STM JOURNALS

Journal of
Production Research & Management
https://journals.stmjournals.com/joprm

ISSN: 2249-4766 (Online)
ISSN: 2347-9930 (Print)
Volume 15, Issue 1, 2025
January–April
DOI (Journal): 10.37591/JoPRM

Research JoPRM

Enhancing Production Line Efficiency: Simulating and Optimizing Single and Parallel Line Processes

Arunesh Mishra[1,*], Rahul Rajput[1], Amit Sharma[2], Arvind Gwatiya[2]

Abstract

During a time of fast-paced industrial growth, increasing production line effectiveness is a core issue for manufacturers looking to maximize output, reduce waste, and stay competitive. This study explores the use of simulation-based optimization methods to enhance single and parallel production line designs. Stepping beyond traditional trial-and-error methods, the research utilizes Siemens Tecnomatix Plant Simulation to simulate actual manufacturing scenarios, considering intricacies like buffer capacities, machine sequencing, and event-driven scheduling. Substantial gains in performance were made by applying optimized parallel line layouts, notably a 24% gain in throughput, 829 to 1,032 units, testifying to the real payback of strategic line-of-production optimization. Such outcomes attest to the merits of forward-looking scenario planning and dynamic allocation of resources based on lean manufacturing philosophy and for delivering on the essence of Industry 4.0. At the center of this strategy are simulation methods like Discrete Event Simulation (DES), System Dynamics (SD), and Agent-Based Modeling (ABM), each with unique strengths based on the complexity and character of the production setting. The study also assesses commonly adopted simulation software like Arena, Simul8, and FlexSim, focusing on their strengths in modeling, performance analysis, and scenario assessment. Concurrently, assorted optimization methods like line balancing, genetic algorithms, and hybrid scheduling models are investigated to optimize workflow distribution and increase system productivity. Visual aids like bottleneck analyzers and Gantt charts also assist decision-making by providing transparent, fact-based insights into system performance. Finally, the research emphasizes that simulation is not only a forecast tool but a strategic tool for designing agile, scalable, and lean production systems. When paired with smart planning paradigms and real-time production feedback, simulation enables organizations to break free from conventional manufacturing limitations and progress toward more adaptive, intelligent manufacturing solutions.

Keywords: Manufacturing optimization, plant simulation, Tecnomatix, parallel and single line processes, production efficiency, simulation

***Author for Correspondence**
Arunesh Mishra
E-mail: arunesh.pankaj@gmail.com

[1]Assistant Professor, Department of Mechanical Engineering, Ram Krishna Dharmarth Foundation University, Bhopal, Madhya Pradesh, India
[2]Assistant Professor, Department of Mechanical Engineering, Vedica Institute of Technology, Bhopal, Madhya Pradesh, India

Received Date: May 14, 2025
Accepted Date: May 24, 2025
Published Date: June 10, 2025

Citation: Arunesh Mishra, Rahul Rajput, Amit Sharma, Arvind Gwatiya. Enhancing Production Line Efficiency: Simulating and Optimizing Single and Parallel Line Processes. Journal of Production Research & Management. 2025; 15(1): 22–32p.

INTRODUCTION

Today's shifting nature of manufacturing means that peak productivity line performance remains a prime goal for manufacturing sectors looking to maintain competitiveness and boost productivity [1]. The development of advanced simulation software such as AnyLogic has enabled manufacturers to simulate line performance in detail, which has been used to identify bottlenecks and analyze different modes of operation to reduce downtime and operating expenses [2]. Furthermore, their use has demonstrated dramatic rises in the productivity of manufacturing, with gains of up to 30% compared to human manufacturing, emphasizing automation's transformative impact on production efficiency [3].

Single and parallel line system comparison studies identify personal strengths and weaknesses characteristic of each configuration [4]. Single-line systems offer effective processes with less flexibility, whereas parallel lines can produce multiple product variants simultaneously for greater flexibility. Parallel arrangements will, however, require more complex coordination and resource allocation plans in place to maintain efficiency [5].

The goal of this research is to explore the technologies and methods applied for simulating and optimizing single line and parallel line processes [6]. According to an analysis of the latest trends in simulation modeling, line balancing techniques, and the use of automation and AI-based technologies, this paper is focused on putting forward an exhaustive understanding of how efficiency in production lines can be increased in various manufacturing settings [7].

Figure 1 illustrates the hypothetical transition from a traditional serial process of design to a complex parallel line process enabled through the aid of digital twin technology in modern manufacturing systems. On the left, the serial process of design is a sequential process, starting with individual demand and sequentially moving through conceptual, mechanical, control, and executive system design, culminating in integration testing. While the process is structured, it is sluggish and less tolerant towards change. Right side has the concurrent process featuring digital twin technology to support concurrent development in multiple fields such as mechanical, control, and executive system design. These are orchestrated by distributed integration testing, leading to faster integration of the system and equipment and ultimately supporting integrated running. Through parallelization of modeling, simulation, layout, and equipment selection, the system maximizes efficiency, reduces development time, and facilitates more agile and flexible manufacturing. The significance of digital twins in transforming static serial processes into dynamic, connected processes in customized production environments is demonstrated by statistics.

