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How Modified BCG Matrix-Based Product Portfolio Optimization Changes Consumer Purchase Behavior: Evidence from Vending Machine Transactions

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Abstract

Product portfolio optimization is essential in automated retail because vending machines operate under severe storage constraints, requiring every Stock Keeping Unit (SKU) to contribute effectively to overall sales performance. However, conventional portfolio management approaches, including the Boston Consulting Group (BCG) Matrix, rely on market-level indicators that are difficult to apply in vending machine environments where external market share data are unavailable. This study proposes a Modified BCG Matrix by replacing Relative Market Share with Relative Sales Performance (RSP) and Market Growth Rate with Sales Growth Trend (SGT) to enable SKU-level portfolio optimization using internal transaction data. A quantitative longitudinal design with an Interrupted Time Series (ITS) approach was employed using 167,018 valid transactions collected from 11 smart vending machines operating in Cikarang, Indonesia, between September 2025 and June 2026. The Modified BCG Matrix guided operational decisions, including facing allocation, replenishment priority, product rotation, replacement, and product delisting. The implementation reduced the active product portfolio from 253 to 146 SKUs (42.3%), increased average daily transaction volume by 28.53%, increased average daily sales revenue by 22.19%, and produced statistically significant immediate intervention effects based on segmented regression analysis. These findings demonstrate that data-driven product portfolio optimization not only improves operational efficiency and sales performance but also reshapes consumer purchase behavior. This study extends the application of the traditional BCG Matrix from the Strategic Business Unit (SBU) level to the SKU level and provides an evidence-based decision-support framework for automated retail portfolio management.

Keywords:
Modified BCG Matrix; Product Portfolio Optimization; Consumer Purchase Behavior; Interrupted Time Series; Smart Vending Machine; Retail Analytics.

1. INTRODUCTION

The rapid adoption of digital payment systems has accelerated the transformation of conventional retail toward cashless and automated retail environments, enabling more seamless consumer transactions and data-driven operational management (Kumoro & Rachmat, 2022; Kumoro et al., 2024). These technological developments have shifted managerial decision-making from intuition-based approaches toward evidence-based strategies supported by continuously generated operational data (Laudon & Laudon, 2004; Davis & Olson, 1984). Consequently, retail businesses are increasingly capable of understanding consumer purchasing patterns, monitoring inventory conditions, and optimizing operational performance through data analytics rather than relying solely on managerial experience (Li et al., 2024; Awamleh et al., 2024).

One of the fastest-growing applications of automated retail is the smart vending machine. Modern vending machines have evolved beyond simple product dispensing devices into intelligent unattended retail platforms capable of operating continuously without on-site personnel. Equipped with digital payment systems, telemetry technology, cloud-based inventory management, and real-time monitoring capabilities, modern vending machines automatically record every transaction, including purchase time, machine location, product selection, payment method, selling price, and transaction status (Ding et al., 2021; Nemoto & Hiraishi, 2024). These automatically generated transaction records provide objective behavioral data that enable retailers to analyze consumer purchasing patterns, evaluate product performance, optimize replenishment decisions, and improve operational efficiency at a much finer level of detail than conventional retail environments (Power & Heavin, 2017; Li et al., 2024). Consequently, smart vending machines have emerged not only as automated sales channels but also as valuable data-driven retail laboratories for evaluating strategic interventions under real operating conditions.

Despite these technological advancements, managing product portfolios remains a major operational challenge in vending machine retail. Unlike supermarkets or convenience stores, vending machines operate under severe physical capacity constraints, allowing only a limited number of Stock Keeping Units (SKUs) to be displayed at any given time. Consequently, every product allocated to the machine directly competes for scarce shelf space, making assortment decisions critical to both operational efficiency and sales performance. Retaining consistently low-performing products may reduce the availability of high-demand items, increase stock-out risks, and limit the effective utilization of vending machine capacity, ultimately leading to lost sales opportunities and lower operational efficiency (Czerniachowska et al., 2022; Grzybowska et al., 2020). Therefore, effective product portfolio management has become an essential managerial strategy for maximizing the performance of automated retail systems operating under limited-capacity conditions.

