On stress-testing the target cycle time in aerospace manufacturing systems

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1 Introduction

Aircraft assembly lines are characterized by low-volume production, extensive manual work, limited buffer space, specialized resources, long cycle times, and a large network of external suppliers. Unlike in the automotive industry, where a cycle takes only a few minutes, a single cycle in aerospace assembly can last several days or even weeks. For technical reasons, many tasks require skilled manual labor. Assembling large, complex aircraft components requires fine human dexterity, and specialized skills that are difficult to automate or teach to robots[1].

In a growing aerospace market, meeting planned delivery dates becomes increasingly difficult because of numerous known and unknown performance detractors (worker absence, equipment breakdowns, missing parts, etc.). To the best of our knowledge, only limited research has addressed how to model and manage operations under uncertainty in aircraft assembly lines [2, 3]. A first step in this direction is to assess how, and to what extent, a nominal scheduling decision can withstand uncertainty. In this work, we focus on stress-testing a given Target Cycle Time (TCT) in aerospace manufacturing systems.

2 Stress-testing the target cycle time and first results

To evaluate the quality of a baseline sequence (i.e., order in which tasks are performed on assigned resources) against disturbed processing times, we employ a stress-testing procedure that disturbs the processing times of tasks according to a set of detractor scenarios Ω. We start from a baseline sequence S^*, determined using reference processing times and a given target cycle time (TCT). We then stress-test S^* by evaluating its performance over Ω. For each scenario $\omega \in \Omega$, we compute the resulting makespan $C_{\max}(S^*, \omega)$ and collect these values into a set, which approximates the distribution of stress-tested cycle times. Based on the resulting empirical distribution, we derive the service level, i.e., the probability that the stressed cycle time remains below or equal to TCT.

Numerical experiments were conducted on the benchmark instances of the deterministic time-constrained scheduling problem with multiple modes provided in [1]. After assuming that the deterministic processing times correspond to the reference values, a baseline sequence S^* was computed using CPLEX by solving the model proposed in [1]. In this study, we focus specifically on operator absences and derive a set of related representative scenarios. In this work, operator absences are modeled as additional time units added to the reference processing times of tasks. Since the problem is multi-mode, each task can be executed using different

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[1] `https://www.assemblymag.com/articles/86900-high-flying-robots`

combinations of operators, which enables us to capture how operator availability affects task durations and overall schedule feasibility.

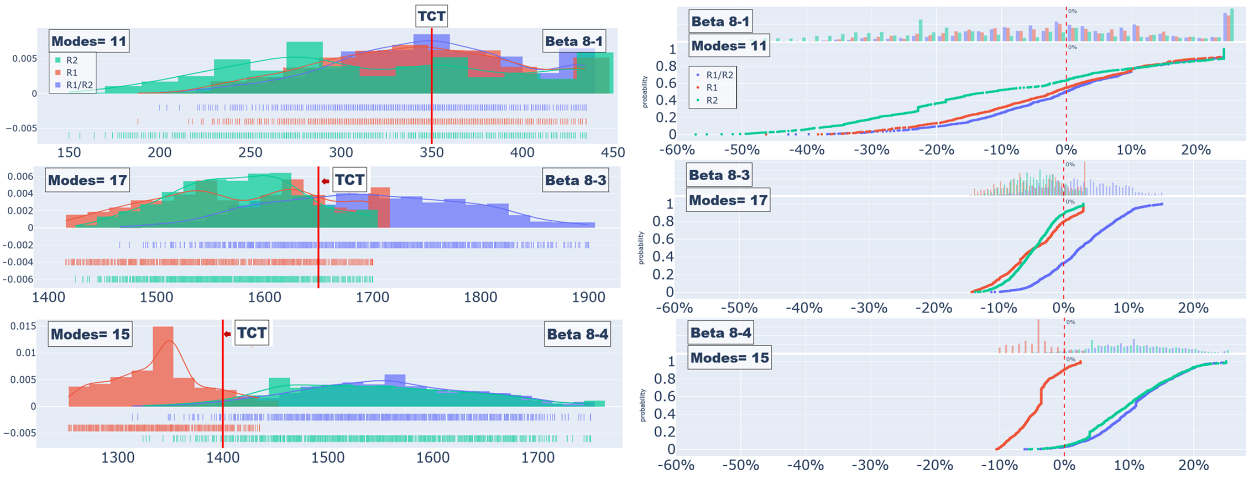

FIG. 1: Example of simulated distributions of stressed cycle times versus the target cycle time.

Fig. 1 illustrates how performance is affected under uncertainty and shows differences in sensitivity when operator $R1$, operator $R2$, or both $R1/R2$ are absent. The stress-testing results reveal clear differences across the instances. In the strong-overlap case (`Beta 8-1`), the disturbed cycle-time distributions of $R1$ and $R2$ blend, with long right tails and low service levels. The moderate-overlap solution (`Beta 8-3`) shows partial separation of regimes. S^* remains relatively robust to disturbances on $R1$ and $R2$, while $R1/R2$ has a stronger impact on variability. In the clear-divergence case (`Beta 8-4`), the regimes operate in distinct domains with limited cross-influence, although $R2$ and $R1/R2$ disturbances remain critical. Overall, overlap structure and tail behavior provide informative indicators of sequence robustness and resource criticality.

Stress-testing a given TCT, by quantifying how a baseline sequence, performs under operator absence scenarios, raises several further questions about which statistical properties a scheduling solution must exhibit to cope effectively with uncertainty, which control strategies best mitigate disturbances, how these strategies can be combined to enhance robustness and resilience, and when the system should switch between them to maintain performance.

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