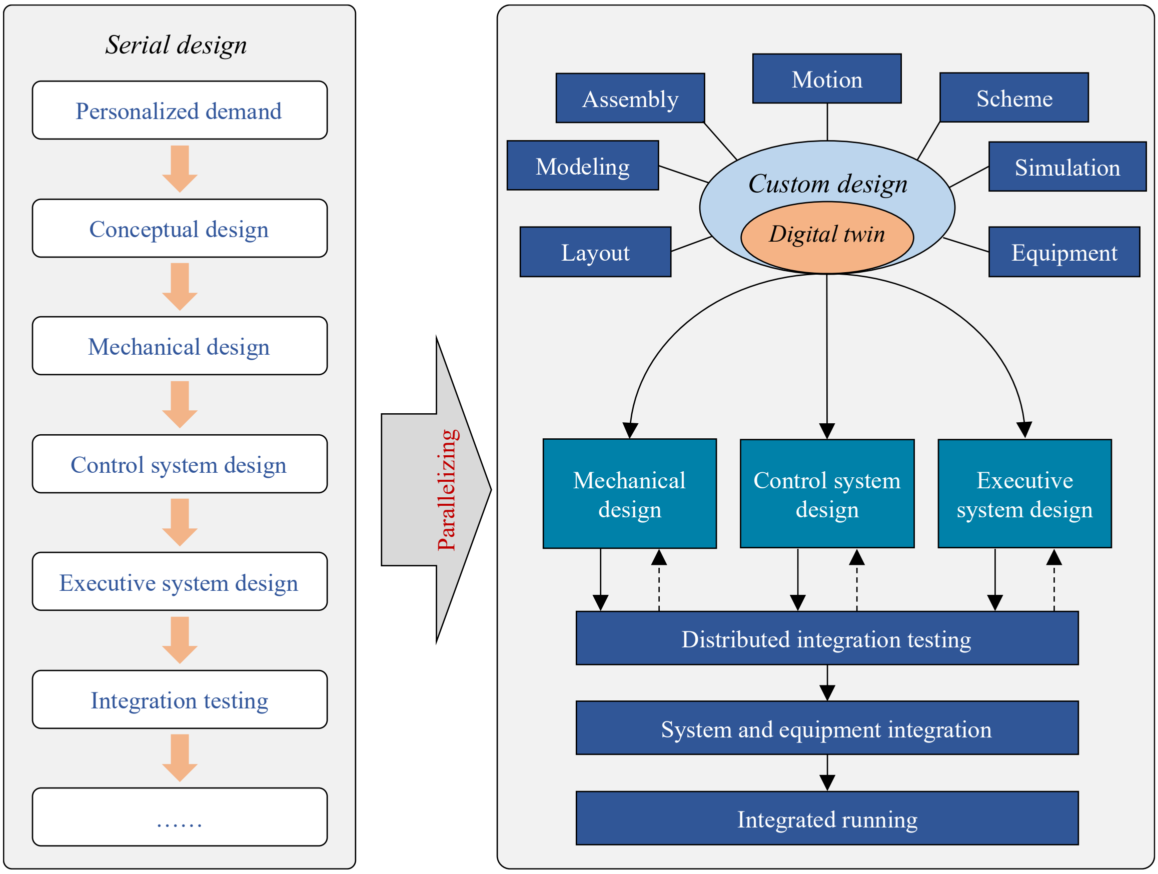


Figure 1. Single and parallel line processes in production.

ISSN: 2249-4766 (Online), ISSN: 2347-9930 (Print)

SIMULATION TECHNIQUES IN PRODUCTION LINE MODELING

Simulation methods are leading the way in modeling production line processes and maximizing production lines, making the operation of a system clearer and supporting decision-making. Discrete Event Simulation (DES) is one example, which is best at simulating intricate manufacturing systems by modeling operations as discrete events. For example, determination of the effectiveness of DES in the production layout and material distribution analysis and its application in bottleneck identification and efficiency improvement [8]. Employed DES to simulate an actual manufacturing line using historical data in order that inefficiencies within the system could be identified and improvement cases proposed. System Dynamics (SD) and Agent-Based Modeling (ABM) also provide other methods to simulate production systems. ABM emphasizes agents' interactions in autonomous frameworks to simulate emergent behavior in manufacturing systems [9]. There was a study to show the use of ABM in manufacturing execution system design and verification, indicating ABM's ability to deal with dynamic and complex production systems. Conversely, SD focuses on systems' feedback loops and time lags, giving a macro view of production process [10]. For instance, a paper in which applications of SD for measuring manufacturing performance, pointing out its strength in strategic decision-making. Numerous software packages enable application of such simulation techniques. Arena of Rockwell Automation is characterized by ease of use and the ability to model discrete processes in any scenario. Simul8 provides quick modeling functionality, ideal for quick analysis of manufacturing potential. FlexSim includes 3D visualization feature, allowing better comprehension of intricate systems [11]. A comparative study evaluated the tools, highlighting the advantages each offers within varying production environments [12]. Table 1 shows a comparative table summarizing the key simulation methods and tools used in production line optimization. Summarily, integration of DES, ABM, and SD, supplemented with specialized software, gives manufacturers powerful tools to simulate, analyze, and improve production lines, thereby enhancing efficiency and flexibility of industrial processes.

OPTIMIZATION STRATEGIES FOR SINGLE AND PARALLEL LINES

Improving the efficiency of single and multi-line production processes depends significantly on the incorporation of advanced optimization methods like lean manufacturing, efficient line balancing, and smart scheduling techniques. Lean manufacturing focuses on the scientific detection and removal of production bottlenecks and encourages fluid workflow and eliminates unnecessary delays. Recent developments in simulation-based bottleneck analysis have demonstrated considerable value in simplifying production arrangements and boosting throughput in both linear and parallel line arrangements [13, 14].

Table 1. Comparative table summarizing the key simulation methods and tools used in production line optimization.

Simulation method	Description	Application example	Strengths	Reference no.
Discrete Event Simulation (DES)	Models' operations as a series of discrete events	Used for layout analysis and material distribution; identifies bottlenecks	Effective for detailed modeling of event-driven processes	[8]
Agent-Based Modeling (ABM)	Models systems through autonomous interacting agents	Applied in manufacturing execution system design	Captures complex and dynamic behaviors	[9]
System Dynamics (SD)	Focuses on feedback loops and time delays	Used for manufacturing performance assessment	Ideal for strategic-level analysis and long-term planning	[10]
Arena (by Rockwell Automation)	DES software with user-friendly interface	Widely used in modeling discrete manufacturing systems	Ease of use, flexible modeling	[11]
FlexSim	Simulation tool with 3D visualization	Helps understand complex system layouts	Intuitive 3D visualization, ideal for complex systems	[12]

Line balancing, one of the core processes in assembly line design, deals with the most efficient division of work between workstations to eliminate idle time and improve cycle efficiency. Methods such as integer programming and heuristic algorithms have been widely used to tackle complex production scenarios, such as U-shaped layout and multi-model manufacturing plants [15]. These technologies also have a focus on variables like task flexibility, walking distances, and the employment of reconfigurable equipment to improve the operational flexibility. In simultaneous production systems, in which multiple lines operate in parallel, resource allocation becomes even more complex. Scheduling algorithms are key with regard to task scheduling maximization, machine usage maximization, and manpower control. Line balancing, one of the core processes in assembly line design, deals with the most efficient division of work between workstations to eliminate idle time and improve cycle efficiency [16]. Methods such as integer programming and heuristic algorithms have been widely used to tackle complex production scenarios, such as U-shaped layout and multi-model manufacturing plants. These technologies also have a focus on variables like task flexibility, walking distances, and the employment of reconfigurable equipment to improve the operational flexibility. In simultaneous production systems, in which multiple lines operate in parallel, resource allocation becomes even more complex. Scheduling algorithms are key with regard to task scheduling maximization, machine usage maximization, and manpower control. Operations management studies indicate the superiority of hybrid scheduling models coupled with genetic algorithms and simulation software, especially in situations of variable demand or tailored production. These methods as a whole yield improved throughput, improved responsiveness, and enhanced total system performance [17]. The application of digital tools such as discrete-event simulation and AI-based planning systems also improves the precision of decision-making. Combined, these optimization techniques allow manufacturers to improve throughput, lower costs, and be better suited to respond to dynamic market conditions in both single-line and parallel-line environments.

