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Research paper

An Optimization Approach to Model the Waste Collection Process

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Abstract

Optimizing the waste collection process is helping in reducing the costs and the waste environmental effects.Waste collection requires applying modified technologies in designing and managing the waste collection areas.Waste collection problem represents a special case of the general collection problems. It needs to consider additional constraints and qualified resources. In this study a modified capacitated clustering approach is applied and implemented in order to distribute the waste bin nodes into dissimilar groups (clusters). These clusters are having different weights depending on the available trucks. Each truck has certain capacity (size) and it must visit each waste bin ones. It must also assign to one cluster only. The number of cluster can be estimated according to the available number of trucks and their capacities. The developed clustering process will optimize the total distances joining the waste bins in each cluster.
Waste quantity generation is applied and generated as uniform probability distribution random variables based on the historical data of the collected averages. The final result shows a large reduction (about 40 %) in the travelled route in comparing this study suggestion and the municipality route. This study develops scheduling process to assign the available trucks into shifts to collect and empty all the waste bin nodes.

Keywords: *Waste collection, Capacitated Clustering problem, uniform distribution, waste value estimation, distinct node approach, nearest neighbor.*

1. Introduction

Waste collection (WC)isa complex and challenging management problem in any city or crowded places. Economic and social situation is heavily affecting the process of Waste collection[1].Waste represent all the useless and unwanted things produced from industrial, houses, government offices and commercial activities in any district[2].
The process of waste collection is part of general waste management process. It represents a crucial and complex process in succeeding the entire waste management process. Various technologies and disciplines can be compromised in the process of collection, transfer and transportation of wastes[3].
Clustering is a vital applicable process in waste collection and transportation. Many clustering approaches are developed in literatures[4]. In this study a developed capacitated clustering approach is suggested and applied.
The Capacitated Clustering Problem (CCP) is to collect a set of n nodes (eg. Bin nodes) into c disconnect clusters with known weight or capacity. CCP represents a combinatorial optimization problem. In the CCP, given n nodes with known weights (quantities inside each node) can be collected into c dissimilar clusters. Each cluster is initially created by selecting certain node as a cluster head (CH) or (seed) of this cluster. It aims to minimize the sum of distances connecting the CH to all other cluster nodes. The sum of all the cluster nodes weights does not exceed a fixed cluster capacity and every node is assigned to one cluster only [5].This study aims to optimize the waste collection process by minimizing the total traveled distances (cost), manage and arrange the adjacent nodes in clusters depending on the available waste quantities and resources. Creating dissimilar clusters is performed according to the available trucks types. A real graph is also developed to represent all the available (links or arcs) roads and weighted bins as vertices in this study area of interest (AOI). The developed clustering approach in this study is depending on the available heterogeneous trucks capacities and bins waste quantities. This study is to model the waste collection problem as an optimization problem. The objective is to collect and transfer maximum quantity in a minimum distances or costs.

2. Related Works

Many methods and algorithms have been proposed for optimizing the routing aspects of solid waste. Many papers have modeled the optimization problem of waste collection and transport as variants of the node Routing Problem (NRP). N. Mostafa*et al* (2017) suggested a two-step method to resolve the capitated vehicle routing problems with a heterogeneous fleet. They tried to minimize the total cost or travelling distance [7].M.A. Hannan *et al* (2017), proposed a modified particle swarm optimization (PSO) algorithm to determine the best waste collection and route optimization solutions [8]. An algorithm was proposed by M. A. Mohammed *at el* (2017)to find an optimal route result for Vehicles Route Problem (VRP) using K -Nearest Neighbor Algorithm (KNNA) [9].

3. Modeling the Waste Collection Process

In this study the wastes are collected initially into waste container located near the houses and on the road sides. Each container is represented as a node. Each node contains variable quantity of wastes (less or equal to its size).In this study, a virtual bin is

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suggested to be located in the beginning and ending of each street. The quantities in these two bins represent the total quantity produced by the houses along this street. Such assumption represents the process of letting the waste trucks to pass through each street and collect wastes from houses containers. The clustering process represents the vital step to validate the waste collection process. In this step nodes are used to perform and create the clustering process. A set of neighbor bin nodes are collected into groups to represent clusters according to their waste quantity or capacity.

