Markov decision process for dynamic task assignment in mixed-model assembly lines under processes time uncertainty with moving workers and portable equipment

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1 Introduction

Product individualization is an increasingly critical factor of success in the manufacturing sector. Manufacturers must incorporate mass customization, while maintaining a sufficiently large production volume and product differentiation. These strategies are no longer simply opportunities for competitive advantage, but rather conditions for a company's long-term success. Using a production system that can accommodate different models of products without losing productivity is essential for a company. In particular, manufacturers are switching to mixed/multi-model assembly lines due to dynamic market changes and increased demand for customization [1].

A mixed-model assembly line's performance is influenced heavily by the process times of the tasks that need to be assembled because each item has different tasks and operating times. This challenge can be overcome by ensuring the line is highly reconfigurable. Therefore, in this research, we study a balancing problem for a mixed-model assembly line considering walking workers and uncertain process times.

Mixed-model Assembly Lines (MALs) are essential in individualizing consumer demand since they can produce different product references simultaneously on the same line to benefit from an efficient production process [2]. The models may differ in product variants because their production requires different task times and restrictions. Walking workers at the stations is a restrictive assumption for multi-manned assembly line balancing problem formulations. Walking workers between stations enable such lines to arrange stations' capacity in accordance with the production sequence [3, 4]. In the present work, we investigate the benefit of walking workers to face deviations in the tasks' duration.

2 Problem definition and solution approach

This section discusses the balancing problem for a mixed-model assembly line with Walking Workers and Uncertain Process Times (MALBP–W–UP). In this setting, products move towards the next station simultaneously at the end of every takt time. The classical assembly line balancing problem asks to assign tasks to stations in such a way that the sum of the processing time of the tasks in a station respects the takt time. In our work, we consider the case where the number of workers and their equipment must also be allocated to the station, and these parameters affect the process duration. In addition, we assume the process duration to be unknown and given by a probability distribution conditional on the number of workers and their equipment. The objective is to minimize the cost of the line. We replace the classical constraint that requires meeting the takt time in each station by a probabilistic constraint that requires completing all tasks of each item before it reaches the last station with a given probability.

Reconfiguration refers to the movement of workers and the re-assignment of tasks. The task and worker assignments at each station are dynamically done depending on the state of the line in the operational phase of this problem. To adapt the capacity at stations before the arrival of an entering product, workers can shift from one station to another at the end of each takt. Walking times are assumed to be negligible in comparison with the takt and processing times. Depending on the equipment needed, tasks can be assigned to any station, and equipment can be doubled to increase reconfigurability. Workstations are sequentially occupied as products enter the line, creating different sequences of pairs of station-product models that change every takt.

Product orders are not limited by the stations in the line and can be defined as a sequence of product models entering the line. The considered problem is modeled as a Markovian Decision Process (MDP). A typical MDP consists of states, actions, a transition matrix, and transition rewards.

In this study, we consider different MDPs for items. In other words, each item's production is associated with a distinct MDP. In each decision stage for each model, the system is in a state, and an action is selected from the actions set associated with that state. The probability of switching from one state to another with an action is calculated. The most common methods for finding the optimal policies for MDPs are the linear programming method, the policy iteration algorithm, and the value iteration algorithm. In comparison to other approaches, linear programming is rarely used to solve MDPs. However, the LP solution methods are efficient and flexible enough to accommodate various constraints that link the different MDPs.

Moreover, in order to obtain the optimal MDP policy, we propose a Mixed-Integer Linear Programming (MILP) model. Since the proposed model, due to the excessive number of states and associated actions, cannot be solved with commercial solvers, we decompose the problem with the Benders decomposition method and solve it accordingly. The numerical results prove the performance of the proposed solution method.

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