A MILP-based heuristic for minimizing the number of reassignments under balancing multi-model reconfigurable manufacturing lines

Abdelkrim R. Yelles-Chaouche[1,2], Evgeny Gurevsky[3],
Nadjib Brahimi[4], Alexandre Dolgui[2]

[1] IRT Jules Verne, Bouguenais, France
[2] IMT Atlantique, LS2N, Nantes, France
[3] LS2N, Université de Nantes, France
[4] Rennes School of Business, France

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1 Context

The multi-model line balancing problem (MuMLBP) arises when several product types from a same family need to be produced in a single line. More precisely, it consists in finding, for each product type, an admissible line configuration subject to different constraints such as task precedence relations and cycle time of each product. Switching from one product configuration to another necessitates a re-balancing of the line. This latter lies in the reassignment of tasks between the existing workstations to fulfill the constraints of the new product. As a result, one of the objective in a MuMLBP consists in minimizing the setup time, cost or effort when re-balancing the line. Previous studies propose an approach that combines precedence graphs of each product into a single one. Hence, the problem is transformed to the well-known simple assembly line balancing problem (SALBP) and a single rigid line is designed to produce all the products without need to re-balance it [1]. Such a solution approach for MuMLBP quickly reaches its limits when the products are not similar, since combining precedence graphs becomes impossible. In this situation, each product needs to be considered separately.

The emergence of the concept of reconfigurable manufacturing systems (RMS), as systems allowing to be easily reconfigured, made it possible to consider a reconfigurable line able to handle several types of products [2]. As a result, many recent studies have proposed optimization approaches to design a multi-product reconfigurable line [3]. In this scope, we consider in the present paper a single line composed of a fixed number of reconfigurable workstations. Such a line is able to produce multiple type of products in separate batches. In order to be produced for each type of product, a specific corresponding line configuration is necessary. We refer to a line configuration as a set of tasks assigned to the workstations in a way that the precedence relations between them and the cycle time constraint are satisfied for each type of product. Because of the fact that the task precedence graph may be different for each product type, the line has to be re-balanced to meet the requirements of the new product type to be produced. As a result, a natural optimization problem arises which consists in determining an admissible line configuration of each product type so that the total number of task reassignments is minimized.

2 Studied problem

Given a fixed number of workstations, a cycle time and a precedence graph for each product, a MILP formulation was first developed to tackle the above described problem. The MILP model was then reinforced by two pre-processing techniques that introduce and calculate tasks assignment intervals. This formulation was solved using a commercial MIP solver on a series of small, medium and large size instances. The results showed that the used MIP solver was able to easily solve small size instances whereas it lacked in solving medium and large size ones.

To tackle this, a new heuristic named as Halt-and-Fix is developed. The latter is an iterative MILP-based approach which idea consists in analyzing a feasible solution found by a MIP solver within few seconds, then identifying certain characteristics that will be added as new constraints in the next iteration. Thus, reducing the search space.

More precisely, the first step of Halt-and-Fix consists in running the MIP solver. After the time period T, if a feasible solution is found, the solver is interrupted and a first solution is returned. Using this latter, an algorithm identifies the tasks that are assigned to the same workstations, *i.e.*, tasks that do not need to be reassigned when switching from product r_1 to product r_2. As a result, a set $K(r_1, r_2)$, which includes the previously identified tasks, is constructed from which new inclusion constraints are added to force these tasks to be assigned to a same workstation. The next iteration consists in using the previously found solution as a warm-start one and solving the problem with the newly added constraints. If a better solution is found within T, the solver is interrupted and the new found solution is analyzed, then $K(r_1, r_2)$ is updated. Otherwise, if no better solution is found, the solver continues to solve until it finds it. A more formal description of the described approach is given below.

Algorithm 1: Halt-and-Fix Heuristic

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1. Set $K(r_1, r_2) = \emptyset$ for each $(r_1, r_2)$. Set the best feasible solution $s^{(B)}$ as empty one.
2. Start to solve the MILP model with $s^{(B)}$ as a warm start solution. If an optimal solution is found within the time period $T$, then go to Step 4. Otherwise, if the time period $T$ is expired and no optimal solution is found, then continue to solve and go to Step 3 only if a new feasible solution $s$ better than $s^{(B)}$ is found.
3. Interrupt solving and based on the solution $s$, update the set $K(r_1, r_2)$ for each $(r_1, r_2)$. Reset $s^{(B)} := s$ and repeat Step 2.
4. Stop, the final heuristic solution is found.
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The obtained results with the above-described heuristic outperforms those found with the MIP solver (without interruption) in terms of the `CPU` time as well as the `GAP` within the time limit of 600 seconds. For example, when dealing with large size instances of 100 tasks, the heuristic finds solutions up to 47.37% better compared to the MIP solver. A detailed result analysis will be reported during the presentation.

References

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