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A relax-and-fix heuristic approach for the capacitated dynamic lot sizing problem in integrated manufacturing/remanufacturing systems

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Abstract: In this paper, the capacitated dynamic lot sizing problem in integrated manufacturing/remanufacturing systems is addressed. These kinds of production systems are designed to satisfy the demands of different classes of single-level products not only by manufacturing raw materials, but also by remanufacturing returned products. A single machine with a limited capacity in each time period is used to perform both the manufacturing and remanufacturing operations. A mathematical programming formulation is proposed to optimally solve this problem. Since the problem is NP-hard (it is a generalized version of the classical capacitated dynamic lot sizing problem), a relax-and-fix heuristic is developed to solve the problem in a reasonable amount of time. To evaluate the efficiency of the proposed algorithm, some experimental instances are generated and solved. The obtained results show the effectiveness of the proposed algorithm.

Keywords: Remanufacturing; Production planning; Capacitated lot sizing; Relax and fix heuristic; Optimization.

1. INTRODUCTION

Today, due to the waste growth and land disposal restrictions, most of production companies try to incorporate sustainable elements in designing and managing their plants (Giglio et al., 2017). Remanufacturing systems are production plants that contribute to reduce the waste sent to the environment and they are also very effective from an economic point of view. In this class of systems, returned worn-out products are produced to new like conditions through a series of industrial processes (Naeem et al., 2013). The produced products can be sold with the same price of new products but they are less costly. For this reason, remanufacturing systems have gained lots of attentions in academic and industrial environments especially over the past two decades.

In the last five decades, many works in the scientific literature deal with dynamic lot sizing of manufacturing systems. Survey on such researches can be found in Drexl and Kimms (1997); Buschkhl et al. (2010). However, few studies on the dynamic lot sizing with product returns and remanufacturing (DLSPR) appeared in literature (Richter and Sombrutzki, 2000; Richter and Weber, 2001; Beltrán and Krass, 2002; Teunter et al., 2006, 2009; Schulz, 2011; Baki et al., 2014; Parsopoulos et al., 2015; Sifaleras et al., 2015; Zouadi et al., 2015). More specifically, one of the main extensions of DLSPR problem, the capacitated lot sizing problem with product returns (CLSPR), has gained little attention. In this class of problems, different items or products can be produced in each time period; the production of each item or product consumes a known amount of units of capacity, and only a limited production capacity is available in each period. Li et al. (2007) dealt with the capacitated dynamic lot sizing problem with return products under substitution; they assumed that there are three ways to fulfill the demands of two given products: manufacturing new products, remanufacturing the returned products, and outsourcing; in this connection, they proposed a mathematical formulation and a genetic algorithm to solve the problem. Pan et al. (2009) addressed the capacitated dynamic lot sizing problem with product returns and disposal option; by assuming that the capacities of production, disposal and remanufacturing are limited, and that backlogging is not allowed, they formulated the problem as a general model and proposed a dynamic-programming approach to solve it. Zhang et al. (2012) studied a variant of CLSPR in which a production system manufactures raw materials and remanufactures collected used products in order to fulfill the (separate) demands for them; they formulated the problem as a mixed-integer programming model and developed a Lagrangian relaxation-based solution approach for it. Sahling (2013) addressed a multi-product lot-sizing problem with