PROPOSED METHODOLOGY

Siemens Tecnomatix is a complete digital manufacturing system that supports the whole product lifecycle and combines several production disciplines. It is a component of the Siemens PLM Platform and has tools for quality and production management, automation and robotics planning, component planned and confirmation, assembling planning and validation, and plant design and optimization. Through the planning, simulation, and execution of processes, Tecnomatix allows effective and optimized manufacturing processes. The three components of the objective: Investigate, Implement, and Improve are the main emphasis of the approach utilized to complete the research work (Figure 2).

RESULT AND DISCUSSION

The outcome of plant simulation tool inquiry and taking into account the actual transfer line environment is the result of manufacturing loss research in numerous domains and identification (Figure 3). To better simulate the real-world conditions in the production line, a model for a straightforward production line (a transfer line) is constructed in the Siemens Techno matrix plant simulation. This model is seen in Figure 4.

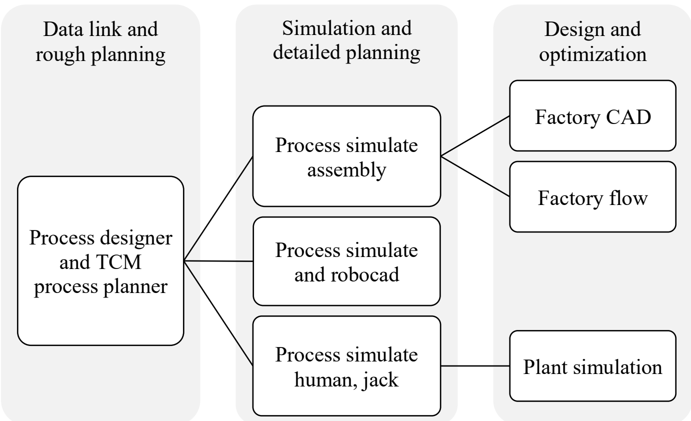


Figure 2. Tecnomatix groups according to use.

Journal of Production Research & Management
Volume 15, Issue 1
ISSN: 2249-4766 (Online), ISSN: 2347-9930 (Print)

The analysis is performed on the one move line where the model was created. There is a source and several processes in this single transfer line, all of which are ending at the drain. Now, change it as the process that was required to create it by changing the item as the origin as the material that was used as well as process names they are as drilling, punching, boring, shaper, lathe and painting assembly. Finally, padding them with the aid of an event controller is required to be drawn in order to analyze the whole process, and it is set for 5 days in this model (5:0:0:0). Additionally, it displays the simulation summary report. With its aid, the simulation speed can also be adjusted, and the statistics report's findings demonstrate that this model can be made to run faster (Figures 5–10).

- *Step 1:* Parallel or mixed transfer line for multiple operation explained (Figure 7).
- *Step 2:* Parallel or mixed transfer line for multiple operation with multiple buffer explained (Figure 8).
- *Step 3:* Parallel or mixed transfer line for multiple operation with multiple buffer within the 3rd step (Figure 9).
- *Step 4:* Parallel or mixed transfer line for multiple operation with multiple buffer and experimental setup explained (Figure 10).

Parallel Process

The overall throughput according to the model, as shown in Figure 11, is only 829 units, and the median lifespan is 8, and if higher throughput up to 1000 units is desired, some adjustments are required since the equation is a mixed line.

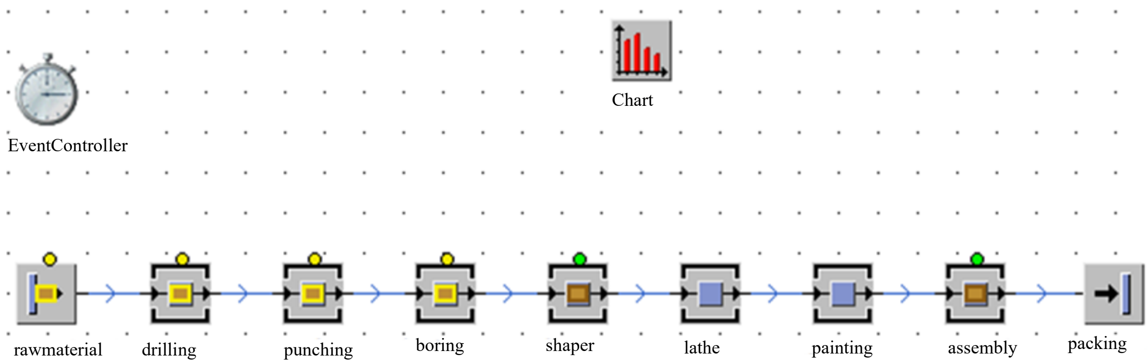


Figure 3. Single transfer line for multiple operations.

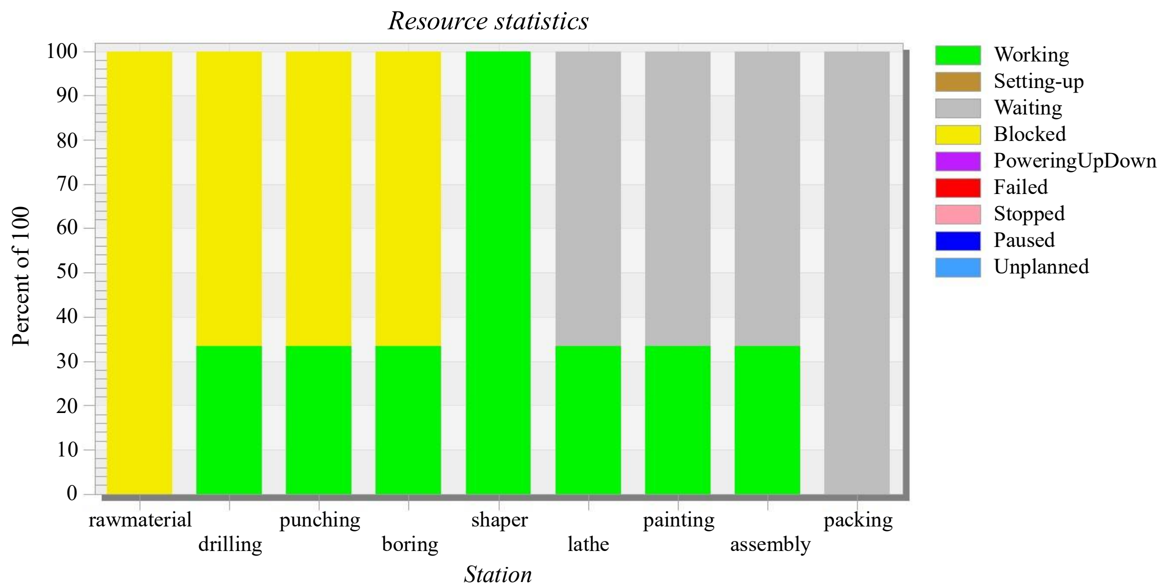


Figure 4. Chart of single transfer line for multiple operations.

