A Appendix 1 - CPO model

In CPO, without preemption, modeling is simple and efficient, as tasks are single fixed intervals and strong filtering algorithms (e.g., edge-finding [21]) apply directly. With preemption, however, each task must be split into multiple unit-length optional intervals, dramatically increasing combinatorial complexity and making propagation more difficult.

The extensive CPO model used for experiments is the following (note that when an optional interval is absent, it is not belonging to any interval). Explanations follow the model. In the following, if not specified, consider $i \in \{0, ..., |\mathcal{J}| - 1\}$, $j \in \{0, ..., n_i\}$, $k \in$ Operators. We write $\delta_c^{\text{lo}}, \delta_c^{\text{hi}}, u_c, v_c$ the quadruplet values of MW constraint c.

$$\min \quad \max_{i,j} \left(\text{endOf}(W_{i,j,P_{ij}}) \right)$$

$$\begin{aligned}
&\text{interval } W_{ij\ell}, \text{ size} = 1 && \forall i, \forall j, \forall \ell \in \{1, \ , P_{ij}\} && \text{(V1)}\\
&\text{interval } O_{kc\lambda}, \text{ optional }, \text{size} = 1 && \forall k, \forall c \in \text{MW}_k, \forall \lambda \in \{1, \ , \delta_c^{\text{lo}}\} && \text{(V2)}\\
&O_{kc\lambda} \subseteq [u_c, v_c] && \forall k, \forall c \in \text{MW}_k, \forall \lambda \in \{1, \ , \delta_c^{\text{lo}}\} && \text{(C1)}\\
&\textsc{EndBeforeStart}(W_{ij,\ell-1}, W_{ij,\ell}) && \forall i, \forall j, \forall \ell \in \{2, \ , P_{ij}\} && \text{(C2)}\\
&\textsc{EndBeforeStart}\left(W_{i,j,p_{ij}}, W_{i,j+1,0}\right) && \forall i, \forall j \in \{0, \ , n_i - 1\} && \text{(C3)}\\
&\textsc{NoOverlap}\left(\underset{\forall i,j \in \text{T}_k, \ell}{[W_{ij\ell}]} \cup \underset{\forall c \in MW_k, \lambda}{[O_{kc\lambda}]} \right) && \forall k && \text{(C4)}\\
&\delta_c^{\text{lo}} \leq \sum_{\lambda=1,\dots,\delta_c^{\text{lo}}} \left(O_{kc\lambda} \in [u_c, v_c]\right) \leq \delta_c^{\text{hi}} && \forall k, \forall c \in \text{MW}_k && \text{(C5)}
\end{aligned}$$

In this model, we have two *families* of decision variables. For each task j of each activity i, we add as many unit-length interval variables (V1) as the processing time of the task (indexed by ℓ). To deal with MW constraints, the model also features a set of interval variables O. For every MW constraint c, we add to operator k δ_c^{hi} unit-length *optional* interval variables (V2). If these optional variables are included in the final solution, they must be scheduled within the interval $[u, v]$ (C1). These variables allow flexibility in how rest periods are scheduled to satisfy workload regulations. The objective is still to minimize the makespan. Constraint C2 enforces sequential execution of a task: for each unit ℓ of any task ij except the last, the shift represented by variable $W_{ij\ell}$ must end before $W_{ij(\ell+1)}$ begins. Precedence constraints between successive operations of the same activity are also imposed (C3). Constraint C4 enforces a no-overlap condition, ensuring that for each operator, all its working (W) and rest (O) days do not overlap in time. Lastly, this model handles the workload requirement (C5). For each operator k and each constraint MW_k c defined over a time window $[u, v]$, the model requires for at least δ_c^{lo} and at most δ^{hi} optional intervals to be present in this window.