SIMULATING SELF-CHECKOUT OPTIMIZING STAFFING LEVEL TO MAXIMIZE SUPPORT OF SELF-CHECKOUT SYSTEMS

How Intentional and Accidental Fraud Decreases Customer Satisfaction

Zheng, Zhi; Miranda, Victor; & Hughes, Alex

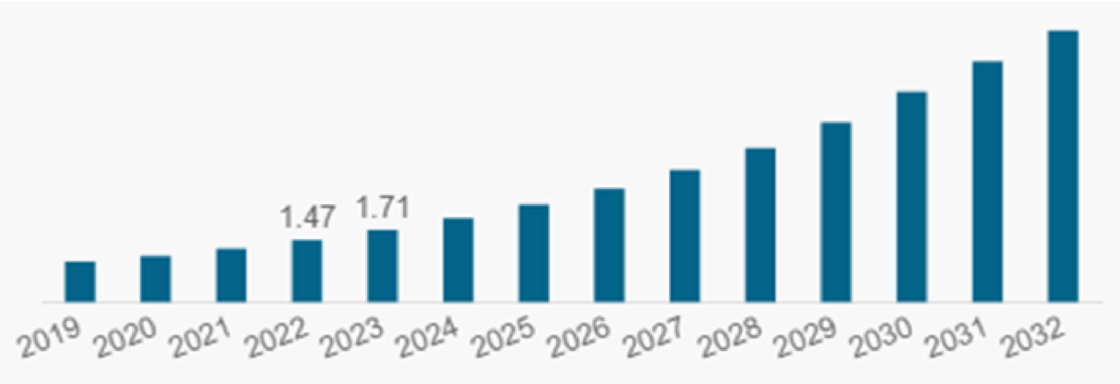
4/29/2024

1. Introduction

1.1 Background

In recent years, the world of retail transactions has undergone a significant transformation with the widespread adoption of self-checkout systems (SCO). Initially introduced in 1992, SCO stations have evolved to become ubiquitous in almost every grocery store. These kiosks offer numerous benefits, including reducing labor costs, speeding up customer checkout queues, and minimizing the store's checkout footprint. Projections indicate that the global self-checkout system market is poised for substantial growth, projected to escalate from $5.64 billion in 2024 to a staggering $18.01 billion by 2032, showcasing a compound annual growth rate (CAGR) of 15.6% during the forecast period (Fortune Business Insights). This exponential expansion underscores the pivotal role self-checkout systems play in reshaping the retail experience worldwide.

Figure 1. Noth America Self-Checkout System Market Size, 2019 - 2032 (USD Billion)



Note: Data pulled from Fortune Business Insights

1.2 Problem Statement

However, amidst this surge in implementation, a pressing concern looms over the integrity of self-checkout systems: the prevalence of intentional and non-intentional fraudulent activities that impede the expected speed and efficiency of the system's implementation. The question then arises: How can retail stores maximize the use of SCOs and enhance efficiency while addressing fraudulent activities?

1.3 Objectives

- Determine the optimal staffing level to support SCOs efficiently, minimizing labor costs while maintaining operational effectiveness.
- Implement strategies to maximize the utilization of SCOs, enhancing efficiency and throughput to improve overall store productivity and customer experience.

1.4 Scope and Limitations

This study scrutinizes the operational efficiency and efficacy of SCOs, concentrating on refining staffing requirements and enhancing system utilization. It explores factors pivotal to the seamless functioning of SCOs, including workflow optimization, technological integration, and user interface enhancements. While considering normal distribution estimates of fraud issues, both intentional and accidental fraud are examined, excluding concerns related to promotional items, barcode reading errors, or payment discrepancies. Furthermore, the study does not encompass analyses of customer behavior, staying focused solely on the operational aspects of SCOs.