Beyond operational efficiency, product portfolio decisions also influence consumer purchase behavior. Purchasing decisions are shaped not only by consumers' intrinsic preferences but also by characteristics of the retail environment, including product availability, assortment composition, product visibility, and ease of access. In automated retail settings such as smart vending machines, where purchase decisions are typically made quickly under limited information and restricted product choices, the composition of the available assortment becomes particularly important. A well-optimized product portfolio increases the likelihood that consumers encounter products matching their preferences, whereas excessive numbers of consistently low-performing products may reduce the visibility and availability of high-demand items. Consequently, product assortment functions not only as an inventory management decision but also as a form of retail choice architecture that shapes consumer purchase behavior by modifying the purchasing environment without restricting consumers' freedom of choice. Understanding this behavioral mechanism is therefore essential for developing data-driven product portfolio optimization strategies capable of improving both consumers purchasing outcomes and sales performance.

Product portfolio optimization has long been recognized as an important strategy for improving retail performance. Among the most widely used portfolio management tools, the Boston Consulting Group (BCG) Matrix classifies products based on Relative Market Share and Market Growth Rate, providing strategic guidance for resource allocation across business units. However, these dimensions were originally developed for evaluating Strategic Business Units (SBUs) rather than individual Stock Keeping Units (SKUs), making their direct application to vending machine operations problematic (García-Vidal et al., 2023). In automated retail environments, product-level market share is rarely available because vending machine operators typically rely on internal transaction records instead of external market statistics. Consequently, conventional BCG classifications cannot adequately capture the operational characteristics of vending machine retail, where product decisions must be based on actual sales performance and observed sales trends rather than market-level indicators.

Although previous studies have investigated product assortment optimization, vending machine operations, and consumer purchasing behavior, these research streams have largely developed independently. Existing studies on vending machines have primarily focused on demand forecasting, inventory optimization, recommendation systems, or consumer food choices, whereas portfolio management studies have generally emphasized strategic product classification without evaluating its operational and behavioral impacts under real retail conditions. Furthermore, conventional applications of the BCG Matrix remain dependent on Relative Market Share and Market Growth Rate, limiting their applicability at the Stock Keeping Unit (SKU) level where external market share data are typically unavailable. Consequently, limited empirical evidence exists on how a data-driven product portfolio optimization strategy can simultaneously improve consumer purchase behavior and sales performance using actual transaction records from automated retail environments. Accordingly, addressing these gaps requires an integrated analytical framework that combines SKU-level product portfolio classification, operational optimization, consumer purchase behavior analysis, and longitudinal intervention evaluation based on real-world transaction data.

To address these limitations, this study proposes a Modified BCG Matrix that replaces the traditional BCG dimensions with Relative Sales Performance (RSP) and Sales Growth Trend (SGT), enabling product portfolio classification at the Stock Keeping Unit (SKU) level using internal transaction data. The resulting portfolio classifications serve as the basis for operational decisions, including facing allocation, replenishment prioritization, product rotation, replacement, and product delisting. Rather than functioning solely as a descriptive portfolio analysis tool, the proposed framework directly supports managerial decision-making by translating product classifications into actionable portfolio optimization strategies suitable for automated retail environments.

Beyond proposing a new portfolio classification framework, this study also evaluates whether product portfolio optimization produces measurable changes in consumer purchase behavior and sales performance. To achieve this objective, the study employs Interrupted Time Series (ITS) analysis using segmented regression to assess intervention effects based on longitudinal transaction records collected before and after portfolio optimization. Compared with conventional before-and-after analyses, ITS provides a more rigorous approach for distinguishing intervention effects from underlying temporal trends, thereby strengthening causal inference in operational evaluations (Bernal et al., 2017; Wagner et al., 2002).

