Proceedings of the 7th Asia Pacific Conference on Industrial Engineering and Operations Management
Bangkok, Thailand, March 25-27, 2026

Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AP07.20260098
Published: March 25, 2026

Development of the HDDs Assembly Line to Improve Throughput Using Simulation Method

Thanakorn Sangrit and Paphakorn Pitayachaval
Engineering Institute of Systems Engineering
Suranaree University of Technology
Nakhon-Ratchasima,Thailand
thanakorn.sangritz@gmail.com, paphakorn@g.sut.ac.th

Abstract

The growing demand for high-capacity hard disk drives (HDDs) has driven the need for highly efficient and fully automated manufacturing systems. The transition from nine to ten recording platters, together with an increase in spacer rings from eight to nine in new HDDs products, enhances data storage capacity but introduces a significant bottleneck in the Platter and Ring Installation (PRI) process. The additional platters and rings increased the assembly cycle time, leading to reduced throughput and elevated work-in-process (WIP) levels. This study presents a simulation-driven system design approach to analyze and mitigate the identified bottleneck. A combined fishbone diagram framework was adopted to support structured system development, while FlexSim discrete-event simulation was utilized to model the baseline production flow, evaluate machine-level cycle time constraints, and quantify throughput limitations. Based on simulation insights, a Tunnel Lifter concept was designed to enable dynamic bypassing of active PRI stations, thereby reducing unnecessary waiting and improving flow continuity. Structural feasibility of the proposed design was assessed through Finite Element Analysis (FEA) to ensure adequate stiffness and load-bearing capability under defined operating conditions. Simulation results indicate that the proposed design concept significantly improves line balance and throughput performance.

Keywords
Hard Disk Drive, Automation, Cycle Time Reduction, Tunnel Lifter, Bottleneck

1. Introduction
The hard disk drives industry continues to play a critical role in large-scale data storage infrastructures, particularly for data centers and cloud computing platforms. Despite the increasing adoption of solid-state storage technologies, HDDs remain the most cost-effective solution for managing the rapidly growing volume of data driven by artificial intelligence (AI), the Internet of Things (IoT), and edge computing applications. As a result, HDDs manufacturers face increasing pressure to enhance production systems toward higher precision, efficiency, and automation to sustain future scalability and volume requirements. In complex automated manufacturing environments, production congestion, resource imbalance, and material handling constraints are known to significantly affect throughput and WIP levels, as reported in prior manufacturing system studies, thereby motivating the need for systematic production flow analysis and bottleneck-oriented system optimization in high-volume HDDs manufacturing lines.

Recent advancements in HDDs technology have increased the number of recording platters from 9 to 10, together with an increase in spacer rings from 8 to 9. As illustrated in Figure 1, this design change introduces additional platter and spacer interfaces, which significantly increase the number of mechanical components and overall process complexity. Each additional platter–spacer pair requires extra handling, positioning, and alignment steps during the Platter and Ring Installation PRI process, directly increasing station-level cycle time and amplifying serial flow dependency in the assembly line. These effects are particularly evident in the PRI process, where precise positioning and controlled assembly forces are critical. Under the current production configuration, 5 PRI machines operate with serial flow dependency, causing the assembly cycle time to increase substantially due to the additional platters and rings, resulting in an average processing time that exceeds the line cycle time of the production line. Such cycle time mismatches have been widely reported to cause throughput degradation, WIP accumulation, and line imbalance in highly interconnected manufacturing systems.