2. Literature Review

Theft has been a major concern as retail stores go from a staffed checkout line to a self-checkout line. The paper *An anti-theft system based on the self-checkout* by Yuxuan et al. explores an advanced anti-theft system for self-checkout called Siemen's LOGO (2019, Yuxuan et al.). This system is equipped with powerful anti-theft technology including radio frequency detection, photoelectric counting, video monitoring and an anti-theft electric door. The system can count the items on the conveyor belt and matches the number of items left after the scanner to prevent the user from scanning a lower priced item instead of the item that is on the conveyor belt. The radio-frequency module is an effective double check of the scanner to make sure the labels match up. The magnetic detection module detects when an item is taken off the conveyor belt without having been scanned. When any suspicious event occurs, the employees are notified so they can handle the incident. A video camera records the scanning for review. The paper recommends a system for lowering theft rates (2019, Yuxuan et al.).

A study conducted by Nagul, R.R. titled *Grocery store -Optimizing waiting line times through simulation analysis* used a simulation program called SimQuick to study the dynamics of waiting in lines at grocery stores. In this simulation three shopping lines were used with a store entry and exit. In their simulation, each line had a clerk and bagger to help facilitate fast movement, and the simulation focused on 4 pm to 9 pm on a weeknight. During this time, about 180 people enter the store (Nagul, 2024). Their study found a mean cycle time of customers of about 10.3 minutes but suggested that opening just one more line would decrease this time by two minutes (Nagul, 2024).

A study done on with the Simul8 program, involving waiting lines was explored in the paper *Comparative Study in the problem-solving using service line queuing theory and Simul8* by Peralta et al. in 2012. The study discusses queuing theory which is a collection of mathematical models to determine the movement of people in lines and is a subject of interest in operations research. These models can take in different variables such as random events, dynamic phenomena, and other complex relationships (Peralta et al., 2012). The study advocates for discrete event simulation with Simul8 as a viable option for studying queuing theory. The results of their study on student service wait lines concluded that Simul8 was effective in helping them determine more effective queuing setup (Peralta et al., 2012). They found in certain setups that bottlenecks occurred and caused an increase in the amount of time students had to wait in line (Peralta et al., 2012). Peralta's study and results help validate our methods and tool selection of Simul8 software and that it can give meaningful results.

3. Methodology

3.1 Selection of Simulation Software

For this project, we use SIMUL8 to simulate complex retail scenarios for the self-checkout stations. The decision was based on several compelling features of SIMUL8:

- Discrete-Event Simulation: Key for accurately depicting the fluctuating nature of customer interactions in retail settings, SIMUL8 excels in handling the variability in customer arrivals and transaction times.
- Real-Time Analytics and Visualization: The capability of SIMUL8 to perform real-time adjustments and visualize outcomes on the fly is crucial for evaluating how different scenarios affect the system's efficiency, particularly in response to fraudulent activities.

This combination of functionalities makes SIMUL8 an indispensable tool for analyzing the nuances of self-checkout operations and understanding the broader impact of security breaches.

3.2 Data Analysis and Application

The foundational data for this simulation, sourced from the "Fraud Detection in Grocery Shopping Transactions" dataset on Kaggle, was rigorously analyzed to ensure its applicability:

- Statistical Analysis: Utilizing RStudio, we conducted an in-depth statistical review of the dataset to identify anomalies and validate the consistency of the fraud rate with established benchmarks in the retail sector.
- Utilization of Analyzed Data: Instead of integrating the entire dataset directly into the simulation, we extracted the critical metric of average fraud occurrence rate from our analysis. This rate was then applied to simulate the frequency of breakdowns at

checkout stations due to fraud, simplifying the model while focusing on the most impactful data.

3.3 Simulation Model Implementation

In the SIMUL8 environment, we used the statistically validated fraud occurrence rate to model potential disruptions.

Station Breakdowns Modeling: The simulation uses the fraud rate to determine the probability of operational disruptions at self-checkout stations, simulating the impact of fraud on the system. This strategic application of the fraud rate enhances the realism of the model, allowing us to explore effective strategies for mitigating fraud’s impact on operational efficiency and customer satisfaction.

This tailored approach enhances the simulation's efficiency and ensures it closely mirrors real-world operational challenges. By doing so, it provides a solid foundation for formulating strategies to boost system resilience against fraud and to ascertain the minimal number of human workers needed.

