Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

An optimization model for collection, haul, transfer, treatment and disposal of infectious medical waste: Application to a Greek region

Gerasimos Mantzaras, Evangelos A. Voudrias *

Department of Environmental Engineering, Democritus University of Thrace, GR-67100 Xanthi, Greece

ARTICLE INFO

Article history:
Received 20 March 2017
Revised 31 July 2017
Accepted 21 August 2017
Available online xxxx

Keywords:
Infectious medical waste management
Optimization model
Cost minimization
Transfer stations
Infectious medical waste treatment

ABSTRACT

The objective of this work was to develop an optimization model to minimize the cost of a collection, haul, transfer, treatment and disposal system for infectious medical waste (IMW). The model calculates the optimum locations of the treatment facilities and transfer stations, their design capacities (t/d), the number and capacities of all waste collection, transport and transfer vehicles and their optimum transport path and the minimum IMW management system cost. Waste production nodes (hospitals, healthcare centers, peripheral health offices, private clinics and physicians in private practice) and their IMW production rates were specified and used as model inputs. The candidate locations of the treatment facilities, transfer stations and sanitary landfills were designated, using a GIS-based methodology. Specifically, Mapinfo software with exclusion criteria for non-appropriate areas was used for siting candidate locations for the construction of the treatment plant and calculating the distance and travel time of all possible vehicle routes. The objective function was a non-linear equation, which minimized the total collection, transport, treatment and disposal cost. Total cost comprised capital and operation costs for: (1) treatment plant, (2) waste transfer stations, (3) waste transport and transfer vehicles and (4) waste collection bins and hospital boxes. Binary variables were used to decide whether a treatment plant and/or a transfer station should be constructed and whether a collection route between two or more nodes should be followed. Microsoft excel software was used as installation platform of the optimization model. For the execution of the optimization routine, two completely different software were used and the results were compared, thus, resulting in higher reliability and validity of the results. The first software was Evolver, which is based on the use of genetic algorithms. The second one was Crystal Ball, which is based on Monte Carlo simulation. The model was applied to the Region of East Macedonia – Thrace in Greece. The optimum solution resulted in one treatment plant located in the sanitary landfill area of Chrysoupolis, required no transfer stations and had a total management cost of 38,800 €/month or 809 €/t. If a treatment plant is sited in the most eastern part of the Region, i.e., the industrial area of Alexandroupolis, the optimum solution would result in a transfer station of 23 m^3, located near Kavala General Hospital, and a total cost of 39,800 €/month or 831 €/t. A sensitivity analysis was conducted and two alternative scenarios were optimized. In the first scenario, a 15% rise in fuel cost and in the second scenario a 25% rise in IMW production were considered. At the end, a cost calculation in €/t/km for every type of vehicle used for haul and transfer was conducted. Also, the cost of the whole system was itemized and calculated in €/t/km and €/t. The results showed that the higher percentage of the total cost was due to the construction of the treatment plant.

1. Introduction

Mathematical programming has been used to optimize municipal solid waste (MSW) management systems, including haul and transfer (Abdelli et al., 2016; Laureri et al., 2016; Son and Luati, 2016; Das and Bhattacharyya, 2015; Sanjeevi and Shahabudeen, 2016; Hemmelmayr et al., 2013a, 2013b; Zsigraiova et al., 2013; Chatzouridis and Komilis, 2012; Apaydin and Gonullu, 2011; Faccio et al., 2011; Kuo and Wang, 2011; Gupta and Sharma, 2011; Arribas et al., 2010). Such techniques have also been used for healthcare waste, but the applications are very limited (Budak and Ustundag, 2013; Almeida, 2011; Shih and Lin, 2003; Shi et al., 2009). For example, Shih and Lin (2003) used dynamic programming and integer linear programming methods with multicriteria optimization for planning of infectious medical waste (IMW)

* Corresponding author.
E-mail address: voudrias@env.duth.gr (E.A. Voudrias).

http://dx.doi.org/10.1016/j.wasman.2017.08.037
0956-053X/

collection systems. Shi et al. (2009) presented a mixed integer linear programming model with cost minimization for medical waste reverse logistics networks and used a genetic algorithm method to solve the proposed model. Budak and Ustundag (2013) developed a mixed integer linear programming model to determine the optimal number and location of the facilities, by minimizing total cost. Other authors used GIS tools to optimize health care waste management systems (Shanmugasundaram et al., 2012; Alagoz and Kocasoy, 2008). Chaerul et al. (2008) used a goal programming approach for resolving complexities in healthcare waste management.