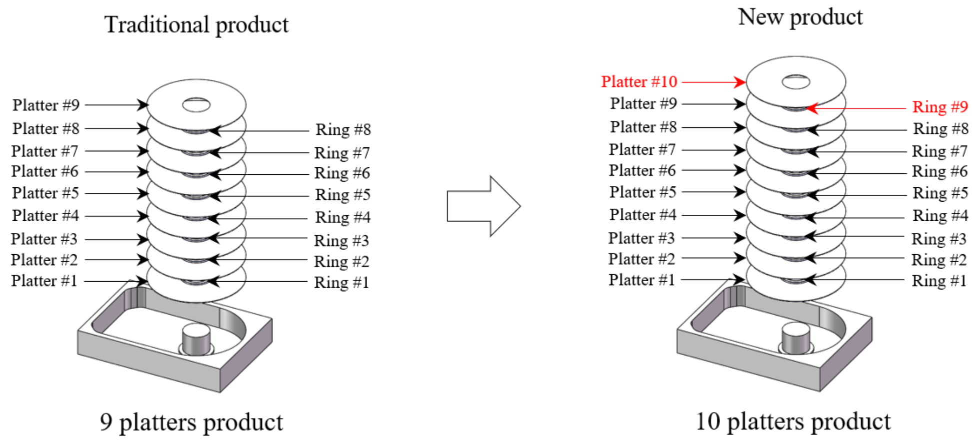

Figure 1. Platter and spacer in HDDs

To systematically address these challenges, simulation-based analysis has been widely applied to evaluate production flow behavior, identify bottlenecks, and assess improvement concepts at the planning stage. In parallel, structured problem analysis methodologies such as the fishbone diagram provide a formal framework for organizing potential causes, identifying root causes, and supporting design improvement activities in complex mechatronic and production systems.

In this study, the fishbone (cause-and-effect) diagram is adopted as a structured problem analysis framework for system-level design and development. Within this framework, a Tunnel Lifter concept is proposed for a fully automated HDDs assembly line to systematically identify contributing factors to flow inefficiencies and enable dynamic bypassing of active PRI stations, thereby improving material flow continuity. To support design feasibility at the conceptual stage, FEA is employed to evaluate the structural integrity and load-bearing capability of the proposed lifting mechanism, consistent with prior studies on lifting and material handling system design (Dengiz et al. 2018; Nie et al. 2022; Sealy 2012; Li and Li 2025).

1.1 Objective

This paper addresses the existing limitations within the PRI process in a fully automated hard disk drive assembly line, where the current bottleneck significantly impacts overall production efficiency, as commonly observed in complex manufacturing systems with flow imbalance and congestion effects. The primary objective is to apply a fishbone diagram as a structured problem analysis approach to systematically identify contributing factors to flow inefficiencies and support the design and development of a Tunnel Lifter mechanism, consistent with prior studies that employ fishbone-based root cause analysis for engineering design improvement and failure causality modeling. The proposed concept enables incoming drive units to bypass active PRI working zones without unnecessary waiting, thereby improving material flow continuity. In addition, FEA is conducted to evaluate the structural performance and mechanical reliability of the proposed lifting mechanism under defined operating conditions, following established approaches in lifting and material handling system design. The measurable targets of this research include reducing the PRI cycle time to 21.5 seconds per unit, decreasing work-in-process, improving overall line balance, and increasing throughput of the automated assembly system. The expected outcome is enhanced manufacturing readiness and scalable production capability to support high capacity of new HDDs products.