4. Model Development

4.1 Simulation Model Design

Our simulation utilizes detailed diagrams and flowcharts to map out the interactions and processes within the self-checkout system, each component designed to reflect actual retail operations:

1. Customer Arrival: We employ a non-homogeneous Poisson process to model customer arrivals, capturing fluctuating rates throughout the day. This approach effectively simulates the variations in customer inflow, with peak periods from 3 PM to close and lighter traffic earlier in the day.

2. Queue Management: The simulation ensures that customers experience a realistic average wait time of approximately one minute in line, aligning with observed queue times in typical retail settings.

3. Transaction Processing: At the self-checkout stations, transaction times are modeled using a normal distribution with a mean of two minutes and a standard deviation of

two minutes, capturing the expected variability in how long different transactions take.

4. Exit Flow: This component tracks customers as they complete their transactions and exit the system, providing an end-to-end view of the checkout process.

The configurations of these components are calibrated to mimic the unpredictability of retail operations, offering a solid base to analyze the impacts of various disruptions, particularly fraud incidents.

4.2 Optimization Strategies

The optimization aspect of our model focuses on resource allocation and minimizing the operational disruptions caused by fraud incidents:

1. Dynamic Staff Allocation: Utilizing an algorithm that dynamically assigns staff to checkout stations based on real-time demand and incident reports, we optimize the number of active registers. This strategy helps reduce queue lengths and wait times, enhancing customer satisfaction.

2. Fraud Incident Management: The model incorporates "if-then" decision rules and employs principles of queue theory to manage and mitigate the effects of fraud. Each fraud incident causes a disruption with an average repair time following a normal distribution (mean = 7 minutes, SD = 2 minutes). These parameters are crucial for simulating the downtime and its impact on checkout flow and customer wait times.

4.3 Diagrammatic Representation

The simulation model includes detailed visual diagrams that outline each step in the self-checkout process:

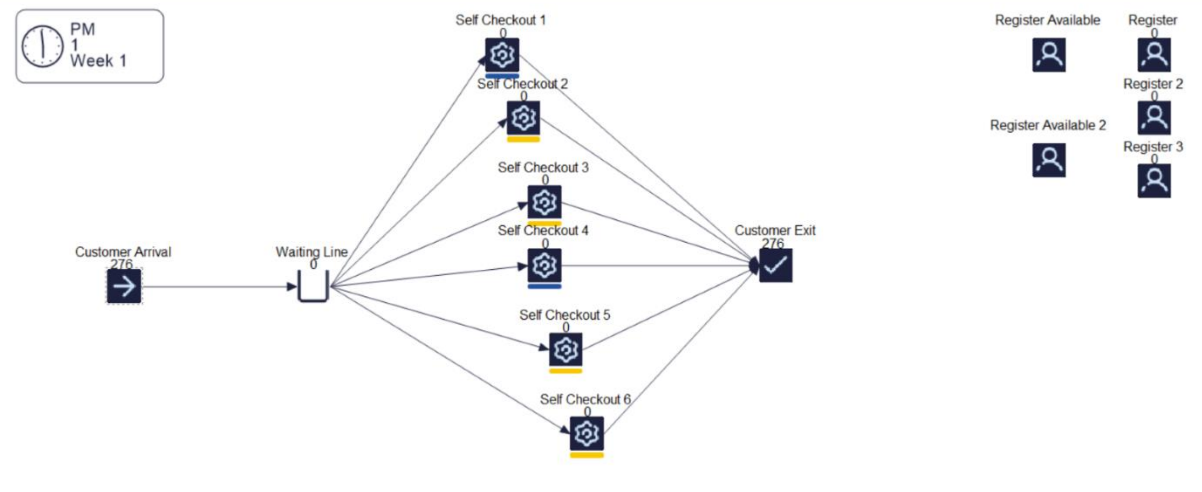
1. Batch Entry of Customers: Depicts how customers enter the system in groups based on daily shopper ranges observed between 200 to 300, reflecting realistic entry patterns into the store.

