the number of available garbage trucks.
- **Collection times**: the times that the garbage truck starts to collect.

This agent has a behavior, as shown in Fig. 6:

- **Control garbage truck agents**: at the beginning of a collection period, it initiates the plan for each garbage truck agent, and demands them to collect the garbage following the plan.

2.3.6. Simulation platform
Our simulation of the MSW collection and transportation is implemented in the simulation platform GAMA (Drogoul et al., 2013). GAMA is integrated and generic tools to support the representation of features usually associated with real complex systems, namely rich, dynamic and realistic environments or multiple levels of agency. It allows modellers, thanks to the use of a high-level presentation of features usually associated with real complex systems, to build, couple and reuse complex models combining various agent architectures, environment representations and levels of abstraction.

3. Case study
Vietnam is the second most populous country in Southeast Asia (after Indonesia) (Arifin and Ananta, 2009). The amount of MSW has been increasing steadily over the last decade. The waste generation rate was 1.45 kg per person per day in city in 2008 (Ministry of and Environment, 2010). Total MSW in cities of Vietnam this year is about 35,100 tons per day.

The waste management system is facing many problems, including inadequate management, lack of technology and human resources, a shortage of transportation vehicles and insufficient funding.

Solid waste management falls under the jurisdiction of several governmental bodies at the national, provincial and municipal levels although there is no unified or standardized system of waste collection. Thus, waste collection rates and efficiency vary from one locale to the next depending on two factors: proximity to the urban centre as well as the size of the city. In many cities, the Urban Environment Company (URENCO) contracted out by the local Peoples Committee – collects, transports and disposes of domestic waste and in most cases, industrial and healthcare wastes as well.

Hagiang is a mountainous province, which locates at the northernmost border of Vietnam, with an important position. The North and West border with the People's Republic of China 274 km long; Caobang province in the East; Tuyenquang province in the South; and Laocai and Yenbai in The West and South-west. Hagiang have 01 city, 10 districts, 05 wards, 13 towns and 177 communes. Hagiang City belongs to Hagiang Province, where is the economic, politic and cultural centre of the province, especially, it has potential economic development and tourism. Increasing in number of tourist, strong economic growth and uncontrolled urbanization in recent years have greatly magnified the problem with Hagiang in the amounts of solid waste generation; the composition of waste has changed as well. The current waste collection and transportation is already overtaxed due to lack of physical facilities and insufficient human and technical resources as can be evidenced by low collection rates and inefficient waste transportation, the issues methods to deal with its solid waste will only become more critical in Hagiang city. We have applied our model to the collection and transportation of MSW at Hagiang city.

The system of collection and transportation of MSW of Hagiang is illustrated as Fig. 7 in which the depot and the landfill are the same one. Hagiang has 33 collection centres as shown in Fig. 8 (the red circle, the depot is the green rectangle). The waste generation rate is 181.4 tones or 365.4 m³.

Hagiang has two vehicles that are responsible for the collection and transportation at two regions. The first one picks up the MSW at the collection centres 14, 25, 31, 26, 27, 23, 21, 20, 32, 17, 18, 19, 16, 15, 24, 33, while the second one manages the rest.

In a day, the vehicles start the collection at 2 moments: 8 h and 17h30. At 8 h, the plan of vehicle 1 is 0 → 31 → 26 → 27 → 23 → 21 → 20 → 32 → 17 → 18 → 19 → 16 → 15 → 24 → 27 → 33 → 23

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the whole traffic network of Hagiang city. The object of this second step is to situate the optimized plan in a dynamic context.

In fact, after finishing the first step, we can obtain the total distance that each vehicle will travel. But, this value is calculated in a static context. With the agent-based model, we model the dynamic of the traffic network of Hagiang city (the population, the other vehicles and so on). So that, this total distance will be more confident.

3.1. Optimization of the MSW collection and transportation at Hagiang city

Our model is depicted in Fig. 9. There are two big steps. Firstly, we apply the algorithm, presented in Section 2.3, with the data from the practice. The result of this step, the optimized plan, is then the input for our agent-based model, in which we model the whole traffic network of Hagiang city. The object of this second step is to situate the optimized plan in a dynamic context.