2. Literature Review

Automation plays a critical role in HDDs manufacturing, where precision assembly, cycle time control, and repeatability are essential for high-volume production. A robotic handling, machine-guided positioning, and motion-controlled mechanisms have been applied to improve productivity and reduce manual variation, while optimization of machine cycle time and reduction of non-value-added waiting are key to minimizing WIP and maintaining stable throughput. Discrete-event simulation has been widely applied to analyze such production flow behavior, identify bottlenecks, and evaluate improvement concepts during the planning stage, with FlexSim being one of the commonly adopted simulation platforms in manufacturing system studies (Kumar and Singh 2024; Lewicki et al. 2024; Pawlak et al. 2024; Purwaningsih et al 2025). In HDDs manufacturing, the PRI process is a critical operation requiring extremely high accuracy due to strict mechanical tolerances, stacking consistency, and alignment requirements. Although automated PRI systems have achieved improvements in alignment of precision and assembly reliability, most operate in a strictly sequential manner, which inherently creates process bottlenecks. This issue is further amplified in HDD products with increased platter and ring counts and higher mechanical complexity, consistent with bottleneck behavior reported in interconnected manufacturing systems (Beamon 1999; Su et al. 2022; Hwang and Park 2023; Vigil 2021). Existing literature provides limited discussion on motion bypass strategies or autonomous parallel handling mechanisms in HDDs assembly lines. In addition to flow and bottleneck analysis, structural validation of lifting and material handling mechanisms is an essential aspect of automation system design to ensure mechanical stability, load-bearing capability, and operational reliability. FEA has been widely applied to evaluate stress distribution, deformation behavior, and safety margins in lifting and handling mechanisms under operational loading conditions (Sealy 2012; Dengiz et al. 2018; Nie et al. 2022; Li and Li 2025). These studies demonstrate that early-stage structural assessment plays a critical role in reducing design risk and supporting reliable implementation of customized automation mechanisms. However, the integration of FEA-based structural validation with motion bypass concepts in HDDs assembly environments remains limited, particularly for fixture-level or workstation-specific handling mechanisms. While FEA is widely used to validate structural and mechanical designs in industrial automation, its application to customized handling systems or fixture-level bypass mechanisms in HDDs environments remains relatively scarce. In parallel, structured problem analysis tools such as fishbone diagrams have been applied to identify root causes of system inefficiencies and support design improvement in complex manufacturing systems (Aurisicchio et al. 2016; Yu et al. 2025; Friederich and Lazarova-Molnar 2024; Sezen and Çinar 2021). Accordingly, this research addresses a clear gap by proposing a Tunnel Lifter mechanism that enables motion bypass within the PRI workstation. The proposed solution is guided by fishbone-based problem analysis and validated through FEA to support bottleneck reduction, improved line balance, and enhanced material flow continuity for high-capacity of new HDDs manufacturing systems.

3. Methods

This research adopts a structured problem analysis and design methodology centered on the fishbone diagram to identify root causes of bottlenecks in a fully automated HDDs assembly line. To establish the baseline process behavior, the current platter and ring installation workflow in the PRI process was first analyzed, as illustrated in Figure 2. Fishbone-based analysis has been applied to systematically decompose complex manufacturing problems, organize contributing factors across multiple dimensions, and support informed engineering decision-making during the design stage.

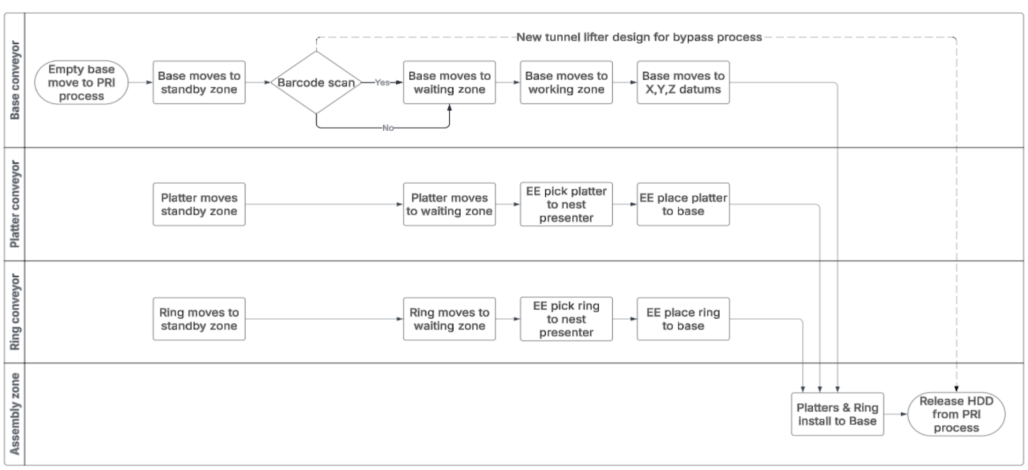

Figure 2. Patter and ring installation workflow

Based on the fishbone analysis, critical factors contributing to flow inefficiencies in the PRI process were identified and translated into design requirements for an improved material handling mechanism. A Tunnel Lifter concept was subsequently developed to address the identified root causes by enabling motion bypass and improving material flow continuity. The conceptual design was supported by CAD modeling and discrete-event simulation to evaluate production flow behavior, assess bottleneck mitigation effectiveness, and analyze potential improvements in cycle time and line balance.