2. Progression to the Waiting Line: Shows the movement of customers from the entry points to the waiting lines, where they are queued for the next available checkout station.

3. Distribution to Checkout Stations: Demonstrates how customers are allocated to one of the six checkout stations for processing their transactions, showcasing the flow and distribution dynamics.

4. Exit from the System: Captures the final stage where customers complete their transactions and leave the system.

Figure 2. Screenshot of SIMUL8 Model



Additionally, the model illustrates the resource allocation for maintenance and repair activities at checkout stations. This visual representation helps highlight the operational strategy for when a checkout station experiences a breakdown due to fraud, which on average occurs every 58.62 minutes.

These enhancements and detailed visualizations not only aid in understanding the system dynamics but also provide a comprehensive framework for testing and improving the efficiency of self-checkout systems in high-volume retail environments. This robust model development ensures a thorough analysis of system performance and the development of actionable strategies to optimize operations and enhance customer satisfaction.

5. Results and Analysis

This comprehensive analysis explores the operational dynamics of self-checkout systems in a high-volume retail environment, focusing on how fraud detection downtime affects customer throughput and checkout efficiency. By leveraging extensive visual aids and model validation techniques, the study provides a nuanced view of performance across weekdays, Saturdays, and Sundays, alongside insights into the effectiveness of implemented strategies.

5.1 Model Validation

Validation Technique (Sensitivity Analysis): Changes in key input parameters, such as the frequency of fraud incidents and staff response times, were tested to assess the robustness of the model.

5.2 Findings from Model Validation

The simulation closely mirrors real-world operations, as demonstrated by the alignment of simulated data with historical benchmarks. This correlation validates the model's accuracy and the effectiveness of the adjustments based on sensitivity analysis and stakeholder feedback.

5.3 Detailed Performance Analysis

Weekday Results:

- Customer Exit Metrics: On average, 1700.2 customers processed transactions daily, with variability indicating fluctuations in customer throughput. Customers spent an average of 14.01 minutes in the system, with about 31.32% completing transactions in under 10 minutes.

- Register Utilization: Registers were utilized at 69.99% capacity, effectively managing high usage, and accommodating peak times.

- Self-Checkout Analysis: The average waiting time was 66%, with transaction processing occupying about 20% of operational time, pointing to high occupancy and potential bottlenecks.

- Queue Dynamics: The average queue size was around 3.5, suggesting moderate wait times but highlighting areas for improvement in queue management.

Weekend Results:

- Saturday Dynamics: An average of 222 customers completed transactions with a slight efficiency improvement over weekdays. Register utilization stood at 64.17%, and the average queue size dropped to 2.58, indicating potential for optimizing resource allocation during weekends.

- Sunday Dynamics: Customer numbers slightly increased to an average of 235.8, with the average time in the system reducing to 12.05 minutes. This day showed enhanced efficiency with 42.32% of transactions completed within 10 minutes and a register utilization of 62.92%.

Saturday and Sunday Comparisons: Despite lower utilization rates on weekends, strategic staffing adjustments maintained operational efficiency, particularly notable on Sundays with an increased transaction completion rate within the set time limit compared to Saturdays.

6. Discussion

6.1 Implications of Findings

The detailed findings from the simulation of self-checkout systems in a high-volume retail environment have significant implications for operational management and strategic decision-making:

1. Operational Efficiency: The consistency in customer throughput during weekdays and the efficiency improvements observed on weekends suggest that targeted staffing strategies and dynamic resource allocation can significantly enhance operational efficiency. Retailers might consider implementing flexible staffing schedules that align more closely with observed peak times and customer flow patterns to optimize labor costs and improve service levels.

2. Strategic Decision-Making: The effectiveness of fraud detection mechanisms during peak periods indicates that investing in advanced security technologies and training for staff could yield substantial returns in terms of reduced downtime and smoother customer experiences. Retailers should evaluate the cost-benefit of such investments, considering the potential increase in customer satisfaction and reduction in lost revenue due to fraud.