Accordingly, this study aims to evaluate the effectiveness of a Modified BCG Matrix-based product portfolio optimization strategy in improving consumer purchase behavior and sales performance within an automated retail environment. Using transaction data collected from 11 smart vending machines operating in South Cikarang, Indonesia, this study integrates SKU-level portfolio classification, operational decision-making, consumer purchase behavior analysis, and Interrupted Time Series (ITS) evaluation into a unified analytical framework. The study makes three primary contributions. First, it extends the traditional BCG Matrix by introducing Relative Sales Performance (RSP) and Sales Growth Trend (SGT) as alternative dimensions for SKU-level portfolio analysis. Second, it demonstrates how Interrupted Time Series analysis can be applied to evaluate operational interventions in automated retail using real-world transaction data. Third, it provides empirical evidence that data-driven product portfolio optimization can simultaneously enhance consumer purchasing outcomes and sales performance, thereby contributing to the growing literature on automated retail, retail analytics, consumer behavior, and data-driven decision-making.

2. RESEARCH METHOD

2.1. Research Design

This study employed a quantitative longitudinal quasi-experimental research design to evaluate the effectiveness of a Modified BCG Matrix-based product portfolio optimization strategy in improving consumer purchase behavior and sales performance within an automated retail environment. The intervention consisted of implementing a data-driven product portfolio optimization strategy across smart vending machines based on SKU classifications generated by the Modified BCG Matrix. Because the intervention was implemented simultaneously across all vending machines without an untreated control group, a quasi-experimental Interrupted Time Series (ITS) design was considered the most appropriate analytical approach. ITS is widely recognized as one of the strongest quasi-experimental methods for evaluating organizational and operational interventions when randomized controlled experiments are impractical, as it enables the estimation of both immediate intervention effects (level changes) and long-term effects (trend changes) while accounting for underlying temporal patterns (Bernal et al., 2017; Wagner et al., 2002). To ensure robust statistical inference, the segmented regression models were estimated using Newey–West heteroskedasticity and autocorrelation consistent (HAC) standard errors, following diagnostic tests that indicated the presence of serial correlation and heteroskedasticity (Newey & West, 1987). The overall research framework consisted of five sequential stages: transaction data acquisition, data preprocessing, SKU performance measurement, Modified BCG Matrix-based portfolio optimization, and intervention evaluation using Interrupted Time Series analysis. The complete research framework is presented in Figure 1.

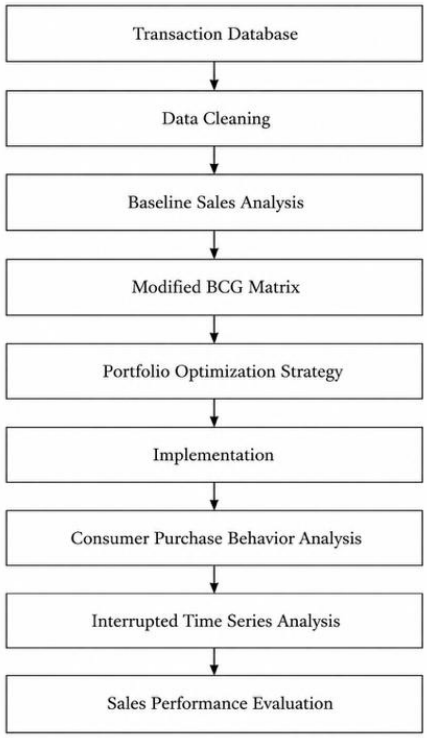

Figure 1. Overall Research Framework

2.2. Research Setting and Data Collection

This study was conducted using operational transaction data collected from 11 smart vending machines located in South Cikarang, Bekasi Regency, West Java, Indonesia. The vending machines were installed across industrial companies, vocational education institutions, and employee dormitories, representing real-world automated retail environments with diverse consumer purchasing behavior.