To verify design feasibility at the conceptual stage, FEA was conducted to evaluate the structural integrity and load-bearing capability of the proposed Tunnel Lifter under defined operating conditions. The application of FEA for validating lifting and material handling mechanisms is well established in industrial automation and mechanical system design. The integrated use of fishbone-based problem analysis, simulation-driven design evaluation by FEA, and FlexSim validation provides a systematic and scalable methodology for addressing bottlenecks in new high-capacity HDDs manufacturing systems.

To implement the proposed methodology, the existing system architecture and machine layout were first analyzed to understand the workflow sequence, material handling behavior, and physical constraints. The configuration of the PRI process in the production line analyzed in this study is illustrated in Figure 3.

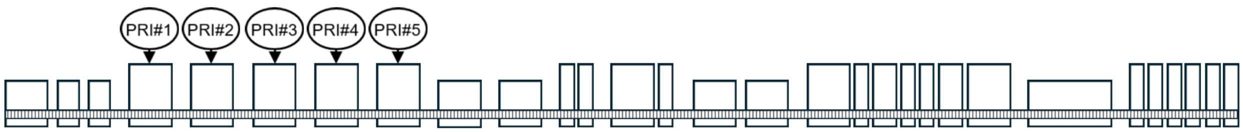

Figure 3. Production line layout

3.1 Baseline Process and Bottleneck Identification

The study began with an analysis of the existing PRI production line to establish baseline process behavior and identify bottleneck conditions. Current workflow characteristics, machine interactions, and material handling sequences were examined to confirm that the overall system performance was constrained by serial flow behavior and waiting at busy stations, which are typical indicators of bottlenecks in interconnected manufacturing systems. This initial assessment verified that the PRI process operated without a bypass mechanism, causing downstream units to wait for ongoing installation activities and leading to cycle time accumulation and throughput degradation.

3.2 Fishbone-Based Root Cause Structuring

A fishbone diagram was constructed to systematically decompose the identified bottleneck into contributing factors across four primary dimensions: Method, Machine, Material, and Man, as illustrated in Figure 4. Method-related factors included serial flow without bypass capability, increased assembly steps, and waiting at occupied stations. Machine-related factors consisted of micro-stoppages, slow actuator and transfer motion, and cycle time exceeding line cycle time. Material-related factors involved increased platter and ring count, high alignment sensitivity, and part-to-part variability. Man-related factors included longer setup time, slow alarm response, and limited operational experience. This structured decomposition enabled clear identification of dominant contributors to flow inefficiency and confirmed that the bottleneck was primarily driven by process sequencing and material handling constraints rather than isolated machine failures, consistent with findings in prior manufacturing system studies. Based on this fishbone-based analysis, the dominant root causes were identified as serial flow dependency and the absence of bypass capability at occupied PRI stations, which directly lead to excessive waiting and cycle time accumulation. Among the four categories, method- and machine-related factors were found to be the primary drivers of throughput degradation, while material- and man-related factors mainly acted as secondary amplifiers. These dominant root causes were therefore translated into explicit design requirements, directly motivating the development of the proposed Tunnel Lifter mechanism.

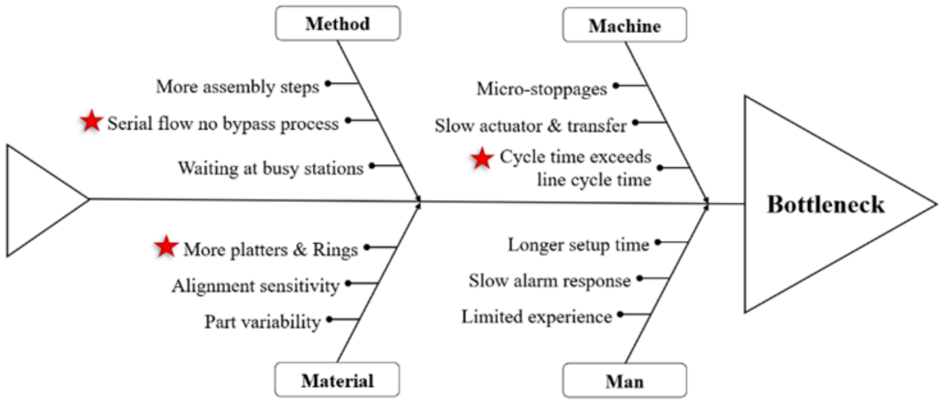

Figure 4. Fishbone diagram

3.3 Translation of Root Causes into Design Requirements
Based on the fishbone analysis, key root causes were translated into explicit engineering design requirements. The most critical requirement identified was the elimination of serial waiting through controlled motion bypass of active PRI stations. Similar root-cause-driven requirement derivation approaches have been shown to be effective in guiding design improvement strategies for complex production systems. Additional requirements included maintaining positional accuracy despite increased platter and ring count, minimizing added mechanical complexity, and ensuring compatibility with existing automated equipment.