In fact, after finishing the first step, we can obtain the total distance that each vehicle will travel. But, this value is calculated in a static context. With the agent-based model, we model the dynamic of the traffic network of Hagiang city (the population, the other vehicles and so on). So that, this total distance will be more confident.

3.1.1. The optimized plan

From the GIS data, we know the position and also the matrix distance, as illustrated in Fig. 8. After applying the first step, the optimized plan for the vehicle 1 is 0 → 28 → 29 → 22 → 5 → 1 → 3 → 4 → 2 → 6 → 7 → 8 → 9 → 13 → 23 → 30 → 12 → 11 → 10 → 5 → 1 → 23 → 0 for the vehicle 2. With the total distance that the vehicles consume is 94 km.

At 17h30, the plan for vehicle 1 is 0 → 26 → 27 → 33 → 23 → 24 → 14 → 15 → 16 → 17 → 18 → 19 → 20 → 21 → 25 → 0, and 0 → 28 → 22 → 5 → 4 → 3 → 1 → 2 → 6 → 7 → 8 → 9 → 13 → 12 → 11 → 10 → 23 → 0 for the vehicle 2. With the total distance that the vehicles consume is 83 km.

3.1.2. Simulation of the optimized plan with ABM

The input data of this simulation is set as follows:

- Road map and building distribution: We extracted this data as a GIS file (Fig. 8). It is the GIS data of Hagiang city which is resulted from the AI Program.
- Collection centres positions: We collected this data by a GIS device. There are 33 collection centres along the road map. Each one has a specific number of bin and an increasing ratio of waste.

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Transport distribution and plans: We refer this data from the statistic data of the National Center of Statistic taken in 2009. On basing on this data, we estimate the number of permanent transport is about 500–1000 on the whole road at any daily moment, the average speed is about 25–50 km/h.

Garbage trucks and their attributes: this data is supported by the URENO of Hagiang. Hagiang has three garbage trucks; two of them are available.

Depot: We collect this data by using a GIS device. Hagiang has only one depot which is also the landfill of the city.

Plan of vehicles: the optimized plans that are calculated from the previous step.

We are interested in the following outputs:

- The travelling distance: the total distance that two vehicles travel in each trip (the morning and the afternoon).
- The used path: the visualization of the path that each vehicle uses to collect and transfer the garbage.

### 3.1.3. Results and discussions

In this section, the simulation results are presented with 4 experiments as follows:

1. **Scenario 1: Using the real data**

   The object of this scenario is to evaluate the ABM. The real data are used about the collection, transportation and plan of Hagiang city as the input. The outputs (the travel distance, the travel and collection time) are then verified with the real data.

   The real plans of the vehicle No. 1 and No. 2 in the morning and the afternoon are present in Tables 1 and 2. In the morning, the total volume of collected waste is 184.5 m³, while it is 180.5 m³ in the afternoon. All vehicles start at 7 am, and terminate at 11 h am, in the morning; while in the afternoon they begin at 16h30 at usually terminate at 20h10. So that, the total times (the travel time and the collection time) of each vehicle spending in the morning is 240 min, and in the afternoon is 220 min.

   In the morning, the average total collection time of the vehicle No. 1, and the average total collection time of the vehicle No. 2 are 202, 140 min respectively; while they are 193, and 124 min in the afternoon.

   The average distance that two vehicles travel in the morning is 94 km, and in the afternoon is 83 km. The maximum speed of each vehicle is 40 km/h. So that, we have:

   - The average total travel time of two vehicles is 141 min in the morning, and 125 min in the afternoon.
   - The average total collection time of two vehicles is 339 min in the morning, and 316 min in the afternoon.

2. **Scenario 2: Optimized plan with real input parameters**

   In this scenario, the optimized plan obtained in the step 1 Fig. 9 is used in order to situate the plan in a dynamic context. The others input parameters are similar to the scenario 1.

3. **Scenario 3: Optimized plan and doubling the speed of garbage trucks**

   The purpose of this scenario is to examine the change of total time (travel time and collection time) when the maximum speed of vehicle is doubled from the normal value. The others input parameters of this scenario are similar to the scenario 2.

4. **Scenario 4: Optimized plan and doubling the speed of collection**

   Average speed of collection at each collection centre is doubled from the normal value. The others input parameters of this scenario are similar to the scenario 2. The total time is investigated in this scenario.

