Production Line Optimization Report

Executive Summary

The optimization of the production line successfully addressed the primary bottleneck, improved workflow balance, and increased overall system efficiency. Key performance indicators show substantial gains: throughput increased by 46%, lead times decreased by 75%, and delays were nearly eliminated. Buffer adjustments and increased storage capacities enhanced resilience, allowing the system to better handle variability in machine performance, demand fluctuations, and supply delays.

Overall, the recommended configuration provides a robust, efficient, and flexible production line that maximizes throughput while minimizing waiting times and bottlenecks, without introducing unnecessary excess capacity. The system is now better prepared to maintain performance under typical operational variations and can serve as a foundation for future improvements in shipment scheduling, predictive replenishment, and storage optimization.

Since the optimized configuration is based on the baseline configuration, it was necessary to align the order arrival parameter for a meaningful comparison. We could not have compared the baseline with our optimized configuration without changing the order arrival rate to 0.15 (as used in the baseline), because the template rate of 0.5 hours would limit the theoretical maximum number of orders to approximately 336 over the full 168-hour simulation. In contrast, an arrival rate of 0.15 hours allows for a theoretical maximum of 1120 orders during the same simulation period.

1 Baseline Analysis

The analysis is based on the KPI values (kpis.json) and visualizations (simulation_analysis.png) generated by the simulation. The analysis focuses on the performance of the production line, identifying the primary bottleneck, and potential secondary constraints to understand where the line is operating efficiently and where delays occur.

1.1 KPI Measurements

KPI	Baseline	Explanation / Findings
Throughput (orders/h)	4.44	The production line produces an average of 4.44 orders per hour.
Average Lead Time (h)	28.8	The order takes average 28.8 hours to complete.
Machine A utilization	37 %	Machine utilization (% of time the machine is active). A is relatively underutilized.
Machine B utilization	52 %	Machine B uses significantly more time, which is a sign of a bottleneck.
Machine C utilization	30 %	Machine C is underutilized; it is waiting for work.
Average buffer A -> B	4.6/5	The buffer utilization is reported as average level / maximum capacity. The buffer operates close to its maximum, causing Machine A to frequently stop.
Average buffer B -> C	0.42/5	The buffer's utilization is low, meaning it is often empty, and Machine C frequently waits for work.
Average Warehouse Inventory	389	A high inventory level suggests excess capacity relative to the production rate.
Delay Rate	0.027	Some shipments are delayed, which increases uncertainty in delivery times.
Average Delay Time (h)	6.36	This represents the average duration of shipment delays.
Total Products Shipped	740	The total number of products delivered during the simulation period.
Total Shipments	37	The total number of shipments completed during the simulation period.

1.2 Bottleneck Identification

Based on the baseline results of the simulation, the primary bottleneck in the production line is Machine B. Machine B has the highest utilization rate (52 %) and the longest processing time (7 min/product) in the line, which limits the throughput of the entire production line and causes an imbalance between production steps.

The bottleneck is clearly visible in the workflow between machines: The buffer between Machine A and Machine B (A->B) is on average almost full (4.6/5), which causes Machine A to wait regularly. At the same time, the buffer between Machine B and Machine C (B->C) is most often almost empty (0.42/5), which leads to underutilization of Machine C. This asymmetric buffer behavior is a typical sign of a bottleneck in the middle process step.

Secondary constraints are mainly related to the structural limits of the system. The limited buffer capacities amplify the imbalance caused by Machine B and increase the waiting time of the upstream and downstream machines. In addition, the limited capacity of the finished goods storage can in individual situations cause waiting for Machine C. On the other hand, the warehouse and logistics do not constitute significant constraints in the baseline scenario, as the inventory level and transport capacity are sufficient in relation to the production volume.

2 Optimization Strategy

During the optimization phase, several alternative parameter values were evaluated through simulation. The following changes represent the configuration that delivered the strongest overall performance improvement without compromising system stability.

2.1 Change 1: Reduce Machine B Processing Time

- Machine B processing_time_minutes 7 -> 5
- Rationale: In baseline, machine B has the longest processing time and is the primary bottleneck of the system. Reducing its processing time directly increases the capacity of the constraint.
- Expected impact: Higher throughput and shorter lead times. Machine C receives work more consistently, upstream blocking is reduced, and overall flow of the production line becomes smoother. The impact of machine failures is also reduced because the bottleneck is less severe.