3.4 Concept Development of the Tunnel Lifter Mechanism
To address the identified root causes, a Tunnel Lifter concept was developed as a material handling solution that allows incoming HDDs units to bypass occupied PRI stations and move directly to available stations. As illustrated in Figure 5(a), the conventional flat lifter configuration blocks material flow when the PRI station is occupied, forcing incoming units to wait upstream and creating serial flow dependency. In contrast, Figure 5(b) shows the proposed Tunnel Lifter design, which introduces an open-through structure that enables HDDs units to pass beneath the active station and continue moving along the conveyor while the installation process is ongoing. This design directly targets the method- and machine-related causes identified in the fishbone analysis by eliminating waiting at occupied stations, decoupling serial flow dependency, and improving overall material flow continuity.

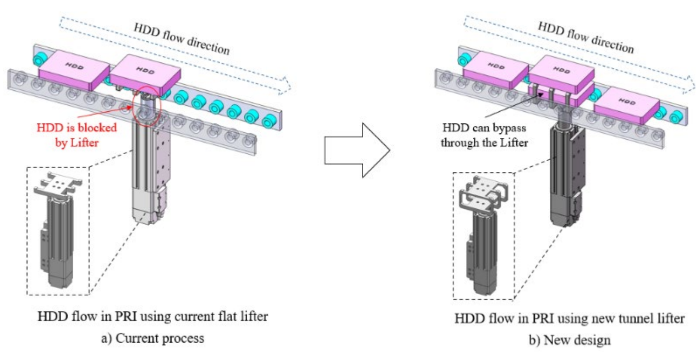

Figure 5. Comparison of HDD flow behavior between the conventional flat lifter and the proposed Tunnel Lifter

3.5 Simulation-Based Flow Evaluation
A discrete-event simulation model was developed in FlexSim to evaluate the effectiveness of the proposed Tunnel Lifter concept under the identified bottleneck conditions. The FlexSim simulation model of the PRI production line, including the implemented bypass logic, is illustrated in Figure 6. Simulation-based analysis has been widely applied to evaluate production flow behavior, identify bottlenecks, and quantify performance improvements during the planning stage. The simulation model incorporated cycle time distributions, station availability, and bypass logic derived from the fishbone analysis. Performance metrics such as effective cycle time, throughput, and line balance

were analyzed to quantify the effectiveness of bottleneck mitigation, consistent with prior studies on manufacturing system performance evaluation. The routing decision for the Tunnel Lifter is determined by rule-based control logic implemented within the FlexSim simulation model. Incoming HDD units are automatically directed through the tunnel to the nearest available PRI station, significantly reducing transfer time and enhancing assembly throughput.

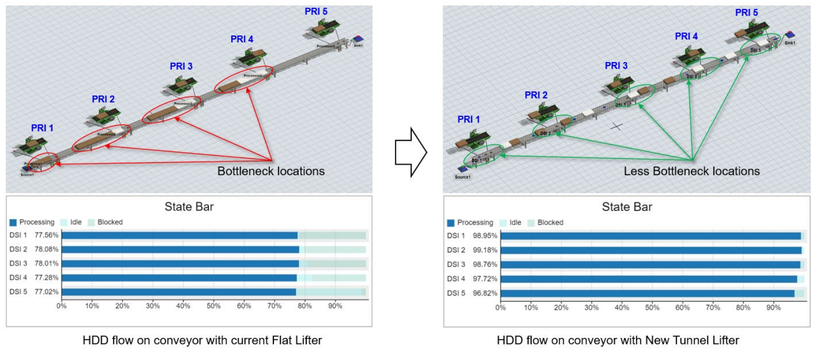

Figure 6. HDDs flow on conveyors by FlexSim simulation

3.6 Structural Feasibility Assessment Using FEA

FEA was conducted to assess the structural integrity and load-bearing capability of the Tunnel Lifter mechanism under defined operating conditions. The application of FEA for validating lifting and material handling mechanisms is well established in industrial automation and mechanical system design. This analysis ensured that the proposed design could support additional handling motions required for bypass operation without compromising mechanical stability or alignment performance.

