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Improved approaches to the network design problem in regional hazardous waste management systems

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ABSTRACT

This paper investigates the network design problem arising from the regional hazardous waste management system. The problem is to identify the locations of various waste facilities, and determine the transportation routes of hazardous wastes and waste residues between those waste facilities. Aiming at minimizing jointly the total cost and total risk, the problem is formulated as a multi-objective mixed integer linear programming model. By exploiting the advantages of the model, three multi-objective optimization approaches are customized to find highly qualified non-dominated solutions. The effectiveness and efficiency of the approaches are examined both on a hypothetical case and a realistic case.

1. Introduction

In China, hazardous wastes are categorized as the solid and liquid wastes exhibiting at least one of the following five characteristics: corrosivity, toxicity, ignitability, reactivity and infectivity. The other solid and liquid wastes which possess unclear hazardous characteristics but present harmful effects on the environment and human health have to be managed as per hazardous wastes. Along with the industrial advancement in the past ten years, a large number of hazardous wastes diverging in types have been generated in the industrial production and manufacturing processes in China. According to environmental statistics annual report 2013 released by the Ministry of Environmental Protection of China, Chinese industries produced 31.57 million tons of hazardous wastes belonging to 49 types in 2013. Of this number of hazardous wastes, 53.9% is recycled and reused, 22.2% is treated and disposed, and 25.7% is stored. The top three hazardous waste types in terms of quantity are the asbestos waste mainly generated from the nonmetal mining industry, the acid waste mainly from the chemical manufacturing industry, and the caustic waste mainly from the paper manufacturing industry.

The biggest difference distinguishing the hazardous waste from the ordinary waste is its hazardous characteristic. If the hazardous waste is not properly managed, it will endanger the ecological environment and human health, and even hinder the sustainable development of the economy. Nowadays many developing countries (e.g. China, India, Turkey) in the world still take the industry as the main force to drive their economic development. As the country becomes more industrialized, the more hazardous wastes will be generated in the industrial processes. Hence, how to manage the hazardous waste in a safe and cost-effective manner is a significant problem in an industrialized country. The hazardous waste management mainly involves the collection, transportation, recycling, treatment and disposal processes. Each process involves complex

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decisions and imposes immediate or long-term risk to the surrounding environment and population. Meanwhile, the decisions of all processes relate with each other and determine the quality and safety of the management of hazardous wastes simultaneously.

In this paper, we investigate the network design problem arising from the regional hazardous waste management system. The framework of the system is a multi-stage multi-facility logistics network as illustrated in Fig. 1. Our problem starts with the waste origins that produce a number of and multiple types of hazardous wastes at every certain time (e.g. a month, half a year, or 1 year). Each type of hazardous waste at each origin is further classified as the recyclable, treatable and disposable portions. Recyclable wastes are transported directly to recycling centers to be recycled and reused. Treatable wastes have to be transported firstly to treatment centers where their potential risk is reduced. Disposable wastes are transported directly to disposal centers with security landfills. Then, each treatment center can be equipped with multiple types of technology, such as solidification and incineration, see LaGrega et al. (2010). However, each type of hazardous waste can only be treated with certain technologies. For example, highly reactive wastes cannot be incinerated. Therefore, treatment centers utilize comparable technologies to treat hazardous wastes as waste residues. Waste residues are also classified as the recyclable and disposable portions which are transported directly to recycling centers and disposal centers, respectively. Finally, the remaining disposable residues after the recycling process at recycling centers are transported to disposal centers such that the management processes of hazardous wastes are completed ultimately.

We define the regional hazardous waste network design problem to identify the locations of recycling centers, treatment centers and disposal centers from their respective candidate sites, and determine the transportation routes of hazardous wastes and waste residues from waste origins to those centers and between those centers, while all corresponding operational and safety constraints are respected. The problem is inherently a multi-objective optimization problem as the solution to the problem should optimize multiple objectives to reflect different perspectives of the stakeholder. In our setting, the environmental protection department of the regional government takes full responsibility for the management of hazardous wastes in the region. The government firstly designs the regional hazardous waste management system, and then attracts private companies to (co-)construct and (co-)operate hazardous waste facilities. Accordingly, on one hand, given the compelling obligation of the government to build a harmonious and livable society, the best solution should impose the least risk to the environment while the economic cost is controlled as low as possible. On the other hand, to encourage private companies to join the hazardous waste market so as to alleviate the government financial burden in the management of hazardous wastes, the best solution should require the least economic cost while the environmental protection regulations imposed by the national standards are satisfied strictly. Hence, it is necessary to consider a multi-objective network design problem to obtain an implementable regional hazardous waste management system.

We would like to call our problem the network design problem (Nema and Gupta, 1999) rather than the location–routing problem as by many related works, i.e. Zografros and Samara (1989), Alumur and Kara (2007), etc., since our problem differs actually from the classical logistics location–routing problem (Nagy and Salhi, 2007) in that the vehicle routing decision is not considered explicitly in our setting. Our problem has received great attentions during the last twenty-five years. A lot of early works on the hazardous waste management considered simplified network design problems. Some researches focused only on the locations of undesirable hazardous waste facilities (e.g. incinerators in treatment centers, landfills in disposal centers), in which the transportation routes between facilities were ignored. Some other studies emphasized only the transportation routes between hazardous waste facilities given that the locations of facilities were pre-determined. Evidently, the locations of hazardous waste facilities significantly affect the transportation cost and risk between facilities. Therefore, the location and transportation decisions of the network design problem in the hazardous waste management should be optimized simultaneously. In what follows, we restrict our attention to the early works focusing on complete hazardous waste network design problems. The related works can be characterized by the framework of the management system,

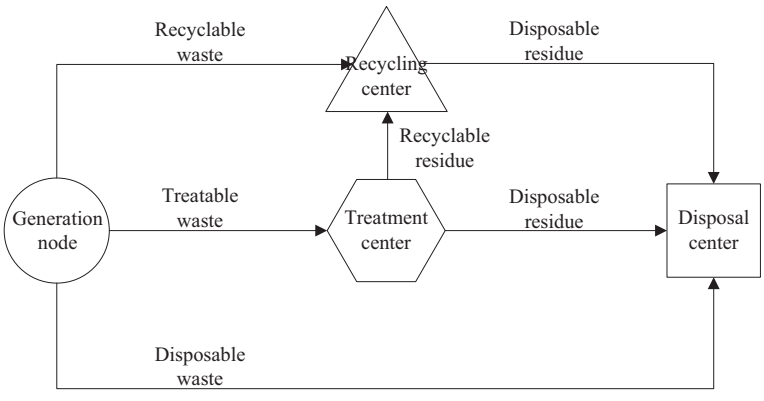

Fig. 1. Framework of the regional hazardous waste management system.