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Using metaheuristic algorithms to solve a multi-objective industrial hazardous waste location-routing problem considering incompatible waste types

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ABSTRACT

Rapid progress in technology is a primary cause of acceleration in the rate of the industrial hazardous waste generation all over the world. Management of hazardous waste has magnetized researcher's attention because of its considerable impacts on the economy, ecology, and the environment. In this regard, this paper addresses a new industrial hazardous waste location-routing problem by putting emphasis on some new aspects in its formulation such as considering restriction about the incompatibility between some kinds of wastes and incorporating routing decisions into the model. Simultaneously minimization of three significant criteria, including total cost, total transportation risk of hazardous waste related to population exposure, and site risk persuades authors to implement two multi-objective evolutionary algorithms, Nondominated Sorting Genetic Algorithm (NSGA-II) and Multi-Objective Particle Swarm Optimization (MOPSO) for tackling the problem. The results obtained from experiments on several problem instances confirm the superiority of NSGA-II over MOPSO in terms of most of the evaluation metrics. Therefore, the significance of the paper is firstly the novelty of the model, and secondly, the comparison of two solution methods allows for the identification of the method resulting in the best results.

1. Introduction

Hazardous Waste Management (HWM) is a global issue that has become a serious concern for industrialized societies during recent years. Wastes could be categorized as hazardous if they possess at least one of the following traits: toxicity, reactivity, ignitability, and corrosiveness. These kinds of wastes are generated by different sources. From large industries to small businesses, households, hospitals, and farms are main sources of hazardous wastes. An inappropriate HWM system as a threat causes substantial harm to the environment, human health, and safety (Herva et al., 2014). Hence, a critical problem for developed countries is managing the hazardous wastes taking account of safety and cost-effectiveness.

Treatment of these wastes and removing corresponding risks are performed mainly using chemical, thermal, and biological methods (Kim et al., 1990). Ion exchange, precipitation, oxidation and reduction, and neutralization are common chemical methods, and high-temperature incineration is a common thermal method which is used for this purpose. Treatment of certain organic wastes, for instance, those from the petroleum industry is done biologically. (Hu et al., 2013). Because of the widely differing physical and chemical characteristics of hazardous wastes, treatment technologies have to be carefully matched to each waste type, taking into consideration the nature of the wastes, the degree of hazard reduction required, as well as economic, and other factors. A general scheme for the compatibility of treatment technologies as well as recovery processes with different types of hazardous waste has been provided in the literature (Edulgee, 2001).

HWM as a complex system primarily consists of the collection, transportation, recycling, treatment, and disposal processes. While disposal of waste has become a serious environmental issue and problem continues to increase with development of industries (Cholake et al., 2017), recycling is critically required to minimize pollution problems and treatment costs (Ren et al., 2017). In other

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words, waste utilization would promote a circular economy industry, reduce the consumption of primary energy and natural resources, and reduce global warming (Wiemes et al., 2017). All these components are very closely interlinked and each component can influence the other (Seadon, 2010). Therefore, the quality and safety of HWM are affected by the decisions taken on all of the aforementioned processes (Zhao et al., 2016).

Three main objectives addressed by researchers in the field of HWM are minimizing the overall costs such as constructing and operating costs related to waste management system (Nema and Gupta, 1999), minimizing the immediate or long-term potential risks that are imposed on the surrounding population centers and environment (i Or, 1994), and increasing the equity of the distribution of the mentioned risks imposed by HWM system (Wyman and Kuby, 1995). Therefore, the optimization of the HWM system requires to pay immense attention to the governmental regulation/policy and industrial/public consciousness (Tsai and Chou, 2004).

The studies associated with HWM optimization problems are classified into three main categories. Because of the importance of optimization of locating decisions in HWM systems, the first category of these studies are related to the location planning (Sumathi et al., 2008). For example, Jabbarzadeh et al. (2016) developed a multi-objective model in order to determine suitable locations for waste processing facilities. Minimization of the total costs, greenhouse gas emissions, and fuel consumption are the significant criteria considered in this study. The second category of HWM studies concentrates on the routing planning. Minimizing the total traveling time and number of applied vehicles considering characteristics of wastes was examined by Minh et al. (2013). Decreasing the negative impacts on the surrounding population centers and environment is the main criterion in a waste collection problem (Ristić et al., 2016). Integration of the two mentioned HWM problems called Hazardous Waste Location-Routing Problems (HWLRPs) and classified as the last category. In comparison to considering location and routing problems separately, modeling the two problems simultaneously could lead to more efficient solutions. In other words, each problem contains complex decisions and the decisions on each problem affect another problem.