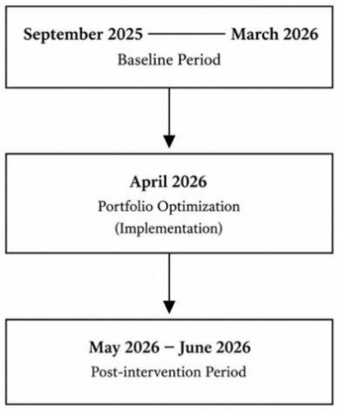

Figure 2. Distribution of the Research Timeline

The dataset covered the period from September 2025 to June 2026 and initially consisted of 186,307 transaction records extracted from the vending machine management system. Each record included transaction date, vending machine identification, Stock Keeping Unit (SKU), product information, payment status, dispense status, quantity sold, selling price, and payment method. After removing failed payment and unsuccessful dispensing transactions, 167,018 valid transactions were retained for analysis.

For product portfolio classification, the baseline period was defined as September 2025 to March 2026, during which 253 active SKUs were evaluated using Relative Sales Performance (RSP) and Sales Growth Trend (SGT). Portfolio optimization was implemented in April 2026, which was treated as a wash-in period because product rotation, facing adjustment, replenishment prioritization, replacement, and SKU rationalization were introduced progressively. Therefore, only transactions recorded from May to June 2026 were used as the post-intervention period in the Interrupted Time Series (ITS) analysis.

Table 1. Characteristics of the Research Dataset

Variable	Description
Study Area	South Cikarang, Bekasi Regency, Indonesia
Number of Vending Machines	11
Operational Locations	Manufacturing companies, vocational dormitories, university campus
Observation Period	September 2025 – June 2026
Initial Transactions	186,307
Valid Transactions	167,018
Baseline Period	September 2025 – March 2026
Implementation Period	Apr-26
Post-intervention Period	May – June 2026
Unit of Analysis	Stock Keeping Unit (SKU)
Number of SKUs (Baseline)	253
Number of SKUs (Post-optimization)	146

2.3. Data Pre-processing

Prior to analysis, the transaction dataset underwent data pre-processing to improve data quality and ensure analytical reliability. Transactions with failed payments, unsuccessful product dispensing, duplicate records, and incomplete information were removed from the dataset, while product names and Stock Keeping Units (SKUs) were standardized to ensure consistent product identification across all vending machines (Power & Heavin, 2017).

The cleaned transaction data were subsequently aggregated into daily SKU-level sales records, which served as the basis for calculating Relative Sales Performance (RSP), Sales Growth Trend (SGT), and consumer purchase behavior indicators. The resulting dataset was then used for Modified BCG Matrix classification and Interrupted Time Series (ITS) analysis.

Table 2. Data Pre-processing Procedure

Step	Description
Data extraction	Export transaction records from the vending machine management system
Data cleaning	Remove failed payment, failed dispensing, duplicate, and incomplete records
Data standardization	Standardize SKU codes and product names
Data aggregation	Aggregate transactions into daily SKU-level sales data
Final dataset	Prepare data for Modified BCG Matrix and ITS analysis

2.4. SKU Performance Measurement

To evaluate product performance, each Stock Keeping Unit (SKU) was measured using two key indicators: Relative Sales Performance (RSP) and Sales Growth Trend (SGT). Relative Sales Performance was calculated by comparing the total sales of each SKU with the average sales of all active SKUs during the baseline period, reflecting the relative contribution of each product to overall sales performance. Sales Growth Trend measured the percentage change in sales between consecutive observation periods, indicating whether product demand was increasing, stable, or declining over time.

These two indicators were selected because they can be derived directly from internal transaction records without requiring external market share information, making them more suitable for vending machine operations than conventional BCG Matrix indicators (Ding et al., 2021). The calculated RSP and SGT values were subsequently used as the basis for product portfolio classification.

