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A mathematical model for municipal solid waste management – A case study in Hong Kong

C.K.M. Lee *, C.L. Yeung, Z.R. Xiong, S.H. Chung

Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

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ABSTRACT

With the booming economy and increasing population, the accumulation of waste has become an increasingly arduous issue and has aroused the attention from all sectors of society. Hong Kong which has a relative high daily per capita domestic waste generation rate in Asia has not yet established a comprehensive waste management system. This paper conducts a review of waste management approaches and models. Researchers highlight that mathematical models provide useful information for decision-makers to select appropriate choices and save cost. It is suggested to consider municipal solid waste management in a holistic view and improve the utilization of waste management infrastructures. A mathematical model which adopts integer linear programming and mixed integer programming has been developed for Hong Kong municipal solid waste management. A sensitivity analysis was carried out to simulate different scenarios which provide decision-makers important information for establishing Hong Kong waste management system.

1. Introduction

Waste is described as the inescapable remainder of the processes of modernization (Scanlan, 2007). Hong Kong, which is regarded as one of the most modern cities in the world, has faced an increasing amount of waste since its rapid urbanization in the 1990s (Chan, 1998). Hong Kong has been actively promoting recycling activities. In 2013, 37% of municipal solid waste was recycled before delivering to landfills. However, around 9500 tonnes of municipal solid waste every day is sent to the landfills, approximately 67% of which is domestic waste. Municipal solid waste occupied nearly 70% of the total average daily quantity of waste from 2009 to 2013 (Environmental Protection Department (EPD), 2015a). These recent statistics reflect that Hong Kong needs a speedy and effective solution before the saturation of the landfills (Yau, 2012).

Shekdar (2009) indicated a typical framework for solid waste management for Asian countries. It includes sources of waste, collection systems, transportation, processing systems and landfilling. This study conducted a review of waste management practices in Asia as shown in Table 1. In summary, the waste management practices in some Asian countries are well developed while some of them are still in their infancy. Owing to the increasing concerns in achieving specific targets in waste management, both countries require municipal solid waste solutions and appropriate suggestions that suit their needs.

Recent research has concentrated on investigating different approaches, systems and mathematical models regarding waste management (Beigl et al., 2008; Yau, 2010). There are various waste management policies such as Pay-As-You-Throw (PAYT) and the deposit refund system (Reichenbach, 2008). These approaches can encourage people to produce less waste but provide limited information to support future waste management. Research on use Web-GIS based system was conducted in Italy for optimizing municipal solid waste selective collection (Rada et al., 2013) and the proposed approach has been extended and applied in Malaysia and China, which shows the feasibility of Web-GIS oriented tools in countries with transient economies. Although actual data can be collected during implementation, existing waste management systems provide restricted insights to support waste management plans. Mathematical models can further leverage the actual data to generate useful information for future waste management.

Bing et al. (2016) summarised the contemporary waste management practices and operations in Europe. The authors pointed out that one of the current problems is overcapacity in waste management infrastructure. Researchers should consider municipal solid waste management in a holistic view so as to take the whole municipal solid waste management process into account.

* Corresponding author.
E-mail address: ckm.lee@polyu.edu.hk (C.K.M. Lee).

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Table 1
A review of current waste management practices in Asia.

	Japan (Tokyo) (Ministry of the Environment Government in Japan, 2010; Environmental Bureau, 2013; Pariatanby and Tanaka, 2014)	Korea (Seoul) (Ryu, 2010; Lee and Paik, 2011; Environmental Bureau, 2013)	Taiwan (Taipei) (Lu et al., 2006; Environmental Protection Administration, 2010; Environmental Bureau, 2013; Pariatanby and Tanaka, 2014)	Malaysia (Manaf et al., 2009; Hannan et al., 2011; Environmental Bureau, 2013; Pariatanby and Tanaka, 2014)
Policy and legislation	Implementation of dirt removal law and waste management law	Implementation of volume-based waste fee system	Implementation of volume-based waste fee system	
Type of wastes	Recyclable waste; bulky waste; household waste; other waste	Recyclable waste; food waste; bulky waste; household waste; construction/demolition debris	Recyclable waste; kitchen waste; bulky waste; other waste	Recyclable waste; food waste; household waste; construction/demolition debris other waste
Collection system	Waste collection by government and local authorities. All urbanized areas are covered under a regular schedule	Waste collection by government or private haulers regularly. Free of charges for recyclable wastes and proper charges for discharging bulky items	Waste collection by government and recycling industry regularly	Waste collection by local authorities. Low waste collection coverage and irregular collection schedule
Transportation	Use waste collection vehicle with a compactor and a compression device		Adopt upgrade waste collection vehicles and recycling trucks	Propose a RFID-based solid waste bin and truck monitoring system
Processing system	Recycle 21% and incinerate 79% material	Recycle 57%, incinerate 17% and landfill 26% material	Recycle 52%, incinerate 46% and landfill 2% material	Recycle less than 5% materials
Landfilling	Cause illegal dumping	Shut down around 80% landfill sites to limit the amount of landfilling	Cause illegal dumping	Cause environmental problems due to uncontrolled open dumping

