Proposal of routing algorithm to optimize the route of collecting and transporting domestic waste in Hue city, Vietnam

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ABSTRACT

This article is aimed to propose applying the routing algorithm based on the algorithm of overall minimum spanning tree to optimize the route of collecting and transporting domestic waste to minimize the distance, and reduce the number of trucks accordingly. Hue is selected as a practical sample. The result shows that the number of trucks reduces by 10 compared to the actual quantity (from 20 to 10), which contributes to the dramatic reduction of system operating cost.

Keywords: Waste vehicle routing, vehicle routing, spanning tree, minimum spanning tree.

I. Introduction

Along with the fast-growing national economy, the management system of urban waste has been comprehensively improved. Besides, science and technologies have been gradually applied in many cities to quickly and efficiently sort out, collect, transport and dispose waste. However, outdated facilities and equipment, limited techniques in solving issues of collecting, transporting and disposing waste cause manpower consuming, high cost of transportation, under-expected economic and environmental results.

In many cities in Vietnam in general and Hue city in particular, collecting and transporting solid waste from transfer stations to landfills are still being manually operated. Specifically, the amount of daily waste is calculated, waste-collecting workers are assigned to collect at fixed gathering points along the roads into bigger waste containers or transport to waste transfer stations, then waste trucks are sent to collect and transport to landfills. The schedule of waste trucks is completely done manually without applying any software or algorithms to optimize the route. In some cases, ArcGis might have been applied to solve this issue, but the results are still unsatisfactory. According to the 2018 statistics data from Hue urban and environmental company, around 220 tons of domestic waste are daily discharged in Hue city and 20 trucks are needed from 6pm to 2 am the next morning to collect and transport all of this quantity, which can be inferred that the ability to collect and transport waste of the city is still limited and weak.

In a study on totally 42 magazines and 65 articles related to the routing of waste trucks from prestige academic database and magazines in the world like Emerald; Elsevier; Wiley; Springer; Ebsco; Scopus; and Metapress etc. The results show that the number of articles related to the routing of waste trucks (WCVRP) having been published from 1974 until now is still limited. Some outstanding authors who tried to reduce the distance are (Beltrami & Bodin (1974); Ronen & Kellerman (1983); Angelelli & Speranza (2002); Viotti & cộng sự (2003); Bautista & Pereira (2004); Bianchessi & Righini (2007); Alagöz & Kocasoy (2008); Kim et al. (2009)... Some others focused on the selection of best positions for waste bins and containers like (Maniezzo (2004); Archetti và Speranza; Sniezek và Bodin (2006); Karadimas et al. (2007); McLeod và Cherrett (2008); Sumathi et al. (2008). And some others studied how to reduce the number of waste trucks like (Clark và Gillean (1975); Aringhieri et al. (2004); Arribas et al. (2009)...[7].

The study of optimizing the municipal waste collection and transportation system is often challenged by various constraints such as the loading capacity of a truck (use one type or multiple types of trucks, trucks of high or low loading capacity?), the locations of transfer stations, one-way streets, two-way streets, the different amount of waste among transfer stations, collection time, speed etc.

This paper is aimed to review, analyze different types of constraints and propose the application of a routing algorithm based on the general minimum spanning tree algorithm with a hope to optimizing the route of collecting and transporting municipal waste to minimize the collection and transportation distance, thereby reduce the number of waste trucks significantly, contributing to reducing the cost of the operating system.

II. MAKING SCHEDULE FOR WASTE TRUCKS

A. Description

Range $V=\{0,1,2,\ldots,n\}$ in which 0 indicates landfills, $\forall i\in V\,|\,i\neq 0$, $0<i\leq n$ indicates the i transfer stations. T_{ij} , the time from Station i to Station j, can be calculated by $T_{ij}=D_{ij}/v$, in which D_{ij} is the distance from Station i to Station j and $v\neq 0$ is the average speed of waste trucks. C_i , t_i are the tons of waste and time of waste collection at Station i. X_{ij} is the variable which can be 1 or 0, $X_{ij}=1$ means a waste truck passing by Station i will continue to Station j, vice versa $X_{ij}=0$. Z_i is the total tons of waste when a waste truck leaves Station i. $Z_{\max}$ is the maximum loading capacity of a waste truck. T_i is the total time of travelling from when a waste truck leaves Station i. $T_{\max}$ is the maximum time for a working shift.