Table 3. SKU Performance Indicators

Indicator	Description
Relative Sales Performance (RSP)	Relative sales contribution of each SKU compared with the average sales of all active SKUs during the baseline period
Sales Growth Trend (SGT)	Percentage change in SKU sales between observation periods, indicating the direction of sales growth

2.5. Modified BCG Matrix Classification

The Modified BCG Matrix was used to classify the performance of each Stock Keeping Unit (SKU) based on Relative Sales Performance (RSP) and Sales Growth Trend (SGT). Unlike the conventional BCG Matrix, which relies on Relative Market Share and Market Growth Rate, the proposed framework utilizes internal transaction data, making it more suitable for vending machine operations where external market share information is unavailable (García-Vidal et al., 2023).

Each SKU was assigned to one of four portfolio categories according to its RSP and SGT values: Star (high RSP and positive SGT), Cash Cow (high RSP and negative SGT), Question Mark (low RSP and positive

SGT), and Dog (low RSP and negative SGT). This classification provided a systematic basis for identifying products that should be maintained, monitored, improved, or removed from the product portfolio.

The classification results served as the foundation for subsequent portfolio optimization by supporting managerial decisions on facing allocation, replenishment priority, product rotation, replacement, and product delisting within a data-driven decision support framework (Power & Heavin, 2017). The complete classification criteria and corresponding operational strategies are summarized in Table 4.

Table 4. Product Portfolio Classification and Recommended Strategies

Quadrant	Performance Characteristics	Recommended Strategy
Star	High RSP, Positive SGT	Increase facing allocation, prioritize replenishment, maintain product availability
Cash Cow	High RSP, Negative SGT	Maintain portfolio position and monitor sales performance
Question Mark	Low RSP, Positive SGT	Product rotation, promotional support, and performance monitoring
Dog	Low RSP, Negative SGT	Replacement, delisting, or portfolio rationalization

2.6. Product Portfolio Optimization Strategy

Following SKU classification, the Modified BCG Matrix was implemented as a decision-support framework for optimizing the product portfolio (Power & Heavin, 2017; García-Vidal et al., 2023). The classification results were translated into operational actions, including facing allocation, replenishment priority, product rotation, replacement, and product delisting. These strategies aimed to improve shelf utilization by allocating limited vending machine capacity to products with stronger sales performance while reducing the presence of consistently underperforming SKUs.

The optimization strategy was implemented during April 2026 as the intervention period across all vending machines. High-performing products received greater shelf exposure and replenishment priority, while low-performing products were selectively replaced or removed from the portfolio (Marinelli et al., 2021; Czerniachowska et al., 2022). This implementation reduced the number of active SKUs from 253 to 146 and established the operational intervention evaluated in the subsequent consumer purchase behavior and Interrupted Time Series analyses.

Table 5. Product Portfolio Optimization Strategy Based on the Modified BCG Matrix

Portfolio Category	Portfolio Characteristics	Operational Strategy
Star	High RSP and positive SGT	Increase facing allocation and prioritize replenishment
Cash Cow	High RSP and negative SGT	Maintain product assortment and monitor performance
Question Mark	Low RSP and positive SGT	Product rotation and selective retention
Dog	Low RSP and negative SGT	Product replacement and delisting

2.7. Consumer Purchase Behavior Measurement

Consistent with the research objective, consumer purchase behavior was operationalized into three observable transaction-based indicators: daily transaction frequency, purchase concentration, and product preference. Rather than relying on survey responses or self-reported measures, this study assessed actual purchasing behavior using observed transaction records collected before and after the implementation of the product portfolio optimization strategy. Daily transaction frequency represented the total number of successful transactions per day, purchase concentration reflected the distribution of purchases across SKUs and product categories, while product preference was assessed through changes in the sales proportion of high-performing products following portfolio optimization.

These indicators were selected because changes in product assortment and product availability can influence consumers' purchasing decisions in automated retail environments (Marinelli et al., 2021; Perfetti et al., 2025). The measured behavioral outcomes were subsequently compared between the pre-intervention and post-intervention periods using Interrupted Time Series (ITS) analysis.