A certain approach is followed in this study to generate the available quantity in each bin each day according to the previous real data and staff experiences in the studied area. In this approach, a variable quantity (size) for each bin node is suggested initially in the process of creating the optimal number of clusters. These clusters are used in modeling the collection process and vehicles utilizations. In this approach certain level of quantity (size) in each bin is generated according to the suitable probability distribution. A uniform probability distribution is found to be suitable for most cases in this process. Equation(1)is developed from [11] is utilized to generate waste quantities in each bin node in this study.

$$F(i) = a + (1-b)*RN \quad (1)$$

Where :

F(i) represent the waste quantity value in a node i each day, a is the minimum expected value of waste quantity in each node, b is the maximum expected value of waste quantity in each node and RN represent a generated random number.

4. Developed Capacitated Clustering Approach

There are many clustering approaches developed to serve different problems in literatures. Clustering is to collect a set of items into one group called cluster depending on certain similar characteristics[6].One of the suitable approaches in modeling and managing the waste collection process is to apply the capacitated clustering approach. Waste collection process deals with the waste quantities (capacities) inside each node and the locations of the neighbor nodes[12].

In this study a modified capacitated clustering approach is suggested to perform the waste collection process. One selected area in Hillah city is suggested as a case study. The number of nodes in the selected area is known in advance and their available quantities are estimated according to the previous data. To develop the process of waste collection, a scientific approaches and the vast information technology advancement are inevitable to be used, implemented and utilized to optimize the effort and cost.

The approach is suggested to distribute the waste bins into variable size groups (clusters). These sizes are governed by the sizes and numbers of the available trucks in each service department each day. The problem is happened when the number of the available trucks is limited or less than the required number to carry the total waste quantity. In this case clusters are one of the best alternatives to manage this problem in a sequence manner. Each truck will assign to one cluster only in each trip and it can visit each node ones. Equation 2 is suggested to represent our approach in this study.

$$\sum number\ of\ trucks \leq \sum number\ of\ clusters \quad (2)$$

A developed CCP is proposed in this study to solve the waste collection problem called "Distinct Node Capacitated Clustering Approach(DNCCA)". This approach is suggested according to the criteria that the collection can be started from the farthest place first from the depot. The depot is representing the department center. The farthest place contains many extreme bin nodes located in certain known coordinates on the streets. Also this area streets length and shapes are clearly known.

One extreme node is selected as the initial node (cluster head) to form and create the first cluster. This cluster size must fit one of the available truck types according to the developed truck availability (a, b, c or d). The trucks availability is changed into fractions (probability) according to their numbers.

The next node is assigned to this cluster selected as the nearest neighbor node among all the neighbor nodes to the CH. The distances between the cluster head and the entire neighbor node are calculated using the Euclidian distance formula. The node with minimum distance is selected and added to the first node and so on till reach the capacity level of this cluster. The process will continue by selecting the rest nodes and forming all the nodes in clusters. After completing the collection process, number of clusters is generated. These numbers are less or equal to number of available trucks. An assignment process must be followed to assign certain truck to a suitable cluster in a sequence manner.

5. Case study

One sector in Hillah city was analyzed and studied to be a sample in this study. All the required data concerning this sector was collected from the municipality of Hillah. Some additional questions related this work is also asked to the staffs to get a detailed knowledge about the working on waste collection and transportation process regulations. To control and manage the waste collection and transportation in this study, more additional data are collected about number of hospitals, schools and other government offices with the expected lived population in each region of this sector. These data are used to estimate the expected waste quantities produced by each person per day. Final indications about the average quantities in each bin node can be estimated in order to develop a modified waste collection process.

6. Problem Formulation

To analyze this sector, A Developed Capacitated Clustering (DCC)Approach can be utilized to model the clustering process that can be used in arranging and organizing the process of waste collection. In AOI there are two virtual bin nodes placed in the beginning and ending of each road. The quantity in these two virtual bin nodes represents the total houses wastes along the road. This suggestion is to force the truck to pass through each road and collect all waste in houses bin nodes.