Voudrias and Graikos (2014) presented a preliminary design of an IMW management system for the Region of East Macedonia-Thrace (EMTR) in Greece. Steam sterilization was used as the treatment technology, but the siting of the treatment plant was not optimized and was placed in the geographic center of the region. Although a collection and transport plan was proposed, the authors indicated that there are several potential such plans, which could be evaluated for selection of the optimum one. Siting of formal transfer stations (TSs) was not considered, instead IMW storage rooms in public hospitals would be used as collection points in each prefecture. However, siting of TSs for IMW hauling is a significant issue regarding management cost minimization, but only sparingly has been addressed (Budak and Ustundag, 2013; Almeida, 2011). Although it is customary to collect and treat IMW from a few large producers, it is difficult and expensive to collect IMW from many widely spread small producers and this is the situation in which use of TSs may be necessary.

TSs for medical waste are operated in the United States, for example in the states of California, Florida, Texas, New York, etc. The medical waste management program of the Public Health Department of the State of California presents tables with medical waste TSs and treatment facilities (CDPH, 2017). The operation of such TSs for medical waste only recently (2012) was introduced in Greece (CMD, 2012). It is apparent that optimization of the system components is necessary to achieve management cost minimization.

The objective of this work was to develop an optimization model to design a collection, haul, transfer, treatment and disposal system for IMW. The model output includes the exact locations of the treatment facilities and TSs, their design capacities (t/d), the number and capacities of all waste collection, transport and transfer vehicles and their optimum transport path, as well as the minimum total management cost. The model was applied to the EMTR in Greece, for which IMW data were available (Voudrias and Graikos, 2014; Graikos et al., 2010; Kizlary et al., 2005; Mandalidis, 2011).

The paper has the following elements of novelty. It extended previous work by Chatzouridis and Komilis (2012) on MSW, by including treatment facilities in the model. In addition, there are significant differences between MSW and medical waste. For example, quantities of IMW are significantly smaller than those of MSW for the same population, with production nodes widely spread. Because IMW is a hazardous waste, special precautions and measures are necessary. For example, there are limits on storage temperature and time and the characteristics of the waste collection vehicles (Voudrias and Graikos, 2014). The novelty in the methodology is that IMW collection is not conducted on the same day for all producers, but varies, depending on the amounts produced. For example, collection frequency for a peripheral health office could be once a month, for a healthcare center once a week, whereas for a hospital every day. This differs from the approach applied in many MSW collection and transport models, but it is necessary to reduce collection and haul cost. However, this introduces significant complexity to the mathematical model, which was developed in this paper. Thus, our objective function is much different from the published for MSW models with constant daily collection patterns. Finally, operation of TSs in IMW management systems along with economic data for TSs and special collection vehicles and bins originating from primary sources are provided. The model can be applied to IMW management problems, in which only candidate locations for the treatment plants and TSs are previously defined and the model determines their numbers, exact locations and capacities.

2. Methodology

The proposed methodology consisted of the following four parts: (1) Exclusion of inappropriate areas for the construction of treatment facilities, (2) siting of all candidate IMW TSs and possible positions of treatment facilities for IMW, (3) model development in a user-friendly environment, such as an Excel® spreadsheet, to minimize total system cost and (4) model application.

2.1. Exclusion of inappropriate areas

Greek legislation (CMD, 2006, 2002) requires that the operation of hazardous waste treatment plants should not cause any damage to the environment and human health. Table 1 summarizes the criteria used in this work, to exclude unsuitable areas for construction of IMW treatment facilities, using the appropriate GIS software (Mapinfo Professional 10.5 of Pitney Bowes Software, Stamford, Connecticut USA).

2.2. Siting of treatment facilities and waste transfer stations

Once the inappropriate areas were excluded, all remaining areas in the region were considered suitable for siting IMW treatment plants. One candidate area for each municipality of the region was selected, based on the following steps: (1) If one or more industrial areas existed within the borders of the municipality the candidate area was sited within the most accessible industrial area and the nearest to most region's hospitals, following the proximity principle. Facilities for management of MSW are considered in industrial areas. (2) If no industrial area existed within the municipality, then among the appropriate areas the nearest to most region's hospitals and most accessible was selected, following the proximity principle.

Concerning the positions of IMW TSs, two siting scenarios were considered, if legal requirements are fulfilled. In the first, scenario A, candidate positions were in a small distance from the regional general hospitals. In the second, scenario B, positions were located nearby the regional facilities for MSW TSs (Chatzouridis and

Table 1
Exclusion criteria of inappropriate areas for the construction of IMW treatment facilities.

Criteria	Exclusion Buffer Zone
Anthropogenic areas	
Residential areas (CMD, 2002)	1000 m
Major road network	500 m
Environmentally sensitive areas	
Surface water and coast line	1000 m
Natura 2000 areas	1000 m
Forest areas	1000 m
Land use	All sites excluded
Areas of permanent irrigation	
Pasture lands	
Cultivated areas	
Other exclusions	All sites excluded
Purely rocky areas	

Please cite this article in press as: Mantzaras, G., Voudrias, E.A. An optimization model for collection, haul, transfer, treatment and disposal of infectious medical waste: Application to a Greek region. Waste Management (2017), http://dx.doi.org/10.1016/j.wasman.2017.08.037