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# Metaheuristic optimization for the Single-Item Dynamic Lot Sizing problem with returns and remanufacturing

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ABSTRACT

The use of metaheuristics for solving the Single-Item Dynamic Lot Sizing problem with returns and remanufacturing has increasingly gained research interest. Recently, preliminary experiments with Particle Swarm Optimization revealed that population-based algorithms can be competitive with existing state-of-the-art approaches. In the current work, we thoroughly investigate the performance of a very popular population-based algorithm, namely Differential Evolution (DE), on the specific problem. The most promising variant of the algorithm is experimentally identified and properly modified to further enhance its performance. Also, necessary modifications in the formulation of the corresponding optimization problem are introduced. The algorithm is applied on an abundant test suite employed in previous studies. Its performance is analyzed and compared with a state-of-the-art approach as well as with a previously investigated metaheuristic algorithm. The results suggest that specific DE variants can be placed among the most efficient approaches, thereby enriching the available algorithmic artillery for tackling the specific type of problems.



## 1. Introduction

The field of *Reverse Logistics* contains all logistics processes beginning with the take-back of used products from customers up to the stage of making them reusable products or their disposal. Reverse Logistics activities have received increasing attention within Logistics and Operations Management over the last years both from theoretical and practical point of view. One reason for this is the more rigid environmental legislation and the growing environmental concerns.

In most countries environmental regulations are in place, rendering manufacturers responsible for the whole life cycle of their product. A common example of these regulations is the take-back obligations after usage (Fleischmann et al., 1997). Another reason is the economic benefits of reusing products rather than disposing them. Reverse Logistics can bring direct gains to companies by dwindling on the use of raw materials, adding value with recovery, as well as reducing disposal costs, which have significantly increased in recent years due to depletion of incineration and land filling capacities. Environmental regulations, “green image” policies due to growing environmental concerns, as well as the potential economical benefits of product recovery, have pushed manufacturers to integrate product recovery management with their manufacturing process. Two very good recent review papers on Reverse Logistics supply chain management are Govindan, Soleimani, and Kannan (2015) and Stindt and Sahamie (2014).

Recovery processes are generally classified into the following five types: repair, refurbishing, remanufacturing, cannibalization, and recycling. *Remanufacturing*, which is the topic of the present work, is the process that brings used products up to quality standards that are as rigorous as those of new products. A remanufactured product is a returned product that a manufacturer puts through its manufacturing process (or remanufactures) in order to restore it to a good-as-new condition. It shall be distinguished from refurbished products, which are returned products that are tested and usually have some parts replaced if the manufacturer deems this necessary to restore the product to working condition. Remanufacturing is a typical example for economically attractive reuse activities, since it transforms used products into like-new products.

After disassembling the returned product, modules and parts are extensively inspected and problematic parts are repaired or, if not possible, replaced with new parts. These operations allow a considerable amount of value incorporated in the used product to be

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regained. Remanufactured products have usually the same quality as the new products and are sold for the same price but they are less costly. A recent review paper in pricing of new and remanufactured products and production planning is given in Steeneck and Sarin (2013). Also, some manufacturers offer the same warranty and service options on remanufactured products as they do on new ones. Typical examples of remanufacturable products include mostly high-value components such as aircraft or automobile engines, aviation equipment, medical equipment, office furniture, machine tools, copiers, computers, electronics equipment, toner cartridges, cellular telephones, and single-use cameras (Fleischmann et al., 1997; Guide, Jayaraman, & Srivastava, 1999; Thierry, Salomon, van Numen, & van Wassenhove, 1995).

Inventory management and control is one of the key decision-making areas while managing product returns. *Dynamic* or *Economic Lot Sizing* (ELS), i.e., determining production orders over a number of future periods in which demand is dynamic and deterministic, is one of the most extensively researched topics in inventory control. However, the ELS problem with remanufacturing options (ELSR), as an alternative for manufacturing, has received quite a bit of attention in the Reverse Logistics literature. A very good recent review paper that offers a general overview of the existing quantitative models for the ELSR problem is Akcali and Cetinkaya (2011).

In the ELSR problem, known quantities of used products are returned from customers in each period over a finite planning horizon. There is no demand for these returned products themselves, but they can be remanufactured such that they become as good as new. Customer demand can then be fulfilled from two sources, namely newly manufactured and remanufactured items. Since both can be used to serve customers, they are referred to as *serviceables* and so the retailer maintains separate inventories for serviceables and returned used product. When ordering a newly manufactured or remanufactured product, the retailer incurs a fixed setup cost. In addition, in each period the retailer incurs holding costs for storing serviceables and returned product in inventory. Thus, in ELSR problem the traditional trade-off between setup and holding costs is extended with remanufacturing set-up cost and holding cost for returns.

