Resource selection and replacement in a circular economy context

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1 Introduction

The majority of the demand for new machines and equipment is driven by two main factors: the necessity to replace aging machines and the requirement for additional machines to accommodate growth or fluctuations in product or service demand [1]. The ongoing challenge that numerous companies face is how to effectively manage machinery and equipment of various ages. Renting is a quick and affordable way to adopt new technology while minimizing working capital expenses and making the most use of scarce resources. Therefore, choosing whether to buy or rent resources might be difficult for industrial executives. Either option is frequently regarded as the more economical option, depending on a number of variables. Process engineers must frequently reconfigure production lines over the lines' life cycle as a result of the various evolutions that product families undergo each year in response to sales and marketing demands. This study focuses on the assembly resource selection problem, taking into account the evolution of product family across the life cycle of the assembly line.

The circular economy (CE) aims to create a new paradigm for growth that pursues economic expansion while minimizing material and environmental impact [2]. CE is viewed as a competitive substitute for the traditional "take, make, dispose" method for handling material and resource flows in manufacturing [3]. The achievement of "closing the loop" in material and resource transfers across product life cycles is one of the circular economy's most ambitious goals. Our study incorporates the circular economy concept by examining alternative methods of resource utilization, including rental, lending, and disposal. As the product evolution is uncertain,we study a robust optimization approach. We present a novel Mixed Integer Linear Programming (MILP) formulation that aims to minimize the total resource selection cost for the worst case. An adversarial approach is also developed to solve larger instances, more efficiently.

2 Problem Description and Methodology

This research focuses on the resource selection problem of a sustainable mixed-model assembly line for numerous production generations. Due to the constant evolution of products and the unstable nature of the production environment in the modern world, we presume that a company desires to design an assembly line that can be reconfigured every 6 to 12 months [4]. In each generation, some new products would replace existing product variants that must be eliminated from the line resulting in multiple scenarios. Each scenario provides a potential definition of the product for each product family and generation. The product models' features match to the product design and include the number of required tasks as well as the processing duration of tasks.

The primary goal of this research is to optimize utilization of resources by proactively identifying the potential for reusing specific modules on other operational assembly lines. A resource or equipment piece(s) may be removed from the line; if the resource will not be used within the next few generations, it may be sold; otherwise, it may be lent to other businesses. In this situation, lending one of the unused resources not only generates revenue, but also enhances industrial resilience by decreasing reliance on newly developed production lines that rely on globally sourced resources/components. In addition, one or more resources or pieces of equipment can be added to the line. If the resource is intended for long-term use, it is advisable to buy it. However, if the resource is only needed for a few generations, renting it may be more cost effective. Furthermore, the management of resources nearing the end of their operational lifespan must be considered. As a result, a new MILP formulation is used to create the resource selection problem, which will determine which of the three decisions will be made for future generations' resources: buy/sell, rent/lend, or send to the manufacturer for recycling or disposal. In the worst-case scenario, the model aims to minimize the total capital and operational costs of future production generations.

To solve the considered problem, we propose an adversarial approach. The adversarial approach is a powerful method for dealing with robust optimization problems. This method is usually referred to as a two-step robust optimization method since it consists of two stages: the master problem and the sub-problem. The adversarial approach begins with a finite set of scenarios for the uncertain parameter. In the initial problem stage, the optimal decisions for the present set of scenarios are determined. The sub-problem then finds a scenario for the uncertain parameter that makes the previous solution to the master problem infeasible. This scenario is added to the set of scenarios for the master problem, and the resulting robust optimization problem is solved. This approach iteratively improves the solution's robustness. In this study, an adversarial approach for identifying the worst-case scenario for product families is developed. Figure 1 provides an illustration of the framework of the proposed adversarial approach. In the presentation, we will explain the approach's result and compare them with the results of MILP.

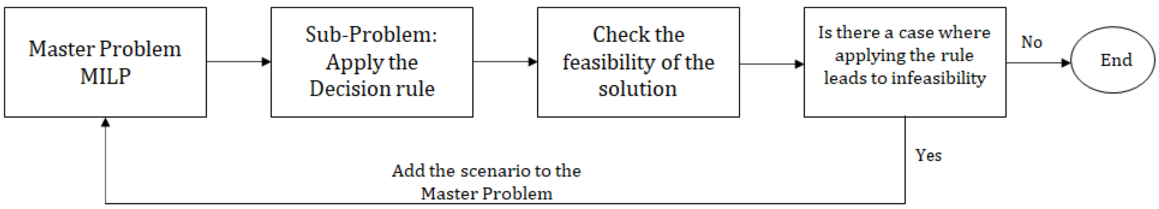

FIG. 1: Adversarial Approach

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