A Balancing approach for infectious medical waste allocation problem: Application to a real case in Tunisia

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***Abstract*—The hazardous waste management is a universal issue that involves the allocation of hazardous waste generators to the appropriate facilities, the routing of the hazardous wastes from their different generator points to the appropriate treatment facilities and the facilities location problems. The medical waste management is one of the major hazardous waste challenges in most healthcare facilities in the developing countries. In this paper, we focus on the medical waste allocation problem that consists on classifying the different generator points into clusters in order to identify the working area of the appropriate treatment facilities. The proposed approach consists on the optimization of minimizing distances between hospitals belonging to the same cluster and maximizing equity distribution of risk between clusters. In this regard, we developed a new wave-algorithm based on *k*-means algorithm to the infectious medical waste allocation problem. The proposed approach is used to solve a problem with real data in the west of Tunisia.**

Keywords—Hazardous Waste Allocation; Balancing; K-Means Algorithm; Clustering; Equity; Wave Algorithm; Infectious Medical Waste Management

1. Introduction

Recently, special attention was paid to the issue of hazardous waste management. Medical waste (MW) is one of the hazardous waste that requires a rigorous management. It consists mainly of pathological waste, infectious, chemical, pharmaceutical and household and sharps that are contaminated with blood, infectious agents, tissues, organs, etc. (Alagoz and Kocasoy, 2008). The waste generated from hospitals is now recognized as a serious problem that may have detrimental effects either on the environment or on human being through direct or indirect contact. Exposure to hazardous healthcare waste can result in disease or injury (WHO, 1999). Diseases like typhoid, cholera, acquired immunodeficiency syndrome (AIDS), and viral hepatitis B can be transmitted through the mismanagement of hazardous hospital waste (Mato and Kasenga, 1997). Recently, the management of Medical Waste presented a series of challenges for many developed and developing countries. These works can be classified into four main categories: the description of the national hazardous medical waste framework (Abdullah *et al*., 2008; Abd Es-Salem, 2010; Al Khatib and Sato, 2009), estimation of healthcare waste generated (Cheng *et al*., 2009; Jahandideh *et al*., 2009), choice of the appropriate techniques for disposal (Karaginnidis *et al*., 2010; Ali *et al*., 2010) and the choice of the appropriate transportation firm (Hsu *et al*., 2008; Gumus, 2009).

The novelty of this paper is to improve the overall medical waste management by the zoning of the healthcare facilities generators into zones. The zoning problem consists on partitioning the healthcare facilities into clusters under the assumption that the facilities belonging to the same cluster will be later served by the same treatment center. In this regard, we present a new balancing approach based on k-means algorithm for the medical waste allocation problem (section 2). This approach is later applied to a real case study in Tunisia (section 3). In section 4, we provide some concluding remarks.

2. Proposed Method

The clustering problem aims to divide a set of *m* items into *k* clusters. In our study, the target is to divide a set of healthcare facilities into *k* clusters, taking into account that one cluster is equivalent to one treatment center. Here, we use the *k*-means clustering algorithm (Macqueen, 1967) which is one of the most widely used partitioning algorithms. It is a simple iterative clustering that partitions a given dataset into a user-specified number of clusters *k*. The algorithm is simple to implement and to run, relatively fast, easy to adopt, and it is common in practice. It is evaluated using the measure of the intra distance between items in the same cluster (to be minimized) and the inter distance between items in different clusters (to be maximized).

In this work, the equity between clusters is also considered. We need to have balanced clusters in term of equity distribution of risk presented by the hazardous waste. Actually, the *k*-means result provides clusters based on distances between items. The items distribution has a great effect on the final result. Hence, we need to take into account the equity between clusters that corresponds to the equity distribution of risk between the different treatment centers.

3.1. The Equity Easure

The quantity of hazardous waste generated in their different sources has to be balanced between all clusters. Let's consider the *k*-means result. We denote by: Q_i : The quantity of hazardous waste in cluster $i, i \in (1...k)$; $\bar{Q}$: The average of hazardous waste quantity considering all items in *k* clusters: $\bar{Q} = \frac{\sum \mathrm{Q_i}}{k}\left(i \in (1...k)\right)$

To evaluate the *k*-means result, we need to compute L value which tends to zero with the improvement of the clustering result.

$$L = \sum_{i=1}^{\mathrm{k}} \left| Q_{\mathrm{i}} - \bar{Q} \right|$$

Here, we are looking to the equity. *L* will be measured after getting the *k*-means result and then apply the wave method to balance clusters if needed. The following paragraph gives details of the wave method that we propose in this paper.