The coordinates (x ,y) of each virtual bin node are generated by GIS and/or net logo graphs. The distances (d_{ij}) among nodes are calculated.

Numbers of virtual waste bins are collected in one cluster depending on their locations, their waste quantity and bin capacity. Each node contains certain value of waste measured by size or weight. In this study weights (w_i) are considered.

Weights can be measured really by the municipality each day in each bin node. An expected value is considered in this study depending on estimating the average value between the service department knowledge and GIS estimation. From the service department knowledge we found the average waste in each bin is about (230 kg) While from the GIS estimation we found the average value in each bin is about (270 kg)and the resulted average waste value in each bin will be (250 kg).

To expect a suitable and close to real values of wastes distributions in each bin a uniform probability distribution is used to generate random variates. Each generated random variable (w_i) is used to represent the waste weight in bin node i. Homogeneous

bins (of 1100 liter and 500 kg weight) are available and used by the service department in AOI.
The following mathematical model is developed to simulate this problem:

6.1 Assumptions

n number of virtual bin nodes in the AOI
c number of the generated clusters.
$n1_i$number of nodes in cluster i. (i = 1,2,…..,c)
w_i : weight in node i.
d_{ij}: distance between node i and node j.
list : distances sequence in each cluster .
C_L : Cluster capacity (l = a, b, c and d).
V : number of available trucks
Vc_l : truck capacity (size or type) (l = a, b, c and d).

$$\sum_{i=1}^{c} n_i = n \quad (3)$$

Let M be the binary matrix, such that

$$M_{IJ} = f(x) = \begin{cases} 1, & \text{if a bin is assigned to a cluster i} \\ 0, & \text{otherwise} \end{cases} \quad (4).$$

6.2 The Model

The objective is to minimize the total cost

$$min \sum_{j=1}^{C} \sum_{i=1}^{n1_k} d_{ij} \quad (5)$$

Subject to:

$$\sum_{i=1}^{n1_k} w_i <= C_l (\text{ l = a, b, c and d}). \quad (6)$$

$$\sum_{j=1}^{c} \sum_{i=1}^{n1_k} n_{ij} = n \quad (7)$$

7. Simulation Results

Developing a simulation approach to imitate the proposed model using a multi-agent based modeling environment programming language (net logo 6.0.1) is considered in this study.
The studied AOI is deeply analyzed using GIS environment and service department staffs information. The data in table (1) is collected and concluded after many meetings and interviews. We found a very large number of the waste containers (small house containers) allocated along the streets. These number of containers with their locations and coordinated are being very hard challenging and un-controllable problem.
To facilitate this problem, a virtual bin is suggested to be located in the beginning and ending of each street. Table (1) collected data about the designated sector in this study.

Table 1: Available data about the sector

Total area m2	No of region	population	No. of house	No. of node	Estimated Total waste	Real data collected	Total length of road
9076022.9	17	76098	12247	1022	275940	235060	159266.0

Additional data is collected about the available trucks and their types (capacity).Table (2) shows the available trucks used to serve the above mentioned sector in AOI.

Table 2: The available trucks

No.	Type	Number	Size	Weight
1	A	12	10m3	5000 kg
2	B	7	6m3	3500kg
3	C	2	2m3	1500kg
4	D	1	16m3	8500kg

Data in table 2 is treated to estimate the fraction (probability) for the availability of each truck type. These fractions are indicated in figure 1. These fractions are used as a base in estimating and creating the optimal suitable heterogeneous clusters.