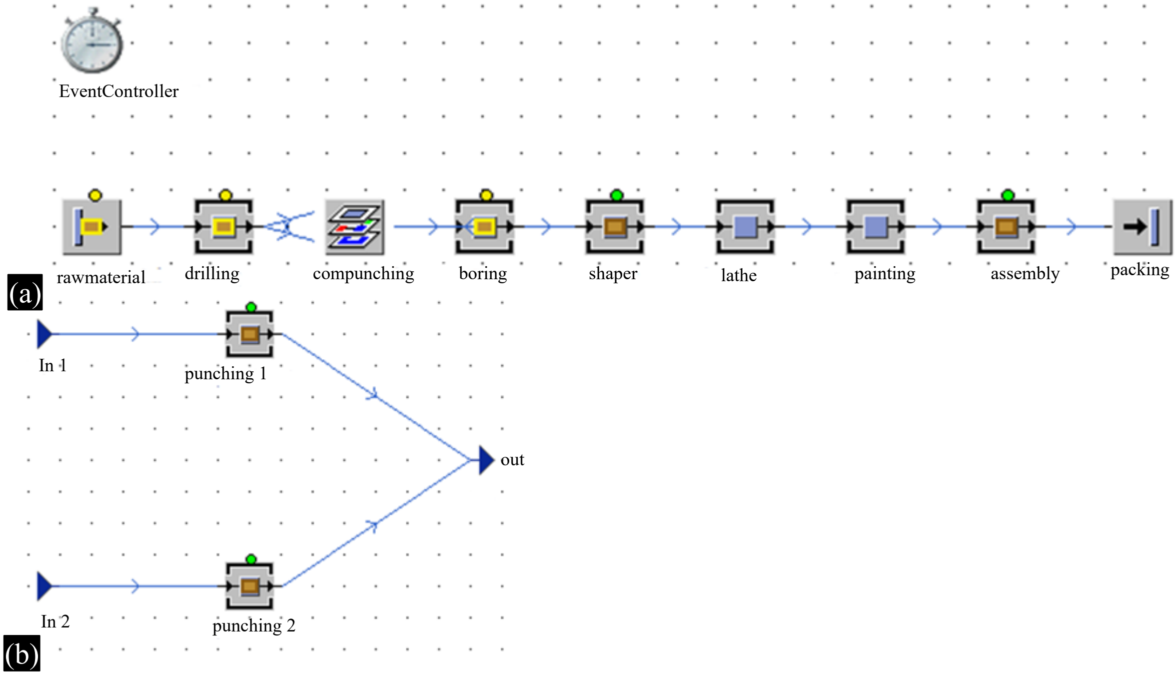


Figure 5. Single transfer line for multiple operations with framework. (a) Single transfer line; (b) Single transfer line for multiple operation.

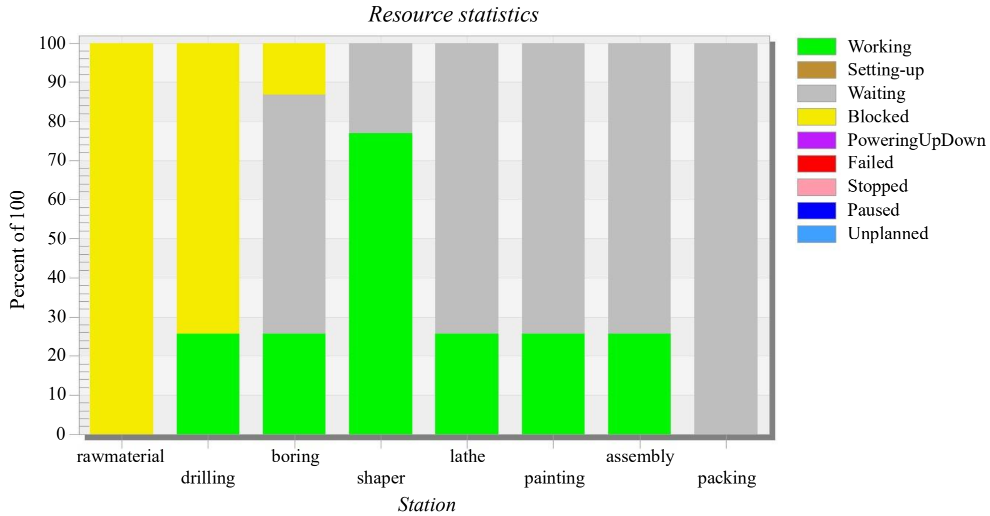
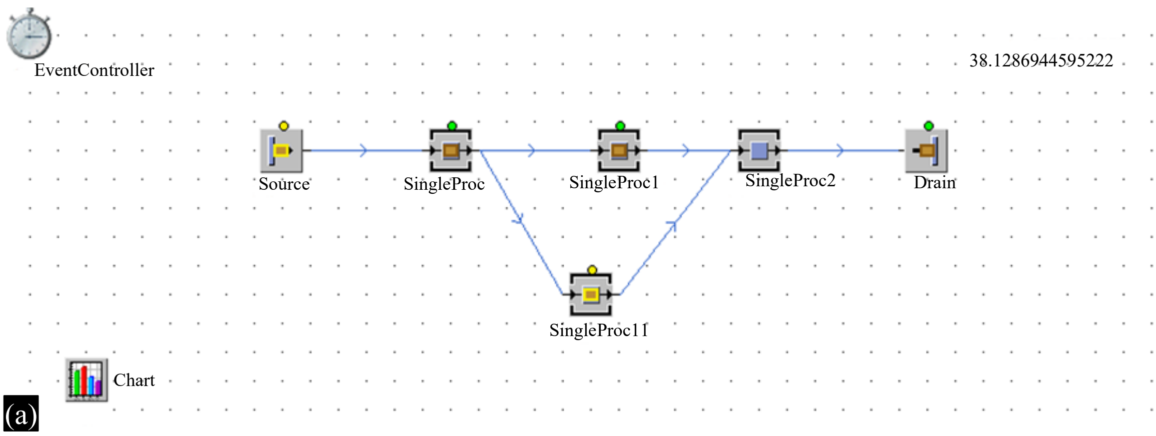
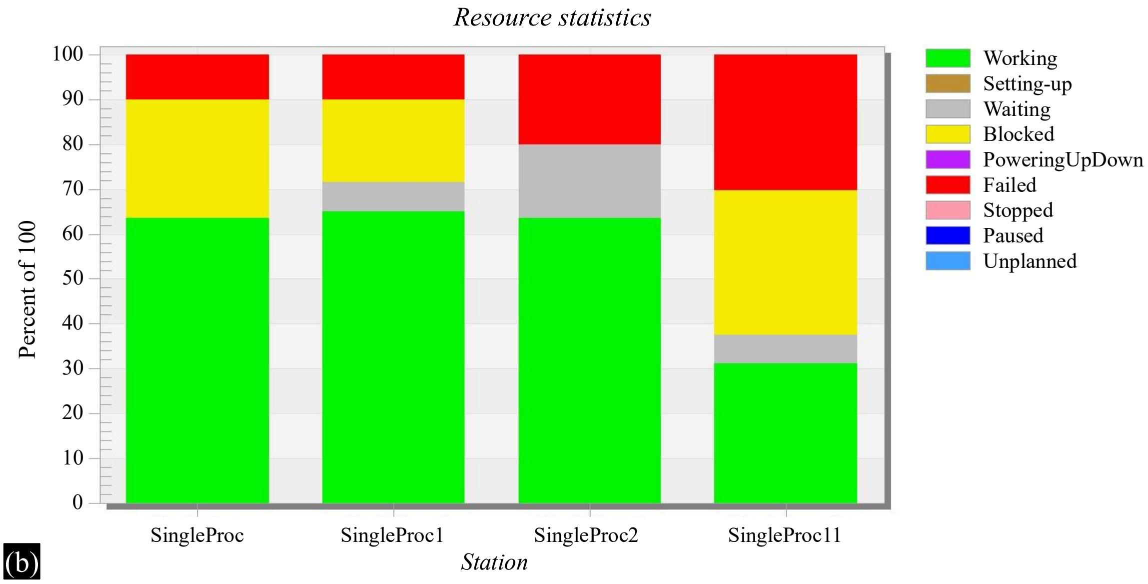


