A CP model for interactive project scheduling in space industry

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1 Introduction

As modern production environments tend to be increasingly complex and stressful for production process supervisors [1], providing interactive decision support tools (DSTs) is seen as a relevant way to help humans better organize and monitor operations, in the face of production uncertainties. Consideration of the actual needs and capabilities of supervisors in the DST development process thus seems to be a prerequisite for the development of usable, accepted and effective tools. The results presented in this paper synthesize the findings of an ongoing multidisciplinary project taking interest in human-centered design of DSTs related to production supervision. This work was conducted in partnership with a major French company specialized in space technologies, which provided our case study.

2 A CP-based approach

The wide variety of performance indicators, situations and decision-makers, as well as the multi-faceted nature of the production process, make the search for an optimal solution unnecessary. The satisfiability of constraints is obviously a relevant property to be checked in real time. The ability to quickly compute good lower/upper bounds on well-targeted performance indicators is also of major interest to supervisors. In case of inconsistent constraints, providing explanations to decision makers and helping them to recover the desired satisfiability can also be of great help. Finally, the ability to quickly generate detailed feasible solutions is also useful.

The above features can be met in the constraint programming paradigm in which many researchers precisely focused for decades on designing algorithms able to efficiently prove constraint satisfiability, propagate time/resource constraints to refine variable domains, or provide minimal inconsistent constraint sets (see e.g. [2] for a survey) . The remainder of this section discusses a CP model for project planning environment, specifically addressing how work and resources can be disaggregated, i.e., how constraints can be settled to link the disaggregated/aggregated decision variables all together.

In this model, the time horizon is assumed to be modeled as a set of period T of identical length, each period being indexed from 1 to $|T|$ (a period corresponds to a shift in our case study). Cumulative resources, each of them representing a set of disjunctive resources, are distinguished. K^* refers to as the set of all the disjunctive resources (i.e., the set of all operators or system states in our case study). $\mathcal{K}$ is the set of all the possible subsets of resources (e.g., a subset represents a category of operators or a specific state of the system). A subset K in $\mathcal{K}$ can be modeled as a cumulative resource, Q_K being its capacity. The project is defined by a set of tasks J. We refer to $\mathcal{A}$ as the set of precedence constraints, i.e., $(j \prec j') \Leftrightarrow (j, j') \in \mathcal{A}$. Each task $j \in J$ can be decomposed into p_j subtasks of duration equals to one period. A task has to be allocated to a set of periods (Dom_j is the index of periods where subtasks of j can be carried out) and a *set* of cumulative resources $\mathcal{K}_j \in \mathcal{K}$. Furthermore, each subtask of j must be assigned to a disjunctive resource belonging to K, for each $K \in \mathcal{K}_j$ and to a specific period of Dom_j.

The decision variable $x_{j,i}$ models the index of the period assigned to subtask i of task j ($j \in J$, $i \in [1, \ldots, p_j]$). The domain $Dom(x_{j,i})$ of $x_{j,i}$ is initialized to Dom_j. The value of variable $y_{k,t}$ is t ($t \in T$) if resource k ($k \in K^*$) is made available at period t, else 0 ($Dom(y_{k,t}) = \{0, t\}$). $w_{K,t}$ is the intensity of set of resources $K \in \mathcal{K}$) required at period t ($Dom(w_{K,t}) = [0, \ldots, Q_K]$). $w'_{K,t}$ is the capacity of resource K made available at period t ($Dom(w'_{K,t}) = [0, \ldots, Q_K]$). A dummy variable $w'_{K,0}$ is defined for unused resource units in order to keep the available capacity and the assigned capacity balanced for each K.

For all $K \in \mathcal{K}$, X^K is the array of all variables $x_{j,i}$ with $j \in J,\ K \in \mathcal{K}_j,\ i \in [1, \ldots, p_j]$. For all $K \in \mathcal{K}$, Y^K is the array of all variables $y_{k,t}$ with $k \in K, t \in T$. Finally, for all $K \in \mathcal{K}$, W_K (resp. W'_K) is the array of all variables $w_{K,t}$ (resp. $w'_{K,t}$), such t is in $\{0\} \cup T$. The CP model is presented below. Constraints (1) guarantee that two subtasks belonging to the same task are not executed in the same period. Constraints (2) model the precedence constraints. Bin-packing constraints (3) models the link between x and w variables : x are the items to be assigned to bins w, where each w is associated with a set of resources and a specific period. Similarly, the link between y and w' variables is modeled by bin-packing constraints (4) : y are the items to be assigned to bins w', where each item $y_{k,t}$ with $k \in K$ has to be assigned either to bin $w'_{K,0}$ or $w'_{K,t}$. Constraints (5) ensure that, for each period, the number of assigned resources is higher than the resource consumption.

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\begin{aligned}
x_{j,i} &< x_{j,i+1} & \forall j \in J,\ \forall i \in [1, \ldots, p_j - 1] \quad (1)\\
x_{j,p_j} &< x_{j',1} & \forall (j, j') \in \mathcal{A} \quad (2)\\
&bin\_packing(W_K, X_K) & \forall K \in \mathcal{K} \quad (3)\\
&bin\_packing(W'_K, Y_K) & \forall K \in \mathcal{K} \quad (4)\\
w_{K,t} &\le w'_{K,t} & \forall K \in \mathcal{K},\ \forall t \in T \quad (5)
\end{aligned}
$$

3 Conclusion and perspectives

A preliminary CP model has been provided in order to support the various human-in-the-loop decision processes. It integrates resource and task aggregation and will be updated soon to also deal with time abstraction. The various ways of using the algorithms that check consistency on this model, provide lower/upper bounds on performance indicators or recover consistency are currently under study. They will be implemented to assess the real usability, acceptability and efficiency of the proposed approach. Future research works will address the multi-agent nature of the decision problems, as well as the negotiation mechanisms they involved.

Références

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