Improving Production Efficiency at Factoriffic Custom Lamps

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[Date]

Abstract

Contents

1 Executive Summary

Objective: The primary goal of this study was to enhance the operational efficiency of Factory X, focusing on two key machines. Our aim was to identify bottlenecks and assess the effectiveness of various improvements in production speeds and queue capacities.

Methodology: We conducted comprehensive computer simulations under different scenarios, each involving 1000 trials. These simulations tested changes in production speeds and adjustments in queue lengths. Key to our approach was a rigorous testing and validation of the model, ensuring the simulation results accurately reflect potential real-world outcomes.

Key Findings:

1. *Machine 2 as the Central Bottleneck:* Machine 2 was identified as the major bottleneck. Doubling its production speed significantly reduced the average queue length from 32.7206 to 0.5319, markedly enhancing system efficiency.

2. *Queue Space Limitations:* Despite the queue being initially limited to 4 and found inadequate, increasing the queue capacity did not effectively resolve the bottleneck issues. This suggests the primary constraint lies in production speed.

3. *Handling Increased Order Volume:* The system managed a 25% increase in order volume effectively with Machine 2's production speed doubled, keeping the average queue length at Machine 2 low at 1.0868.

4. *Minimal Impact from Machine 1 Improvements:* Enhancements in Machine 1's production speed had minimal effect on reducing system queue lengths.

Testing and Validation: We implemented a comprehensive testing strategy, including a 30,000-unit 'burn-in' period for system stabilization, followed by extensive simulation runs for reliable data analysis. The model's robustness was validated using a variety of tests such as unit, integration, and regression tests, along with thorough test coverage analysis.

Recommendations:

- Focus on enhancing Machine 2's production speed, as this directly addresses the main bottleneck and significantly improves throughput and system efficiency.

- Optimizing Machine 2's production speed prepares the factory to efficiently handle potential future increases in order volume, ensuring sustainable growth and productivity.

2 Introduction

In this report, we meticulously examine the production processes of Factoriffic Custom Lamps, particularly at Factory X. Our primary objective is to enhance operational efficiency, anticipating an increase in orders due to our recent advertising initiative.

Primary Objectives: Our investigation revolves around two key concerns: firstly, evaluating if the space available for lamps in the queue for Machine 2 is adequate; and secondly, assessing the potential benefits of speeding up either Machine 1 or Machine 2.

Methodology: To address these questions, we employed a specialized simulation program developed in Julia. This program, initially crafted by a preceding engineer, underwent thorough verification and validation. We scrutinized both the code and its underlying assumptions, making necessary adjustments. Our approach included detailed analysis and parameter tuning within the simulation to derive meaningful insights and solutions.

Early Findings: We found that the waiting area for Machine 2 could be a problem. Making either machine faster does help, but how much it helps depends on how many orders we have, like if we get 25% more orders than now.

3 Background

3.0.1 The system

Our study focuses on the production line at Factoriffic Custom Lamps, specifically within Factory X. This line, designated as the System Under Study (SUS), is centered around two key components: Machine 1 and Machine 2.

Operational Process: The production process starts with incoming lamp orders, which are initially queued for processing by Machine 1. After the first stage of manufacturing is completed in Machine 1, the lamps enter a second queue, awaiting further processing by Machine 2. A critical aspect of this system is the limited capacity between these two stages; the queue can only accommodate four orders at any time. If this capacity is reached, Machine 1 halts until space becomes available.

Completion and Delivery: Once the lamps are processed by Machine 2, they are ready to be shipped to customers, marking the end of their journey through the production line.

3.1 Schematic Diagram

The schematic diagram (Figure 1) illustrates the physical layout and key components of the production line. Orders enter the system and are initially queued for Machine 1. Post-processing at Machine 1, they are queued again for Machine 2. There is a limited waiting area for the queue before Machine 2, accommodating a maximum of four orders. The diagram highlights the flow of orders through the system and the interaction between different components.

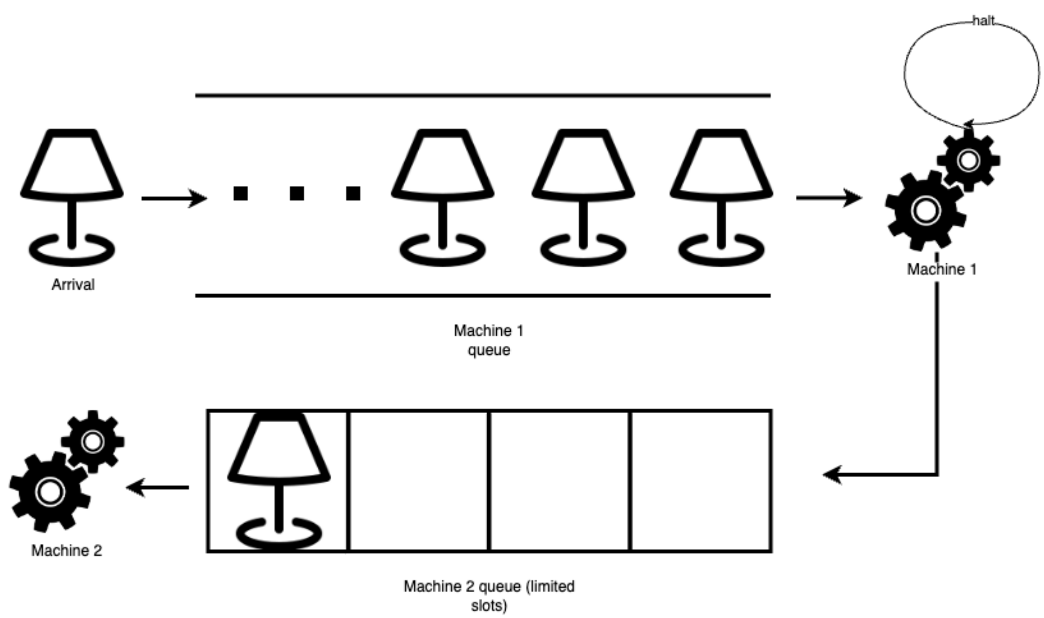

Figure 1: Schematic diagram of the Factory X production line.

