Resource-constrained balancing of assembly lines to optimize their productivity and robustness in a reconfigurable environment

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1 Context

The main objective of this study is to balance reconfigurable assembly lines with a fixed number of workstations in presence of uncertain tasks and limited resources. These latter can be used to improve the corresponding production process. Balancing such a line means assigning a set of necessary assembly tasks to workstations, while satisfying task precedence constraints and aiming to optimize certain production goals.

The load of each workstation in such a line (or balance) is calculated as the sum of the processing time of all the tasks allocated to it. The corresponding line cycle time is defined as the load of the most charged workstation and its inverse value, known as *production rate*, is considered here to asses the productivity of the studied line balance.

In order to address the presence of uncertain tasks, the concept of *stability factor* [2] is used in this work as a robustness indicator. This indicator represents, among others, the maximum rate of increment that can be applied to the nominal processing time of any uncertain task without compromising the admissibility of the line balance with respect to its cycle time.

To handle a potential fluctuation in demand or uncertainty in task processing times, the aforementioned resources can be used to adjust or maintain the production capacity for a given line balance. This process is named a *reconfiguration*. To do this, one resource item can be applied for improving either the productivity or the robustness of the line balance. In practice, this can be achieved by decreasing the nominal processing time of all the tasks for one workstation (to improve productivity) or by parallelizing a workstation (to improve robustness). Moreover, multiple resource items can be used for any workstation to enhance productivity and robustness at the same time. In what follows, a line balance with assigned ressource items to workstations is called a line configuration.

Since the number of ressource items is limited, it is very important to use them efficiently. Thus, the optimization problem studied in this work can be formulated as follows: identify a line balance that provides the best trade-off between productivity and robustness (both to be maximized) among all its possible line configurations derived by distributing given resources items.

2 Proposed approach

In order to efficiently handle the distribution of resource items to workstations, a tree structure, entitled as the *tree of non-dominated configurations (or TNDC)*, is used. Each node of this tree corresponds to a line configuration, its root to an initial line balance and its height is equal to a given number of resource items. Starting from the root, the tree is established iteratively level by level using the width-first principle. Thus, from each node of level i, several child nodes for level $i+1$ are derived by allocating at first one resource item for any bottleneck workstation with respect to productivity and then one resource item for any bottleneck workstation with respect to robustness. Finally, any configuration that is dominated in the sense of Pareto (according to the two mentioned indicators) by at least one other configuration of the same level is excluded from the tree. As a consequence, each level includes a variety of non-dominated configurations that share the same number of resource items, but whose allocation and nature vary from one configuration to another.

To evaluate the quality of the trade-off provided by the TNDC for a line balance, a bi-objective based measure, inspired by [1], is used. It is noted HV and calculated as $\sum_{i=1}^{n} HV_i$, where n is the height of the tree and HV_i is a standard hyper-volume (a scalar value), computed on the basis of the outcomes provided by the configurations of the respective i-th TNDC level in the corresponding bi-objective space. The aggregate hyper-volume HV can also be considered as an appropriate scalability measure [3], since a line balance with a larger value of HV can provide a better scope of reconfiguration with regards to productivity and robustness.

In order to determine a balance with the greatest value of HV, a simulated annealing algorithm is developed. The structure of the implemented algorithm is similar to that proposed by [4, p. 7–15]. A list heuristic is used to provide an initial line balance. A neighborhood balance is generated randomly by moving one task from its initial workstation to another one. This movement is performed in a way that does not compromise the admissibility of the line balance. The HV measure is used in the algorithm as a fitness function for evaluating new generated line balances, which are represented by their TNDC. The annealing parameters are determined empirically. The details of numerical experiments for the application of this algorithm to the studied problem and their computational results will be presented at the conference.

References

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