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An optimization model for reverse logistics network under stochastic environment by using genetic algorithm

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ABSTRACT

Recovery of used products has become increasingly important recently due to economic reasons and growing environmental or legislative concern. Product recovery, which comprises reuse, remanufacturing and materials recycling, requires an efficient reverse logistic network. One of the main characteristics of reverse logistics network problem is uncertainty that further amplifies the complexity of the problem. The degree of uncertainty in terms of the capacities, demands and quantity of products exists in reverse logistics parameters. With consideration of the factors noted above, this paper proposes a probabilistic mixed integer linear programming model for the design of a reverse logistics network. This probabilistic model is first converted into an equivalent deterministic model. In this paper we proposed multi-product, multi-stage reverse logistics network problem for the return products to determine not only the subsets of disassembly centers and processing centers to be opened, but also the transportation strategy that will satisfy demand imposed by manufacturing centers and recycling centers with minimum fixed opening cost and total shipping cost. Then, we propose priority based genetic algorithm to find reverse logistics network to satisfy the demand imposed by manufacturing centers and recycling centers with minimum total cost under uncertainty condition. Finally, we apply the proposed model to a numerical example.

1. Introduction

1.1. Reverse logistics

Increasing interest in reuse of products and materials is one of the consequences of growing environmental concern throughout the past decades. Waste reduction has become a prime concern in industrialized countries [1]. For a variety of economic, environmental or legislative reasons, companies have become more accountable for final products, after they sell those products. Reverse logistics is the process of moving goods from their typical final destination to another point, for the purpose of capturing value otherwise unavailable, or for the proper disposal of the products [2]. According to the American Reverse Logistics Executive Council, Reverse Logistics is defined as: "The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal." A reverse logistics system comprises a series of activities, which form a continuous process to treat return-products until they are properly recovered or disposed of. These activities include collection, cleaning, disassembly, test and sorting, storage, transport, and recovery operations. The latter can also be represented as one or a combination of several main recovery options, like reuse, repair, refurbishing, remanufacturing, cannibalization and recycling [3]. Reverse logistics is practiced in many industries, including those producing steel, aircraft, computers, automobiles, chemicals, appliances and medical items. The effective use of the reverse logistics can help a company to compete in its industry. Reverse logistics has become increasingly important as a profitable and sustainable business strategy. There are a number of situations for products to be placed in a reverse flow. Normally, return flows are classified into commercial returns, warranty returns, end-of-use returns, reusable container returns and others [2]. Implementation of reverse logistics especially in product returns would allow not only for savings in inventory carrying cost, transportation cost, and waste disposal cost due to returned products, but also for the improvement of customer loyalty and futures sales [4]. Reverse logistic systems are more complex than forward logistic systems. This complexity stems from a high degree of uncertainty due to

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the quantity and quality of the products [5]. Reverse logistics is receiving much attention recently due to growing environmental or legislative concern and economic opportunities for cost savings or revenues from returned products. Barros et al. [6] proposed a mixed integer linear programming (MILP) model based on a multi-level capacitated warehouse location problem for the sand and consider its optimization using heuristic procedures. The model determined the optimal number, capacities, and locations of the depots and cleaning facilities. Kirkke et al. [7] presented an MILP model based on a multi-level uncapacitated warehouse location model. They described a case study, dealing with a reverse logistics network for the returns, processing, and recovery of discarded copiers. The model was used to determine the locations and capacities of the recovery facilities as well as the transportation links connecting various locations. Jayaraman et al. [8] proposed an MILP model to determine the optimal number and locations of distribution/remanufacturing facilities for electronic equipment. Jayaraman et al. [9] developed a mixed integer programming model and solution procedure for a reverse distribution problem focused on the strategic level. The model determines whether each remanufacturing facility is open considering the product return flow. Min et al. [10] proposed a Lagrangian relaxation heuristics to design the multi-commodity, multi-echelon reverse logistics network. Kim et al. [11] proposed a general framework for remanufacturing environment and a mathematical model to maximize the total cost saving. The model determines the quantity of products/parts processed in the remanufacturing facilities/subcontractors and the amount of parts purchased from the external suppliers while maximizing the total remanufacturing cost saving. Min et al. [12] proposed a nonlinear mixed integer programming model and a genetic algorithm that can solve the reverse logistics problem involving product returns. Their study proposes a mathematical model and GA which aim to provide a minimum-cost solution for the reverse logistics network design problem involving product returns. Ko and Evans [4] presented a mixed integer nonlinear programming model for the design of a dynamic integrated distribution network to account for the integrated aspect of optimizing the forward and return network simultaneously. They also proposed a genetic algorithm-based heuristic for solving this problem. Lee et al. [13] proposed a multi-stage, multi-product, MILP model for minimizing the total of costs to reverse logistics shipping cost and fixed opening cost of facilities. They also proposed a hybrid genetic algorithm for solving this problem.