3.2 Event Diagram

The event diagram (Figure 2) illustrates the sequence of events in Factory X's production line, starting with an order's arrival and tracking the process through Machine 1, queuing for Machine 2, processing at Machine 2, and culminating in the shipping of the final product. This diagram is crucial for understanding the dynamic interactions and dependencies within the production line.

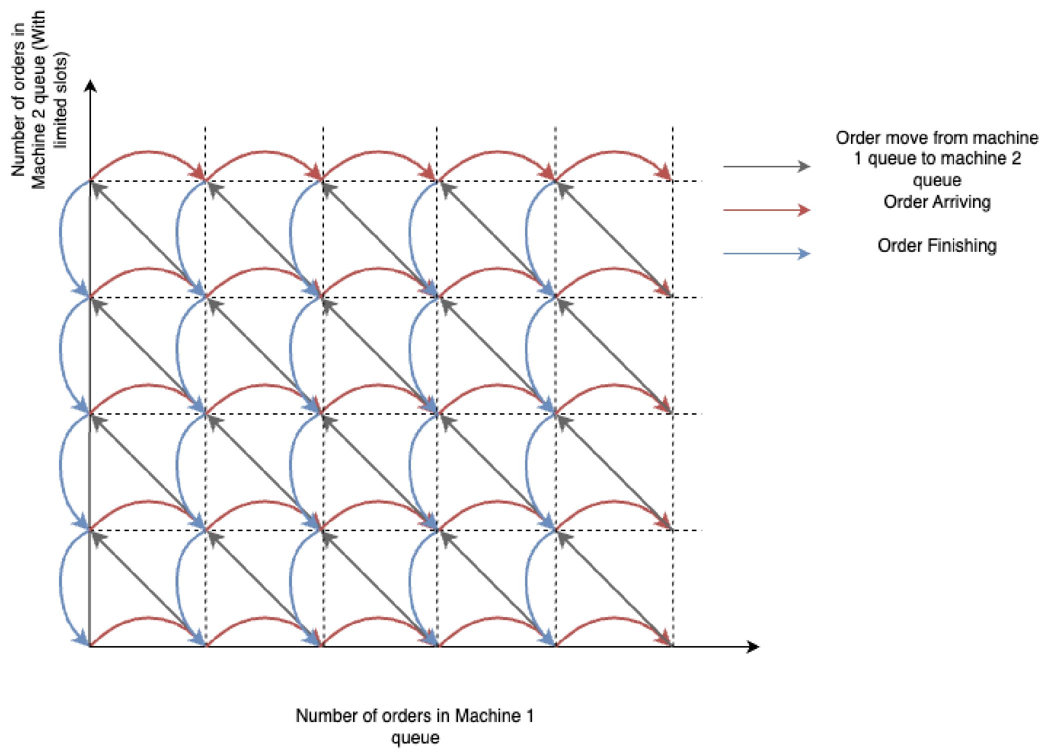

Figure 2: Event diagram of the Factory X production line.

3.3 Flow Chart

The flow chart (Figure 3) details the decision-making process in the production line, encompassing the journey from order arrival to shipment readiness. It includes steps such as checking the availability of Machine 1, assessing queue capacity before Machine 2, and determining shipment timing. This chart is instrumental in comprehending the operational logic and overall process flow.

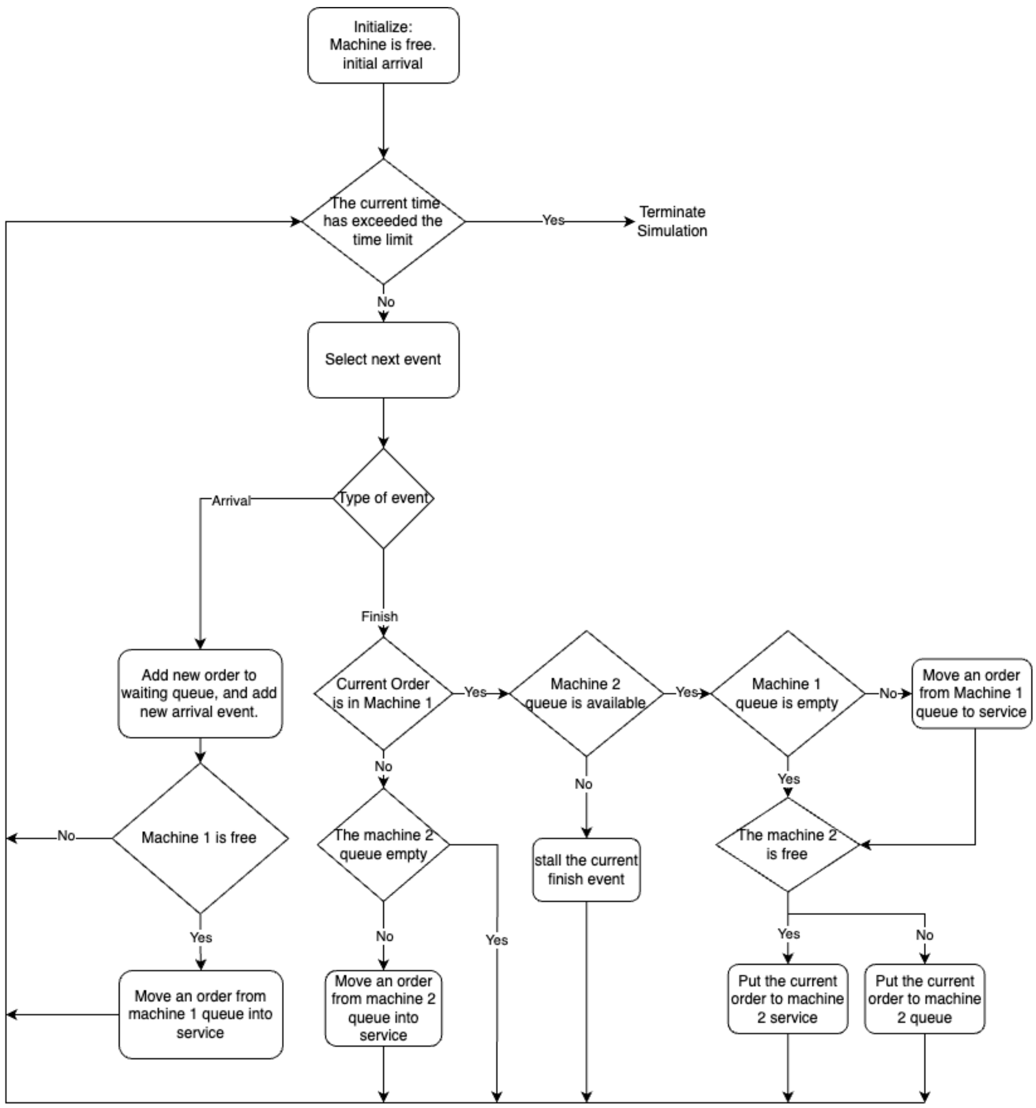

Figure 3: Flow chart of the Factory X production line.

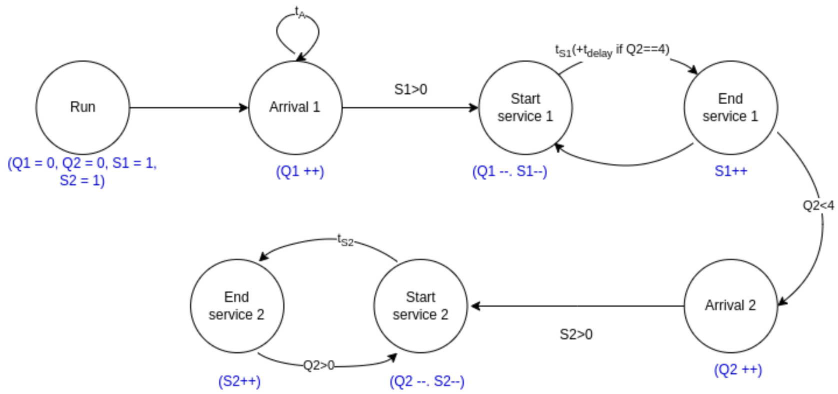

Figure 4: The Event Graph of the Factory X production line.

3.4 Event Graph

The Event Graph (Figure 4) provides a visual representation of the varies events of the system. One noteworthy point is that once the service end, but the queue length 2 is at limit (==4) the service 1 will be pending until queue length 2 is free (¡ 4).

3.5 The Simulation

3.5.1 The model assumption

This section details the assumptions underlying our simulation model. These assumptions are critical for the validity and interpretation of the simulation results.

1. **Distribution of Service Times:** The processing times for both machines are assumed to follow specific statistical distributions. Machine 1 operates with a *Normal distribution*, reflecting its consistent processing patterns. Machine 2's times are modeled with an *Exponential distribution*, indicative of the more variable nature of its tasks.

2. **Inter-Arrival Time Distribution:** The arrival of orders is modeled using an *Exponential distribution*, reflecting the random and independent nature of customer order placement.

3. **Queue Input Ordering and Independence:** The queuing system for both machines is assumed to follow a *First-In, First-Out (FIFO)*

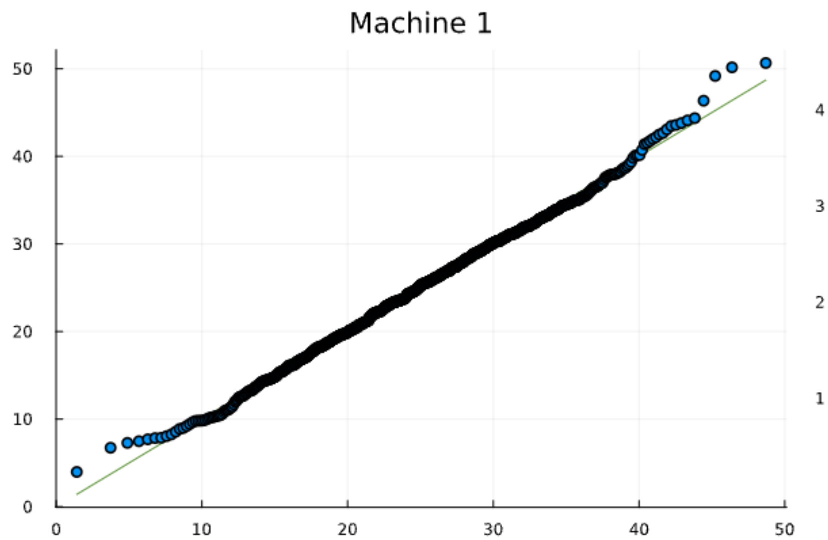

Figure 5: QQ plot of Machine 1's processing times against normal distribution $N(25, 7.18^2)$.

order. This reflects the standard operational procedure in manufacturing settings. Additionally, we assume independence between the arrival of orders and the processing times of the machines, ensuring that each event occurs without influence from the other.

4. **Absence of Priorities and Pre-emption:** Our model assumes no prioritization of orders and no pre-emption in processing. All orders are treated equally and are processed to completion once started, without interruption or reordering based on priority.

5. **Size of Available Waiting Space:** The model incorporates a specific limitation in the waiting space for processed items. Specifically, only four orders can be queued at any given time for the Machine 2. This constraint plays a critical role in the system's throughput and efficiency.

