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# A bi-objective model for the used oil location-routing problem

Jiahong Zhao [a], Vedat Verter [b,*]

[a] School of Business, Guangzhou University, China
[b] Desautels Faculty of Management, McGill University, Canada

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ABSTRACT

A staggering amount of used oils (e.g., 1.4 billion gallons in the U.S.) are generated annually as part of our industrial lifestyle. These are harmful to the population and environment in the vicinity of the transport routes as well as the storage, treatment and disposal facilities. In this paper, we provide an analytical framework to simultaneously answer the following questions: Where should the used oil storage, treatment and disposal facilities be located? What are the most appropriate capacity levels for these facilities? Which routes should be used among the different echelons of facilities in the used oil collection network? Focusing on the hazardous ingredients of used oils that are airborne on release, we propose an environmental risk measure by incorporating the Gaussian plume model in the box model. We present a bi-objective model for the location-routing problem so as to minimize the total environmental risk and the total cost. We use a modified weighted goal programming approach, which proved to be computationally efficient through a wide range of tests. The application of the proposed analytical framework in Chongqing of Southwest China provided interesting managerial insights.



## 1. Introduction

Due to the heightened awareness for environmental preservation, hazardous waste management has become a popular concern in recent years. In this paper, we focus on a particular type of waste i.e., *used oil*, which encompasses any contaminated oil that has been through its intended use cycle. Used oil needs to be handled as a hazardous waste, particularly when it is mixed with certain other wastes and displays any of the following four characteristics: ignitability, corrosiveness, reactivity or toxicity [1]. Over 350,000 t of used oil is produced annually in the U.K. [2] whereas nearly 1.4 billion gallons of used oil is generated in the U.S. [3] each year. Even though most of this waste can be recycled (or cleaned), large quantities of used oil continue to be improperly disposed. In China, for example, about 782,100 t of used oil was emptied into the river system in 2007 [4]. Note that this volume qualifies used oils as the third most important pollution source in China. Evidently, there is a pressing need for the design and development of integrated used oil collection, storage and processing systems. We aim at filling this gap from the network design perspective.

We define the *used oil location-routing problem* as the simultaneous optimization of facility location, capacity acquisition and vehicle-routing decisions so as to minimize the associated total cost and environmental risk. Similar to other hazardous wastes, the management of used oil comprises the processes of transportation, storage, treatment and disposal [5]. Each of the latter three processes can be performed at a different facility. It is also possible to co-locate the storage, treatment and disposal of used oil in which case, the site would be an *integrated facility* [6]. In this paper, we assume that a central decision-maker is required to locate multiple facilities with proper capacity levels, and design vehicle routes visiting all the used oil generation and processing sites.

The optimization of the used oil location-routing problem has bearings on the economy and the environment. The economic impact, measured as cost, is primarily due to the expenditure on facility location, capacity acquisition, and transportation. The impact on the environment, however, can be quantified as the risk to the population and the environment due to a release incident—en route or at a facility. Therefore, the integrated development of a facility and transport network configuration that considers both cost and risk is necessary.

Used oil is an ignitable liquid that contains high levels of heavy metals posing a significant threat to the environment. Petrochemical industries, manufacturing companies, mining and smelter operations, in general, are the major generation points for used oil. The concentration of heavy metals in the used oil increases because of the friction in a metallic cylinder. As reported in Table 1, Pb, Zn, Ba, Cr and Al are the top five heavy metals contained in the used oil, where lead (Pb) constitutes the major concern [7]. When used oils are released from their container, e.g., due to a fire accident, these toxic contaminants and their compounds represent a direct hazard to the environment.

* Corresponding author.
*E-mail address:* Vedat.verter@mcgill.ca (V. Verter).

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A used oil release accident, however, is an extremely low probability event, albeit it can cause serious damage. For this reason, in assessing the environmental risk, we focus on the consequence evaluation. Specifically, we study the "off-specification used oil" which exhibits the toxicity characteristic for lead (D008) [1].

We conceive the used oil collection and processing problem as a three-layer framework, where the generation node, the storage facility and the integrated facility are in different echelons. We assume that the treatment and the safe disposal of used oils are both done at the integrated facility site. As illustrated in Fig. 1, the vehicles originating from the storage facilities perform a tour to collect the available waste at the generation nodes, where used oils are produced as a by-product of the industrial activity. The material collected at the storage facilities is often directly transported to integrated facilities by larger vehicles.