The first effort to address a HWLRP with a single type of hazardous waste is related to Zografros and Samara (1989). To locate the disposal facilities and to determine the efficient routes between demanding nodes and disposal facilities, a goal-programing model was proposed by authors which optimizes the travel time, transportation risk, and site risk. Alumur and Kara (2007) addressed a multi-objective location-routing problem to manage multiple types of hazardous wastes. In order to design an effective HWM system, they incorporated some constraints which have been ignored in the literature into their model. For example, the type of technology for each treatment center was considered as a decision variable and the compatibility between waste and treatment technology was addressed as a linear constraint in their proposed model. The problem of establishing incinerators by considering standards of the air pollution was addressed by Emek and Kara (2007) in a HWLRP incorporating recycling and treatment facilities. To achieve the minimum transportation cost and to satisfy the constraint of air pollution, they developed an integer programming model. The work of Zhang and Zhao (2011) is an example for HWLRP under the uncertain conditions. Minimizing the total costs and maximizing risk equality were the objectives of their study. A comprehensive overall of various objective functions including operation costs for different HWM system facilities, revenues from selling recycled wastes, initial investment costs for opening each center distinguishes the work of Boyer et al. (2013) from the previous studies in this area. Considering direct routes for shipping wastes to disposal centers was another feature of their work. In order to complete the HWM network, Samanlioglu (2013) considered direct routes from recycling centers to disposal centers for shipping non-recyclable wastes. Assessing site risk for different facilities is another contribution of that work. That work was extended by introducing fuzzy satisfaction concept and human feeling factors to the model by Ghezavati and Morakabatchian (2015). In addition to generation nodes, several nodes called warehouse nodes were considered in the network which wastes are gathered. In some previous studies, the routes are supposed to be a tour. For example, Zhao and Verter (2015) examined a used oil location-routing problem with the same starting and ending points for vehicles. Significant features of the aforementioned studies on a HWLRP and the current study are shown in Table 1.

As can be founded from Table 1, incompatible characteristics of different types of hazardous wastes have not been considered in the previous HWLRPs. Furthermore, these studies did not incorporate the routing decisions into the designing phase of the HWM system. With respect to these gaps as well as some realistic assumptions disregarded in the previous studies, some distinguishing features of this study are as follows:

- addressing different types of wastes
- considering waste-waste compatibility requirements
- incorporating the collection vehicle routing decisions into the problem
- considering a heterogeneous fleet of vehicles in terms of capacity and maximum allowable travelled distance
- application of multi-objective evolutionary algorithms to handle the HWLRPs

Table 1
Significant feature of this study and relevant hazardous waste location-routing problems.

Study	System framework			Compatibility		Rout			Vehicle		Objective		
	Treatment	Recycling	Disposal	Waste-Waste	Waste-Technology	Generation-Facility	Facility-Facility	Generation-Generation	Homogeneous	Heterogeneous	Cost	Risk	Equity
Zografros and Samara (1989)			✓		✓	✓			✓		✓	✓	
Alumur and Kara (2007)	✓		✓			✓	✓		✓		✓	✓	
Emek and Kara (2007)	✓	✓	✓		✓	✓	✓		✓		✓	✓	✓
Zhang and Zhao (2011)	✓		✓		✓	✓	✓		✓		✓	✓	
Boyer et al. (2013)	✓	✓	✓		✓	✓	✓		✓		✓	✓	
Samanlioglu (2013)	✓	✓	✓		✓	✓	✓		✓		✓	✓	
Ghezavati and Morakabatchian (2015)	✓	✓	✓			✓	✓	✓	✓		✓	✓	
Zhao and Verter (2015)	✓		✓		✓	✓	✓		✓		✓	✓	
This study	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	