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A fuzzy-robust stochastic multiobjective programming approach for petroleum waste management planning

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A B S T R A C T

This paper proposes a fuzzy-robust stochastic multiobjective programming (FRSMOP) approach, which integrates fuzzy-robust linear programming and stochastic linear programming into a general multiobjective programming framework. A chosen number of noninferior solutions can be generated for reflecting the decision-makers' preferences and subjectivity. The FRSMOP method can effectively deal with the uncertainties in the parameters expressed as fuzzy membership functions and probability distribution. The robustness of the optimization processes and solutions can be significantly enhanced through dimensional enlargement of the fuzzy constraints. The developed FRSMOP was then applied to a case study of planning petroleum waste-flow-allocation options and managing the related activities in an integrated petroleum waste management system under uncertainty. Two objectives are considered: minimization of system cost and minimization of waste flows directly to landfill. Lower waste flows directly to landfill would lead to higher system costs due to high transportation and operational costs for recycling and incinerating facilities, while higher waste flows directly to landfill corresponding to lower system costs could not meet waste diversion objective environmentally. The results indicate that uncertainties and complexities can be effectively reflected, and useful information can be generated for providing decision support.

1. Introduction

Petroleum industries are associated with a variety of environmental problems. Among them, petroleum wastes have gained much attention in recent years since pollution from them may pose serious adverse impacts and risks to the eco-environment and human health [1,2]. To mitigate and reduce the impacts, these wastes are generally shipped to landfill, recycling and incinerating facilities for treatment and disposal. In management such petroleum wastes, how to allocate them to various facilities is a critical issue for the decision makers. Efforts on waste diversion and creation of an integrated petroleum waste management (PWM) system are thus desired for solving the aforementioned waste-flow-allocation problems. In addition, such systems are becoming sophisticated with the increasing waste generation rate, improved cost for transportation and operation, reduced availability of land resources, the growing public opposition toward landfill treatment, and the increasing demand for benefits from wastes recycling [1,3]. In planning PWM systems, a variety of impact factors interact with each other with dynamic, multi-period, and multiobjective features [4–6]. The decision makers generally prefer that multiple conflicting management objectives can be satisfied simultaneously. Moreover, many system objectives, parameters,

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impact factors, and their interactions are associated with inherent uncertainties [7–9]. Effective reflection of such system complexities is crucial and desired for addressing the trade-offs among multiple objectives and providing valuable decision support in planning petroleum waste management under uncertainty.

Multiobjective programming (MOP) is a useful tool for helping the decision makers to facilitate decision making with multiple conflicting objectives, which can offer feasible methods for generating compromise decision alternatives [10–16]. To deal with the uncertainty associated with the decision-making processes, inexact MOP approaches have been widely developed [17–21]. They were mainly related to fuzzy multiobjective programming derived from fuzzy sets theory [22–27], stochastic multiobjective programming based on probability theory [28–30], and their hybrids [31,32]. Previously, a variety of multiobjective programming models have been developed and applied for environmental management problems. For examples, Alidi [33] developed a multiobjective optimization model based on goal programming method for management of hazardous waste from petrochemical industry. Giannikos [34] studied the issues of location of disposal and treatment facilities and transportation of hazardous wastes through a multiobjective model. Nema and Gupta [35] advanced a multiobjective integer goal programming model for planning regional hazardous waste management systems, where the objectives of minimization of total risk and total cost were considered. Issues of hazardous wastes allocation and optimal configuration of treatment and disposal facilities were identified with minimum cost and minimum risk. Minciardi et al. [36] proposed a multiobjective solid waste management model for supporting the decisions on optimal flows to landfill, recycling and various types of treatment plants. Four objectives related to economic costs, unrecycled waste, sanitary landfill dispoal and environmental impacts were minimized. Srivastava and Nema [37] presented a multiobjective multi-period location–allocation model for planning solid waste disposal facilities in Delhi, India.

Most of the previous studies endeavored to convert the multiobjective functions into a deterministic problem through fuzzy programming method and min-operator. They are effective to handle the uncertainties between objectives and/or constraints of the MOP models through integration of the decision makers' aspiration levels. However, they may encounter difficulties when both left- and right-hand side coefficients of the models' constraints were of fuzzy features. Robust programming (RP) based on fuzzy sets theory is an effective way to tackle such difficulties. It can enhance the robustness of the optimization process and the generated solutions by delimiting an uncertain decision space through dimensional enlargement of the original fuzzy constraints [38–42]. However, there were few studies on incorporation of robust programming within a general inexact MOP framework.

Therefore, when sufficient information is available for identification of probability distributions and fuzzy membership functions, one potential approach for accounting for the above problems is to integrate fuzzy-robust programming and stochastic linear programming into a multiobjective programming framework. This leads to a fuzzy-robust stochastic multiobjective programming (FRSMOP) approach. It can help plan the petroleum waste-flow-allocation options under multiple objectives, and manage the related activities in an integrated PWM system under uncertainty. Its applicability will be demonstrated through the planning of a hypothetical petroleum waste management system. The proposed FRSMOP method can effectively reflect and address the fuzzy and random uncertainties in the decision-making processes without many unrealistic simplifications, and thus increase the stability and robustness of the solutions.

2. Methodology

2.1. Multiobjective linear programming

A general multiobjective linear programming (MOP) problem can be formulated as follows:

$$Min\ f_h = C_h X, h = 1, 2, \ldots, m, \quad (1a)$$
$$Max\ f_k = C_k X, k = m+1, m+2, \ldots, n. \quad (1b)$$

Subject to:

$$AX \leqslant B, \quad (1c)$$
$$X \geqslant 0, \quad (1d)$$

where f_h and f_k are different objectives, $A \in \{R\}^{p \times n}$, $B \in \{R\}^{p \times 1}$, $C \in \{R\}^{1 \times n}$, $X \in \{R\}^{n \times 1}$, R denotes a set of real numbers, and symbols h, k, m, n and p represent real integer numbers. Basically, weighting and e-constraint methods are utilized to evaluate the trade-offs among the multiple objectives. Since it is difficult to define weights for reflecting the decision-makers' preference levels, e-constraint method is employed in this study. A set of noninferior alternatives can be generated through a two-step process. The first step is to obtain the optimal solution for each of the objective functions; the second is to merely choose one objective to be minimized (or maximized) while others as constraints. The model (1) can thus be rewritten as follows:

$$Min\ f_i = C_i X, i \in N. \quad (2a)$$

Subject to: