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Modeling and Simulation of Minimarket Cashier Queues to Reduce Customer Waiting Time at Indomaret Tuntungan I

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Abstract

Customer satisfaction in the modern retail industry is significantly influenced by the efficiency of cashier services. Long waiting times can lead to dissatisfaction and potential customer loss. This research aims to analyze and optimize the cashier queuing system at Indomaret Tuntungan I using a discrete event modeling and simulation approach. Primary data on customer arrival intervals and service times were collected through direct observation. A simulation model was constructed using Arena software to replicate the existing system, which operates with two cashiers and separate queues. Several optimization scenarios were proposed and tested, including adding cashiers and implementing an integrated single queue system. The key performance metrics measured were average customer waiting time, queue length, and cashier utilization. The simulation results demonstrate that the combined scenario, featuring a single queue with one additional cashier activated during peak hours, yielded the most significant improvement. This configuration successfully reduced the average waiting time by 67.4% to 2.55 minutes, decreased the maximum queue length to 2.8 people, and achieved a balanced cashier utilization rate of 68.7%. The findings provide a data-driven recommendation for minimarket management to enhance service speed through a synergistic approach of queue restructuring and dynamic resource allocation.

***Keywords**: Queue Modeling, Discrete Event Simulation, Waiting Time, Retail Optimization, Arena Software.*

1. Introduction

The Indonesian minimarket retail sector operates in a highly competitive landscape where customer satisfaction is a primary determinant of loyalty [1]. A critical factor directly impacting customer perception is the waiting time at the checkout counter. Extended queues during peak hours frequently lead to customer dissatisfaction and increase the risk of losing patrons [2]. Indomaret Tuntungan I branch faces similar operational challenges, with regular customer complaints regarding prolonged payment processing, especially during evening rush periods. This situation suggests a potential misalignment between available service capacity and the fluctuating demand patterns of customers.

Conventional analytical queuing models, such as the M/M/s model from queuing theory, provide a foundational framework for analyzing waiting line systems by examining elements like arrival patterns and service mechanisms [3]. However, these models often rely on simplifying assumptions that may not fully capture the complex and non-stationary dynamics of real-world retail environments, such as highly variable service times and non-constant arrival rates [4]. To address these limitations, discrete event simulation (DES) has emerged as a more flexible and powerful tool. DES enables the modeling of complex dynamic systems by accommodating variability and interdependencies between processes, allowing for the testing of various "what-if" scenarios in a risk-free virtual environment before implementation [5], [6].

Recent studies in retail service optimization highlight two primary strategies. The first is capacity optimization, such as deploying flexible cashier staffing based on predicted customer volume. The second is queue process restructuring, notably the implementation of a single queue (serpentine line) feeding multiple servers. Integrated single-queue systems have proven effective in reducing waiting time inequality among customers and improving server efficiency by preventing idle cashiers while other lines remain long [7]. A combination of these approaches often yields a synergistic effect greater than the sum of its parts [8].

Previous research provides a relevant foundation. [9] successfully used Arena simulation to optimize cashier scheduling in a supermarket, demonstrating a 35% reduction in waiting time. However, their study focused on an environment with typically larger, more complex transactions. Meanwhile, [8] explored the comparison of single and multiple queue systems in a minimarket context, but their analysis was more theoretical. [10] also performed a queuing analysis for a minimarket in Bandung, but their approach was more descriptive and did not integrate an in-depth financial feasibility analysis as conducted in this study.

Addressing this identified research gap, this study is designed with the following objectives: (1) To build an accurate discrete event simulation model of the cashier queuing system at Indomaret Tuntungan I; (2) To analyze the performance of the existing system based on key metrics like waiting time, queue length, and server utilization; (3) To propose and test improvement scenarios through simulation to identify the optimal configuration for minimizing customer waiting time. The novelty of this research lies in the comprehensive application of DES to test a combined strategy of dynamic capacity addition and queue management restructuring within the specific context of an Indonesian minimarket.

2. Main Body

2.1. Research Methodology and Simulation Modeling

This study employs a quantitative approach using discrete event simulation modeling. The research location was Indomaret Tuntungan I. Primary data was gathered through direct observation over seven consecutive days during the peak period from 4:00 PM to 7:00 PM. The data recorded for each customer included their arrival timestamp and total service time at the cashier, resulting in a sample of 630 transactions. Statistical analysis using Input Analyzer in Arena Simulation Software 16.0 determined that the inter-arrival time follows an Exponential distribution with a mean of 102 seconds, while the service time follows a Normal distribution with a mean of 185 seconds and a standard deviation of 67 seconds [4].

The base simulation model was constructed to replicate the existing condition: a system with two cashiers and two dedicated queues. The model underwent verification and validation. Validation was performed by comparing the average waiting time output from 30 simulation replications with the actual observed average using a t-test. The result showed no significant difference (p-value > 0.05), confirming the model's validity [5], [6].

Subsequently, four experimental simulation scenarios were designed and tested:
1. Scenario 0 (Baseline): Existing condition (2 cashiers, 2 separate queues).
2. Scenario 1 (Added Capacity): Addition of one permanent cashier (3 cashiers, 3 separate queues).
3. Scenario 2 (Queue Restructuring): Implementation of a single queue system with 2 cashiers.
4. Scenario 3 (Combined Strategy): Integration of a single queue with one additional cashier activated during the peak period (3 cashiers, 1 queue).

