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### ► To cite this version:

Ilhem Slama, Oussama Ben-Ammar, Simon Thevenin, Alexandre Dolgui. Stochastic approaches for multi-echelon disassembly lot-sizing under random lead times. CIE50 Proceedings, American University of Sharjah, Oct 2023, Sharjah, United Arab Emirates. hal-04292083

**HAL Id: hal-04292083**

**<https://imt-mines-ales.hal.science/hal-04292083v1>**

Submitted on 17 Nov 2023

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# Stochastic approaches for multi-echelon disassembly lot-sizing under random lead times.

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## Abstract

With the increasing focus on environmental issues, manufacturers are facing pressure to adopt end-of-life item collection practices and maximize the reuse of components or sub-assemblies to their fullest potential. The decision-making processes for disassembly planning and components inventory management become critical as they directly impact a company's production costs and service level. In this particular context, Reverse Material Requirements Planning (RMRP) is a widely utilized method to determine the optimal lot sizes of end-of-life (EoL) products for disassembly, ensuring sufficient component supply. Traditionally, these lot sizes are calculated based on deterministic and dynamic demand assumptions when disassembly lead times are either zero or deterministic. However, in this work, we investigate optimization approaches for RMRP systems that consider disassembly lead time uncertainties, in a disassembly multi-echelon lot-sizing problem. We proposed stochastic programming models based on a Monte Carlo simulation approach whose performance is validated that are validated Their performance is validated on several numerical tests.

*Keywords:* Reverse logistic, disassembly lot-sizing, random lead time, stochastic programming

## 1. Introduction and related publications

Environmental and energy issues are becoming increasingly big issues. Product recovery processes have become an indispensable focus of attention for the industry and for the reverse logistics management research community. There have been numerous papers on this issue, with a strong focus on reverse logistics supply-chain optimization problems due to their role in reducing environmental impacts [1]. Here we investigate disassembly systems, which are one of the key links in the reverse logistics network. The disassembly process is a methodical extraction of valuable components. The scholarship has considered a number of disassembly optimization problems, including the disassembly line balancing problem, the disassembly sequencing problem, and the disassembly lot-sizing problem, etc. The disassembly lot-sizing (DLS) problem is examined in this study. Finding the best lot sizes for various time periods while reducing the expenses of the disassembly system constitutes a DLS challenge. These lot sizes are typically calculated based on deterministic and dynamic demand assumptions when disassembly lead times are zero or deterministic.

Many researchers have applied stochastic, [e.g., 2, 3, 4] and deterministic algorithms [e.g., 5, 6] to determine the optimal disassembly scheduling of complex end-of-life (EoL) product. Managing disassembly operations under the uncertainty of the disassembly process is very challenging in practice, due to the lack of planning and control systems for the remanufacturing systems. When an EoL product is disassembled, it is fundamental to ensure that it is the right model to be supplied. Owing to the complexity of the disassembly operation that is done manually, the workforce is often the major factor that provokes the uncertainty of the disassembly process in terms of its timing, and then, the disassembly operation of EoL product faces stochastic disassembly lead times. However, due to the uncertainty of the disassembly process, it is very hard to determine the availability

of a specific component. This uncertainty may be caused also by technical problems (absenteeism, limited disassembly capacity, quality problem, etc.). In this paper, the uncertainty of lead time is modeled through scenarios over the planning horizon.

The multi-echelon disassembly lot-sizing problem is taken into account. To address the static and dynamic decision frameworks, a two-stage and multi-stage model is created, respectively. Many solution approaches are suggested because two-stage and multi-stage stochastic algorithms are not practical in large-scale applications. First of all, for the static framework, we proposed a new reformulation of the inventory constraint that greatly lowers the overall number of scenarios and enables real-time static judgments. Second, we created heuristics for the dynamic framework, combining them with a Monte Carlo sampling method. Finally, we use a rolling horizon implementation for the dynamic framework.