Table 6. Consumer Purchase Behavior Indicators

Indicator	Description
Daily transaction frequency	Total number of successful transactions per day
Purchase concentration	Distribution of purchases across SKUs and product categories

Product preference	Changes in the sales proportion of high-performing products following portfolio optimization

2.8. Interrupted Time Series Analysis

Interrupted Time Series (ITS) analysis with segmented regression was employed to evaluate the impact of the Modified BCG Matrix-based product portfolio optimization strategy on consumer purchase behavior and sales performance. ITS is widely recognized as one of the most robust quasi-experimental approaches for assessing intervention effects when randomized controlled experiments are not feasible because it estimates both immediate changes in outcome levels and changes in post-intervention trends while accounting for underlying temporal patterns (Bernal et al., 2017; Wagner et al., 2002).

The intervention was implemented in April 2026 following the completion of the Modified BCG Matrix classification and portfolio optimization process. Because April represented a transition period during which facing adjustment, replenishment prioritization, product rotation, replacement, and SKU rationalization were progressively introduced, it was treated as a wash-in period. Accordingly, the observation period was divided into three phases: the baseline period (September 2025–March 2026), the implementation period (April 2026), and the post-intervention period (May–June 2026).

The segmented regression model evaluated changes in consumer purchase behavior, represented by transaction volume, and sales performance, represented by sales revenue. To ensure reliable statistical inference, the regression model was subsequently evaluated using residual diagnostic tests. When autocorrelation or heteroscedasticity was detected, Newey–West heteroskedasticity and autocorrelation consistent (HAC) standard errors were applied to obtain robust parameter estimates (Newey & West, 1987).

Table 7. Variables Used in the Interrupted Time Series Analysis

Variable	Description
Time	Sequential monthly observation period
Intervention	Dummy variable indicating pre- and post-implementation periods
Post-intervention Trend	Interaction between time and intervention period
Transaction Volume	Monthly number of successful transactions
Sales Revenue	Monthly sales revenue generated by the vending machine network

2.9. Statistical Analysis and Diagnostic Tests

All statistical analyses were performed using Python (statsmodels package). Descriptive statistics were first used to summarize SKU performance, portfolio composition, consumer purchase behavior, and sales performance before and after the intervention. The effects of the portfolio optimization strategy were subsequently evaluated using segmented regression within the Interrupted Time Series (ITS) framework.

To ensure the validity of the regression model, residual diagnostic tests were conducted prior to interpreting the intervention effects. Serial correlation was assessed using the Durbin–Watson statistic and the Ljung–Box test, while heteroskedasticity was evaluated using the Breusch–Pagan test. Because the diagnostic results indicated the presence of autocorrelation and heteroskedasticity, the final ITS model was estimated using Newey–West heteroskedasticity and autocorrelation consistent (HAC) standard errors, which provide robust statistical inference without altering the regression coefficients (Newey & West, 1987). Statistical significance was determined at a 5% significance level ($p < 0.05$).

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Dataset Overview

The final analytical dataset consisted of 167,018 valid transactions collected from 11 smart vending machines operating in South Cikarang, Bekasi Regency, Indonesia, between September 2025 and June 2026. Following the data pre-processing procedure, only transactions with successful payment and successful product dispensing were retained, ensuring that the dataset accurately represented actual consumer purchasing behavior. During the baseline period (September 2025–March 2026), 253 active Stock Keeping Units (SKUs) were evaluated using the Modified BCG Matrix. After the portfolio optimization strategy was implemented in April 2026, the active product portfolio was reduced to 146 SKUs, representing a 42.3% reduction in the overall assortment.

Figure 3 illustrates the overall change in the product portfolio before and after optimization. The reduction in the number of active SKUs reflects the portfolio rationalization process, in which low-performing products were selectively removed while greater shelf capacity was allocated to products with stronger sales performance. This optimized portfolio served as the basis for the subsequent analyses of SKU classification, consumer purchase behavior, and Interrupted Time Series (ITS).