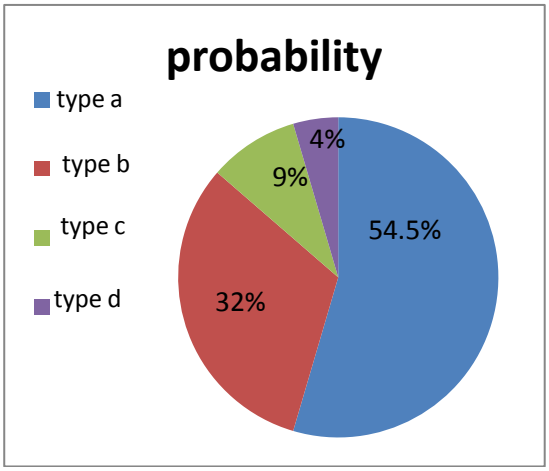

Fig. 1: Trucks availability fractions

Figure 2 shows a snapshot of the developed graph for the designated sector area. It contains 1022 nodes (as virtual bin nodes). These nodes are distributed into dissimilar capacitated clusters to suite the available trucks. Each truck can be assigned to one similar cluster only depending on its type and size. From the fraction results we found that 54.5% of the created clusters must be of type (a) with weight (5000kg), 32% of the created clusters are of type (b) with weight (3500kg), 9% of the created clusters are of type (c) with weight (1500kg) and4% of the created clusters are of type (d) with weight (8500kg).

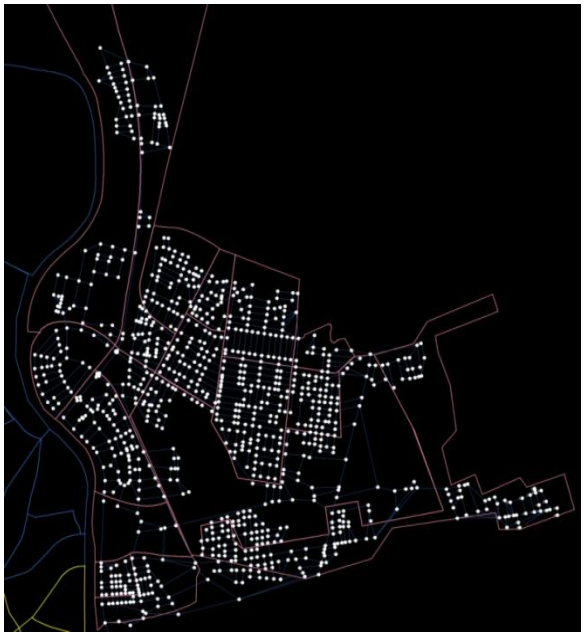

Fig. 2: waste bin nodes as net logo snapshot

The waste quantity (weight) in each bin node (container) is uniformly distributed. This quantity weight is ranging from the value of (a) which equal to 0 (minimum possible value)and(b) which represent its maximum weight. In this study and depending on the available information, the minimum value of waste found in each bin is estimated to be 10 kg. Implementing the proposed model using values for (a and b) in equation (1) to generate and estimate the waste values in each bin each day. Figure (3) presents

the randomly generated values of the waste quantity in each bin node in certain day.

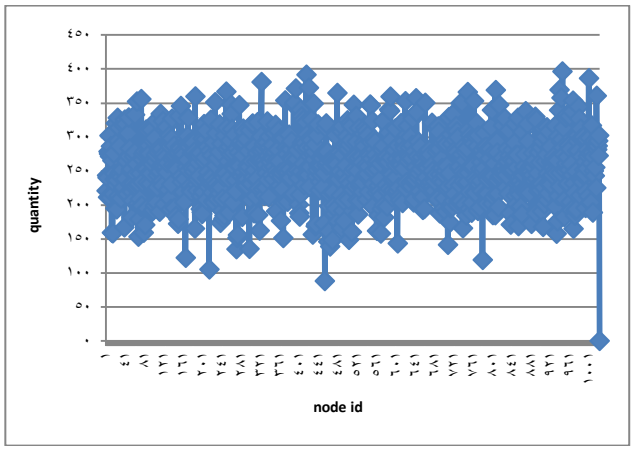

Fig. 3: The expected bins quantity

A (DNCCA) is performed and implemented on these area, nodes and fractions to generate heterogeneous clusters. These heterogeneous clusters are accumulating all the bin nodes with their allowed weight limits. Figure 4 shows the resulted clusters after applying a(DNCCA) algorithm using Net logo.

