High Multiplicity RCPSP with Hierarchical Activities and Learning Effect

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1 Context Description

In numerous industries, particularly within manufacturing, it is commonplace to encounter scheduling environments where multiple projects share limited resources, each requiring execution on several occasions. The scheduling problem in such an environment is referred to as the High Multiplicity Resource-Constrained Project Scheduling Problem (HM-RCPSP) [1], and it is also encountered as a challenge in the design of a Satellite Assembly Line (SAL). The SAL design has the particularity of having to produce highly heterogeneous satellites, either in terms of their assembly processes or the number of units to be built, while sharing the resources and machinery of the factory. It can be described as follows: (1) there are several satellites of different categories that need to be built, each having to be completed before a specific deadline; (2) the building process of satellites from different categories must execute a different set of activities; (3) each activity occupies a specific amount of resources, i.e., machines and workers, during its execution; and (4) there are two kinds of relationships existing between activities: a (well-known) precedence relationship, which describes the execution order of activities, and a hierarchical relationship, which expresses the fact that an activity encompasses other activities, thereby starting (resp. concluding) with the earliest (resp. latest) among its encompassed activities.

In factories, the duration to perform an operation varies over time. As a production system operates, workers learn the manufacturing process, the required gestures, how to use the tools, and how to control the supply chain, among other factors. Consequently, the overall system becomes more efficient. For instance, the time required to build the 10th exemplar of a product may be equal to half of the time taken for the first one. This phenomenon is known as the *learning effect*, and the variation in duration based on the number of repetitions (of the same operation) is referred to as a *learning curve* (or *learning model*). A historical review and comprehensive survey about learning curves can be found in [2].

This work takes into account the learning effect in SAL design, or more specifically, focuses on a HM-RCPSP with hierarchical activities and learning effect (HM-RCPSP/H-L). So far, a lot of studies have been conducted on scheduling problems considering the learning effect among the characteristics of the problems [3]. However, to the best of our knowledge, no study has yet explored the HM-RCPSP/H-L.

2 Contribution

To account for the learning effect, our approach involves counting the number of times an activity has been entirely completed before the start of each of its occurrences. Subsequently,

the duration of each occurrence is calculated from the learning curve (specified by the user). Due to this phenomenon, the duration of each activity becomes a variable in the problem. Additionally, this problem is highly constrained by resource capacity, making the Constraint Programming (CP) paradigm particularly well-suited for solving it.

We propose a CP Optimizer's model that is adapted to the multi-repetitive project schema, featuring additional constraints to accommodate both the hierarchical relationship between activities and the learning effect. Moreover, we prove the existence of symmetrical solutions for HM-RCPSP/H-L that can be broken by some constraints. We have also formulated an Integer Linear Programming (ILP) model for comparison. The objective is first to minimize the sum of tardiness of all projects, then minimize the makespan of schedules. Experiments are performed with real industrial data for Satellite Assembly Line using IBM CP Optimizer & CPLEX version 22.1.1. Figure (1) represents the performance comparison of the CP approach involving the learning effect, with and without the symmetry-breaking constraint.

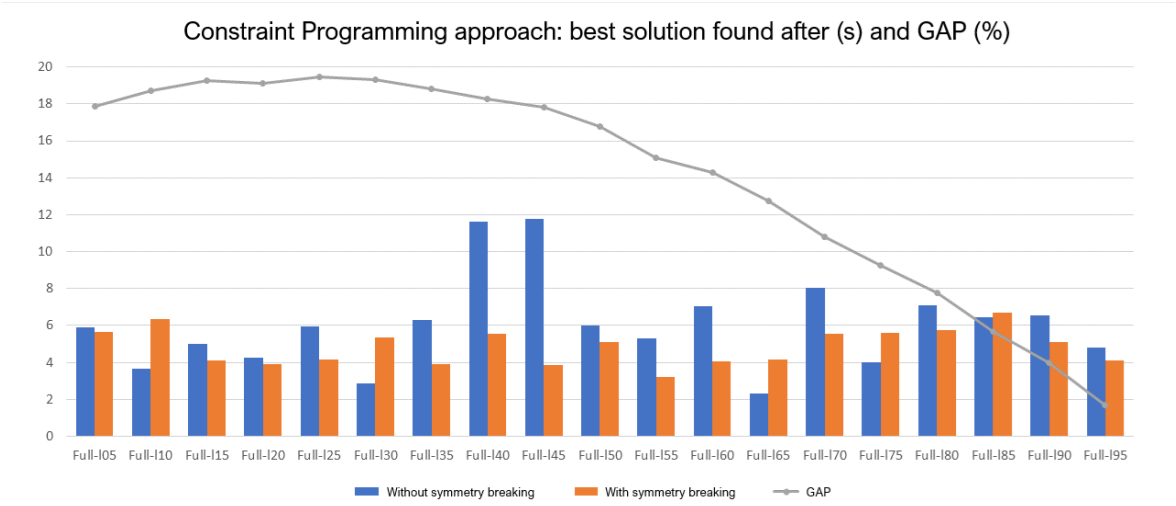

FIG. 1: Performance comparison of the CP approach involving the learning effect, with and without the symmetry-breaking constraint

3 Conclusion and Perspectives

We have shown that there exists a noticeable difference in the overall duration of a project when schedules takes the learning effect into consideration. This proves that this phenomenon is an important factor and cannot be ignored in a multi-repetitive project scheduling environment. We have observed on some real industrial data for the problem HM-RCPSP/H-L that our CP approach outperforms our ILP one. However, in very large-scale instances, we believe that CP might become less efficient, whereas a well-designed metaheuristic could take the lead.

References

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