6. **The distribution time for machine 1** production is normal distribution with mean of 25 and variation of 7.2

7. **The distribution time for machine 2** is exponential distribution with mean of 59

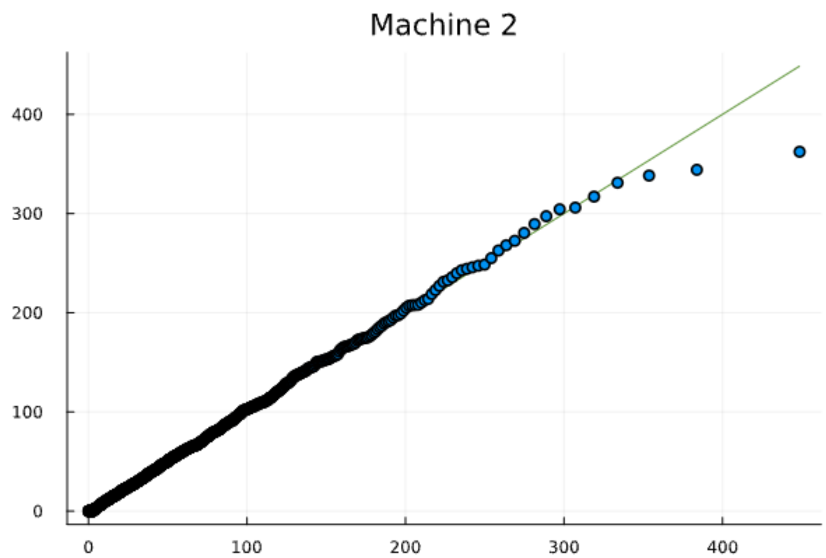

Figure 6: QQ plot of Machine 2's processing times against exponential distribution exp(59).

8. **The distribution time for the order interarrivial time** is exponential distribution with mean of 60.

These assumptions have been validated against real-world data, with the QQ plots (Figures 5, 6, and 7) providing graphical confirmation of our distributional assumptions for processing and inter-arrival times. We can verify that the collected data closely follow the distribution.

3.6 Verification

To ensure the simulation codebase's accuracy and reliability for Factory X, extensive testing was carried out. This section details the methodologies and outcomes of these tests.

3.6.1 Unit Testing

The objective of the unit testing was to validate individual components of the codebase. This testing focused primarily on initializing functions and randomization processes. Each unit test was designed to check the functionality of component functions. A key finding was that the initial codebase

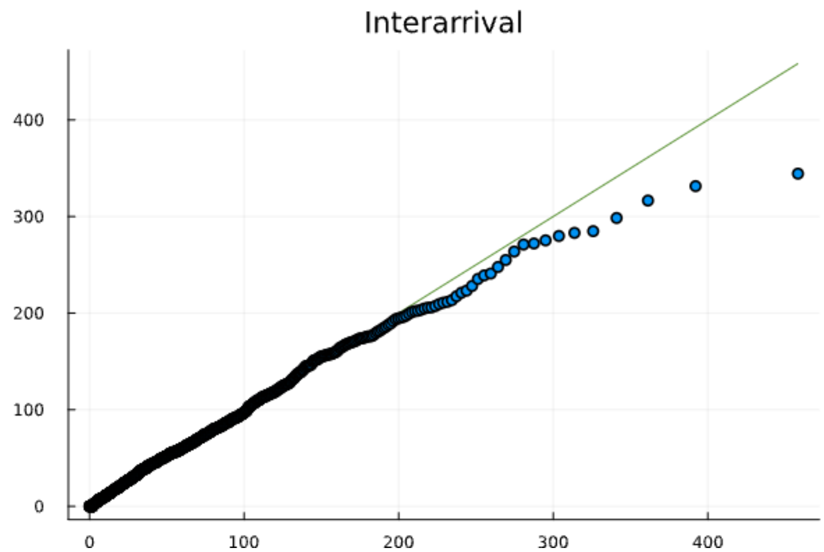

Figure 7: QQ plot of interarrival times against exponential distribution exp(60).

used deterministic time for Machine 1 instead of Normal distribution time. We have done a sensitivity test following the determine if this would effect the simulation result.

3.6.2 Integration Testing

Integration testing aimed to verify the combined functionality of multiple code components. This included conducting tests covering critical logic paths within the main simulation. Scenarios such as new order completion in Queue 1 when Queue 2 is full, new order completion when Queue 2 is available, order completion in Queue 2, and the arrival of new orders when Machine 1 is occupied were tested. The integrated components functioned as expected in all these scenarios.

We also test running the whole simulation on 100 seeds with multiple parameters, the result all come out as with reasonable expected values.

3.6.3 Regression Testing

The purpose of regression testing was to ensure that new code changes did not negatively impact existing functionalities. This involved the continuous

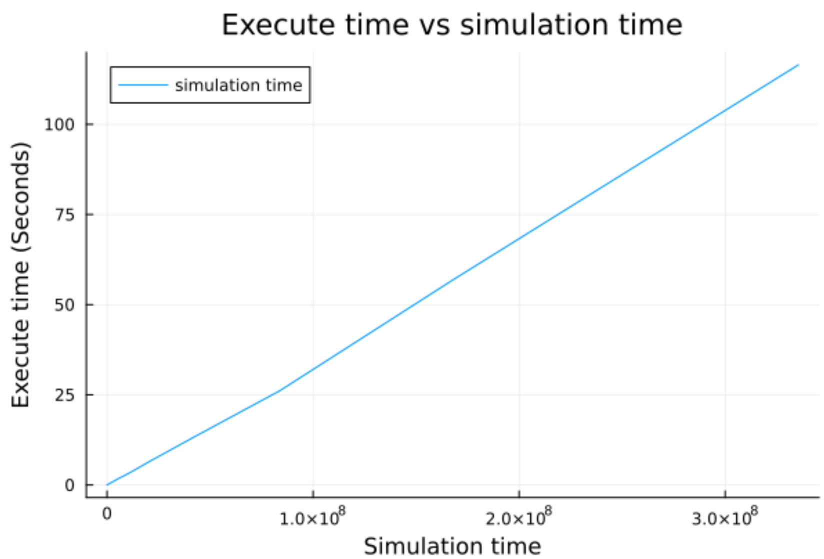

Figure 8: Simulation execution time

execution of test code after every modification. No regression issues were identified, ensuring that all modifications maintained the integrity of the code.