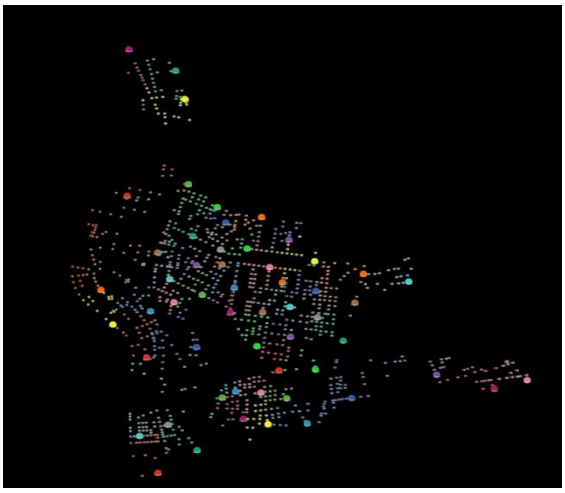

Fig. 4: clustering creation steps

The trucks fractions are found to be identical to the resulted clusters fractions after implementing this study algorithm. Total number of clusters, number of nodes in each cluster and number of clusters from each type are shown in figure 5.

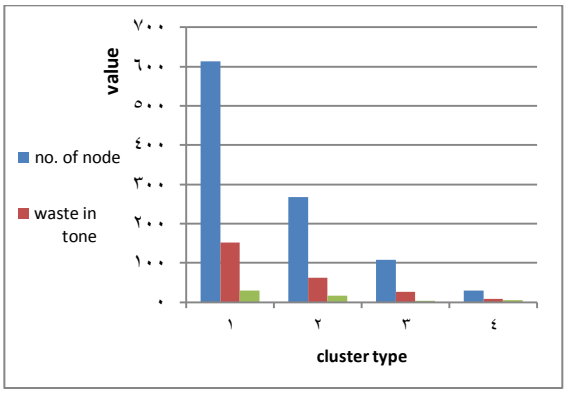

Fig. 5: Relation between the number of node, number of cluster and the amount of waste in each cluster type

Figure 6 representsthe number of clusters while figure 7 represents the amount of waste in each cluster.

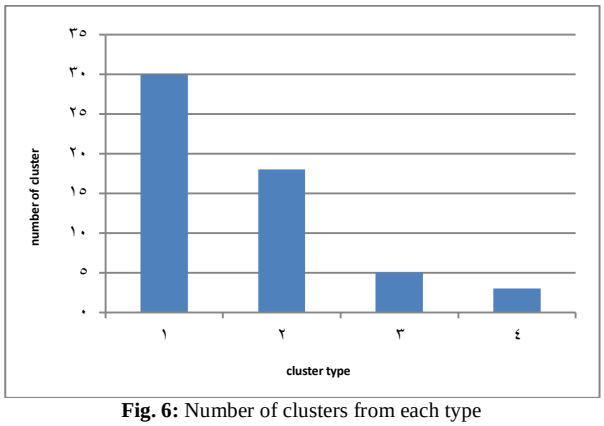

Fig. 6: Number of clusters from each type

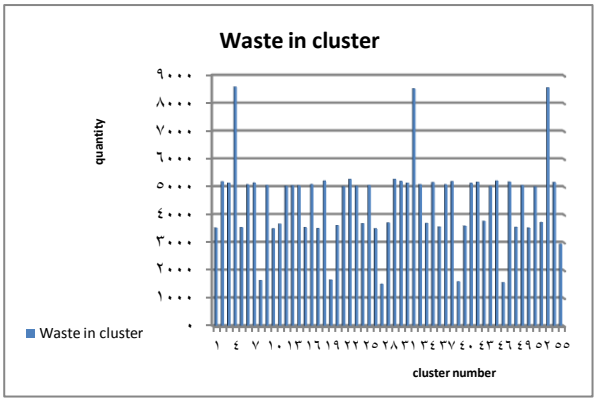

Fig. 7: Amount of waste in each cluster

Figure 8 shows the relationship between the number of nodes and there joining distances in each cluster while Figure 9shows the municipality collection zones, distances and their nodes.