This project pertains to the design and development of a mathematical model for municipal solid waste management. Although there are many existing waste management systems around the world, most of them consider implementing different policies to handle waste problems. Scenario analysis or mathematical modelling for waste management have not yet been widely adopted, especially in Hong Kong. Hence, a mathematical model is developed based on the typical framework for solid waste management in Asian countries. Beyond considering the whole municipal solid waste management process, this model also attempts to utilize the capacity of incinerator outside Hong Kong to improve the waste problems.

2. Mathematical models for municipal solid waste management

Operation research techniques provide guidance for decision-makers to select best strategies or choices among a set of options (Ghiani et al., 2014). As a result, various mathematical programming models were established to facilitate waste management and planning (Dai et al., 2001). For example, the incineration process (Yang et al., 2002), amount of waste from residents (Benítez et al., 2008), formation of perched leachate zone in landfills (Di Bella et al., 2012) and greenhouse gas emissions (Mavrotas et al., 2013) have been developed. These models emphasis on specific areas and have not yet taken the whole municipal solid waste management process into account.

Some researchers attempt to investigate mathematical models for the entire municipal solid waste management. These models mainly focus on handling vehicle routing problems. Son and Louati (2016) proposed a municipal solid waste collection model to optimize the routes between transfer stations and sites for inhomogeneous vehicles. The objective function attempts to maximise the collected waste amount and to lessen the environment emission regarding vehicles. The proposed model addressed the limitations of existing vehicle routing models. A case study was conducted at Danang city in Vietnam. The results indicated that better routes with shorter travelling distance and operational hours could be proposed by the mathematical model.

Owing to the escalating labour cost, Das and Bhattacharyya (2015) developed an integer programming model for municipal solid waste management to optimize the collection and transportation routes. The objective function aims to minimise the collection and transportation cost during the waste management process. The authors divided the municipal solid waste management system into four parts and optimised the routes from part one to part four. The performance of the mathematical model has been realised by the data collected in Kolkata in India. Although the proposed model is able to lessen the path length for municipal solid waste management, it provides limited information regarding the usage of the waste management facilities and infrastructures.

Ghiani et al. (2014) conducted a review regarding operation research in solid waste management. The authors indicated the problems in solid waste management involve strategic, tactical and operational dimensions which can be solved by operation research techniques. Apart from highlighting the general features which are considered by the existing mathematical models, the authors presented a mixed integer programming model for strategic planning in solid waste management. The objective function aims to minimise the total cost incurred over the solid waste management system. The model which is a generalization of literature has not yet implemented in real situation. It can act as a foundation for developing future solid waste management model.

Badran and El-Haggar (2006) also suggested a mixed integer programming model for municipal solid waste management and planning at Port Said in Egypt. The model recommends a combination of waste management infrastructures with optimal numbers and locations so as to minimise the total cost. Two scenarios were generated and sensitivity analysis was conducted. The results indicated that the optimal scenario for municipal solid waste management is able to generate profits.

Costi et al. (2004) presented a mixed integer nonlinear programming decision support model to facilitate governments or urban planners to design and develop waste management infrastructures including incineration, disposal, treatment, and recycling.

A case study of this model was conducted at Genova in Italy. This model defines waste flows to various waste management infrastructures. The mixed integer programming approach determined a combination of optimal number of facilities and locations to minimise the waste management cost. Apart from main infrastructures such as incinerators, landfills and recycling plants, the model also takes separators into consideration.

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