3.6.4 Performance Testing

Performance testing assessed the efficiency of the simulation code. It involved analyzing the code's execution time in relation to the simulation parameters. The code executed efficiently in proportion to the simulation time, as further supported by the performance testing illustrated in Figure 8.

3.7 Validation

Validation of the simulation model was a crucial step in ensuring its accuracy and reliability. Discussions with the Subject Matter Expert (SME) played a pivotal role in this process. Through these discussions, we were able to confirm several critical assumptions about the system at Factory X.

One key validation was confirming that the processing time for Machine 1 follows a normal distribution. This finding aligns with the assumptions used in our simulation model and is vital for accurately predicting machine behavior and throughput. Additionally, it was verified that the system operates on a First-In-First-Out (FIFO) basis. This means there is no prioritization or preemption in the processing of orders, an important factor in modeling the flow of orders through the factory.

3.7.1 Testing Data Assumption

Furthermore, we conducted rigorous testing on the distribution times of various elements within the system. This included the interarrival times of orders and the production times for both Machine 1 and Machine 2 567. The results from these tests were consistent with our initial assumptions, providing further validation for our model.

The successful validation of these assumptions and parameters has significantly increased our confidence in the simulation model. This assures us that the model provides a reliable representation of the actual operations at Factory X, forming a solid foundation for the proposed improvements and changes based on this model.

3.7.2 Sensitivity Analysis

We performed a test to see if setting the machine production time differently affects our system. The test was conducted in two scenarios, each with 1000 trials:

- One with a fixed (deterministic) production time.
- Another where the production time varied, following a normal distribution with a standard deviation of 7.18 minutes.

We measured the queue length at the second machine in both scenarios. Our objective was to find out if the method of setting production time significantly impacts the queue length. The results are presented in the table below:

T-Test Results:

Test Statistic: -0.7551
P-value: 0.4503
Degrees of Freedom: 1994.0

The high P-value from the T-Test suggests that the differences in production time settings (deterministic vs. normal distribution) do not significantly

Measurement	Deterministic	Normal distribution
Mean	3.5364	3.5282
Standard Deviation	0.2454	0.2424
Margin of Error	0.0152	0.0150
95% Confidence Interval	(3.5212, 3.5516)	(3.5131, 3.5432)

Table 1: Comparison of Deterministic and Normal Distribution Settings for Machine 1, measuring average queue length at Machine 2, with a burn-in period of 30000, in a 100000 time simulation

impact the queue length at Machine 2. This aligns with our understanding that Machine 2 is the main bottleneck in the system, and thus variations in Machine 1's production time do not substantially affect Machine 2's queue.

4 Results

4.1 Mathematical Analysis of the Production System

This section presents an efficiency analysis of a production system comprising two machines with different production times and queue characteristics. The analysis involves three scenarios: the original system, improvement with doubled Machine 2 speed, and further enhancement by reducing the interarrival time by 20%.

System Parameters and Formula:

- Interarrival time of orders: follows an Exponential distribution.
- Machine 1's production time: Deterministic, constant.
- Machine 2's production time: follows an Exponential distribution.
- Machine 1 has an indefinitely large queue space.

The system is modeled as an M/M/1 queue, where the average queue length (L) is calculated using:

$$L = \frac{\rho}{1 - \rho} \tag{1}$$

where ρ is the traffic intensity (λ/μ).

Scenario Analysis:

1. *Original System:* Interarrival time = 60, Machine 2 production time = 59. Resulting L $\approx$ 59.
2. *Doubled Machine 2 Speed:* Machine 2 production time halved to 29.5. Resulting L $\approx$ 0.967.
3. *Reduced Interarrival Time by 20%:* Interarrival time decreased to 48 (20% less than the original). Resulting L $\approx$ 1.595.

The original system, with a queue length limited to 4, proves inadequate when compared to the much higher calculated average queue length of approximately 59, suggesting a significant risk of bottlenecks. While theoretical adjustments, such as doubling the speed of Machine 2 and reducing the interarrival time, indicate a reduction in queue length, their practical impact remains to be validated. Simulations will be presented in following session to confirm th.

4.2 Exploratory Analysis

4.2.1 Burn-In and Simulation Time

Our simulations, conducted with 1000 different seeds, indicate that a 30,000 time unit 'burn-in' period is typically sufficient for system stabilization, as shown in Figure 9. Although there's a slight trend of increase in measurements in the subsequent 10,000 units, the change is negligible.

It's important to note that burn-in times can vary with different simulation parameters. In our case, the 30,000-unit period is a conservative estimate, particularly since other parameters tend to stabilize more quickly.

Given this, we have set our total Simulation time (T) at 200,000 units. While this is less than 10 times the burn-in period — a common rule of thumb — it is considered adequate due to the already generous burn-in duration and the quicker stabilization observed with other parameters.

4.3 Original system simulation

The simulation results, as illustrated in Figure 9, consistently show the queue length reaching its maximum capacity of 4, indicating a bottleneck in the system. The ensemble average queue length is also observed to be relatively high. Key statistical measures obtained from the simulation are as follows:

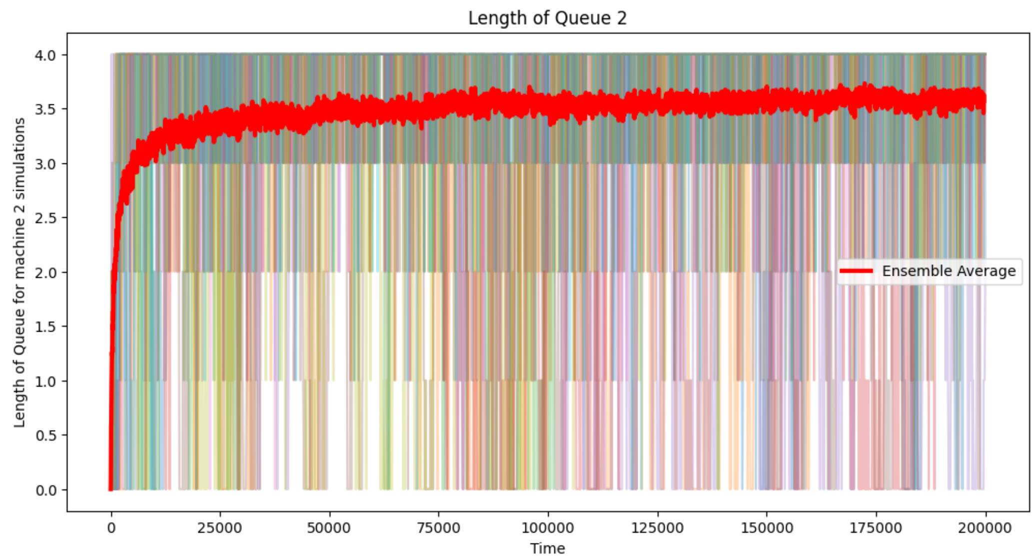

Figure 9: The simulation with original parameter over 1000 seeds for queue length 2, and the ensemle average

- Mean queue length: 3.5364
- Standard Deviation: 0.2454
- 95% Confidence Interval: (3.5212, 3.5516)

These results underscore the **inadequacy** of the queue capacity in the current system configuration, leading to frequent saturation of the queue.

4.4 System Improvement Simulation

We conducted simulations to evaluate various improvements in our system:

- Increase Machine 1's production speed to [23, 21, 19, 17, 12.5] minutes per product.
- Enhance Machine 2's production speed to [55, 50, 45, 29.5] minutes per product.
- Expand Machine 2's queue length to [5, 7, 11, 19].

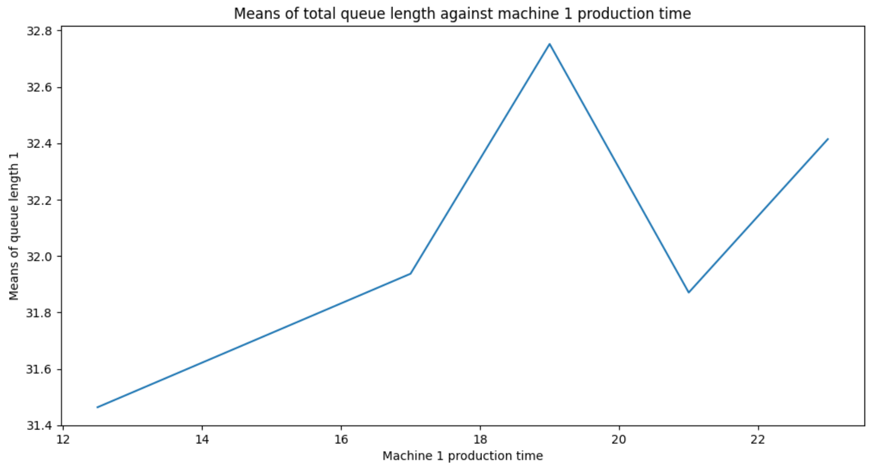

Figure 10: Effect of Machine 1's speed improvement

Despite expert advice against increasing Machine 2's queue length due to cost concerns, we included it for thorough analysis. The effectiveness of these improvements was measured by observing the queue length at Machine 1.

4.4.1 Improving Production Speed of Machine 1

Figure 10 shows that enhancing Machine 1's speed slightly reduces the system queue length, with a marginal decrease from 32.7206 to 31.4634 when production time is halved. Figure 11 further indicates that even at maximum improvement, the reduction in queue length is minimal, suggesting limited impact on overall system efficiency.

4.4.2 Improving Queue Length and Production Speed of Machine 2

Figure 12 demonstrates that increasing Machine 2's queue space from 4 to 19 offers a slight reduction in average queue length from 32.7206 to 31.5583. However, as shown in Figure 13, even with maximum queue expansion, the system still struggles with increasing queue lengths, indicating limited effectiveness.

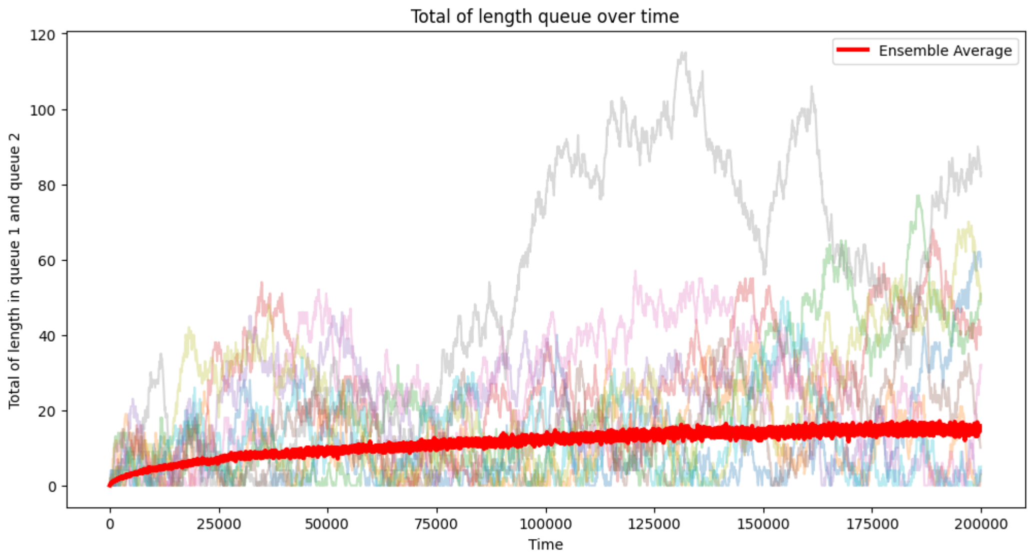

Figure 11: System queue length over time with Machine 1's production time reduced to 12.5 minutes/product

