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Variable neighborhood search for the bi-objective post-sales network design problem: A fitness landscape analysis approach

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ABSTRACT

Post-sales services are important markets in electronics industry due to their impact on marginal profit, market share, and their ability to retain customers. In this study, designing a multi-product four-layer post-sales reverse logistics network operated by a 3PL is investigated. A bi-objective MILP model is proposed to minimize network design costs as well as total weighted tardiness of returning products to customers. To solve the proposed model, a novel multi-start variable neighborhood search is suggested that incorporates nine neighborhood structures and three new encoding–decoding mechanisms. In particular, a fitness landscape measure is employed to select an effective neighborhood order for the proposed VNS. Extensive computational experiments show the effectiveness of the proposed heuristic and the three encoding–decoding mechanisms. The proposed method finds significantly better Pareto optimal sets in comparison with the original Priority method based on the number and the quality of obtained Pareto optimal solutions. In addition, it shows high efficiency by finding near-optimal solutions for the single objective versions of the problem.

1. Introduction

Repair service networks are an important type of reverse logistics networks. These networks offer repair and post-sales services to respective customers. In fact, offering post-sales services for high-tech products is an important secondary market for many electronics manufacturers (e.g., electronics, computers and their accessories, cell phones, and house appliances). Besides being a source of competitive differentiation, post-sales services could increase manufacturers' market share and retain customers [1]. In addition, customer awareness, nongovernmental organizations, and governmental/international regulations have persuaded many companies to adopt eco-friendly post-sales systems as one of their long-term strategies to reduce adverse environmental and ecological impacts of their obsolete products and waste [2].

Nevertheless, the complexities surrounding post-sales services necessitate careful and effective planning of post-sales networks. For example, S.A. Inc. – a major post-sales service provider for computers and laptops in Iran – tries to offer post-sales services to customers in more than 300 cities for more than 250 products belonging to 15 different brands [3]. Diverse locations of post-sales service centers and the availability of the necessary repair equipment have significant effects on costumers' access and experience. Hence, these factors have a significant impact on the customers' service level for the post-sales service networks. In addition, the cost-efficient operation of these networks requires complex interactions between post-sales service centers, collection centers, warehouses, and disposal centers.

A well-known approach to deal with the aforementioned issues is the reverse logistics network design problem (RLNDP). This problem concerns strategic level decisions such as selecting facilities location, distribution points, inventory levels, and the structure of transportation networks to sustain efficient reverse logistics channels [4]. RLNDP is usually comprised of determining three decisions: (1) number and location of facilities specific to a reverse logistics system (e.g., collection centers, recovery facilities, repair facilities, and/or disposal centers), (2) capacity of facilities, and (3) material flows. A well-designed reverse logistics network provides cost savings, help retaining current customers, and attract more potential customers [5].

In this paper, designing an effective VNS for the post-sales reverse logistics network design problem is investigated. In this problem, a third party logistics provider (3PL) offers post-sales services for multiple products belonging to different manufacturers. The 3PL reverse logistics network consists of four layers including production plants, repair facilities, collection centers, and disposal centers. Multiple decisions including location of repair facilities, allocation of repair equipment, and material flows between different network layers are considered. In addition, various assumptions such as products bills of materials (BOM),

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replacing irreparable products with new products, limited capacity of production plants and repair facilities, and the limit on the maximum number of repair equipment assignable to each repair facility are considered. These assumptions are well matched with characteristics of post-sales service providers for electronics products. In fact, various electronics products of a specific manufacturer usually share relatively similar design schemes (e.g., TV, cell phone, tablet, and laptop), while the used components are different.

Considering the above discussion, a bi-objective mixed integer linear programming model and an effective multi-start variable neighborhood search are presented to tackle this problem. Along with considering nine different neighborhood structures, three new encoding–decoding mechanisms are implemented in the proposed heuristic to obtain better Pareto optimal (non-dominated) solutions. In addition, a fitness landscape analysis approach is employed to select an effective neighborhood order for the proposed VNS. To the best of our knowledge, as there is limited research on the application of VNS in designing supply chain networks [3,6], no fitness landscape analysis exists for these problems. Computational experiments confirm the proposed method effectiveness to solve both the single objective and bi-objective versions of the research problem.

