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Research article

Hazardous waste management system design under population and environmental impact considerations

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ABSTRACT

This paper presents a multi objective mixed integer location/routing model that aims to minimize transportation cost and risks for large-scale hazardous waste management systems (HWMSs). Risks induced by hazardous wastes (HWs) on both public and the environment are addressed. For this purpose, a new environmental impact definition is proposed that considers the environmentally vulnerable elements including water bodies, agricultural areas, coastal regions and forestlands located within a certain bandwidth around transportation routes. The solution procedure yields to Pareto optimal curve for two conflicting objectives. The conceptual model developed prior to mathematical formulation addresses waste-to-technology compatibility and HW processing residues to assure applicability of the model to real-life HWMSs. The suggested model was used in a case study targeting HWMS in Turkey. Based on the proposed solution, it was possible to identify not only the transportation routes but also a set of information on HW handling facilities including the types, locations, capacities, and investment/operational cost. The HWMS of this study can be utilized both by public authorities and private sector investors for planning purposes.

1. Introduction

A hazardous waste (HW) is defined as any waste that possesses hazard properties (such as toxicity, flammability, carcinogenicity, reactivity, corrosivity, etc.) that make it a substantial present or potential hazard to humans and the environment and thus requires strict controls in the course of handling, transportation, processing and disposal. Hazardous waste management systems (HWMS) entail collection of HWs, their transportation to facilities with proper processing technologies or final disposal.

Due to the various risks involved, safety is the foremost priority for all HWMSs however; inherent complexities to the design and operation of these systems bring challenges. Every HWMS should address handling of many wastes classified as hazardous with various chemical and physical properties, which may impact humans and environment in different ways and require a specific type of processing. Due to these complexities of handling HWs, there are several issues involved in modeling entire HWMSs. Firstly; HWs can possess diverse characteristics limiting their compatibility with certain types of processes (waste-to-technology compatibility) (Alamur and Kara, 2007; Nema and Gupta, 1999; List and Mirchandani, 1991; Jennings and Sholar, 1984). Second, significant risk of HWs to humans and the environment influences stakeholder perceptions and priorities of decision makers. Last, even when HWs are processed properly, hazardous process residues may arise as a result of waste handling operations, which may need further processing.

Previous studies modeling HWMSs has various levels of complexity in terms of their coverage of the range of HWs and management options. Some studies included only a single type of HW with a single technology, which presents a non-inclusive approach to complicated HW management problem (Alcada-Almeida et al., 2009; Rakas et al., 2004; Cappanera et al., 2004; Killmer et al., 2001; Sihimizu, 1999; Giannikos, 1998; Jacobs and Warmerdam, 1994; Stowers and Palekar, 1993; ReVelle et al., 1991). Other studies improved their coverage by handling single HW/limited number of technologies (Wyman and Kuby, 1995), multiple HWs/single process (Hu et al., 2002; Wang et al., 2008) and multiple HWs with limited number of technologies (Emek and Kara, 2007). A more realistic representation of HWMSs is provided by Nema and Gupta (1999), Koo et al. (1991), and Jennings and

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Suresh (1986) who investigated multiple HW/multiple technology systems. In an early study, the model of Jennings and Sholar (1984) allowed generation of multiple waste types from individual sources and co-location of facilities of different technologies (i.e. integrated facilities). Processing residues of HW treatment operations, which themselves can be classified as hazardous were considered only in a small number of studies (Alamur and Kara, 2007; Nema and Gupta, 1999; Hu et al., 2002; Jennings and Suresh, 1986).

Another important aspect of HWMS aside from waste-to-technology compatibility is the risk associated with transportation of HWs and operation of HW facilities. Hazardous wastes need to be safely transported from each point of generation to appropriate facilities for processing and disposal. Moreover, process residues arising from hazardous waste facilities should also be directed to proper destinations. This makes transportation to be one of the fundamental components of a HWMS that requires careful consideration during planning. Although incidents involving hazardous materials are not frequent, consequences can be severe (Erkut et al., 2007; Brown et al., 2000). It is highly possible that the effects of an incident would extend beyond human receptors. In the case of an incident, possible impacts include injuries and death, clean-up costs, property damage, product loss, and environmental damage (Federal Motor Carrier Safety Administration, 2001). Although risks on population are addressed in all hazardous wastes/hazmat routing studies (Table 1), environmental risks associated with the HWMSs are overlooked.

Previously, environmental risks were suggested as relevant decision-making criteria by Jennings and Sholar (1984) and Martinez-Alegria et al. (2003). Few attempts to quantify environmental risks were based on exceedance of the time needed by ecosystems to recover from damage (Jonkman et al., 2003), cost to mitigate environmental pollution (Anand, 2006), clean-up costs (Saat et al., 2014), and the area of environmental components within a certain bandwidth (Jennings and Suresh, 1986). Pradhananga et al. (2014) obtained the Pareto optimal solutions for a hazardous material transportation problem and compared CO_2, NO_x and particulate matter emissions originating from transportation.

In order to ensure economic and technical feasibility as well as safety for both public and the environment; locations, technologies and capacities of hazardous waste processing and disposal facilities need to be carefully selected. In the course of the decision-making process, sources that might create multiple types of hazardous wastes with diverse characteristics should be considered. Further; the type, location, size of waste transfer, treatment and disposal facilities and shipment routes should be determined. In the planning phase, it is crucial to recognize the above complications to comprehend aspects that differentiate HW management from non-HW management. Similarly, while modeling a HWMS, simplifying assumptions that may contradict the nature of HW management or its underlying principles, including the precautionary, proximity, waste hierarchy and polluter-pays should be avoided.

Aim of this study is to develop a mathematical model that is capable of representing a complex HWMS, which takes cost and risks of HW management operations and their trade-offs into account. This model intends to present a better understanding of the practical concerns of HW management and be applicable to existent HWMSs. During development of the conceptual model, a number of aspects including waste classes, waste management principles, and waste-to-technology compatibilities were taken into consideration. Based on our conceptual model; we develop a multi-objective mixed integer location/routing model for a national HWMS. This model is capable of determining HW transportation routes, facility locations and capacities. Effects of different HW management strategies and stakeholder priorities can be assessed through scenario development and comparison. To test its effectiveness, the model is applied to Turkey to plan an economical and safe HWMS. Within the scope of the case study, minimum cost, environmental risk, population risk and total risk scenarios are evaluated.

Table 1
Population risk models utilized.

	Risk model								
	Traditional risk	Population exposure	Incident probability	Perceived risk	Conditional risk	Maximum population exposure	Expected disutility	Mean variance	Demand satisfaction
Erkut et al. (2007)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Jonkman et al. (2003)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Kara et al. (2003)	✓	✓							
Nema and Gupta (1999)	✓								
List and Mirchandani (1991)	✓								
Zhang et al. (2000)	✓								
Fabiano et al. (2002)	✓								
Carotenuto et al. (2007)	✓								
Alamur and Kara (2007)		✓							
Stowers and Palekar (1993)		✓							
ReVelle et al. (1991)		✓							
Verter and Kara (2001)		✓							
Verter and Kara (2008)		✓							
Current and Ratick (1995)		✓							
Pradhananga et al. (2014)		✓							
Lovett et al. (1997)		✓	✓						
Huang et al. (2005)		✓	✓						
Jacobs and Warmerdam (1994)			✓						
Giannikos (1998)				✓					
Erkut and Ingolfsson (2005)									✓