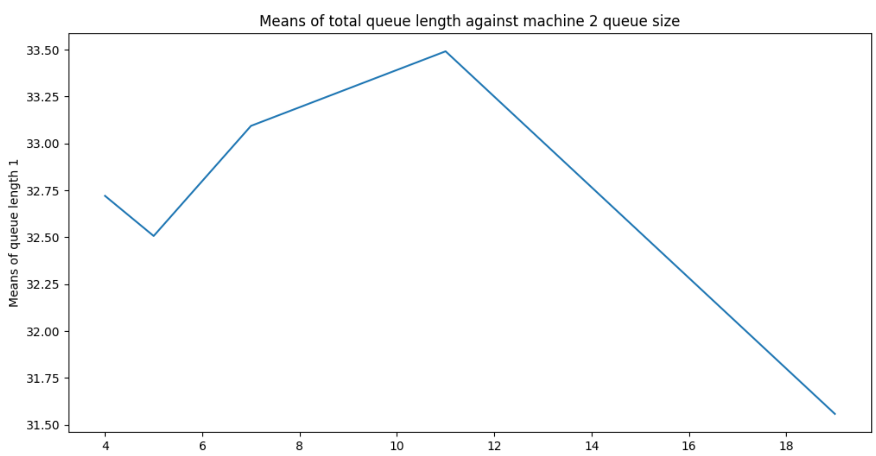

Figure 12: Effect of expanding Machine 2's queue space

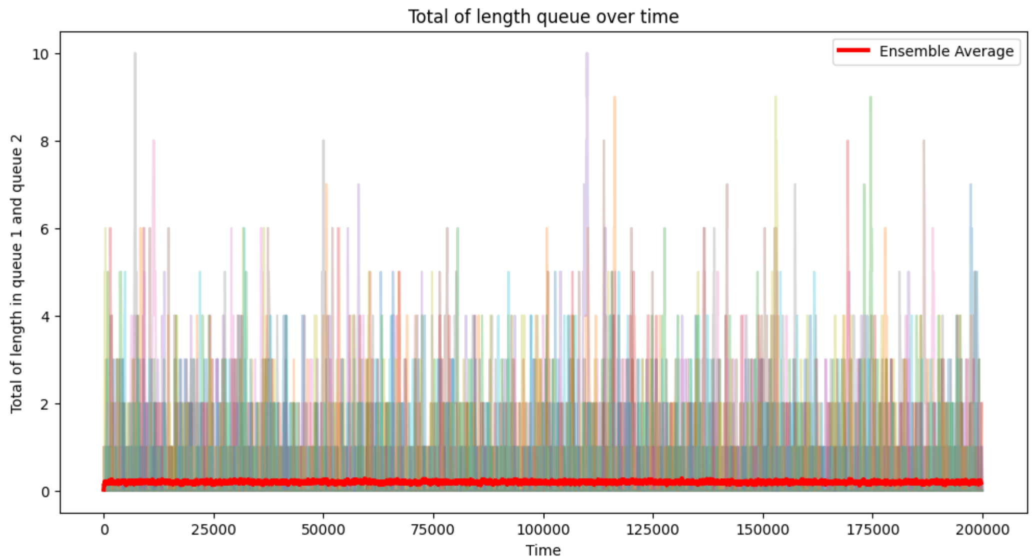

Figure 13: System queue length over time with Machine 2's queue space increased to 19

4.4.3 Effectiveness of Improving Machine 2's Production Speed

Figure 14 highlights a significant improvement in the system's queue length, decreasing dramatically from 32.7206 to 9.6669 with a modest increase in Machine 2's production speed. Further enhancement to 29.5 minutes per product stabilizes the system queue at minimal value of 0.5319, as seen in Figure 15, indicating that the system effectively process new incoming orders.

In conclusion of improvement testing, our best investment is to improving machine 2 production speed.

4.5 Order Increase Simulation

In this simulation, we modeled a 25% increase in order volume by reducing the inter-arrival time from 60 to 48 units, representing a 20% decrease. To assess the system's capacity to handle this surge, we doubled the production speed of Machine 2, setting its mean production time to 29.5 units. The results, shown in Figure 16, indicate that the system is more than capable of comfortably dealing with this increased volume of orders. Despite the higher influx, the average queue length at Machine 2 remained low, underlining the