2.2 Change 2: Increase Buffer Capacities

- buffer_A_B_size: 15 & buffer_B_C_size: 15
- Rationale: Small buffers in the baseline caused frequent blocking and sensitivity to machine failures. Increasing buffer capacity allows the system to absorb variability.
- Expected impact: [Reduced delays and improved throughput. Upstream machines don’t have to stop when downstream machines are busy or temporarily unavailable. Downstream machines remain productive because work-in-progress can wait in the buffers.

2.3 Change 3: Small increase to Warehouse Capacity

- parts_warehouse: capacity: 500 -> 550
- Rationale: This change is not intended to significantly increase throughput. Instead, it provides a small safety margin against variability in demand and warehouse replenishment timing. The baseline warehouse capacity is already sufficient under normal conditions, but slightly larger capacity improves robustness.
- Expected impact: Reduced risk of part shortages during raised demand or delayed replenishments. Production stoppages due to empty warehouse are less likely.

2.4 Change 4: Increase Finished Goods Storage Capacity

- finished_storage: 30 -> 50
- Rationale: Limited finished goods storage can cause machine C to block when shipments are delayed or waiting for a full lorry.
- Expected impact: Machine C can continue operating without unnecessary waiting, reducing blocking at the end of the line and improving overall flow stability.

3 Results

This section examines the ability of the optimized configuration of the production line to tolerate disturbances and maintain performance under uncertain conditions. The assessment is based on simulation model assumptions, stress tests, and risk management measures. The purpose is to identify potential single risk points, assess the system's resilience to machine failures, demand fluctuations, and part delivery delays, and plan measures to minimize bottlenecks and production disruptions.

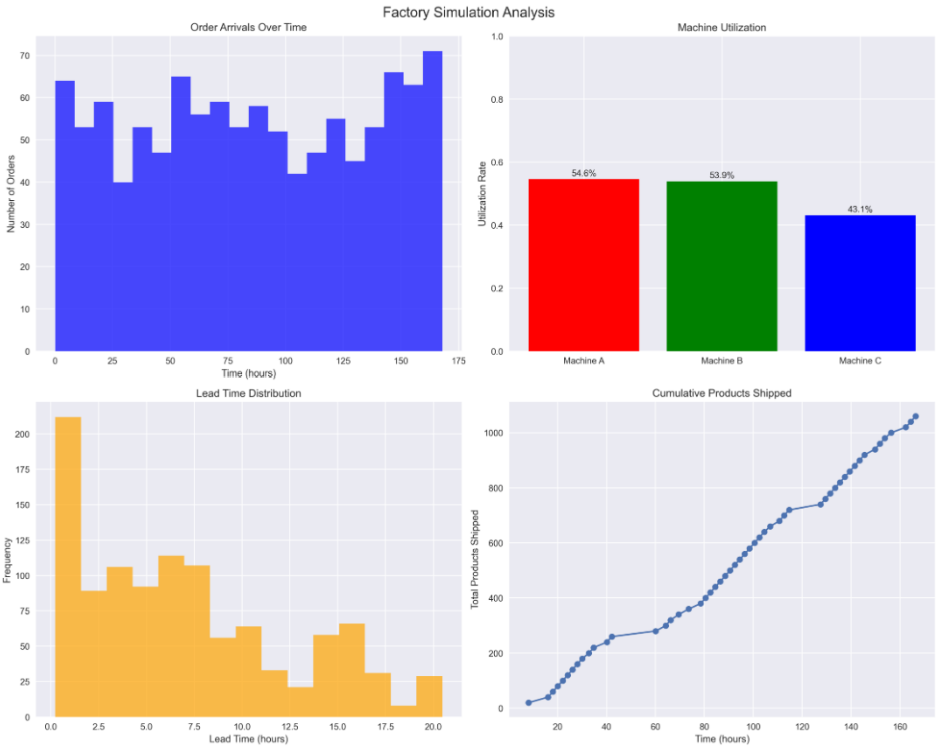
3.1 KPI Comparison

KPI	Baseline	Optimized	Change
Throughput (orders/h)	4.44	6.47	+2.03
Average Lead Time (h)	28.8	7.07	-21.73
Machine A utilization	37 %	55 %	+18 %
Machine B utilization	52 %	54 %	+2 %
Machine C utilization	30 %	43 %	+13 %
Average buffer A -> B	4.6/5	6.9/15	-50 %

Average buffer B -> C	0.42/5	2.1/15	+67 %
Average Warehouse Inventory	389	352	-37
Delay Rate	0.027	0.0	-0.027
Average Delay Time (h)	6.36	0.0	-6.36
Total Products Shipped	740	1060	+320
Total Shipments	37	53	+16