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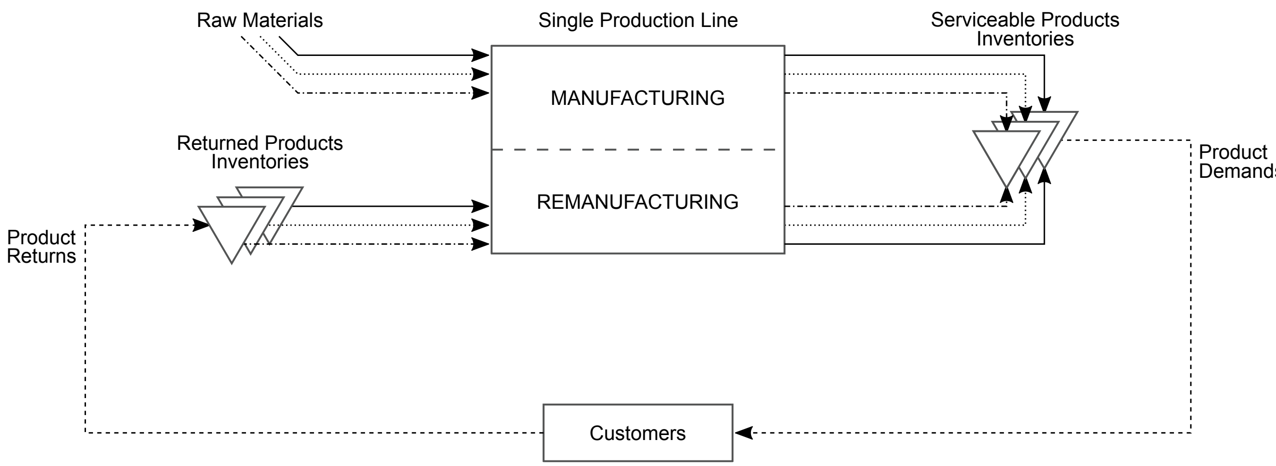

Fig. 1. The integrated manufacturing/remanufacturing system.

product returns and remanufacturing subject to a capacity constraint. He proposed a column-generation approach to determine lower bound bounds and transferred the obtained lower bound into a feasible solution by a truncated branch-and-bound approach using CPLEX. Sahling (2016) extended the problem and incorporated vendor selection into production and remanufacturing planning subject to emission constraints. A fix-and-optimize approach and a solution approach that combines column generation and a fix-and-relax heuristic are presented to solve the extended problem. Roshani et al. (2016) addressed the capacitated dynamic lot sizing problem in a closed remanufacturing system; they assumed that the demands of products are satisfied by only remanufacturing used products returned to the system and that a single machine with limited capacity is used to perform the remanufacturing operations; to solve the problem, they developed a simulated annealing algorithm utilizing an efficient neighborhood generation mechanism to always generate feasible neighbor solutions for the problem.

According to our best knowledge, there is no published study proposing a MIP-based solution approach for the capacitated lot sizing problem in integrated manufacturing/remanufacturing systems with joint setup (CLSP-MR-JS) in which different classes of single level products are produced using a single machine. In this paper, a mathematical formulation and a relax-and-fix heuristic (RFH) are proposed to address this research gap.

The remaining of the paper is as follows. In section 2, a mathematical programming formulation of the problem is described. The proposed RFH is presented in section 3 and computational studies are reported in section 4. Finally, concluding remarks are in section 5.

2. MATHEMATICAL PROGRAMMING FORMULATION

In this section, after the definition of the considered class of problems, a mathematical programming formulation is presented for CLSP-MR-JS. This formulation is a generalization of the mathematical formulation of the lot sizing problem with product returns proposed by Richter and Sombrutzki (2000) for pure remanufacturing systems.

2.1 Problem definition

We take into consideration the capacitated dynamic lot sizing problem in an integrated manufacturing/remanufacturing system designed to satisfy demands of different classes of single-level products by both manufacturing raw materials and remanufacturing returned products. In this problem, it is assumed that whenever a raw material is manufactured or a used product is remanufactured, they have the same qualities (so they are called serviceable products) and they can be used to satisfy the customer demands. The demands for each product and the number of used products returned to the system in each period (over a finite planning horizon T) are considered deterministic and known in advance. A simple sketch of the system is shown in Fig. 1.

The system utilizes a single machine to manufacture raw materials and remanufacture returned products. The capacity of the single machine is limited and the manufacturing and remanufacturing processes of each product, as well as the setup, consume known amounts of capacity in each time period. The problem is to determine the number of products manufactured and remanufactured in each period to satisfy the customer demands, so that total remanufacturing costs, return and serviceable products inventory costs, and setup costs are minimized.

2.2 Problem assumptions

The following assumptions are made.

- Different single-level products are produced through both manufacturing of raw materials and remanufacturing of returned products.
- The demands of products can be satisfied by both manufacturing raw materials and remanufacturing returned products.
- Demands and returns are deterministic and may vary over time.
- Backlogging is not allowed.
- Shortage is not allowed.
- Remanufacturing and holding unitary costs, as well as setup costs, are know in advance.
- Lot streaming is not allowed.
- The single machine is always available.