3. Customer Satisfaction: The data showing a significant percentage of transactions completed under the time limit, particularly on Sundays, highlights the importance of quick service to customer satisfaction. Retailers might explore strategies to replicate this efficiency throughout the week, leveraging technology solutions like mobile apps

or more sophisticated self-checkout interfaces to streamline transactions.

6.2 Unexpected Outcomes and Anomalies

1. Anomalies in Data: The unexpectedly high waiting times on Saturdays, despite lower overall customer volumes, suggest a possible misalignment between staff scheduling and actual customer arrival patterns. This anomaly could indicate the need for a deeper analysis of customer behavior on weekends or a review of current scheduling algorithms.

2. Implications for the Model: The discrepancy in waiting times could prompt a revision of the simulation model to better account for the variability in customer arrivals and potentially introduce more dynamic elements into the staffing algorithm. Adjusting the model to incorporate real-time data feeds could also enhance its responsiveness to sudden changes in customer flow.

3. Real-World Applications: For real-world applications, this finding underscores the importance of agility in operational planning. Retailers should consider systems that can adapt quickly to unexpected changes, such as deploying part-time staff on an on-call basis during unexpected peak periods or using predictive analytics to refine customer flow forecasts.

7. Conclusions and Recommendations

Downtime due to fraud is a major issue for big box retailers. In this simulation, the shopping dynamics of self-checkout customers and fraud detection were explored to gain insight into downtime due to fraud. The model emulated a similar configuration of the retailer Costco. Six checkout stations were used in the model, which had a waiting line and associates that were dynamically allocated to the stations as needed.

Fraud downtimes were taken from Kaggle dataset "Fraud Detection in Grocery Shopping Transactions" after analysis in R studio the effected downtime was 7 minutes with a standard deviated 2 minutes. The simulation was run in Sim8 simulation software. The simulation of weekdays found 1700.2 customers processed transactions daily, spent an average of 14.01 minutes, utilizing the registers 69.99% of the time. On Saturday, an average of 222 customers completed transactions with a register utilization of 64.17%, while on Sunday an average of 235.8 customers completed transactions with a register utilization rate of 62.92%. Based on the Simul8 result report, it is evident that the workers possess sufficient flexibility to manage potential additional tasks in response to various scenarios. Also, having three workers on shifts proves adequate for managing the six self-checkout stations.

The simulation validated the hypothesis that dynamically allocated staff, one during the day and two during the evening, and fraud detection mechanisms enhance the operation efficiency of the shopper throughput. Fraud detection mechanisms can reduce the shopping line downtime and have a significant impact on the shopper throughput.

Allocating resources to detection of fraud can help alleviate downtime impacts. The ability of a nearby associate to help the customer when an issue does arise is also effective in alleviating the downtime. Stores would be advised to have adequate staff on standby to handle issues as they occur. Stores are advised to invest in effective fraud detection methods and technologies. These will have a positive impact on the customer throughput and profits for the store.

Technologies that can actively and passively search for fraud would be highly recommended. These technologies can incorporate artificial intelligence, machine learning and computer vision, which are areas of research that should be explored to help with fraud detection. These technologies can have a positive impact on checkout times and customer throughput.

There are many opportunities for future simulation work for fraud detection for shopping lines. More people tend to shop at specific hours, 8 pm Tuesday is the least popular hour to shop and Saturday 10:00 am – 2:00 pm are the most popular hours to shop (Rodger, 2004). These surge and low shopper times can be integrated into the model to show the effects of surge shoppers to the store throughput.

Another consideration that could be integrated into a future model is the associate at the exit. Popular shops like Cosco have an associate checking the receipts of shoppers as they exit the store. These have been helpful in stopping fraud. The impact of this associate is likely to be positive for the model but may not affect customer throughput directly.

Simulations with a long-term focus can be explored. More variables and instances can be utilized to make the model more focused on a longer time scale. Seasonal shopping patterns could be used to determine trends and shopping patterns based on the time of year.

A final recommendation would be to conduct a comparative analysis of different checkout orientations and setups. This could give insight into whether one scheme is more effective than another. This can even be extended to different countries and cultures and if one handles them better than another.

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