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A flexibly structured lot sizing heuristic for a static remanufacturing system

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ABSTRACT

An effective planning of lot sizes is a key strategy to efficiently manage a combined manufacturing/remanufacturing system in the presence of substantial setup costs. Due to its complex interdependencies, optimal policies and solutions have not been identified so far, but several heuristic approaches have been analyzed in recent contributions. The main heuristic shortcuts are forcing equally sized lot sizes over the planning horizon as well as imposing a specific cycle structure, i.e., a sequence of manufacturing batches is followed by a sequence of remanufacturing batches. We are instead proposing a flexibly structured heuristic that allows for differently sized remanufacturing batches. We show in a comprehensive numerical study that our approach outperforms other existing approaches in more than half of all instances by up to 17%.

1. Introduction

In recent years, the idea of incorporating backward flows into traditionally forward-oriented supply chains has received increasing attention in theory and industry. When managed efficiently, this extension promises new opportunities to create profits from the recovery of products, components, and materials. Interestingly, firms cannot only create value from properly functioning product returns but also when a broken product is returned.

Thierry et al. [22] name five options to handle the recovery of broken product returns ranging from simple repair to recycling. Among these options, remanufacturing product returns is especially interesting as it attempts to bring product returns to an as-good-as-new quality standard. By doing so, remanufacturing firms provide their customers a cheap alternative to expensive new products while being environmentally friendly at the same time.

Remanufacturing a product commences in general with the disassembly of the product which is followed by a thorough inspection of all components obtained. All recoverable components are then mechanically remanufactured. Combined with new components, these remanufactured parts are assembled into the final remanufactured product. Remanufacturing activities can be found in a large variety of industries (see, e.g., [2], for an overview). To give an example, remanufacturing car related components is a practical source of revenues for automotive companies. In 2008, Volkswagen remanufactured, for instance, 3.83 million components (mainly engines and transmissions) and generated with these activities a revenue of around 600 million € (see [23]).

In his seminal work, Guide [8] describes the complicating characteristics of remanufacturing in industry and elaborates a number of possible research questions that require further attention. Due to the complexity of an industrial remanufacturing system, all research questions can only be formulated to focus on a small part of the entire system. One important stream of research focuses on strategic network design perspectives (see, e.g., [7,3,18]). Another important line of research analyses how remanufacturing and manufacturing operations have to be properly balanced to satisfy customer demand.

In this context, one of the important research questions is the optimal timing and sizing of remanufacturing operations. A lot sizing problem results when substantial setup costs prevail to initiate a (re)manufacturing process. Depending on the characteristics of the demand and return flows, several classes of lot sizing problems (static vs. dynamic and/or deterministic vs. stochastic) can be identified. For the dynamic problem, refer to Teunter et al. [21], Schulz [17], Zhou et al. [24], and Li et al. [10] for more details. An analysis of static and stochastic return flows is provided by Mitra [14].

The first author to analyze the static and deterministic problem setting is Schrady [15]. He proposes to split the infinite planning horizon into identical cycles that are repeated continuously. Each cycle contains a single manufacturing batch that is followed by R equal remanufacturing batches. Henceforth, we will refer to this cyclical structure as the $(R,1)$-policy. By minimizing the total cost (including a setup and a holding cost term), the $(R,1)$-policy allows to find a first solution to this problem. Teunter [19] presents a different policy structure to define a cycle, the so-called $(1, M)$-policy. In

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contrast to Schrady's idea, only a single remanufacturing batch is issued per cycle that is succeeded by M equal manufacturing batches before the next identical cycle commences. Konstantaras and Skouri [9] derive sufficient conditions to determine which class of policy, $(R,1)$ or $(1,M)$, is optimal for a specific problem instance.

Next to formulating the (1, M)-policy, Teunter names two options to further improve the solution. At first, he proposes that a more general (R,M)-policy could reduce the total cost per time unit. This idea has been elaborated by Choi et al. [4] who define such a policy structure. They prove that there is only one cost minimizing sequence of equally sized batches in a cycle for any given (R,M) combination. Moreover, they present an algorithmic procedure to determine the minimum total cost for this policy structure. In comparison to the underlying approach of this contribution, however, they do not allow for variable remanufacturing lot sizes over time. We show that the performance can be considerably increased if this restriction is lifted. Choi et al. [4] procedure has been facilitated later by Liu et al. [11] using a slightly different experimental design as testing environment, however, both contributions derive similar results. The best solution of the $(R,1)$ and $(1,M)$ policies is only seldom improved by using the (R,M)-policy (in about 0.2% of all instances examined). Moreover, the actual improvement is also small (always less than 0.5%).