3.2. The "Wave" Algorithm

Based on the *k*-means result, the "Wave" algorithm proceeds with the measure of the *L* value. The best value (which is not necessary feasible) is where all the Q_i are equal $\left(i \in (1...k)\right)$ and $L = 0.$ Generally, a small deviation from the optimal solution is acceptable by the decision maker. First, and before applying the wave method, we need to evaluate *L*, and decide if the *k*-means result could be accepted. If it is not acceptable by the decision maker we apply the wave method. The wave algorithm is an iterative algorithm. Following is the wave algorithm steps:

(1) Compute *L*

(2) If *L* tends to zero (the solution is accepted by the decision maker), then exit algorithm

(3) Else

(4) Initialize the list of forbidden clusters *FB*: $FB = \varnothing$

(5) Determine the cluster $C_d = \{x_1, ...x_p\}$ (*p* is the cardinality of the cluster C_d) which have $Max\ (Q_i)$

(6) Determine the item x_j which belongs to cluster C_d and have the minimum distance with the center of the cluster : $Min\ \{d(x_j, o_i)\}$ where $j = \{1, ..., p\}$ and $i = \{1, ..., k\} \setminus FB$. The nearest cluster will be denoted as C_a.

(7) x_j leave the cluster C_d and join the cluster C_a.

(8) If $Q_{C_d} > \overline{Q}$ (Evaluate the hazardous waste quantity in cluster C_a)

$FB \leftarrow FB + \{C_d\}$

C_a become C_d

Go to step (6)

(9) Else go to step (1)

In the wave method, the cluster C_d with an important quantity of hazardous waste will be considered. One of its component x_j will leaves this cluster to reach the nearest cluster C_a. The hazardous waste quantity in cluster C_a can also exceed the average $\overline{Q}$. In this case, C_a will also allow one of its components to leave and join the nearest cluster except the cluster that was the origin of this exchange. This process will iterate until we get an acceptable value of L by the decision maker.

This algorithm is very fast since the complexity is in order of $O(m^2k)$, where *k* is the number of cluster and *m* is the number of items.

3. Case study

A real case study is considered to illustrate the applicability of our approach. It is the allocation of the infectious medical wastes generated in 89 public healthcare facilities located in twelve governorates in the west of Tunisia. These hospitals generate an annual average tonnage of infectious medical waste equal to 1197 tons/year. This quantity of infectious medical waste generated is lower than the amount of waste generated in the east of the country, which has a total of 3166 tons/year. Thus, we consider 89 generated points that need to be partitioned into 2 clusters. The number of clusters is required by the decision-maker in the ministry of environment. The table 1 summarizes the different results required by the *k*-means algorithm as well as the wave algorithm based on the *k*-means results.

Table 1. Results

***k*-means Results**	**Wave algorithm based *k*-means result**
Cluster 1 : 821 Cluster 2: 376	Cluster 1: 599 Cluster 2: 598
Total average distance: 23.807	Total average distance: 30.11
$L = \sum_{i=1}^{k} \lvert Q_i - \overline{Q} \rvert = 445$	$L = \sum_{i=1}^{k} \lvert Q_i - \overline{Q} \rvert = 1$

As presented in the table above, the *L* value is decreased from 445 in the *k*-means result to be equal to 1 in the second iteration of the wave algorithm based on *k*-means results. This is shows the impact of the wave algorithm to balance the *k*-means result. Thus, the 89 hospitals points are equally partitioned into 2 clusters with 599 tons in the first cluster and 598 in the second cluster.

4. Conclusion

The medical waste allocation problem is intended to support the decision maker in optimizing the overall medical waste management system. In this paper, it was pointed out the importance of classifying the different generator points in independent groups. We presented a wave algorithm based on *k*-means algorithm looking for the minimization of distances between generators points belonging to the same cluster and the maximization of equity between the different clusters. The distance minimization was firstly optimized through the *k*-means algorithm. However, the result required by the *k*-means algorithm optimizes the distance regardless the equity one. Thus, we proposed a wave algorithm based on *k*-means result that optimizes the equity and assures balancing among the clusters. Our new balancing approach based on *k*-means algorithm optimizes simultaneously the two main objectives commonly used in optimizing the hazardous waste management

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