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Production routing problems with reverse logistics and remanufacturing

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ABSTRACT

This paper introduces a mixed integer programming model for production routing problems with reverse logistics and remanufacturing, which are closed-loop production routing problems addressed for the first time. A solution method of branch-and-cut guided search algorithm is developed. Computational results from instances adapted from benchmarks of production routing problems show that, the algorithm is more effective when pickup requests are relative high. The problem is also easier to solve when production or transportation costs are lower. The optimal decisions are insensitive to the location of remanufacturing depot whether it is geographically centered or centered with gravity.

1. Introduction

Concerns about the environmental impact of transportation and logistic activities have greatly increased in recent years. Since integrated operations can help achieve goals of lesser harm to the environment, while remaining operational effective (Qiu et al., 2017), supply chain optimization problems have attracted much research efforts. Among these problems, the production routing problem (PRP) that jointly optimizes decisions of production, inventory, distribution and routing has recently received a considerable attention (Adulyasak et al., 2015a). This integrated optimization problem is of practical relevance to success in business competitions, especially in modern logistical practices of vendor managed inventory (VMI) and just-in-time (JIT).

Besides integrating operations forward, closed-loop supply chain optimization showed a further reduction in environmental impact (Savaskan et al., 2004). Return flow processes in a closed-loop supply chain usually consists of (1) product collection from consumers; (2) reverse logistics to take collected products back; (3) screening, assorting and disposal to specify the most economically attractive reuse alternatives; (4) remanufacturing; and (5) remarketing to produce and utilize new markets (Iassinovskaia et al., 2017). A closed-loop PRP naturally integrates reverse logistics and remanufacturing. This problem is important because in addition to economic benefits, environmental benefits due to extension of the product useful life, reduced energy and material consumption, pollution prevention, and other sustainability benefits can be expected.

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After the importance of considering production, inventory and routing decisions simultaneously was stressed by Chandra (1993), the PRP was extended in various ways to consider, e.g., multiple plants and heterogeneous fleets of vehicles (Lei et al., 2006), incapacitated production (Archetti et al., 2011), multiple homogeneous capacitated vehicles (Adulyasak et al., 2014a), demand uncertainty (Adulyasak et al., 2015b), multi-item back-order (Brahimi and Aouam, 2015), perishable products(Vahdani et al., 2017), and multiscale production(Zhang et al., 2017) in the past decade. The environmental impact of the PRP has seldom been addressed, with only a few notable exceptions, such as the PRP with carbon emissions (Qiu et al., 2017), and multi-objective production and pollution routing problem with time window (Kumar et al., 2015). However, reverse logistics and remanufacturing are completely ignored to the best of our knowledge.

Battarra et al. (2014) addressed pickup-and-delivery problems for goods transportation, and reviewed various available algorithms. The vehicle routing problem with simultaneous pickups and delivery (VRPSPD), also known as the most studied and most general variant of the one-to-many-to-one (1-M-1) problems, has become increasingly popular. The electric appliances industry, beverage industry, and returnable/reusable transport items (RTI), or returnable/reusable logistical packaging have witnessed the application of the VRPSPD. Exact algorithms such as branch-and-cut method (Subramanian et al., 2013), branch-price-and-cut method (Cherkesly et al., 2015; Qu and Bard, 2015), are relatively new. Inventory routing problems with simultaneous pickups and deliveries (IRPSPD) have been explored only recently (Soysal, 2016; van Anholt et al., 2016; Iassinovskaia et al., 2017). Extending these problems and methods to the PRP is a natural step forward.

Besides, since the importance of considering remanufacturing in closed-loop supply chain was stressed by Savaskan et al. (2004), the research on remanufacturing had mainly focused on inventory system with remanufacturing (DeCroix, 2006; Tao and Zhou, 2014), economic aspect of remanufacturing (Geyer et al., 2007; Chen and Chang, 2012), and marketing issues (Atasu et al., 2008; Agrawal et al., 2015). Applications of remanufacturing cover personal computers and peripherals, B2B information technology equipment, tires, and construction equipment. Concerns were also on practical issues such as supply chain-based barriers (Zhu et al., 2014) and third-party remanufacturing mode selection (Zou et al., 2016). However, little has been revealed when remanufacturing is not only involved with inventory decisions but also with routing decisions.

Our aim is to bridge these gaps by designing a model and algorithm for a closed-loop production routing problem with remanufacturing, simultaneous pickups and deliveries (PRPRPD). The PRP involves combinatorial optimization of both delivery and routing decisions. Exact algorithms, such as branch-and-price (Bard and Nananukul, 2009a, 2010; Qiu et al., 2017) and branch-and-cut (Archetti et al., 2011; Adulyasak et al., 2014a), can solve small and medium sized problems. Heuristics are often applied in other research, e.g., approximation algorithm (Chandra and Fisher, 1994), decoupled heuristic (Fumero and Vercellis, 1999), greedy randomized adaptive search procedure (Boudia et al., 2007), memetic algorithm (Boudia and Prins, 2009), tabu search (Bard and Nananukul, 2009b; Armentano et al., 2011), adaptive large neighborhood search (Adulyasak et al., 2014b), iterative mixed integer programming (Absi et al., 2015), particle-swarm optimization (Kumar et al., 2015), mathematical programming heuristic (Russell, 2017), and multiphase heuristic (Solyalıand Süral, 2017). A hybrid algorithm combining branch-and-cut and heuristic search is promising for the PRPRPD.

The contributions of this paper can be summarized as follows. First, we introduce a real-world variant of the PRP with reverse logistics and remanufacturing. Reverse logistics characterized with simultaneous pickups and deliveries is now mixed with capacitated vehicle routing problems (CVRP), which is unique from the PRP literature. Second, we formulate the PRPRPD as a mixed integer linear programming (MILP) problem with discussions on feasibility and optimality. Third, we introduce valid inequalities to tighten the MILP formulation and design a novel branch-and-cut guided search algorithm as the solution method. Finally, we conduct extensive computational experiments to assess the performance of the proposed algorithm and develop managerial insights through sensitivity analysis. We find that the algorithm is more effective when pickup requests are relative high. The problem is also easier to solve when production or transportation costs are lower. The optimal decisions are insensitive to the location of remanufacturing depot whether it is geographically centered or centered with gravity. When remanufacturing rate is sufficiently high, the manufacturing activities can be totally replaced by remanufacturing ones, resulting a large drop in total costs, given there are enough pickups inventory and new pickups to cover the delivery requests. Our PRPRPD model, algorithm and computational results can serve as a stepping stone for further research of the PRP with return flow (Adulyasak et al., 2015a).

The rest of the paper is organized as follows. Section 2 describes the PRPRPD and introduces a mathematical formulation. Section 3 elaborates a solution method of branch-and-cut guided search algorithm. Extensive computational results are provided in Section 4. We conclude in Section 5 with discussions on future research directions.

2. Problem description and mathematical formulation

2.1. Problem description

The PRP with remanufacturing, pickups and deliveries (PRPRPD) is defined on a complete directed graph $\mathscr{G} = (\mathscr{V}, \mathscr{A})$, where the node set $\mathscr{V} = (\mathscr{N} \cup \mathscr{M} \cup \mathscr{R})$ consists of a set $\mathscr{N}$ of customers, a set $\mathscr{M}$ of manufacturing depots, and a set $\mathscr{R}$ of remanufacturing