1.2. *Stochastic programming*

In most of the real life problems in mathematical programming, the parameters are considered as random variables. The branch of mathematical programming which deals with the theory and methods for the solution of conditional extremum problems under incomplete information about the random parameters is called "stochastic programming". Most of the problems in applied mathematics may be considered as belonging to any one of the following classes [14]:

1. Descriptive problems, in which, with the help of mathematical methods, information is processed about the investigated event, some laws of the event being induced by others.
2. Optimization problems in which from a set of feasible solutions, an optimal solution is chosen.

Besides the above division of applied mathematics problems, they may be further classified as deterministic and stochastic problems. In the process of the solution of the stochastic problem, several mathematical methods have been developed. However, probabilistic methods were for a long time applied exclusively to the solution of the descriptive type of problems. Research on the theoretical development of stochastic programming is going on for the last four decades. To the several real life problems in management science, it has been applied successfully [15]. The chance constrained programming was first developed by Charnes and Cooper [16]. Subsequently, some researchers like Sengupta [17], Contini [18], Sullivan and Fitzsimmons [19], Leclercq [20], Teghem et al. [21] and many others have established some theoretical results in the field of stochastic programming. Stancu-Minasian and Wets [15] have presented a review paper on stochastic programming with a single objective function. Listes and Dekker [22] proposed a multi-product stochastic mixed integer programming for recycling of the sand in reverse logistics network. Liu [23] introduced the stochastic programming methodology to characterize the stochastic traffic for a multi-commodity network model.

1.3. *Genetic algorithm*

GAs are stochastic search techniques based on the mechanism of natural selection and natural genetics [24]. As one of the Evolutionary Computation (EC) techniques, the GA has been receiving great attention and successfully applied for combinatorial optimization problems [25]. GA is very useful when a large search space with little knowledge of how to solve the problem is presented. It belongs to the class of heuristic optimization techniques, which include simulated annealing (SA), Tabu search, and evolutionary strategies. It has been with great success in providing optimal or near optimal solution for many diverse and difficult problems [26].

Representation is one of the important issues that affect the performance of GAs. Usually different problems have different data structures or genetic representations. Tree-based representation is known to be one way for representing network problems. There are three ways of encoding tree: (1) edge-based encoding, (2) vertex-based encoding and (3) edge-and-vertex encoding [27].

Michalewicz et al. [28] used matrix-based representation GA which belongs to edge-based encoding for solving linear and nonlinear transportation/distribution problems. When m and n are the number of sources and depots, respectively, the dimension of matrix will be $m \times n$. Although representation is very simple, this approach needs special crossover and mutation operators for obtaining feasible solutions.

Gen and Cheng [27] introduced spanning tree GA (st-GA) for solving network problems. They used Prüfer number representation for solving transportation problems and developed feasibility criteria for Prüfer number to be decoded into a spanning tree. Syarif et al. [29] proposed spanning tree-based genetic algorithm by using Prüfer number representation for solving a single product, three stage supply chain network (SCN) problem. Xu et al. [30] applied spanning tree-based genetic algorithm (st-GA) by the Prüfer number representation to find the SCN to satisfy the demand imposed by customers with minimum total cost and maximum customer services for multi objective SCN design problem. Although Prüfer number developed to encode of spanning trees, had been successfully applied to transportation problems, it needs some repair mechanisms to obtain feasible solutions after classical genetic operators.

In this study, to escape from these repair mechanisms in the search process of GA, we adopt at here the priority-based encoding method. Gen et al. [25] used priority-based encoding for a single-product, two-stage transportation problem. Altiparmak et al. [31] applied priority-based representation to a single-product, single-source, and three-stage SCN problem, Altiparmak et al. [32] proposed this encoding to a single-source, multi-product, multi-stage SCN problem. Lee et al. [13] proposed a hybrid genetic algorithm with priority-based encoding method.