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MAXIMIZING THROUGHPUT, DUE DATE COMPLIANCE AND OTHER PARTIALLY CONFLICTING OBJECTIVES IN SEMICONDUCTOR PRODUCTION

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ABSTRACT

Semiconductor production is a highly complex interplay of human, machine, material, and method. With state-of-the-art meta-heuristics as the baseline for WIP scheduling, Nexperia Hamburg is exploring more advanced methods to optimize production. By combining simulation with an event-driven dispatcher, a constraint solver, and a digital twin for metrics and monitoring, we have created a powerful testbed to evaluate production planning methods. The integrated digital twin of the selected bottleneck production area provides not only data to drive the planning process but also enables transparency and predictive analytics to allow revealing further unused production potential. In particular, we compare various meta-heuristics, combinatorial optimization, and reinforcement learning. We study how to balance – sometimes conflicting – optimization objectives in an epitaxy production area in a high-throughput wafer fab. To enable line engineers, we propose a robust and transparent scheduling method selection and verification process.

1 INTRODUCTION

Driven by the enormous demand for semiconductors, manufacturers strive to optimize existing production lines. However, because of the high cost associated with loss of tool capacity or material, changes to production planning need to be prepared extremely carefully. Even experienced line engineers sometimes struggle to predict the impact of new resources such as staffing or tools, or procedural changes, due to the complex interplay of human, machine, material, and method (4M). Furthermore, picking an optimal scheduling policy is typically only feasible through simulation (Fowler et al. 2015).

Epitaxy refers to a type of crystal growth. In semiconductor production, films are grown epitaxially on semiconductor substrate wafers. In the studied production site at Nexperia, the epitaxy area was found to be a bottleneck area. In this study, we present how the area was modeled and optimized, as well as the process to onboard line engineers. While previous studies often exclusively focus on the methodological part, we put a special emphasis on enabling line engineers to consume a complex simulation model in their daily work through a fully automated model verification and selection process.

2 SIMULATION MODEL: EPITAXY IN SEMICONDUCTOR PRODUCTION

Together with epitaxy line engineers at Nexperia, we have established a very detailed process description that accounts for staffing, tool properties, maintenance schedule, as well as setup, engineering, and qualification requirements. Identified scheduling requirements include a variety of partially conflicting objectives such as (1) tool utilization uniformity in the area, (2) setup avoidance, (3) minimization of lot starts during shift breaks, (4) throughput maximization, (5) due date compliance, (6) consideration of maintenance tasks within tolerance time windows, (7) minimization of intralogistics within the area.

The simulation model was implemented using the open-source simulation engine kalasim. Kalasim (Brandl 2022) is a discrete event simulator that enables complex, performant, dynamic process models. It provides a statically typed declarative API to define simulation entities and process definitions and supports dependency injection, modern persistence, structured logging as well as automation capabilities. Kalasim helped us to overcome the limitations of previously used UI-centric simulation products and allowed us to express the complex dynamics of the studied epitaxy process more efficiently. In our model, we included not only the production process itself but also a wide range of complementary processes such as qualification, maintenance, engineering, and material preparation. Also, staff such as operators and maintenance engineers were carefully modeled to match their availability and shift schedule.

We have studied various meta-heuristics as a baseline to match current planning regimes realized with the SYSTEMA dispatcher in production at Nexperia Hamburg. These heuristics account for the complex capability requirements from a tool and material perspective, timers to constrain processing within a time range, inventory ratios for upstream and downstream WIP balancing, and classical techniques such as earliest due date or setup avoidance. Furthermore, we have modeled the scheduling objectives with OptaPlanner (De Smet 2006) as a constraint-optimization solver including a multifactorial cost function. Apart from the discussed production objectives, our solver accounts for various hard constraints such as tool assignments, tool capabilities, or recipe restrictions, to ensure the feasibility of the computed planning solution.

3 RESULTS & SUMMARY

By analyzing shopfloor data, we gathered statistics to parameterize the proposed model. Simulation data were matched with the shopfloor data to ensure a high prediction accuracy concerning tool, staffing, and material statistics. Simulation data were also fed into a digital twin model (Luhn et al. 2015) designed for semiconductor frontend production analytics. It is developed as an event-driven, integrated, scalable, real-time digital factory twin solution for up-to-date factory analytics, reporting, and optimization. Using its built-in metrics and KPIs, we have validated our model on a wide range of scenarios provided by line engineers from Nexperia. In addition, expert reviews with line engineers helped to validate our model.

We have studied the complex interplay of human, machine, material, and method (4M) in an epitaxy production process. We present evaluation results and simulation data for different production settings to overcome baseline performance using a multifactorial constraint solver. Also, we highlight the complementary processes, such as model verification to enable line engineers to adjust a complex planning solution before a go-live using the developed integrated test-bed.

This presentation is part of an ongoing research collaborative initiative AISSI “Autonomous Integrated Scheduling for Semiconductor Industry” together with Bosch, D-SIMLAB, and academic partners from KIT, exploring how to push the boundaries of production scheduling using AI and simulation.

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