This paper is organized as follows. First, a survey of recent relevant studies is given in Section 2. In Section 3, the research problem under study is defined and discussed in detail. A new mathematical model for the bi-objective post-sales closed-loop reverse logistics network design problem is presented in Section 4. In Section 5, a new variable neighborhood search algorithm is proposed to solve the research problem. Specifically, the encoding–decoding methods for the single objective and bi-objective versions of the research problem are discussed in Sections 5.1 and 5.2. Then, VNS neighborhood structures and the outline of the proposed heuristic are described in Sections 5.3 and 5.4, respectively. The extensive computational experiments for designing and evaluating the proposed heuristic method are discussed in Section 6. Finally, the paper conclusion and some of its possible future research directions are given in Section 7.

2. Literature review

In this section, recent advances in reverse logistics network design and their closely related problems (i.e., integrated forward/reverse supply chain network design problems) are reviewed. A recent review of network design problems in the reverse logistics and the closed-loop supply chain literature is given in [7].

Broadly speaking, reverse logistics networks could be categorized into four categories as follows [8]:

2.1. Directly reusable network

In this type of network, returned products or objects may be reused as new products or transportation equipment readily or with minor reprocessing. Limited studies on these networks include [9,10]. Lu et al. [10] considered this setting within the simple plant location problem and tackled it using a Lagrangian heuristic. Lee and Dong [9] proposed a two-stage decomposition heuristic based on location–allocation and network flow problems for locating hybrid distribution–collection facilities and determining material flows.

2.2. Remanufacturing network

Remanufacturing networks try to recover returned products and their components as inputs for remanufacturing processes. These networks are one of the most studied types of reverse logistics networks. Listeş [11] presented a stochastic model for a single echelon supply chain network design problem with forward and reverse flows. Different scenarios represented uncertainty of demand and products rate of return. A branch-and-cut algorithm was developed to maximize the chain profit. Lu and Bostel [8] proposed a Lagrangian heuristic to solve an integrated four-layer model for forward/reverse flows for a supply chain with remanufacturing operations. Demirel and Gökçen [12] presented an integrated remanufacturing reverse logistics network design model and solved via CPLEX. Sasikumar et al. [13] developed a dynamic 7-layer model to maximize profits of a truck tire remanufacturing network and solved it via LINGO. Finally, Pishvaee et al. [14] proposed a bi-objective memetic algorithm for designing a five-layer integrated reverse/forward supply chain network with hybrid facilities (responsible for distribution, collection, and inspection). The considered objectives are minimizing supply chain total costs and maximizing responsiveness.

2.3. Repair service network

Similar to the directly reusable network, repair services and post-sales networks have attracted limited attention. Du and Evans [15] proposed a hybrid scatter search algorithm based on the dual simplex and ε-constraint methods to design a 3PL's post-sales reverse logistics network consisting of collection centers, repair facilities, and production plants. Their proposed heuristic tried to minimize the total costs and the total tardiness of returning products back to collection centers for the network. Later, Zegordi et al. [16] and Nikbakhsh et al. [17] extended this problem to consider disposal centers and interval uncertainty of demand, respectively. Rappold and Roo [18] proposed a non-iterative two-stage approximation approach for locating repair facilities and determining inventory and capacity decisions in a single-echelon service part supply chain with stochastic demand. Finally, Eskandarpour et al. [3] considered a five-layer post-sales network for repairing components of returned products. They proposed a parallel VNS heuristic to find Pareto optimal solutions of three objectives, namely total fixed and variable costs, total tardiness, and environmental pollution.

2.4. Recycling network

Another widely studied reverse logistics network type is the recycling network, which tries to recycle raw material from returned products. Listeş and Dekker [19] developed a two-stage stochastic programming model to design a three-layer reverse logistics network with stochastic demand and supply. de Figueiredo and Mayerle [20] considered a three-layer reverse logistics network design problem integrated with pricing of financial incentives. To maximize the number of collected products, a three-stage hybrid heuristic was proposed. Lee and Dong [21] proposed a hybrid simulated annealing based on the sample average approximation method to design a dynamic reverse logistics network. In another study, Wang and Hsu [22] proposed an integrated model for designing a five-layer closed-loop supply chain and solved it via a genetic algorithm based on a spanning tree structure. Pishvaee et al. [23] proposed a simulated annealing for designing a four-layer reverse logistics network. Kara and Önüt [24] studied a case of paper recycling in Turkey and proposed two mathematical models based on stochastic programming and robust optimization. Finally, Vahdani et al. [25] proposed a hybrid methodology based on robust optimization, queuing theory, and fuzzy multi-objective programming to design a reliable integrated forward/reverse logistics network with collection and recycling facilities.

In addition to the above studies, some studies have considered two or more recovery processes, including Jayaraman et al. [26], Sayed et al. [27], Mutha and Pokharel [28], Alumur et al. [29], and Dat et al. [30]. Finally, few studies have considered no particular