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PRODUCTIVITY AND BOTTLENECK ANALYSIS THROUGH FAST ITERATIVE DISCRETE-EVENT SIMULATION IN TRANSFORMER MANUFACTURING

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ABSTRACT

The manufacturing of medium and large power transformers is characterized by a high-mix, low-volume production model, with extensive customization across units. This complexity introduces significant challenges in shop-floor operations, particularly in personnel allocation and planning for material flow, WIP movement, and order prioritization. While conventional tools like spreadsheets and simple equations can support basic productivity and risk analysis, quantitatively assessing bottlenecks and evaluating countermeasures is still a significant challenge. Given the constraints on time and resources, accurately estimating the impact of interventions is crucial. However, building detailed factory models and running simulations to explore hypotheses about bottlenecks and their mitigation is often time-consuming, requiring extensive data collection and setup. To address this, we developed a lightweight industrial simulator based on the Rapid Modeling Architecture (RMA) that enables rapid exploration of current bottlenecks and potential countermeasures. This tool supported hypothesis testing and provided valuable insights to guide improvement efforts.

1 BACKGROUND AND CHALLENGE

The manufacturing of medium and large power transformers is characterized by a high-mix, low-volume production model, with extensive customization across units. This complexity introduces significant challenges in shop-floor operations, particularly in personnel allocation and planning for material flow, WIP movement, and order prioritization. To address these issues, we employed discrete-event simulation (DES) to model and evaluate multiple operational scenarios. The simulation framework enabled a deeper understanding of the dynamic interactions on the shop floor and offered insights for improving planning efficiency and resource utilization.

Conventional tools like spreadsheets, Gantt charts, and basic analytical models are commonly used to assess factory performance. While useful for high-level planning, these tools struggle to capture the real-time interactions and dependencies that lead to bottlenecks; they are especially limited in evaluating the impact of potential countermeasures, such as changes to layout or facility configuration.

Simulation is a powerful alternative, allowing us to explore how changes affect factory performance under varying conditions. However, detailed simulations can be costly and time-consuming to build, requiring significant effort to collect data and tune models. This limits their usefulness when quick decisions are needed. To address these challenges, we developed a lightweight simulation model for transformer manufacturing. It enables fast exploration of bottleneck scenarios and countermeasure hypotheses, providing timely insights with minimal setup effort.

2 RMA-BASED DES FOR FAST ITERATIVE BOTTLENECK EVALUATION

To address the challenge of identifying and evaluating production bottlenecks in transformer manufacturing, we developed a lightweight discrete-event simulation model of the factory by following the RMA (Kato and Hu 2025). This model enables us to quickly replicate key operational dynamics and test various hypotheses regarding potential bottlenecks. By simulating different what-if scenarios, we explored the effects of several countermeasures. Our focus was to improve the layout and facility configurations, which we believed were contributing factors to performance limitations.

3 KEY SIMULATION RESULTS

We conducted a series of simulation experiments by varying the layout, facility configuration, and the number of workers to evaluate their impact on operational performance. We modeled the factory based on its layout, collected process cycle times, and identified simulator parameters. The results are shown in Figure 1. We began by analyzing the effect of workforce size, aiming to identify an adequate number of workers to balance throughput and activity rates. Next, we tested a hypothesis that increasing the number of workstations would reduce lead time. However, the simulation results revealed that the bottleneck did not lie within those stations. This led us to shift our focus to machine availability. We found that adding only one specific type of machine led to a 110-hour reduction in lead time, indicating it was a key constraint in the production flow. Modeling and iterative updates of the target system were completed in a total of 9 hours.

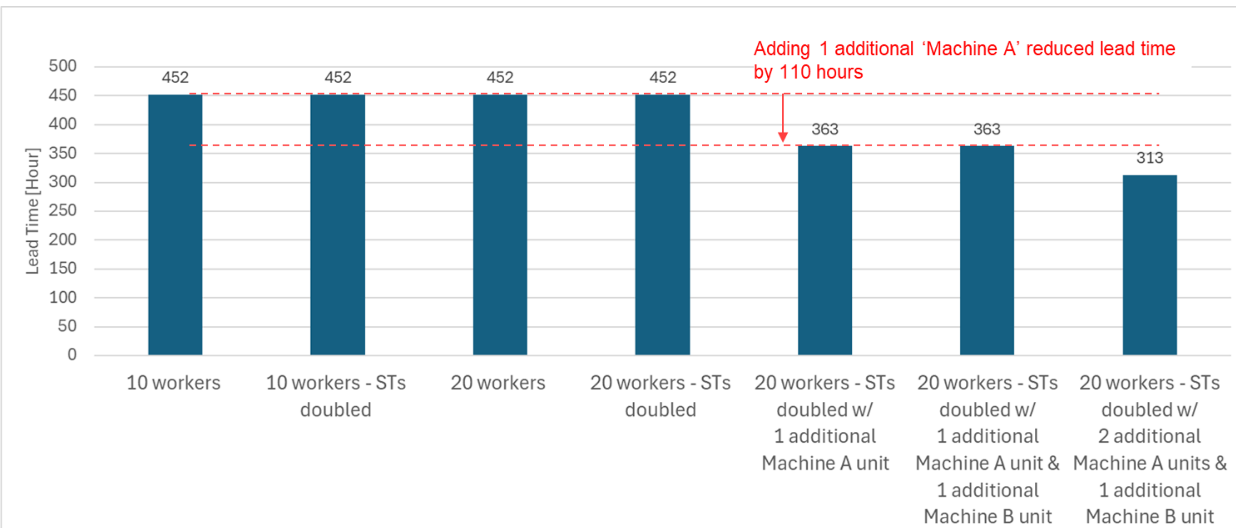

Figure 1: Simulation results showing the calculated lead times for a given product mix. Each bar represents a different factory configuration, varying the number of workers, stations, and machines.

4 CONCLUSION AND FUTURE WORK

We developed a lightweight discrete-event simulation model to rapidly analyze bottlenecks in transformer manufacturing and evaluate potential countermeasures. The simulation revealed that increasing the number of stations did not reduce lead time as expected, while adding a specific machine significantly improved performance. We will refine this countermeasure through further simulation studies and explore its impact under different production scenarios.

5 REFERENCES

Kato, T., and Z. L. Hu. 2025. "Rapid Modeling Architecture for Lightweight Simulator to Accelerate and Improve Decision Making for Industrial Systems." *IEEE International Conference on Automation Science and Engineering (CASE)*, August 17–21, 2025, Los Angeles, California, USA.