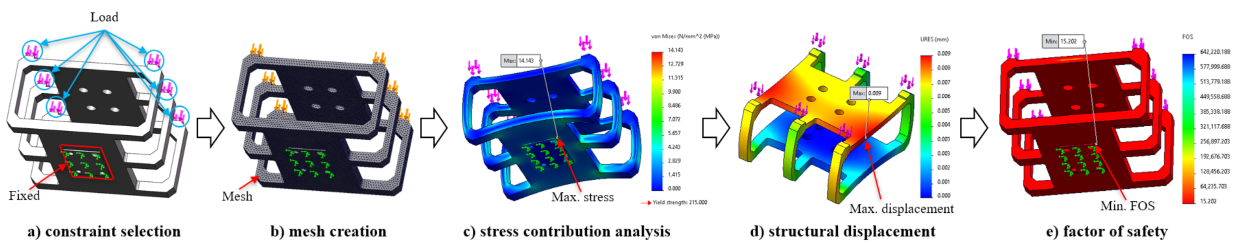

Figure 7. FEA simulation modeling

FEA of the tunnel lifter system was conducted using the SolidWorks Simulation package by first simplifying the model through the removal of non-critical components, such as the actuator and bracket, to reduce simulation time; the system was constrained at the bottom-mounted pad connected to the actuator bracket with a total load of 160 N was applied uniformly to the six tunnel lifter fingers (Figure 7(a)), and a high-quality, high-density mesh consisting of 201,311 nodes and 129,604 elements was automatically generated (Figure 7(b)), under which the stress distribution and deformation were evaluated based on the maximum distortion energy theory (von Mises criterion), revealing a maximum von Mises stress of 14.14 MPa (Figure 7(c)), a maximum deformation of 0.009 mm at the top-middle region of the upper plate (Figure 7(d)), and a minimum Factor of Safety (FOS) of 15 (Figure 7(e)), confirming that the stress level remains well below the material yield strength and that the resulting deformation is negligible, thereby validating the structural adequacy and functional reliability of the proposed design.

4. Data Collection

Data collection in this study was conducted to establish a baseline operational profile of the existing PRI process and to support fishbone-based bottleneck analysis and simulation modeling. Operational data were obtained from Manufacturing Execution System (MES) logs, machine performance records, and manual time-study observations under standard mass-production conditions over a continuous two-week period. Key parameters collected included machine cycle time, throughput rate, WIP queue length, buffer utilization, and delay time distribution, which represent critical indicators of flow efficiency and process constraints. The collected data were validated through outlier screening, repeatability checks, and cross-verification between automated logs and manual measurements. The validated dataset was subsequently used as input for fishbone-based root cause analysis, discrete-event simulation modeling in FlexSim, and for defining design constraints and load conditions for structural evaluation.

5. Results and Discussion

This section presents the simulation-based performance evaluation of the proposed Tunnel Lifter concept. The results focus on key production performance indicators, including effective cycle time, WIP accumulation, and throughput behavior, as illustrated in Figure 8. compares the effective machine cycle time between the baseline configuration using the conventional flat lifter and the improved configuration incorporating the proposed Tunnel Lifter. The observed reduction in cycle time indicates enhanced processing efficiency, which directly contributes to higher throughput under the same operating conditions. All results were obtained from the discrete-event simulation model developed in FlexSim, using validated baseline data described in Section 4. The discussion interprets the results in relation to the fishbone-based root causes identified in the earlier analysis. The simulation results provide a quantitative assessment of how the proposed bypass mechanism influences system-level flow behavior under representative operating conditions. By comparing baseline and modified simulation scenarios, the analysis highlights the impact of eliminating serial flow dependency on overall line balance and resource utilization. Particular attention is given to changes in effective cycle time and station waiting behavior, which directly reflect the dominant method- and machine-related causes identified through fishbone analysis. The results therefore establish a clear linkage between the identified root causes and the observed performance trends in the simulated production system, supporting an objective evaluation of the proposed concept at the design stage.