Up-to-date, different variants of the ELSR problem have been studied. In Richter and Sombrutzki (2000), the classical Wagner–Whitin model (Wagner & Whitin, 1958) is extended by introducing a remanufacturing process. It was shown that there exists an optimal solution that is a zero-inventory policy. Also, a dynamic programming algorithm to determine the periods where products are manufactured and remanufactured, was proposed. Richter and Weber (2001) extended the previous models by introducing variable manufacturing and remanufacturing costs and proved the optimality of a policy starting with remanufacturing before switching to manufacturing.

A variant of ELSR with disposal of returned used products at a cost was considered in Golany, Yang, and Yu (2001), and it was shown that this problem is NP-complete under general concave production and holding costs. The same setting was studied in Yang, Golany, and Yu (2005), where a polynomial-time heuristic was developed to solve the problem. Pineyro and Viera (2009) proposed and evaluated a set of inventory policies designed for the ELSR problem, under the assumption that remanufacturing used items is more suitable than disposing of them and producing new items. A Tabu Search approach was proposed, aiming at finding a near-optimal solution. Teunter, Bayindir, and Van den Heuvel (2006) studied ELSR with separate setup and joint setup for manufacturing and remanufacturing. For the case of joint setup cost, they provided an exact polynomial-time dynamic programming algorithm. They also studied and compared the computational performance of modified versions of three well-known heuristics, namely *Silver-Meal* (SM), Least Unit Cost, and Part Period Balancing, for the separate and joint setup cost cases. Helmrich, Jans, Den Heuvel, and Wagelmans (2014) showed that both models studied in Teunter et al. (2006), with separate and joint setup costs, are NP-hard problems and also they proposed and compared several alternative mixed-integer programming formulations of both problems. Ahiska and Kurtul (2014) studied an inventory control problem for a periodic review stochastic hybrid manufacturing/remanufacturing system with two products and substitution.

The multi-product economic lot scheduling problems with returns, in the case of separate production lines for manufacturing and remanufacturing, was studied in Teunter, Kaparis, and Tang (2008). The authors proposed a mixed integer programming model to solve the problem for a fixed cycle time, which can be combined with a cycle time search to find an optimal solution. In Teunter, Tang, and Kaparis (2009) the ELSR problem was considered with two sources of production: manufacturing of new items and remanufacturing of returned items. For both cases, a mixed integer programming formulation was presented for a fixed cycle time, and simple heuristics were proposed for the determination of the optimal solution.

In Zanoni, Segerstedt, and Tang (2012) the multi-product ELSR problem was further analyzed, extending the scheduling policy from the common cycle to a basic period policy. A simpler scheduling policy was introduced, which can be solved with near-optimal solutions and has the potential to improve the cost performance in the system. Schulz (2011) proposed a generalization of the SM-based heuristic introduced in Teunter et al. (2006) for the separate setup cost case. The enhanced SM variants exhibited significantly better performance in terms of the average percentage error from the optimal solution.

Recently, both trajectory-based and population-based metaheuristics were used to tackle the ELSR problem. A Tabu Search (TS) algorithm was proposed in Li, Baki, Tian, and Chaouch (2013), while the Particle Swarm Optimization (PSO) algorithm was investigated in Moustaki, Parsopoulos, Konstantaras, Skouri, and Ganas (2013). In addition, recent works on the Wagner–Whitin and relevant inventory optimization problems (Piperagkas, Voglis, Tatsis, Parsopoulos, & Skouri, 2011; Piperagkas, Konstantaras, Skouri, & Parsopoulos, 2012) demonstrated the potential of effectively solving these problems by using modern population-based optimization algorithms, namely PSO, Differential Evolution, and Harmony Search. Although most of the studied algorithms were primarily designed for real-valued optimization problems, proper modifications in their operation as well as in formulation of the problem can render them applicable also on integer and mixed integer problems, such as the one under consideration. The reported good performance triggered our interest in further studying such algorithms on the ELSR problem.

In the present work, we considered a state-of-the-art population-based algorithm, namely *Differential Evolution* (DE). In the past, DE has been successfully applied on mixed integer engineering design problems. Recently, it was shown to be clearly superior than another popular algorithm of the same type, namely Genetic Algorithms (GAs), while its solutions were shown to lie also very close to exact Branch-and-Bound methods (Ponsich & Coello Coello, 2011). Moreover, the DE operators are based on difference vectors and they significantly differ from the corresponding GA binary operators (see also Feoktistov, 2006).

The performance of DE was assessed on the test suite proposed in Schulz (2011). The algorithm was also compared with the established SM-based variants from Schulz (2011), which constitute part of the state-of-the-art for this kind of problems. Our aim was to probe the potential of DE to serve as promising alternative for tackling the ELSR problem, enriching the available