Markov decision process for the robust optimization of mixed-model assembly lines with walking workers

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1 Context and motivation

Product customization and frequent market changes force manufacturing companies to switch to the mixed-model assembly lines from simple assembly lines which are able to produce only a single product model. The sequence of product models entering the assembly line has a significant impact on the mixed-model assembly line performance. This is because the product units may require different assembly operations and processing times. Typically, in such lines, the sequence is selected to avoid successive product units with long process time at a station. For instance, Renault inflicts a ratio of product units with complex operations in the production sequence [2]. There are many situations where the production sequence on the assembly line may not be perfectly controllable. For instance, product units may be removed from the initial sequence because they fail quality test, some orders may be added/removed, or some companies face highly variable demands.

To well adjust the line's production capacity to the requirements, the line can benefit from the concept of reconfigurability which provides an ability to quickly adapt the workers and machines, to the incoming product models [1]. In this work, line's reconfigurability is obtained by moving workers between stations and equipment duplication. The reconfiguration allows shifting the production capacity from takt to takt with the required level of productivity.

This work studies a multi-manned mixed-model assembly line balancing problem with walking workers ($MALBP-W$) where the product units can enter the line in any sequence. Precisely, the unknown infinite product sequence is considered which is subjected to frequent changes in the product models demand. The product units enter the line one-by-one and consecutively occupy sequential workstations over time (at the end of each takt). We also study a dynamic assembly operation assignment strategy for the line where operations can be re-assigned at the end of each takt depending on the new product unit entering the line and depending on the position of other product models on the line. Therefore, because of the complexity of the problem, modelling this problem is challenging. Taking into account the highly dynamic and stochastic nature of the studied problem, we decide to develop the Markov Decision Process (MDP) as the solution method. To the best of our knowledge, this paper is the first attempt to develop an MDP model for a $MALBP-W$ with dynamic operation assignment. We consider two variants of this model. The first one is stochastic to minimize the expected cost of workers and equipment ($MALBP-W^{Sto}$). The second one is robust to minimize the workforce and equipment cost for the worst takt ($MALBP-W^{Ro}$). Two stochastic and robust mixed-integer linear programming (MILP) models are proposed to solve the problems.

2 Studied problem and methodology

The studied problem $MALBP - W$ has two main stages. The design stage makes decision on the number of workers and the equipment assignment to stations for any possible order of products entering the line. At the operational stage, the product units entering the line are revealed takt by takt, and operations and workers are assigned to the stations depending on this information. We aim to design a line that can self-adjust to the incoming product models considering dynamic operation assignment.

Rather than other optimization techniques, the MDP is a modelling framework commonly used in reinforcement learning which is one of the main machine learning paradigms. Applying the machine learning approaches in operations research problems is absorbing huge attention of researchers, recently. An MDP expresses a sequential decision-making problem under uncertainty. It describes the process of transformation of the system's current state to another state through actions. An MDP consists of states, actions, transition matrix, and transition rewards. In each decision step of the MDP, the system is in a state $d \in \mathcal{D}$, and the agent selects an action a in the set A_d of possible actions in state d. The system goes from one state to another with a probability, and $Tr_a(d \mid d')$ provides the probability to transition from state d to state d' with action a. According to the uncertainty of the product sequence and the dynamic unit-dependent changes of operation assignment, the states, actions, transition probability matrix, and reward function are defined.

The proposed approach consists of two phases: pre-processing and mathematical programming, see Figure 1. At the first phase, all elements of the MDP are created: states, actions, transition probabilities, and reward function. To reduce the complexity of the model, we propose several reduction rules to simplify and enhance its performance. These rules reduce the number of generated states and actions. Moreover, because the transition matrix still demands a lot of computational effort, we propose a decomposition algorithm. According to this algorithm, the whole transition matrix with all states and actions is decomposed in sub-matrices with less transitions which improves the efficiency of the model. At the second phase, two $MILP$ models are built to solve stochastic ($MALBP - W^{Sto}$) and robust ($MALBP - W^{Ro}$) versions of the problem as were defined before.

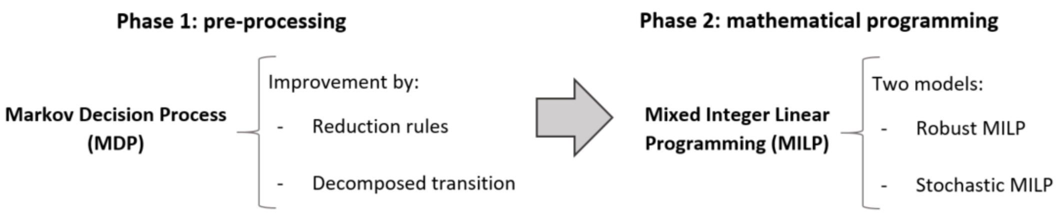

FIG. 1: The framework of the proposed methodology.

This study is our initial attempt to apply MDP using mathematical programming to a line balancing problem. This work opens interesting future research directions. The detailed comparison between the performance of the studied dynamic operation assignment and other possible operation assignment strategies, fixed and model-dependent operation assignments, studied in the literature are given. The details of the MDP and MILP models with extensive results and managerial insights will be presented and discussed during the conference presentation. Several future research directions will also be given.

References

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