# The Use of Chance Constrained Programming for Disassemble-to-Order Problems with Stochastic Yields

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**Summary.** Stochastic yields from disassembly complicate the planning of so-called disassemble to order problems, where a specified amount of components must be harvested from various models of returned products. Chance constraint programming, a branch of stochastic programming, has proven useful in several applications of operations management. This contribution will first formulate a novel chance constrained programming model for the single-period disassemble-to-order problem. We will then illustrate its application using an example, and highlight the tradeoff between service and costs which emerges. We also suggest a variety of extensions to the basic model, many of which will likely prove to be trivial and relevant to industry.

## 1 Introduction

Within the realm of closed loop supply chain management, products which are no longer needed by customers are collected and transported back to the manufacturer [1]. The firm receiving these returned products (called *cores*) can either recover material through recycling, remanufacture the products, or otherwise properly dispose of the cores. Remanufacturing cores entails disassembling the core completely, cleaning and inspecting the parts, adding newly produced parts, and reassembling the product to meet "good as new" quality standards. This option is particularly advantageous when there is a market for remanufactured products, as seen in e.g. automotive parts and photocopiers.

Planning remanufacturing starts by converting the demand for remanufactured models to a demand for components based on an MRP explosion. Given demand for components, it must then be decided how many cores to disassemble in order to fulfill this demand. This is complicated by the uncertainty surrounding the quality of the returned products, which manifests itself in random component-specific yields from disassembly [2]. This yield uncertainty is such that using the mean yield rate (and

thereby treating the problem as deterministic) often fails to provide an adequate number of components.

Two well-known alternative stochastic programming approaches are recourse models and chance constraint programming (CCP) models. In recourse models, decisions are first separated into first stage (made before the revelation of the random variable, here the yield) and second stage (made after the random variable is realized). Thus the second stage recourse decisions (which are weighted by penalty costs in the objective function) compensate for the effects of the randomness and ensure the feasibility of constraints [3]. The disadvantage of recourse models is that (1) quantifying these recourse costs is often quite difficult and (2) these models are difficult to solve for realistic sized problems. In certain situations however, it suffices that the constraints hold with a certain probability (practical examples might include e.g. emergency services or power system generation planning). Under CCP and in contrast to recourse models, constraints cannot be fulfilled in any case (there is no recourse) and therefore we seek to define an acceptable amount of risk that the constraints are violated [3].

This work will provide an initial look into how CCP models might be employed in disassembly planning under stochastic yields. In the next section, we will put forth the model and demonstrate its application through a numerical example paying particular attention to the tradeoff between service and cost. In the final section, we will provide some concluding remarks and suggest extensions which are of special interest from a practical point of view.

## 2 Model

In this section, we will use CCP to model a disassemble-to-order problem with stochastic yields. We assume (1) that cores are completely disassembled, (2) that there is no restriction on either the amount of cores which can be obtained from the market or (3) the disassembly capacity, (4) that disposal costs are negligible, (5) that demand for leaves is deterministic, (6) that the firm has no ability to procure leaves as an alternative to disassembly, and (7) that management has defined a service level (a prescribed probability that the demand is fulfilled) for each leaf. Additionally, for this initial work we will restrict our attention to a single planning period. While these assumptions are somewhat restrictive, many enjoy substantial empirical support. In the authors' experience, many products are completely disassembled prior to remanufacturing, among them being automotive engines. Superfluous leaves are often recycled for material rather than being landfilled, and as such generate a marginal amount of revenue, which motivates the assumption of negligible disposal costs. Although the assumption of deterministic demand is easy to relax, it is often the case in practice that demand is specified by another division, and can therefore be treated as given. This leaves yield uncertainty as the only source of stochastic influences. The ability to procure parts to be used in remanufacturing either from serial in-house production (which is particularly advantageous when being produced in mass) or through an external supplier might not be possible later in the life cycle as mass production has stopped and suppliers might be uninterested in providing relatively small quantities to the firm (or might only provide such parts at a high cost and/or long lead times). We will later discuss the case when lead times are