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A Digital Twin-based Framework for Adaptive Production Control

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In the current era of Industry 4.0 and cyber-physical systems, the way production systems are designed and managed has been significantly transformed by digital technologies. In this context, the Digital Twin (DT) has emerged as a promising simulation paradigm to support decision-making through various engineering applications. In fact, DT can be considered a virtual replica of a physical system capable of reproducing its behavior by relying on simulation models and real-time data integration. DT typically enables improvements in production processes by simulating alternative scenarios to allow the evaluation of the impact of changes in how the system is designed and operated. By predicting system behavior, DT can assist in making informed decisions, identifying potential issues, and allowing performance optimization.

Despite extensive research on DT for the area of production planning and control, the focus remains mainly related to scheduling, and very few studies have investigated the use of DT for enhancing existing production control mechanisms or for developing new ones. To address this literature gap, the authors propose a new framework for adaptive production control based on existing control mechanisms and rules, focusing on throughput, work-in-progress, and resource utilization. Leveraging on DT predictive capabilities and inspired by model predictive control theory, the proposed framework supports the optimization of production control parameters, allowing to adapt to changing production conditions and to maintain stable production performance over time. Control parameters dynamically modify mechanisms and rules which determine how orders are sequenced, released, and routed, changing the overall system behavior.

To validate the effectiveness and quantify the benefits of the proposed framework, experiments were conducted in fully virtualized environments. The framework was proven capable of increasing throughput while reducing WIP, thereby improving the overall performance of the manufacturing system. The proposed framework offers several advantages, drastically improving traditional production control mechanisms. Control can be optimized predictively according to simulation results and the rolling horizon approach enables the framework to adapt to changing production conditions, ensuring system stability and robustness over time. In conclusion, this study contributes to the research in production planning and control methods based on DT by proposing a framework for adaptive production control, highlighting the importance of predictive insights for optimization under changing system conditions.

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