The second possible improvement option mentioned by Teunter [19] is to allow for scheduling differently sized (re)manufacturing batches in a cycle. This idea has been analyzed at first by Minner and Lindner [12] who show with a Lagrange-multiplier approach that initiating equal remanufacturing batches in a cycle does not have to be optimal. Yet, these authors do not evaluate the actual benefit of scheduling differently sized remanufacturing batches.

Feng and Viswanathan [5] contribute to the discussion by considering an (R,M) type policy with differently sized remanufacturing batches. As in our approach, a sequence of manufacturing batches is followed by one remanufacturing batch in each subcycle. However, for facilitating the solution finding process, they allow for only two classes of subcycles. In contrast, our approach is more flexible by not limiting the number of classes to two. Thus, we are pushing the idea of the subcycle approach even further and allow for a flexible sequence of manufacturing/remanufacturing batches while the size of the remanufacturing batch may vary for every single setup. While Feng and Viswanathan [5] conclude that the total costs can only be slightly decreased with two subcycle classes, we find that introducing an even more flexible structure of manufacturing/remanufacturing sequences can decrease costs substantially by up to 17.5% when allowing for differently sized remanufacturing batches compared to the best (R,M)-policy with equally sized (re)manufacturing batches.

The main objective of this contribution is to comprehensively analyze the benefits of scheduling differently sized (re)manufacturing batches within a flexible cycle structure. We will show that different batch sizes can reduce the total cost substantially for a large number of problem instances. The remainder of this work is organized as follows. Section 2 introduces the basic modeling assumptions and outlines the solution finding process of the above-mentioned policy structures. In Section 3, we introduce our flexibly structured $(R,M)^{flex}$ heuristic which we extensively test in a numerical study with the experimental design of Choi et al. [4]. The results of this study can be found in Section 4. Finally, Section 5 presents a short summary and an outlook on future research opportunities.

2. Basic modeling assumptions and current solution approaches

2.1. Basic modeling assumptions

Since a remanufacturing system contains a large number of different planning tasks, we restrict our attention to a simplified model setting that focuses on analyzing a smaller subset of problems in greater detail. In general, one possibility to model a remanufacturing system is to describe its relevant processes and stocking points. Due to their importance, there are many options to illustrate the existing interdependencies of the corresponding inventory levels and processes. After conducting a thorough literature review, Akçalı and Çetinkaya [2] elaborate 14 different settings to model these interdependencies that can be found in the literature. Among these settings, one (named 2SP-c) seems to be of special interest as it has been applied in a large number of scientific contributions. In our work, the basic modeling approach coincides with their 2SP-c setting. Its relevant stocking points and processes are presented in Fig. 1.

In this simplified model, a remanufacturing firm faces a constant and continuous demand (denoted by λ) for a single product. To obtain remanufacturable products, the remanufacturer takes back products from his customers when they have no further use for it. We assume that only a fraction (denoted by α) of the entire customer demand returns to the remanufacturer who keeps all returns in a corresponding used product inventory (at a given holding cost h_R per item and time unit).

After collecting some returns, the remanufacturer issues a remanufacturing batch to recover these returns which brings them to an as-good-as-new condition. In this work, we omit different quality levels of remanufactured products and refer interested readers to Mitra [13] for a more detailed analysis on this subject. Each remanufacturing run necessitates a specific setup (that incurs a cost of K_R), for instance to adjust the required tools. All successfully remanufactured products are stored in a final product inventory (at a given holding cost h_F per item and time unit) from which the customers receive their orders.

When interpreting the holding cost h_R and h_F as cost of capital tied up in inventory, the latter is always larger since more effort has been put into a final product than into a remanufactured one. A detailed discussion on the topic on how to set the holding cost parameters in a remanufacturing environment can be found in Teunter et al. [20]. Since α is typically smaller than 1,

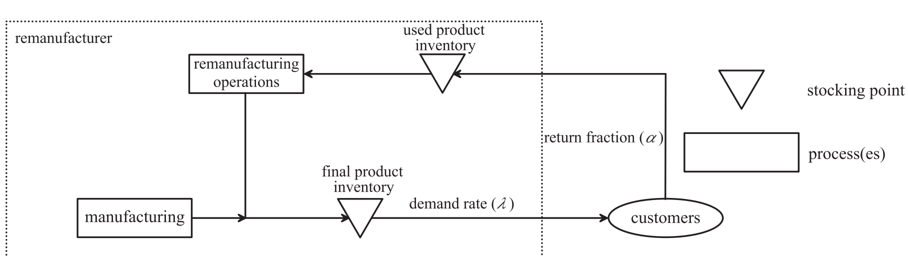

Fig. 1. Simplified inventory model for a remanufacturing system.