Figure 6. Charts for single transfer line for multiple operations with framework.

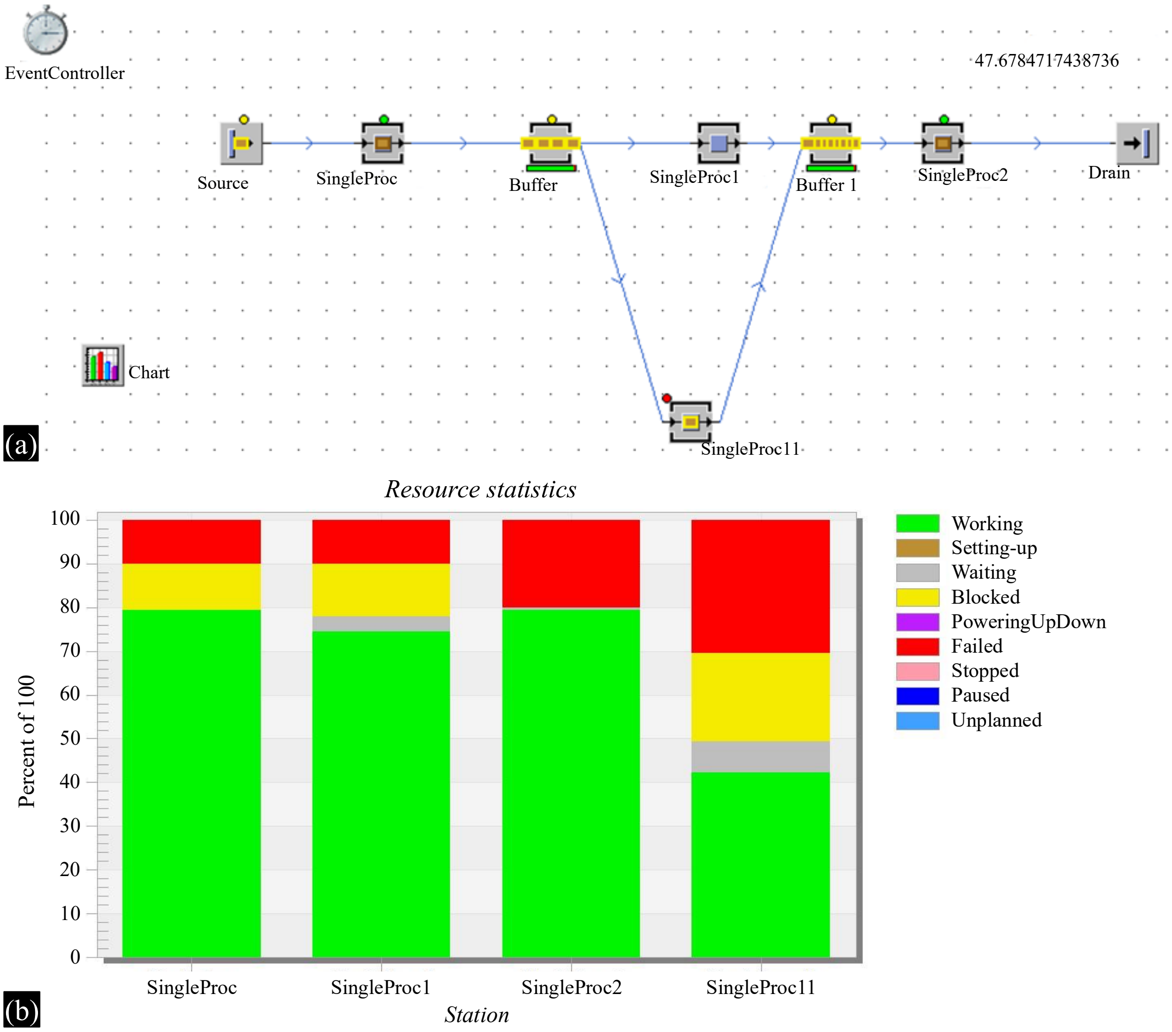


Journal of Production Research & Management
Volume 15, Issue 1
ISSN: 2249-4766 (Online), ISSN: 2347-9930 (Print)



(b)

Figure 7. Parallel or mixed transfer line for multiple operations. (a) Parallel transfer line; (b) Mixed transfer line.