Each scenario was executed for 30 replications with a simulation run time of 180 minutes and a 30-minute warm-up period. Output data was analyzed using a one-way ANOVA test and a post-hoc Tukey HSD test to determine statistical significance.

2.2. Results and Discussion

2.2.1. Model Validation and Baseline Performance

The simulation model was successfully validated. The average waiting time from 30 replications of the baseline scenario was 7.82 minutes with a 95% confidence interval of [7.41 ; 8.23] minutes, which was not significantly different from the actual observed average of 7.95 minutes (p-value = 0.124). Under this baseline condition, the maximum queue length reached 8.2 people, and the average cashier utilization was critically high at 85.3%, indicating a system bottleneck.

2.2.2. Comprehensive Performance Analysis of All Scenarios

The simulation results for all four scenarios are summarized in Table 1. A one-way ANOVA test confirmed a highly significant difference in the average waiting times across the scenarios (p-value = 1.2E-45). A subsequent Tukey HSD post-hoc test verified that all improvement scenarios performed statistically better than the baseline, with Scenario 3 (Combined Strategy) being the significantly best performer.

Table 1: Comparative Performance Analysis of Simulation Scenarios

Scenario	Configuration	Avg. Waiting Time (min)	Reduction vs. Baseline	Max Queue Length	Cashier Utilization (%)
0	2 Cashiers, 2 Queues	7.82	-	8.2	85.3
1	3 Cashiers, 3 Queues	4.15	46.9%	4.7	72.1
2	2 Cashiers, 1 Queues	5.21	33.4%	5.3	83.9
3	3 Cashiers, 1 Queues	2.55	67.4%	2.8	68.7

Scenario 1 shows that adding capacity reduces system load. However, the multiple queue structure remains susceptible to imbalance. Scenario 2 proves the advantage of a single queue in promoting fairness and operational efficiency, ensuring no cashier is idle while customers wait. Scenario 3, the combined approach, yields optimal performance. The 67.4% reduction in waiting time and the balanced cashier utilization rate of 68.7% demonstrate clear synergy between intelligent queue management and well-timed capacity adjustment.

2.3.3. Statistical Significance Test Results

To ensure the reliability of the findings, detailed statistical tests were conducted. Table 2 presents the results of the Tukey HSD test for pairwise comparisons between scenarios, confirming that all differences are statistically significant ($p < 0.01$).

Table 2: Tukey HSD Test Results for Pairwise Scenario Comparison

Pairwise Comparison	Mean Difference (min)	Lower 95% CI	Upper 95% CI	Significant (p < 0.01)
Scenario 3 vs 0	-5.27	-6.01	-4.53	Yes
Scenario 3 vs 1	-1.60	-2.34	-0.86	Yes
Scenario 3 vs 2	-2.66	-3.40	-1.92	Yes
Scenario 1 vs 0	-3.67	-4.41	-2.93	Yes
Scenario 2 vs 0	--2.61	-3.35	-1.87	Yes
Scenario 1 vs 2	-1.06	-1.80	-0.32	Yes

2.2.4. Sensitivity and Cost-Benefit Analysis

A sensitivity analysis was conducted on Scenario 3 by simulating a 20% increase in customer arrival rate. The average waiting time increased to 4.88 minutes. Although this represents a 91.4% increase from Scenario 3's normal performance, it is still 37.6% better than the original baseline condition (7.82 minutes). This confirms the robustness of the proposed strategy.

A cost-benefit analysis was performed to evaluate implementation feasibility. The main costs are a one-time expense for physical queue modification and the recurring cost for one part-time cashier during peak hours. Benefits were estimated from the economic value of saved customer time and prevention of customer loss. The calculation, summarized in Table 3, yields a compelling Benefit-Cost Ratio (BCR) of 9.87, indicating high financial viability.

Table 3: Cost-Benefit Analysis for Implementing Scenario 3

Component	Type	Monthly Value (IDR)	Remarks
		COSTS	
Operational Cost (Additional Cashier)	Recurring	1,350,000	3 hours/day, 30 days/month
Total Monthly Cost		**1,350,000**	
		BENEFITS	
Customer Time Savings	Recurring	11,831,000	Economic value conversion
Prevention of Customer Loss	Recurring	1,500,000	Estimated 2 customers/day
Total Monthly Benefit		**13,331,000**	
		FEASIBILITY METRICS	
Benefit-Cost Ratio (BCR)	-	9.87	13,331,000/ 1,350,000
Payback Period (Initial Investment)	-	< 0.5 month	For IDR 1,500,000 layout modification

3. Conclusion

Based on the discrete event simulation analysis, it is concluded that the cashier queuing system at Indomaret Tuntungan I has significant optimization potential. The integration of queue management restructuring into a single-line system with dynamic capacity addition during peak hours proves to be the most effective strategy. This combined configuration successfully reduced average customer waiting time by 67.4% compared to the existing condition while achieving more balanced cashier utilization.

The findings offer practical, data-driven recommendations. Management is advised to modify the checkout area to accommodate a single queue and implement flexible staffing to activate an additional cashier during the 4:00 PM to 7:00 PM peak period. The financial feasibility analysis, showing a Benefit-Cost Ratio of 9.87, strongly supports the investment as highly profitable for long-term service quality improvement.

For future research, the study can be expanded by incorporating variables such as digital payment impacts and promotional campaign effects. Applying the developed model in other minimarket branches would also be valuable for assessing its generalizability.

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