3.2 Visualization

As a result of the optimization, production line performance improved significantly. Throughput increased from 4.44 to 6.47 orders per hour, and the average lead time decreased from 28.8 hours to 7.07 hours. Machine utilization levels were balanced: Machine A increased from 37 % -> 55 % and Machine C from 30 % -> 43 %, while Machine B remained almost unchanged. This reduced underutilization and improved the workflow at the end of the line. Buffer states changed favorably: the A->B buffer decreased in relation to capacity, which reduced the waiting time of Machine A, and the B->C buffer increased, which reduced the underutilization of Machine C. The inventory level decreased slightly but remained sufficient. Delays were almost completely eliminated, and the number of delivered products and shipments increased, which shows that the optimization was successful in improving efficiency and reducing bottlenecks.



4 Resiliency Assessment

This section examines the ability of the optimized configuration of the production line to tolerate disturbances and maintain performance under uncertain conditions. The assessment is based on simulation model assumptions, stress tests, and risk management measures. The purpose is to identify potential single risk points, assess the system's resilience to machine failures, demand fluctuations, and part delivery delays, and plan measures to minimize bottlenecks and production disruptions.

4.1 Model Assumptions

The simulation relies on several simplifying assumptions that may not fully reflect real factory conditions. Machine failures and repairs are modeled as random events with immediate access to maintenance resources. Product quality issues, such as defects or rework, are not considered. In addition, human factors such as workforce availability, shift schedules, and human error are not modeled. These assumptions reduce variability compared to real-world production systems.

4.2 Stress Test Analysis

If machine failures occur 50% more frequently, machine availability decreases and production interruptions become more common, leading to lower throughput and increased lead time variability. Larger buffers help absorb short disruptions but cannot fully mitigate long or repeated breakdowns.

A sudden 30% increase in demand does not result in a proportional throughput increase due to capacity constraints. Instead, work-in-progress and buffer levels increase, causing longer average and maximum lead times.

If parts replenishment is delayed by 12 hours, the impact depends on inventory levels at the time of the delay. With sufficient stock, production can continue with limited impact, but if inventory runs out, the entire production line stops until replenishment resumes.

4.3 Risk Mitigation

Risk mitigation is mainly achieved through increased buffer sizes between machines and larger finished goods storage, which reduces sensitivity to short-term variability. Reducing the processing time of the former bottleneck (Machine B) provides additional capacity slack. However, the system still depends on single machines and a single logistics resource, meaning robustness is achieved primarily through buffering rather than redundancy.

5 Recommendations

This section summarizes the final recommendations for the production line configuration, including the optimized parameters, the priority order of implementations, and potential areas for future improvement.

5.1 Recommended Configuration

Based on optimization results, the following parameter values are recommended for implementation:

- Machine B processing time: 5 minutes
- Buffer A -> B capacity: 15
- Buffer B -> C capacity: 15
- Parts warehouse capacity: 550
- Finished goods storage capacity: 50

This configuration provides the best balance between throughput, lead time, delivery reliability, and system stability without introducing unnecessary excess capacity.

5.2 Implementation Priority

The recommended changes should be implemented in the following order:

- Reduce machine B processing time (7 -> 5 minutes):
    - Directly addresses the primary bottleneck and delivers the largest improvement in throughput and lead time.

- Increase buffer capacities (5 -> 15 units):
    - Larger buffers reduce blocking and starvation, improving flow stability and resilience to variability.

- Increase finished goods storage capacity (30 -> 50 units):
    - This prevents blocking at Machine C when shipments are delayed or waiting for transport

5.3 Future Opportunities

Further improvements could enhance flexibility, responsiveness and long-term efficiency:

- Flexible shipment
    - Adjust shipment departures dynamically based on real-time production and order status.
        - *Benefit:* Reduces waiting time for finished goods and optimizes transport utilization.
- Predictive replenishment
    - Use demand forecasts and predictive analytics to trigger warehouse replenishments proactively.
        - Minimizes the risk of stockouts, reduces the need for excess safety stock, and prevents production stoppages.
- Finished good storage size improvements
    - Further increasing or modularizing storage capacity to better handle peak demand and maintain smooth production flow.
        - Prevents Machine C from blocking when storage is full and maintains smooth production flow.

Implementing these improvements would enhance the production line's responsiveness, resilience to variability, and overall operational efficiency, while providing a foundation for future growth and adaptability.