(a)

(b)

Figure 8. Parallel or mixed transfer line for multiple operations with multiple buffers. (a) Parallel transfer; (b) Mixed transfer.

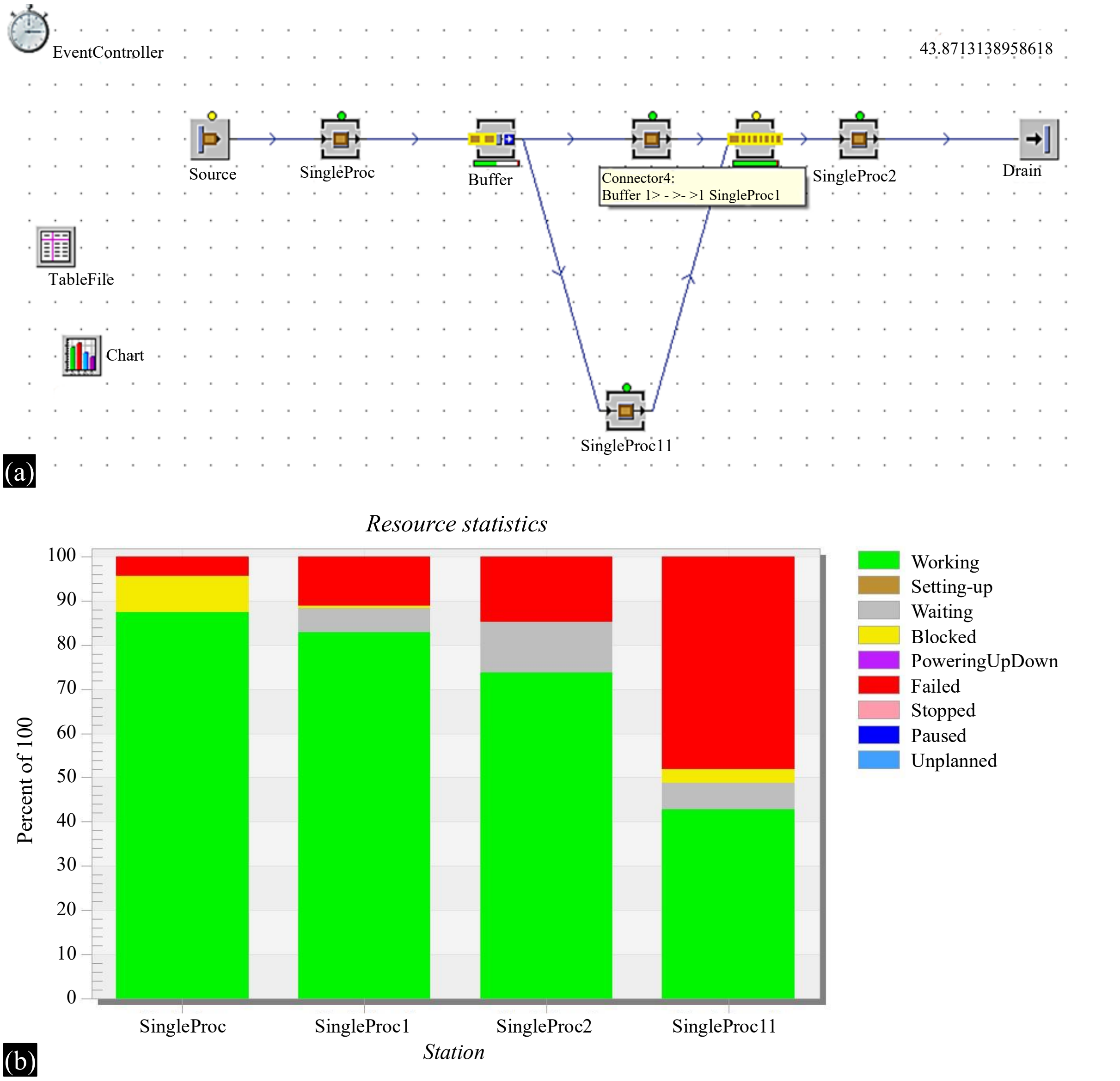
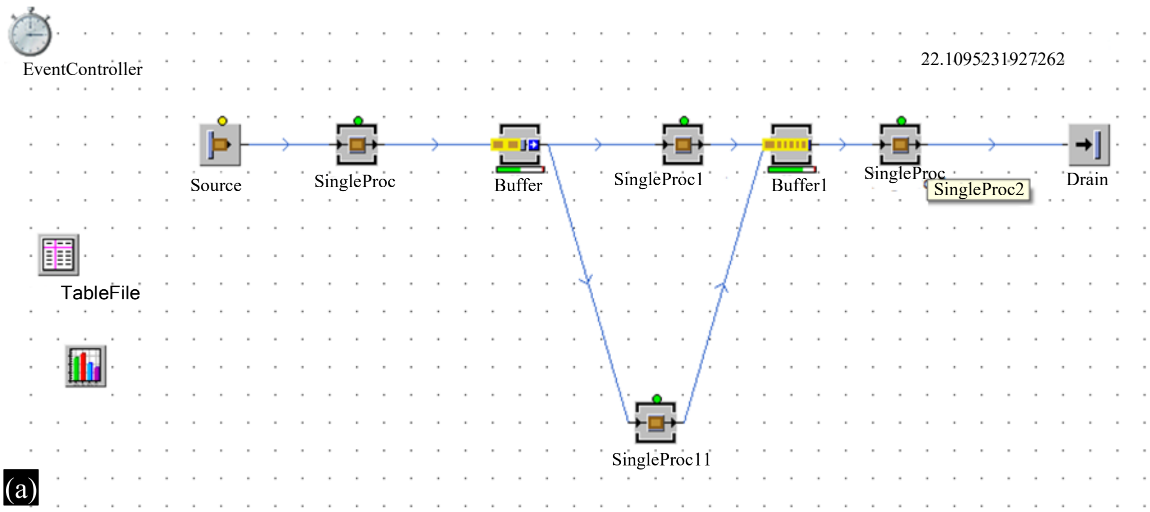


Figure 9. Parallel or mixed transfer line for multiple operations with multiple buffers. (a) Parallel with buffer; (b) Mixed with buffer.