B. Mathematical model

$$\min F=M\sum_{\forall i\in V,i\neq 0}X_{i0}+\sum_{\forall i\in V}\sum_{\forall j\in V}T_{ij}X_{ij} \quad (1)$$

S.t.

$$\sum_{\forall j\in V}X_{ij}=1,\ \sum_{\forall j\in V}X_{ji}=1\left(\forall i\in V\,|\,i\neq 0\right) \quad (2)$$

$$Z_i\leq Z_{\max} \quad \left(\forall i\in V\,|\,i\neq 0\right) \quad (3)$$

$$X_{ij}\left(Z_j-\left(Z_i+C_j\right)\right)=0\ \left(\forall i,j\in V\,|\,i\neq 0\right) \quad (4)$$

$$T_i\leq T_{\max} \quad \left(\forall i\in V\,|\,i\neq 0\right) \quad (5)$$

$$X_{ij}\left(T_i-T_j+T_{ij}+T_j\right)=0\ \left(\forall i,j\in V\,|\,i\neq 0\right) \quad (6)$$

$$0<Z_i\leq Z_{\max},Z_0=0 \quad \left(\forall i\in V\,|\,i\neq 0\right) \quad (7)$$

$$0<t_i\leq T_{\max},t_0=0 \quad \left(\forall i\in V\,|\,i\neq 0\right) \quad (8)$$

$$X_{ij}\in\{0,1\},\ X_{0j}=0,\ X_{ii}=0\ \left(\forall i,j\in V\right) \quad (9)$$

In the model, the objective function no. (1) consists of 2 parts, part 1 is the number of waste collection routes, part 2 is the distance of each route, in which M is a positive integer and big enough to optimize the number of routes. $\sum_{\forall j\in V}X_{ij}=1$ of (2) requires each station $i\neq 0$ must link to another transfer station or a landfill (j cannot be equal to i because it is stated $X_{ii}=0$ in (9)). $\sum_{\forall j\in V}X_{ji}=1$ of (2) requires each transfer station has only one truck come. If $\sum_{\forall j\in V}X_{ji}=0$, Station i is the initial station (the first) in the schedule, which means the truck will come directly to this station. (3) and (5) require that the total amount of waste in the route no. i cannot exceed the truck loading capacity and the time of travelling in the route no. i cannot exceed the time of a working shift. It should be noted that (4) and (6) are applied when Station i is connected to Station j, then all stations with Station i included (even Station i has the total amount of waste changed) have to satisfy (3) and (5). (7) requires that a cycle is not formed. (8) requires that the time to collect at each transfer station cannot exceed the time of a working shift.

III. ROUTING AGORITHM

This part presents the routing algorithm based on the algorithm of general minimum spanning tree to optimize the route for waste trucks. This algorithm is designed to have a routing schedule for waste trucks to obtain 02 goals which are the minimum number of routes and the minimum total time of travelling and all routes must satisfy every requirement of the mathematical model stated in (2.2).

A. Steps of the algorithm

This part presents the routing algorithm based on the algorithm of general minimum spanning tree to optimize the route for waste trucks. This algorithm is designed to have a routing schedule for waste trucks to obtain 02 goals which are the minimum number of routes and the minimum total time of travelling and all routes must satisfy every requirement of the mathematical model stated in (2.2).

Input: $V=\{0,1,2,...,n\}$;

Output: $X_{ij}, \forall i,j \in V$ $T_{ij}, \forall i,j \in V$

Generate;
do
  foreach ($i \in V \mid i \neq 0$ in which $X_{i0}=1$ and $\Sigma_{i'i}=0, \forall i' \in V \mid i' \neq i$) **do**
    $\Delta = 0$; case=0;
    foreach ($j \in V \mid j \neq 0$ và $j \neq i$) **do**
      tinhDelta (Δ, case, i, j);
    end
    if ($\Delta < 0$) **then**
      Update routes for each case;
    end
  end
while $\Delta = 0$;
foreach ($i,j) \in V$ **do**
  if ($\exists k \in V$ in which $X_{ij}=1, X_{jk}=1$ và $T_{ij}+T_{ik} > T_{ik}+T_{kj}$) **then**
    $F = F-(T_{ij}-T_{ik}+T_{jk}+T_{ki})$;
    Update routes;
  end
end

Algorithm 1: Routing algorithm

From the idea that the number of trucks is the number of routes and vice versa, it can be inferred that the minimum number of routes means the minimum number of trucks. Each route has the initial transfer station from which a truck starts for waste collection. First, the algorithm generates n routes by creating routes algorithm checks and processes from case 1 to 5 until the objective function (1) is optimized.

$$i \rightarrow 0 \left(i \in V, i \neq 0\right)$$

i. Case 1 (case=1): In this case, the number of routes is decreased, $j \rightarrow 0$ is changed to $j \rightarrow i$, the objective function can be reduced by $T_{ji}-T_{j0}-M$. The routes are updated like Figure 1 below.