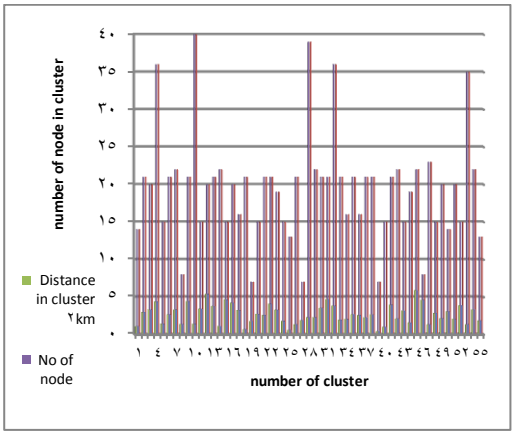

Fig. 8: Number of node and their joining distances

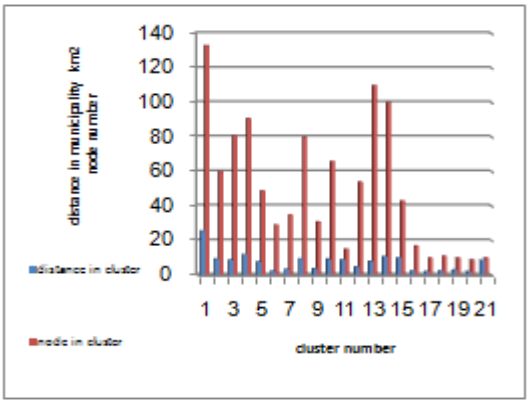

Fig. 9: Municipality zones and their nodes

8. Discussion

Analyzing the results depending on the available resources and the available trucks constraints presented many shortages comparing with the current plan to collect waste in the AOI. Comparing this study results with the municipality services department estimation showed a big gap requires treatment.figure 10shows a comparision between the total distances among nodes in each cluster according to the real service department and this study clustering algorithm. Comparing this study results with the real data and interviews information, their traveled distances are longer than the requird distances in this suggested clustering approach.A value of (40.6) km represents the difference between the two routes.

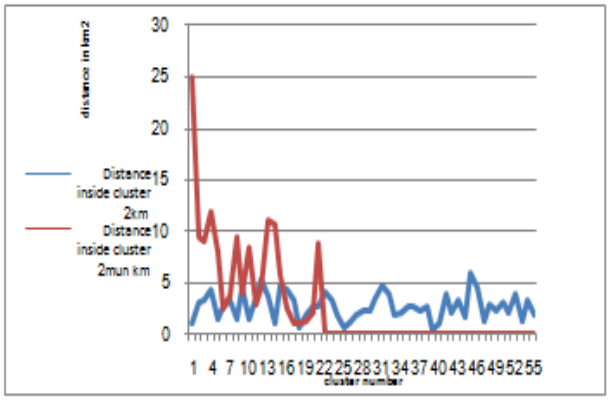

Fig. 10: comparison between node distance

A simple scheduling process is implemented according to this study results to estimate the optimal required number of shifts each day. Three shifts(about 3 trips for each truck) are found to be required to cover and empty all the wastes in bin nodes in this day. Table (4) shows the final optimal suggested scheduling process.

Table 4: The suggested scheduling process

Type	No. cluster	No. of truck	After 1'st trip	After 2'nd trip	After 3'rd trip
A	30	12	18	6	-6
B	18	7	11	4	-3
C	5	2	3	1	-1
D	3	1	2	1	1
total	56	22	34	12	-10

(-) sign mean this truck is not required in this shift.

9. Conclusion

A proposed capacitated clustering approach is developed to model the process of waste collection process in Hillah city. An optimal number of dissimilar clusters is calculated and created according to the available trucks types. A plan can be suggested to assign suitable truck to the suitable place (cluster). Number of required trips for each truck can also be estimated in advance. Such scheduling process will control the collection process and minimizes the total costs and required resources. A time table for each truck can be stated and followed. Each truck driver will know the required route length, places, bin nodes and quantities. A developed capacitated clustering approach shows a large reduction in the travelled distances which resulted in reducing the total cost. The developed approach in this study shows an exponential distribution to the number of nodes in clusters, wastes in clusters and number of cluster from each type as indicated in figure 5.

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