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A hyper-volume based metric for scalable design of reconfigurable manufacturing systems with multiple objectives*

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1 Context

Factors such as global competition, technological progress and increased consumer awareness have made the current market demand highly dynamic and unpredictable. To survive and remain competitive under such circumstances, companies need to adopt manufacturing solutions able to react rapidly and cost-effectively to changes. Reconfigurable manufacturing systems, a concept initially introduced by Koren et al. [4], address this challenge.

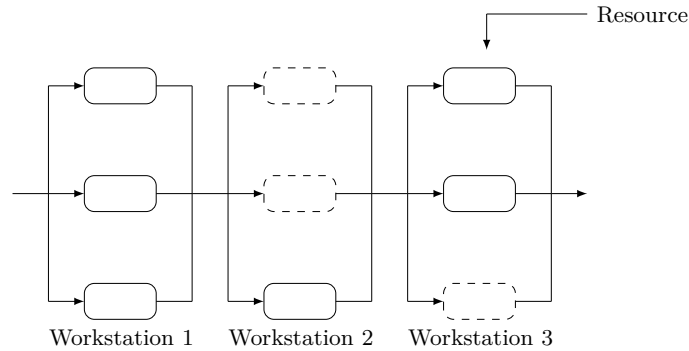


FIG. 1: Reconfigurable manufacturing line

The classical structure of a reconfigurable manufacturing system, as depicted in Figure 1, consists of a set of workstations. The product is processed successively on each of the workstations in a paced manner. Each workstation is equipped with manufacturing resources that can be added or removed, performing the same processing tasks in parallel. The time required to complete a product on a workstation depends on the sum of the processing time of the assigned tasks and the number of resources. A workstation that requires the longest time to complete a workpiece is defined as the bottleneck. This time is referred to as *takt time* and characterizes the overall pace of the production line.

During a takt time interval, each workstation receives a workpiece and releases another. However,

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some tasks can have an uncertain processing time. Any increase in task processing time could potentially compromise the ability of workstations to respect the pace. Idle time, which is the margin between the required time to complete the tasks at a workstation and the takt time, can be used to absorb the uncertainty in processing time, and can be referenced as workstation robustness. The workstation with the lowest level of robustness is the most susceptible to exceed the takt time. It is called the most risky workstation.

Both robustness and takt time depend mainly on two factors: task assignment and resource allocation to workstations. Allocating an additional resource to a workstation can either decrease the time that separates the release of two successive workpieces, thereby enhancing line productivity, or increase the idle time, potentially improving the line's robustness. Since the number of available resources is limited, it is essential to efficiently distribute them among workstations. Thus, we propose a bi-objective approach to offer interesting trade-offs between productivity and robustness.

2 Proposed approach

A configuration refers to a task assignment on workstations and the number of resources allocated to each of them. Each configuration is characterized by its productivity (the inverse of takt time) and its stability factor (a robustness metric proposed by Gurevsky et al. [3]). We propose a recursive process that generates all configurations presenting an interesting trade-off between productivity and stability factor from a defined task assignment. From each configuration, several child configurations could be derived by adding a resource, either on a bottleneck workstation to improve productivity, or on a most risky workstation, to enhance robustness. This process is repeated until the maximum number of available resources is reached. Consequently, a multi-level graph is obtained, in which each level includes a set of configurations sharing the same number of allocated manufacturing resources.

Since we are only interested in configurations presenting a good trade-off between productivity and robustness for the same number of allocated resources, we filter to only maintain the Pareto optimal ones.

In order to assess the quality of the trade-offs offered by the generated configurations, we adopt the hyper-volume metric, as inspired by Cerqueus and Delorme [2]. Initially, the hyper-volume for each level of the graph is computed, then they are summed to obtain the aggregated hyper-volume. This latter characterizes a manufacturing system design through the configurations that could be derived from it. The higher the aggregated hyper-volume, the larger the covered scope of productivity and robustness. Hence, the developed metric enables the evaluation of scalability for a given assignment of tasks, a quality that is considered as the most relevant feature of a reconfigurable manufacturing system.

As a manufacturing system design with a higher aggregated hyper-volume value has a better capability to cope with fluctuations in demand and task processing time, a simulated annealing algorithm is employed to determine the task assignment that maximizes the developed metric. The algorithm is tested on a set of instances derived from the literature and the computational results will be presented during the conference. An extended and more detailed version of this abstract can be found in Arbi et al. [1].

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