Procedure tinhDelta (Δ, case, i, j):
  if ($X_{j0}=1$ and connecting Station j to Station i does not violate any requirement) **then**
    $\Delta = \max\left(\Delta, M+T_{j0}-T_{ji}\right)$;
    case = 1; j* = j;
  end
  if ($X_j^+=0$ and connecting Station j to Station i does not violate any requirement) **then**
    $\Delta = \max\left(\Delta, M+T_{i0}-T_{ij}\right)$
    case = 2; j* = j;
  end
  if ($X_j^+=1$ and connecting Station j to Station i and Station l to Station i does not violate any requirement) **then**
    $\Delta = \max\left(\Delta, M+T_{ij}-T_{i0}+T_{li}-T_{li}\right)$;
    case = 3; j* = j;
  end
  if ($X_j^+=0$ and connecting Station i to Station k does not violate any requirement) **then**
    $\Delta = \max\left(\Delta, T_{i0}-T_{ik}+T_{jk}-T_{j0}\right)$;
    case = 4; j* = j;
  end
  if ($X_j^+=1$ and connecting Station i to Station k and Station l to Station i does not violate any requirement) **then**
    $\Delta = \max\left(\Delta, T_{i0}-T_{ik}+T_{jk}-T_{j0}-T_{li}\right)$;
    case = 5; j* = j;
  end
End Procedure

Algorithm 2: Algorithm to calculate Δ

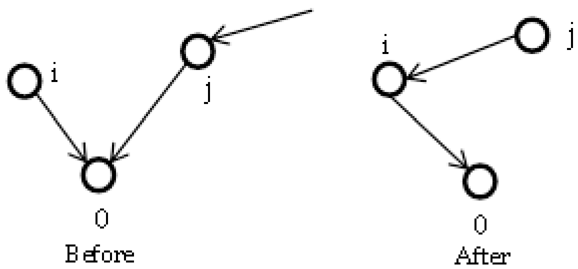

Fig.1. Case 1

ii. Case 2 (case = 2): In this case, the number of routes is decreased, $i \rightarrow 0$ is changed to $i \rightarrow j$, the objective function can be reduced by $T_{ij}-T_{i0}-M$. The routes are updated like Figure 2 below.

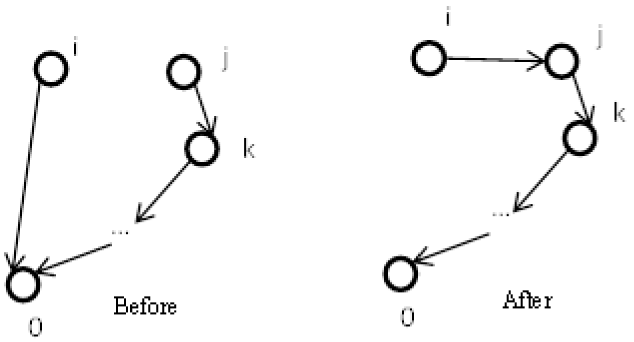

Fig.2. Case 2

i. **Case 3 (case = 3):** In this case, the number of routes is decreased, $i \to 0$ is changed to $i \to j$ and $k \to j$ is changed to $k \to i$, the objective function can be reduced by $T_{ij} - T_{i0} + T_{li} - T_{lj} - M$. The routes are updated like Figure 3 below

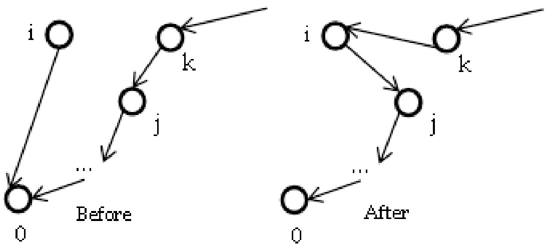

Fig.3. Case 3

ii. **Case 4 (case = 4):** In this case, the number of routes are not decreased but the total distance is shortened, $i \to 0$ is changed to $i \to k$ and $j \to k$ is changed to $j \to 0$. the objective function can be reduced by $T_{ik} - T_{i0} + T_{j0} - T_{jk}$. The routes are updated like Figure 4 below.

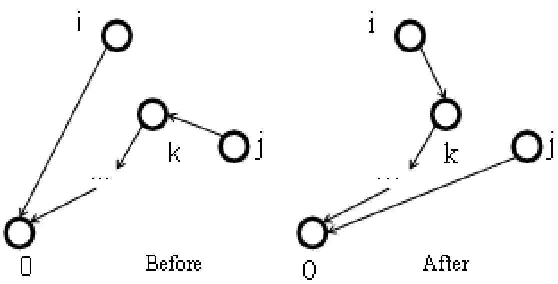

Fig4.Case 4

iii. **Case 5 (case = 5):** In this case, the number of routes are not decreased but the total distance is shortened, $i \to 0$ is changed to $i \to k$, $j \to k$ is changed to $j \to 0$ and $l \to j$ is changed to $l \to i$, the objective function can be reduced by $T_{ik} - T_{i0} + T_{j0} - T_{jk} + T_{li} - T_{lj}$. The routes are updated like Figure 5 below.