### 3.1.4. Results of experiments

We performed 30 experiments for each scenario. Thus, 240 experiments of four scenarios give us the analysis results as follows:

- Total distance of optimal plan is reduced by 11.3%.
- Minimization of cost means not only minimization of travel distance but also the total time (collection time and travel time).
- Thus, comparing total time of four scenarios is investigated in this paper. Concretely, the results of experiments are showed Fig. 11.

After the experiment, with the morning trip, the total distance is reduced to 78 km; while it’s 79 km in the afternoon; as shown in Fig. 10. The total distance is reduced by 11.3%.

In the morning, the calculated distance is almost the same with the simulated value. Because the traffic in the morning is not too complicated. But, it is more difficult in the afternoon, so that this value is greater than the calculated one.

Fuel consumption is an important aspect in waste management. In our model, we haven’t yet examined this information. But, according to Rodrigues et al. (2015) and Kinobe et al. (2015), fuel consumption depends on travel distance, and any feature that increases collection time will lead to higher fuel consumption.

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Table 1

The real plans and waste generation in the morning.
The result about the time (the travel time, and the total time) shown in Figs. 11 and 12, indicates that the travel time and the total time are reduced with the optimal plan. Therefore, the fuel consumption of garbage trucks is also reduced.

The collection time at Hagiang city occupies a large amount of the total time in a trip. It is shown in Fig. 11, with the optimal plan, when the speed of collection is doubled, the total time is reduced by 38%. While when doubling the maximum speed of garbage trucks, the total time is reduced by 15%.

In general, by the result obtained, we have some suggestions:

- The current collection system of Hagiang is inefficient and can be improved.
- The total time in a collection trip at Hagiang depend mainly on the work at collection centres.
- In the MSW collection and transportation, the optimized results that are obtained from mathematical calculations only are not close to the real result when applying in the reality. Because, it depended on many factor, for example the traffic network.

Table 2
The real plans and waste generations in the afternoon.

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<th>Vehicle No. 1</th>
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Table 3
Input parameters.

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<th>Model parameters</th>
<th>Values</th>
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<td>Collection time in the morning</td>
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<tr>
<td>Collection time in the afternoon</td>
<td>17 h</td>
</tr>
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<td>Maximum speed of vehicles</td>
<td>40 km/h</td>
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<tr>
<td>Speed of collection</td>
<td>0.009 m³/s</td>
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</table>

Fig. 11. The total time reduces respectively with the order of four scenarios: Scenario 1 using real plan and normal parameters; Scenario 2 using optimal plan with normal parameter value; Scenario 3 using optimal plan and double garbage truck speed; Scenario 4 using optimal plan and double collection speed.

Fig. 12. The total travel time (in the morning and in the afternoon) of optimal plan is reduced by 11%.
the plan in a dynamic context. The ABM models different entities related to the real system of the municipal solid waste transportation: road agents, collection centres, garbage trucks, depots, and transport agents. It is applied to simulate and calculate the total distance that garbage trucks travel. In the first step MSW collection and transportation are built in a static context. With integrated GIS analysis and the agent-based model, the optimized plan is situated in a dynamic context, in which we examined the impact of the traffic network on the work of garbage trucks. Finally, the results of this paper are achieved:

- Integrating three models (GIS analysis, Equation-based model, and Agent-based model) are feasible.
- Integrating model is more effective than GIS analysis approach by considering the dynamic context.
- Integrating model is less timing simulation cost than that of ABM.
- Integrating simulation allows to visualize the evolution of the MSW collection and transportation.

Experimental results reported for the Hagiang city show the effectiveness of the proposed optimization approach also highlighting that the current periodic collection policy can be improved by optimized collection planning.

Future developments regard the extension of VRP in order to capture the case where the total volume of waste in a collection tour is more that the capacity of the vehicle. Split Delivery Vehicle Routing Problem can help us to resolve the problem. We also need another algorithm to cover the new formalization of the problem such as the Branch Cut algorithm that finds out optimal plan with various garbage trucks in a same routing.

Finally, in future research activity, we need integrate a model to calculate the fuel consumption. In this paper, we just focus on the travel distance, travel time, and the collection time.

Acknowledgment

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References

Medina, Martín, 2008. The Informal Recycling Sector in Developing Countries: Organizing Waste Pickers to Enhance their Impact. Gridlines; No. 44.