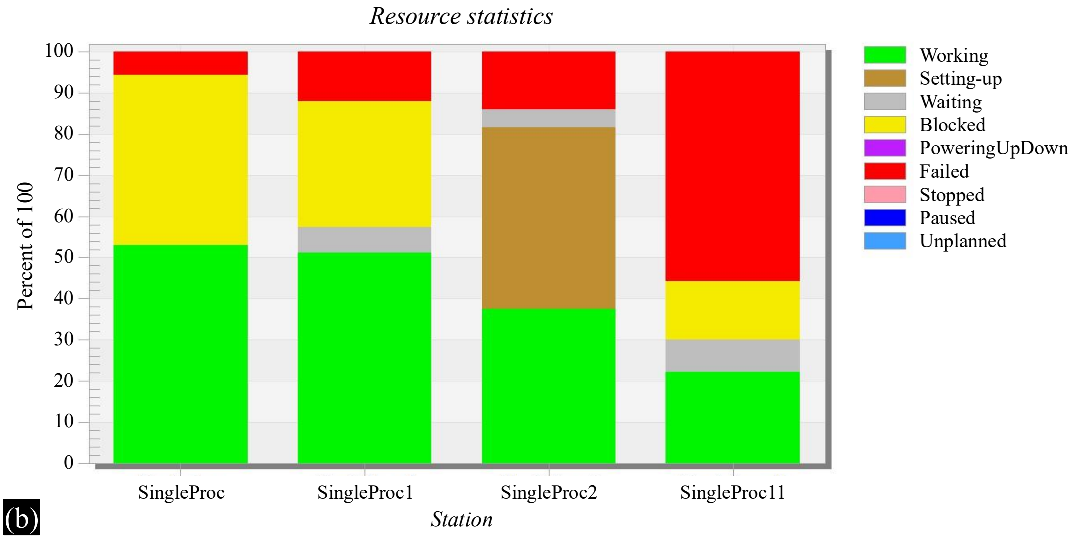


Figure 10. Parallel or mixed transfer line for multiple operations with multiple buffers and experimental setup. (a) Parallel with experimental setup; (b) mixed with experimental setup.

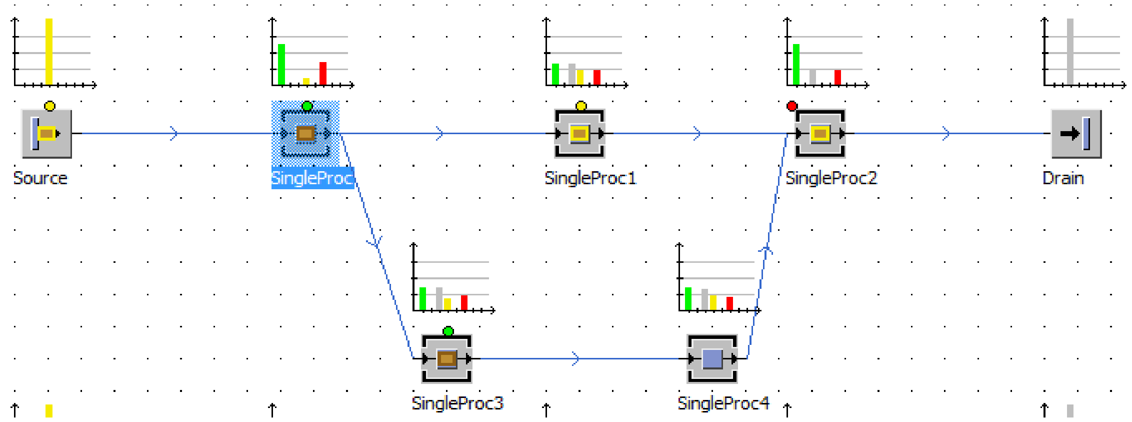


Figure 11. Parallel or mixed transfer line for multiple operations with bottleneck analysis.

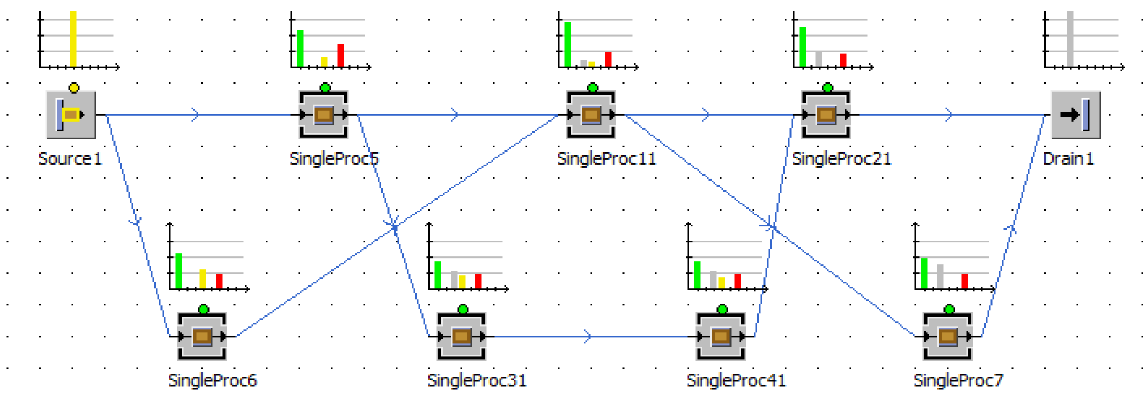


Figure 12. Parallel or mixed transfer line for multiple operations with bottleneck analysis and multiple single process.

The results are better than expected and show that it achieves 1456 total throughput, but it also means that adding two more processes or machines will increase the capital and operating costs, making it impossible to reach the optimal output as the bare minimum gave the additional 627 throughput which is not practical for the optimal move line as the capital and operating investment will also rise (Figure 12).

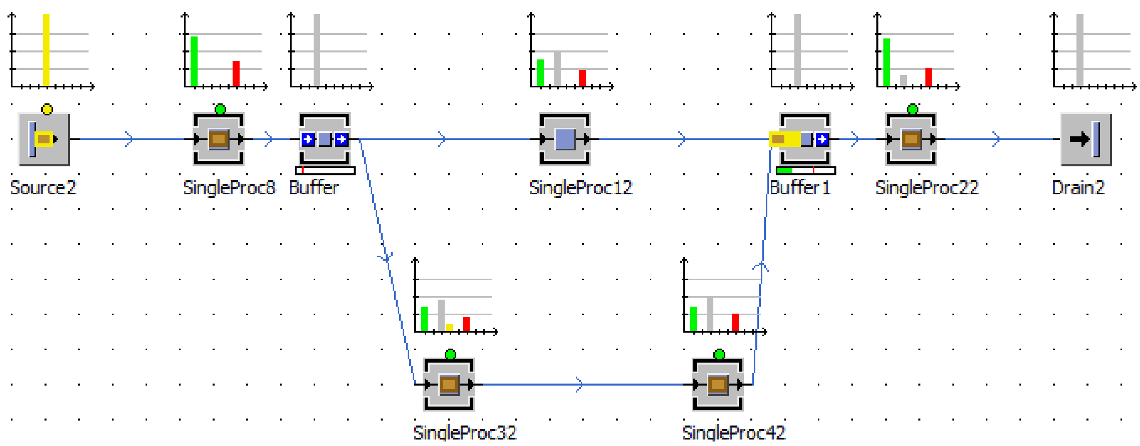


Figure 13. Parallel or mixed transfer line for multiple operations with bottleneck analysis with buffers.