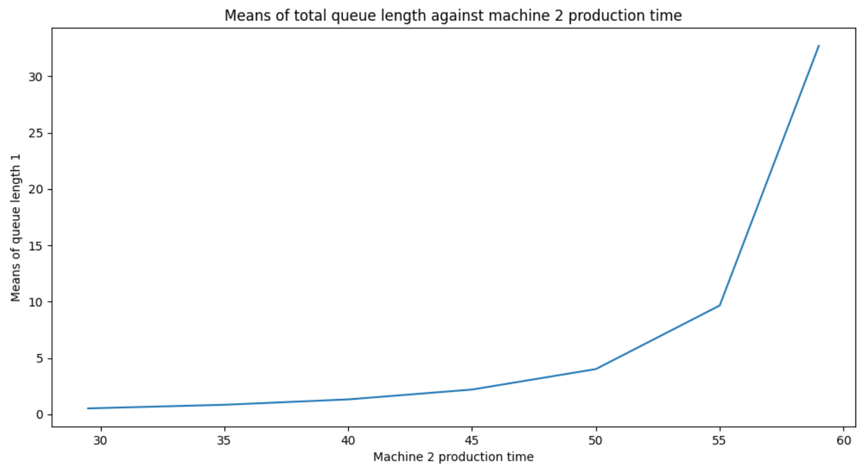

Figure 14: Impact of improving Machine 2's production speed

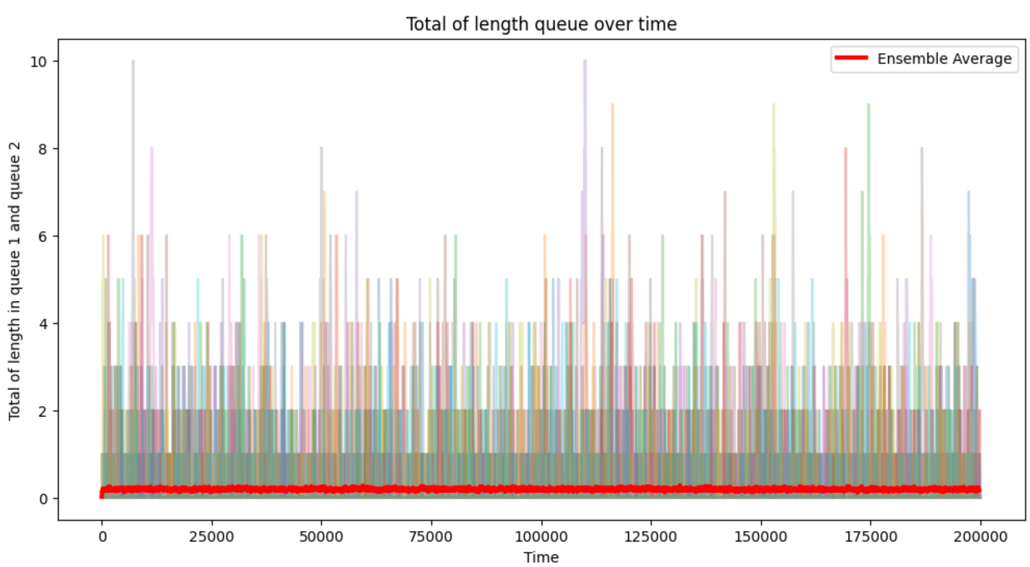

Figure 15: System queue length over time with Machine 2's production time reduced to 29.5 minutes/product

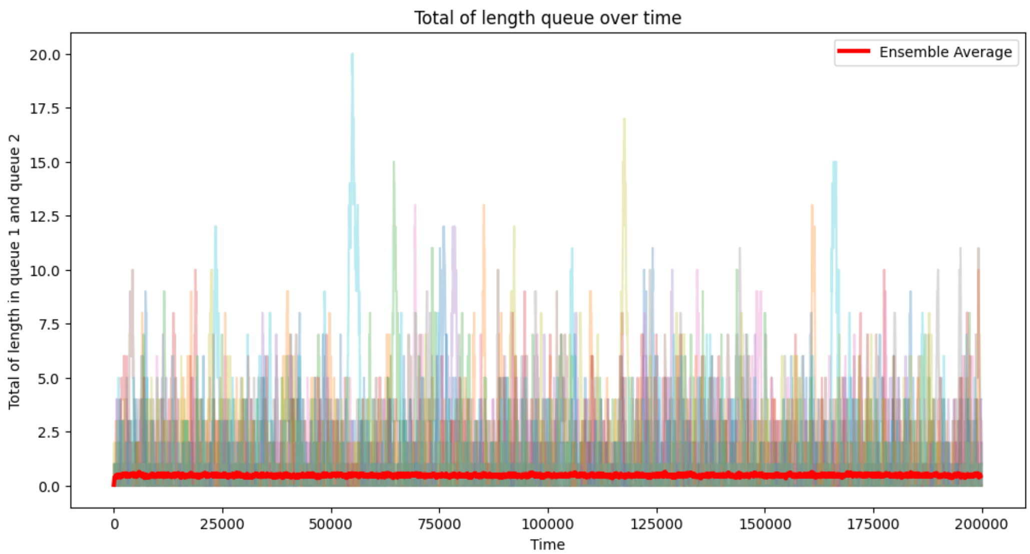

Figure 16: Simulation of a 25% increase in orders with Machine 2's production speed doubled

effectiveness of the speed enhancement. The detailed statistical measures from the simulation are:

- Mean queue length: 1.0868
- Standard Deviation: 0.1291
- Margin of Error: 0.0080
- 95% Confidence Interval: (1.0788, 1.0948)

These metrics underscore the system's robust performance in managing a 25% increase in order volume, reinforcing the success of the improvements made to Machine 2.

5 Conclusion

Our extensive analysis of Factory X's operations, incorporating simulations and expert advice, was focused on optimizing the efficiency of two critical machines. The findings from the simulations were quite revealing:

1. Machine 2's performance was identified as the main bottleneck in the system. Remarkably, by doubling Machine 2's production speed, the average queue length was significantly reduced from 32.7206 to an impressively low 0.5319, greatly alleviating the system's bottleneck.

2. When simulating a 25% increase in order volume with Machine 2's production speed doubled, the system adeptly managed the higher demand. The average queue length at Machine 2 remained low at 1.0868, showcasing its robustness under increased order pressure.

3. Conversely, enhancements in Machine 1's production speed had a minimal effect. The average queue length decreased only slightly from 32.7206 to 31.4634, indicating that Machine 1 is not the critical factor in the system's overall efficiency.

These insights clearly demonstrate that focusing on enhancing Machine 2's production speed is the most effective strategy for Factory X. This single change not only significantly reduces queue lengths but also improves the overall throughput of the system. While improvements to Machine 1 yield negligible results, optimizing Machine 2's speed is crucial for managing current operations and preparing for potential future increases in order volume.

In conclusion, the primary recommendation for Factory X is to concentrate on boosting Machine 2's production speed. This approach will not only streamline current operations but also equip the factory to efficiently handle potential future increases in demand, ensuring sustainable growth and productivity.