In this paper, we propose a model with two objectives—to minimize the total environmental risk and to minimize the total cost—for the used oil location-routing problem so as to determine:

- Where to open storage facilities and their capacity levels,
- Where to open integrated facilities and their capacity levels,
- The number and routes of the vehicles to collect used oil at the generation nodes, and
- How to ship the used oil from the storage facilities to the integrated facilities.

A main contribution of our paper is the incorporation of vehicle routing problem (VRP) as one of the key components of the proposed model. We represent VRP by adopting a two-commodity flow formulation. Our second key contribution is the proposed integration of the Box Model and the Gaussian Plume Model for the assessment of environmental risk. This enables us to pay close attention to the heavy metals contained in the used oil that are airborne upon an accidental release. We measure the environmental risk around each road segment, or facility, as the size of a "box" that contains a given threshold level of contaminants. The impact radius that determines the box size is obtained using GPM. We also developed a solution approach by adapting the weighted goal programming method for solving the arising bi-objective problem. Through a case study and the related test instances, we demonstrate that the proposed analytical approach is amenable to practical implementation in practice.

**Table 1**
Contaminants of potential environmental concern occurring in the used oil.

| Hazardous component | Approximate concentration range (mg/kg) |
|---|---|
| Lead (Pb) | 3700–14,000 |
| Zinc (Zn) | 630–2500 |
| Barium (Ba) | 60–690 |
| Aluminum (Al) | 4–40 |
| Chromium (Cr) | 5–24 |

The remainder of this paper is organized as follows: Section 2 presents an overview of the relevant literature. The bi-objective location-routing model is presented in Section 3, where the proposed environmental risk assessment model is also described. Section 4 presents the solution procedure developed on the basis of the weighted goal programming method through the percentage normalization technique. In Section 5, we outline the application of the proposed analytical approach in studying a realistic case study based on Chongqing, China. In Section 6, we evaluate the proposed model's scalability. Finally, Section 7 provides some concluding comments and future research directions.

## 2. Literature review

To the best of our knowledge there is no academic literature pertaining to the design of used oil collection and processing facility networks, although this waste type accounts for a large portion of the total hazardous waste generated. We start this section by a comprehensive review of the state of the art on the generic hazardous waste location-routing problem, and position our work in this context in terms of its contributions. Then, we provide exceedingly brief overviews of the vast literatures on VRP and environmental risk assessment. The main message of this section is that the prevailing studies neglected the tour planning issues pertaining to the collection of hazardous wastes. Moreover, they overwhelmingly focus on improving public safety, while the mitigation of environmental risk has not been well studied in this context.

### 2.1. Hazardous waste location-routing

Starting from early 1990s, a number of researchers have attempted to address the hazardous waste location-routing problem [8,22]. In Table 2, we provide taxonomy of the existing literature. Evidently, the hazardous waste location-routing problem was first studied by

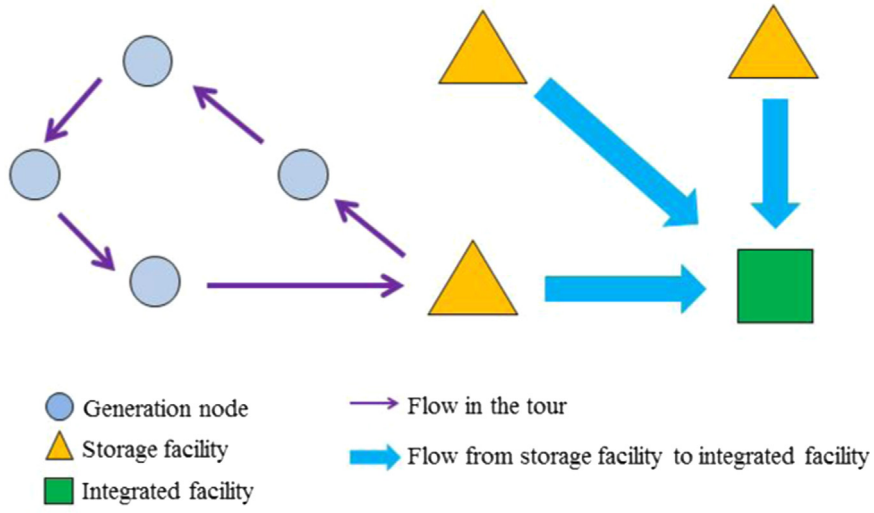


**Fig. 1.** The used oil management framework.