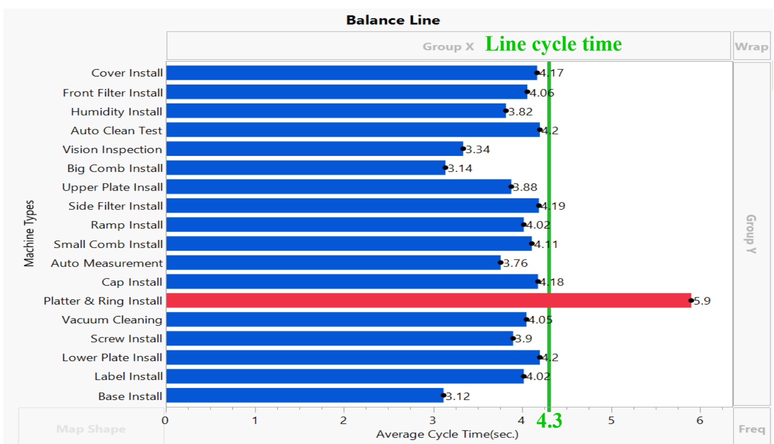

Figure 8. Machine cycle time

5.1 Effective Cycle Time Reduction

Simulation results indicate that the baseline PRI process exhibits an average effective cycle time of 29.5 seconds per unit due to serial flow dependency and waiting at occupied stations. This behavior is consistent with the dominant method- and machine-related causes identified in the fishbone diagram, particularly the absence of bypass capability and cycle time exceeding line cycle time. When the Tunnel Lifter bypass logic was introduced in the simulation model, the effective cycle time was reduced to 21.5 seconds per unit, representing an improvement of approximately 20.57%. This reduction is primarily attributed to the elimination of unnecessary waiting, allowing incoming HDDs units to dynamically bypass busy PRI stations and proceed to available stations. The result confirms that mitigating sequential dependency directly addresses the primary bottleneck mechanisms identified through fishbone-based analysis, as summarized in Table 1.

Table 1. Effective cycle time and throughput comparison before and after Tunnel Lifter implementation

Condition	Machine Cycle time (sec/unit)	Average Machine Cycle time (sec/5 units)	Throughput (Units/hr.)	%Throughput Improve
Current flat lifter	29.5	5.9	610	-
New tunnel lifter	21.5	4.6	768	20.57%

5.2 Discussion

The observed cycle time reduction demonstrates that flow inefficiencies in the PRI process are dominated by process sequencing constraints rather than isolated machine performance limitations. By decoupling serial flow dependency through bypass routing, the proposed concept effectively mitigates the root causes identified in the fishbone analysis. These findings highlight the importance of combining qualitative root cause structuring with simulation-based evaluation when analyzing complex automated manufacturing systems.

6. Conclusion

This study applied a fishbone-based problem analysis combined with discrete-event simulation to investigate bottleneck behavior in a fully automated HDDs assembly line. The analysis identified serial flow dependency and the absence of bypass capability as the dominant contributors to excessive cycle time in the PRI process. A Tunnel Lifter concept was therefore proposed and evaluated through FlexSim simulation. The simulation results indicate that enabling bypass routing can effectively reduce the effective cycle time from 29.5 seconds to 21.5 seconds per unit, representing an improvement of approximately 20.57%. The findings demonstrate that integrating qualitative root cause structuring with simulation-based evaluation provides a systematic and effective approach for early-stage bottleneck mitigation in complex manufacturing systems. The primary contribution of this work is the engineering design and system-level validation of a Tunnel Lifter mechanism for bottleneck mitigation in HDD assembly lines. This study integrates root cause analysis, discrete-event simulation, and preliminary structural assessment to demonstrate a practical design-driven approach for throughput improvement. The current work is limited to simulation-based evaluation. Future work will focus on physical implementation and on-site validation of the proposed Tunnel Lifter under real production conditions.