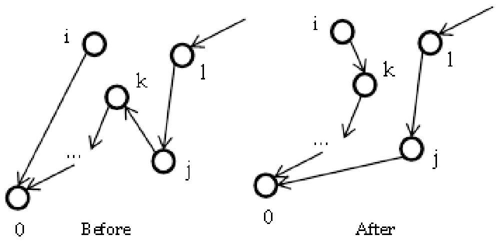

Fig.5. Case 5

IV. RESULTS AND DISCUSSION

A. The authors set the maximum loading capacity for each truck of 6 tons (equal to the actual loading capacity); the average speed of 30 km/h. Using the actual data with 1755 locations of waste bins, and 92 transfer stations and the amount of waste in Hue city, the authors use ArcGis 10.3 to analyze and increase to 110 transfer stations. Together with the detailed transport data of Hue city until 2018, C++ and Routing algorithm are applied to process and the results are shown as follows:

Table 1. The results of Routing Algorithm

Route	**Transported weight（kg）**	**Travelling time (min）**	**Transfer station**
1	2125	75	12->103->0
2	4750	84	20->7->99->0
3	6000	87	23->11->107->0
4	2625	67	30->37->74->106->3->0
5	5875	82	31->14->100->0
6	3375	72	35->104->0
7	4500	80	36->29->101->0
8	4250	77	37->74->106->3->0
9	4500	66	38->50->95->0
10	4875	81	44->5->97->0
11	3875	80	45->1->73->0
12	3250	66	47->88->0
13	3250	68	48->46->0
14	5750	86	49->10->98->0
15	4750	73	56->13->105->0
16	5750	81	57->53->89->0
17	3125	70	58->102->0
18	2875	69	59->110->0
19	2875	67	60->64->0
20	3000	75	61->4->94->0
21	4625	80	62->2->72->0
22	5750	69	65->24->0
23	5847	62	66->41->0
24	4250	67	67->28->0
25	4875	67	68->21->0
26	4375	62	69->22->0
27	5875	63	70->40->0
28	4375	62	71->33->0

29	3375	64	75->16->0
30	5625	69	76->39->0
31	4375	62	77->25->0
32	4875	62	78->19->0
33	3750	61	79->32->0
34	5471	65	80->15->0
35	5750	68	81->9->0
36	4375	68	82->27->0
37	5625	63	83->42->0
38	4750	63	84->43->0
39	5730	62	85->26->0
40	5500	59	86->18->0
41	4875	63	87->52->0
42	5750	50	90->0
43	3000	62	91->34->0
44	3000	66	92->6->0
45	2625	64	93->17->0
46	3750	67	108->8->0
47	5750	80	109->55->63->96->0

B. From Table 1 and analyzed data, the results are rearranged like below:

Table 2. The results of total travelling and transported weight

No.	**Name of truck**	**Total travelling time（min）**	**Transported weight（kg）**
1	Truck 1	356	29980
2	Truck 2	374	27222
3	Truck 3	385	26221
4	Truck 4	333	19500
5	Truck 5	338	19750
6	Truck 6	379	20750
7	Truck 7	300	14125
8	Truck 8	327	20250
9	Truck 9	242	15125
10	Truck 10	252	16375

C. Discussion

The comparison of results from the routing algorithm, ArcGis 10.3 and reality is stated in the below table (Using the function of Location_allocation of ArcGis 10.3 to analyze and select the locations of transfer stations, and using the function of Vehicle Routing Problem to set up parameters to optimize the routes of waste collection and transportation in Hue city, the result is the number of daily used trucks is reduced from 20 to 13.

Table 3. Comparison of results from Routing algorithm, ArcGis and reality

	Routing algorithm	ArcGIS	Reality
Used trucks（pcs）	10	13	20
Travelling time（min）	3286	4560	Unknown

V. CONCLUSION

The routing algorithm based on the algorithm of minimum spanning tree shows its advantages in optimizing the routes of collecting and transporting domestic waste of Hue city, which is shown by the comparison of results from the routing algorithm, ArcGis 10.3 and reality. The number of daily used trucks is reduced from 20 (reality) to 13 (ArcGis 10.3) and 10 (Routing algorithm). The reduced number of trucks and the reduced amount of travelling time will help to reduce the operating cost of the municipal waste collection and transportation system. This should be widely conducted and applied in other cities nationwide to save manpower, operating cost and lessen other environmental issues.

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