As can be seen in Figure 13 at final row, this production line's throughput increased from the previous up to 24% and is now 1032, however the capacity of the buffers is set as default here in order to get the best results at the same running cost.

CONCLUSION

Utilizing computer simulation technologies for production line optimization in turn results in more accurate and effective enhancements of efficiency and resource usage. With careful modeling of single and multi-line configurations, single and parallel bottlenecks can be exposed, system dynamics forecasted, and performance under varying conditions evaluated. Siemens Tecnomatix Plant Simulation was used to conduct thorough analysis of the production system considering parameters like equipment assignment, process flow, and buffer integration. Specifically, the optimized parallel line model demonstrated a clear advantage over traditional linear operations, recording increased throughput without experiencing uncontrolled operational costs. Tailored buffering and resource reconfiguration were key roles in achieving such gains, underlining the merits of dynamic process planning over set configurations. Moreover, practices such as identifying bottlenecks and statistical reporting offered more informative analysis of idle time usage, resource under-exploitation, and overall production beat. These competencies facilitate manufacturers to shift from reactive troubleshooting to proactive system design and optimization. Adopting a simulation-based strategy allows for agile decision-making, promotes cost-effective scalability, and aligns production strategies with lean and smart manufacturing goals. Instead of depending on piece-meal improvements, organizations can now create integrated, future-proof systems that can rapidly respond to fluctuations in demand or operational disturbances. The results confirm that production efficiency is not just the outcome of equipment improvements or labor expansion, but of smart system design fueled by precise modeling and analytical strategy. Optimization based on simulation is found to be a pivotal enabler in the development of sustainable and high-performance industrial processes.

REFERENCES

1. Werner M. Parallel processing strategies for big geospatial data. Front Big Data. 2019; 2: 44. https://doi.org/10.3389/fdata.2019.00044.
2. Lusa A. A survey of the literature on the multiple or parallel assembly line balancing problem. Eur J Ind Eng. 2008; 2(1): 50–72. http://dx.doi.org/10.1504/EJIE.2008.016329.
3. Freitas AA, Lavington SH, Freitas AA, Lavington SH. Basic concepts on parallel processing. In: Mining Very Large Databases with Parallel Processing. Boston, MA: Springer; 2000; 61–69. https://doi.org/10.1007/978-1-4615-5521-6_7.
4. Fowler JW, Mönch L. A survey of scheduling with parallel batch (p-batch) processing. Eur J Oper Res. 2022; 298(1): 1–24. https://doi.org/10.1016/j.ejor.2021.06.012.

5. Fischer R, Plessow F. Efficient multitasking: Parallel versus serial processing of multiple tasks. Front Psychol. 2015; 6: 1366. https://doi.org/10.3389/fpsyg.2015.01366.
6. Nassi JJ, Callaway EM. Parallel processing strategies of the primate visual system. Nat Rev Neurosci. 2009; 10(5): 360–372. https://doi.org/10.1038/nrn2619.
7. Garcia EF, Zúñiga ER, Bruch J, Moris MU, Syberfeldt A. Simulation-based optimization for facility layout design in conditions of high uncertainty. Procedia CIRP. 2018; 72: 334–339. https://doi.org/10.1016/j.procir.2018.03.227.
8. Kordaczek R, Piłat AK. Prototype and Simulation Model of a Robotic Hand. In 2020 IEEE International Conference Mechatronic Systems and Materials (MSM). 2020 Jul; 1–6. https://doi.org/10.1109/MSM49833.2020.9201741.
9. Janeková J, Fabianová J, Kádárová J. Optimization of the Automated Production Process Using Software Simulation Tools. Processes. 2023; 11(2): 509. https://doi.org/10.3390/pr11020509.
10. Mahdi Mohammad, Rise Zeinab, Anvariazar Sahar. Improving Production Line Performance through Simulation and Bottleneck Analysis using AnyLogic Software. 20th International Conference of Modern Research in Management, Economics and Development. 2024; 1–10.
11. Yegul MF, Erenay FS, Striepe S, Yavuz M. Improving configuration of complex production lines via simulation-based optimization. Comput Ind Eng. 2017; 109: 295–312. https://doi.org/10.1016/j.cie.2017.04.019.
12. Choi H, Yu S, Lee D, Noh SD, Ji S, Kim H, Yoon H, Kwon M, Han J. Optimization of the Factory Layout and Production Flow Using Production-Simulation-Based Reinforcement Learning. Machines. 2024; 12(6): 390. https://doi.org/10.3390/machines12060390.
13. Quadras D, Frazzon EM, Mendes LG, Pires MC, Rodriguez CM. Adaptive Simulation-Based Optimization for Production Scheduling: A Comparative Study. IFAC-PapersOnLine. 2022; 55(10): 424–429. https://doi.org/10.1016/j.ifacol.2022.09.430.
14. Zhu L, Zhang Z, Guan C. Multi-objective partial parallel disassembly line balancing problem using hybrid group neighbourhood search algorithm. J Manuf Syst. 2020; 56: 252–269. https://doi.org/10.1016/j.jmsy.2020.06.013.
15. Coutinho DA, Georgiou K, Eder KI, Nunez-Yanez J, Xavier-de-Souza S. Performance and Energy Efficiency Trade-Offs in Single-ISA Heterogeneous Multi-Processing for Parallel Applications. In 2019 IFIP/IEEE 27th International Conference on Very Large-Scale Integration (VLSI-SoC). 2019; 232–233. https://doi.org/10.3390/en13092409.
16. Ahmed R, Doyley MM. Parallel receive beamforming improves the performance of focused transmit-based single-track location shear wave elastography. IEEE Trans Ultrason Ferroelectr Freq Control. 2020; 67(10): 2057–2068. https://doi.org/10.1109/TUFFC.2020.2998979.
17. Balaji V, Lucia B. Combining data duplication and graph reordering to accelerate parallel graph processing. In Proceedings of the 28th International symposium on high-performance parallel and distributed computing. 2019; 133–144. https://doi.org/10.1145/3307681.3326609.

