Preemptive shift-based scheduling with maximum workload constraints

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1 Introduction

With the constant evolution of industry, supervisors are facing increasingly complex planning systems. In this context, decision-support tools (DSTs) can help alleviate the cognitive load experienced by decision-makers. However, according to the results of an ongoing multidisciplinary research project [1], many DSTs suffer from overly techno-centered designs, which often fail to effectively reduce the stress faced by supervisors. The lack of flexibility of many of these tools is underlined. The study highlights the explicit need for human-centered DSTs that cater to the individual decision-making processes, as each person follows their own methodology. When dealing with planning tasks, supervisors must account for real-world constraints, such as labor laws, which influence decision-making. Therefore, it is crucial that planning DSTs incorporate a flexible and responsive approach that is adapted to these constraints while ensuring consistent and realistic decision-making in a dynamic environment.

In the context of satellite industry, effective workforce scheduling is of utmost importance for ensuring operational efficiency and meeting both organizational needs and work laws. We therefore consider the problem of work shifts planning - allocating employees to specific time slots to cover operational demands while verifying constraints such as maximum workload constraints. This constraint is designed to prevent overworking, reduce fatigue, and enhance workers' overall well-being. This problem can be viewed as a preemptive shift-based jobshop scheduling problem (pJSP) with maximum workload constraints (MW), stipulating that, on some particular disjunctive resources k , "at most a fixed number δ_{uv} of shifts along an interval $[u, v]$ of consecutive shifts should be worked". We recall that pJSP is a NP-hard problem.

Let us introduce decision variables $x_i^k = \begin{cases} 1 & \text{if resource k is working at shift i} \\ 0 & \text{otherwise.} \end{cases}$

The maximum workload constraints can be expressed as $\displaystyle\sum_{i=u}^{v} x_i^k \leq \delta_{uv}^k$,

where δ_{uv}^k refers to as the maximum workload allowed in interval $[u, v]$. Note that constraints defining fixed off shifts are specific instances of this general constraint (i.e., setting $\delta_{uv}^k = v - u$).

We choose to tackle this problem using constraint programming (CP) as this paradigm has emerged to be one of the most efficient to solve planning and scheduling problems. Evidences show the ability of a CP model to deal with the previous DST requirements. Indeed, the notion of interval variables (defined by beginning time, end time, duration and energy consumption) provided by such CP solvers sounds promising to deal with such constraint. Moreover, the powerful ability to propagate constraints is also a strong asset regarding decision aid that can be provided to decision-makers.

2 Proposed method

As introduced in the first section, our goal is to manage generic MW constraints. Integrating these constraints into shift-based scheduling models requires the development of a new approach. We initially designed a model using the well-known IBM® ILOG CPLEX Optimization Studio software (CPO), but the need for preemption forced us to model each shift separately, leading to a combinatorial explosion requiring high computational efforts.

To avoid the complexity introduced when considering shifts explicitly, we are now using a solver called Mistral and its specific constraint $PreemptiveNoOverlap$ proposed in [2]. Adapted propagation algorithms in Mistral, such as overload checks, allow to solve pJSP by setting minimal-length execution intervals for tasks, therefore minimizing the maximum makespan. Then, in a second step, from that generic solution, a solution with explicit shifts can be found using Jackson's preemptive polynomial-time algorithm. This method is highly efficient for pJSP, requiring fewer variables (no need to model every shift separately) and fewer constraints. However, it does not deal with MW constraints directly. To address this issue, we propose a new solving method that operates in multiple stages, based on the Mistral model.

The following figure depicts our framework:

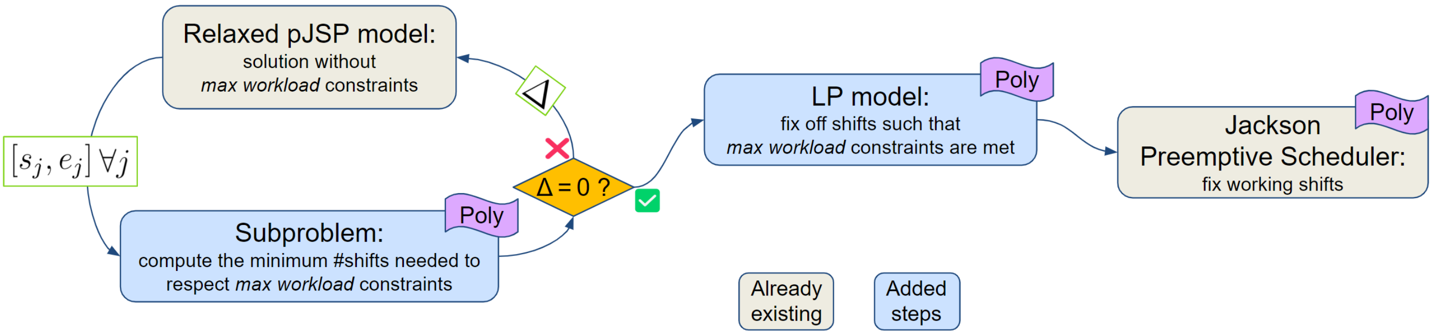

FIG. 1: Multi-stage resolution scheme

1. **Relaxed pJSP model:** This Mistral CP model computes, for every task j, its earliest start date s_j and latest end date e_j for a classical preemptive Jobshop Scheduling Problem and gives the minimum workload δ^i_j that has to be achieved in any interval $[s_i, e_j]$.

2. **Subproblem:** It iteratively determines the smallest value Δ that has to be added to a given δ^i_j in order to cope with MW constraints. This value is updated in the Mistral model, which will then return a new solution. When $\Delta = 0$, we are guaranteed to find a solution of minimal makespan to the problem with MW constraints.

3. **LP model:** It schedules off days to meet MW constraints and ensures that the Jackson Preemptive Scheduler will find a feasible solution.

4. **JPS** [3]**:** This polynomial algorithm schedules working days with preemption.

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