References

Aurisicchio, M., Bracewell, R., and Wallace, K., Rationale mapping and functional modelling to support root cause analysis in engineering design, *Research in Engineering Design*, 27(3), 243–263, 2016.

Beamon, B. M., System reliability and congestion in a material handling system, *Computers & Industrial Engineering*, 36(3), 673–684, 1999.

Dengiz, C. G., Şenel, M. C., Yıldızlı, K., and Koç, E., Design and analysis of scissor lifting system by using finite elements method, *Universal Journal of Materials Science*, 6(2), 58–63, 2018.

Friederich, J., and Lazarova-Molnar, S., Reliability assessment of manufacturing systems: a comprehensive overview, challenges and opportunities, *Journal of Manufacturing Systems*, 72, 38–58, 2024.

Hwang, H., and Park, J., Simulation-based bottleneck identification and flow optimization in automated assembly lines, *International Journal of Production Research*, 61(14), 4275–4292, 2023.

Kumar, A., and Singh, R., Analysing the bottleneck in crankcase cover production using FlexSim simulation, *Journal of Scientific and Industrial Research*, 83(7), 879–885, 2024.

Lewicki, W., Nowak, M., and Kowalski, P., Development of a simulation model to improve the production system using FlexSim,*Applied Sciences*, 14(16), 6957, 2024.

Li, H., and Li, Y., Finite element analysis and structural optimization design of multifunctional robotic arm for garbage truck, *Frontiers in Mechanical Engineering*, 11, 1543967, 2025.

Nie, Q.-Y., Nie, Z.-F., Wang, K., and Liu, T.-R., Structural optimization and mechanical study on lifting mechanism of the multifunctional car transporter, *Heliyon*, 8(11), e11717, 2022.

Pawlak, S., Zieliński, T., and Mazur, A., Analysis of production process parameters using computer simulation at the planning stage,*Applied Sciences*, 14(23), 10863, 2024.

Purwaningsih, R., Shintyastuti, A. R., Arvianto, A., Hapsari, C. A. P., Putri, A. A. A., and Dzulfikar, R. D., Evaluating the impact of autonomous material handling on the performance of production systems: a simulation approach, *Sinergi*, 29(2), 301–316, 2025.

Sealy, W., A finite element study of a patient lift conceptual design, Proceedings of the 10th Latin American and Caribbean Conference for Engineering and Technology (LACCEI), Panama City, Panama, 2012.

Sezen, B., and Çinar, A., Application of fishbone diagram for root cause analysis in manufacturing systems, *Journal of Manufacturing Processes*, 58, 254–267, 2021.

Su, X., Lu, H., and Yan, H., Dynamic bottleneck identification of manufacturing resources in complex manufacturing systems, *Applied Sciences*, 12(9), 4195, 2022.

Vigil, S. J., Automating flow of a material handling system, Master's thesis, Massachusetts Institute of Technology, *Sloan School of Management*, 2021.

Yu, X., Zhang, Y., Chen, J., and Liu, H., A mechanism-driven failure causality modeling approach for mechanical systems combining causal ordering theory and Ishikawa diagram, *Mechanical Systems and Signal Processing*, 210, 111234, 2025.

Biographies

Thanakorn Sangrit graduated from Suranaree University of Technology, with a bachelor's degree in manufacturing engineering in 2008. He is a master's degree candidate in Systems Engineering. He is currently Staff Engineer of Equipment Design Engineering Department in hard disk drive manufacturing. His current research interests are Manufacturing Systems, Lean Manufacturing and Innovation Management, Machine and Equipment Design.

Asst. Prof. Dr. Paphakorn Pitayachaval received the B.Eng. (1998) degree in Industrial Engineering from Suranaree University of Technology, M. Eng. (2011) degrees in Production Engineering from King Mongkut's University of Technology Thonburi and Ph.D. (2009) degrees in Design and Manufacturing Engineering from Asian Institute of Technology. She is a Lecturer, School of Industrial Engineering, Institute of Engineering, Suranaree University of Technology. Her current research interests are Manufacturing System, 3D Printing Design, Lean Manufacturing and Innovation Management.