## 2. Problem description

The case of a multi-echelon disassembly system and one type of end-of-life product is studied. Over the planning horizon, there will be a certain amount of demand from customers for disassembled items (the last level of the BOM). We make the loosely general assumption that there is no external demand for the subassemblies items (intermediate level). However, the parent item  $i$  (can be root item and sub-assembly item) that has been disassembled is available after a stochastic lead time  $L_i$ . These stochastic lead times are the intervals between the beginning of the disassembly process and the availability date of each parent item that has been disassembled. The disassembled quantity of the parent item  $i$  is thus available in period  $t + L_i$  if any disassembly operation begins in period  $t$ .

For each parent item,  $i$  at each time  $t$ , the probability distribution of the disassembly lead time is known and is bounded over predetermined intervals  $[L_i^-, L_i^+]$ . Additionally, a setup cost is incurred in that period if any disassembly order for the parent item is released, and the disassembly capacity is considered to be unlimited over the planning horizon. Finally, we offer a scenario-based stochastic optimization formulation in the current study.

For each item, an inventory holding cost is considered if the amount of disassembled items received exceeds the demand. Conversely, a backlog cost is paid when the demand for the leaf item in a period is backlogged (it can be satisfied in the next periods). The backlog quantity at the end of the horizon can be interpreted as the lost sale and a penalty cost is incurred. In order to meet all leaf item requests and reduce overall system costs, including setup, inventory, lost sales, and backlog expenses, it is necessary to determine the best disassembly order and quantity for each parent item.

## 3. Solution approaches

As mentioned early, two decision frameworks, known as static and dynamic are developed in this paper. The static decisions framework can be represented by a Two-Stage stochastic Mixed Integer Linear Program formulation (TS-MILP). The first stage variables correspond to the decisions made in period 0 before observing the disassembly lead time. These decisions are the setup and disassembly quantity for each item in each period. The second stage variables, also called recourse decisions, correspond to the inventory, backlog, and lost sale levels of each item at the end of each period. These decisions are observed after the realization of the disassembly lead time for each scenario. The proposed two-stage model describes the random lead time through all possible scenarios. However, the size of the scenario set increases exponentially with the number of periods, and the resulting program requires too much time and memory resources to be solved. Consequently, we developed a new formulation of the inventory constraint that significantly reduces the number of scenarios. The resulting model significantly improves the effectiveness of the approach.

The main drawback of the TS-MILP is that it does account for dynamic decision-making over multiple periods of the planning horizon. To extend the two-stage stochastic programming model by allowing revised

decisions in each period, we model the dynamic decision framework with a multi-stage stochastic Mixed Integer Linear Program model (MS-MILP). Because the proposed MS-MILP, is based on all possible scenarios, it is intractable. To make it tractable, an approach coupling Monte Carlo (MC) simulation and the MS-MILP is suggested. Finally, a rolling horizon strategy coupled with a multi-stage is developed to deal with the dynamic decision frameworks. The disassembly decisions are updated in each period of the planning horizon after observing the value of the lead time up to that period. As far as we are aware, there is no efficient approach available for this particular version of the stochastic multi-stage disassembly lot-sizing model.

#### 4. Conclusion

The use of stochastic optimization in the disassembly lot-sizing problem is investigated in this paper. First, in a static and dynamic decision context, we propose a two-stage and a multi-stage model for the multi-echelon uncapacitated lot-sizing problem. Disassembly quantities in the two-stage model are constant throughout the whole horizon. On the other hand, the multi-stage model takes into account the dynamic decision framework in which the disassembly amounts for each period are gradually defined. Second, we suggest effective scenario aggregation, a Monte Carlo sampling technique, and a framework for rolling horizon solutions to cope with large-scale occurrences. Third, we show the effectiveness and performance of the suggested stochastic optimization approaches through numerical experiments. The results show that the stochastic optimization for the disassembly lot-sizing problem is considerably more beneficial in a dynamic setting because the generated plans are significantly less expensive and take up less CPU time than those made by conventional methods. Finally, future research on this topic would be interesting if it took into account other actual model characteristics like consumer demand and yield from disassembly as stochastic. Furthermore, only stochastic programming techniques are considered in this work; nonetheless, a robust model might be recommended.

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