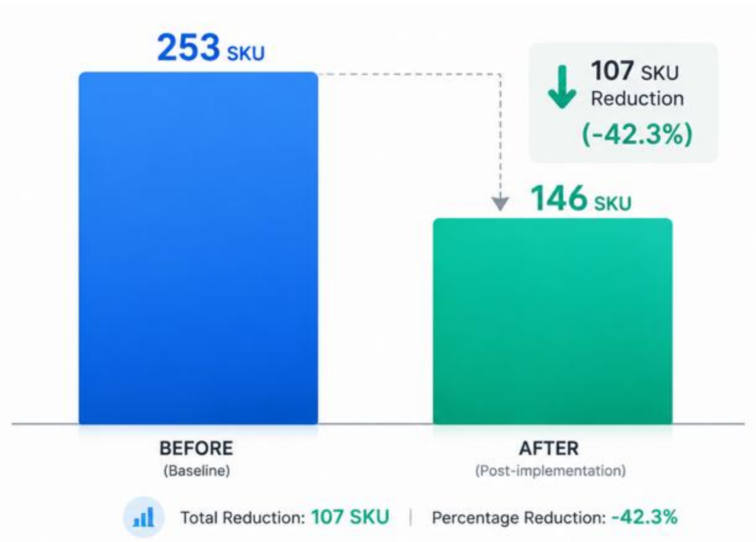

Figure 3. Overview of the Product Portfolio Before and After Optimization

3.1.2. Modified BCG Matrix Classification

The Modified BCG Matrix was applied to classify 253 active Stock Keeping Units (SKUs) into four portfolio categories based on Relative Sales Performance (RSP) and Sales Growth Trend (SGT) during the baseline period (September 2025–March 2026). The distribution of SKUs across the four portfolio quadrants is presented in Figure 4, while the numerical summary is provided in Table 8.

Table 8. Distribution of Stock Keeping Units Across the Modified BCG Matrix

Portfolio Category	Number of SKUs	Percentage
Star	29	11.46%
Cash Cow	11	4.35%
Question Mark	94	37.15%
Dog	119	47.04%
Total	253	100.00%

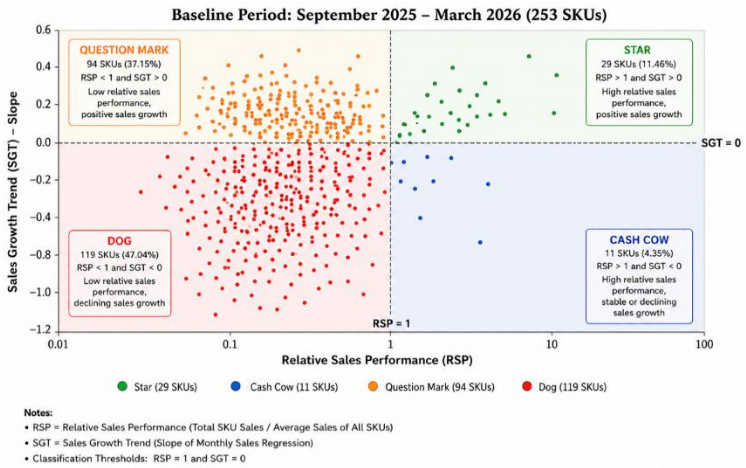

Figure 4. Modified BCG Matrix Classification of 253 Stock Keeping Units (SKUs)

The classification results indicate that the portfolio was dominated by Dog products, accounting for 119 SKUs (47.04%), followed by Question Mark products with 94 SKUs (37.15%). In contrast, Star products represented 29 SKUs (11.46%), whereas Cash Cow products accounted for only 11 SKUs (4.35%). Overall, approximately 84% of the portfolio consisted of products with relatively low sales performance (Dog and Question Mark), while only about 16% belonged to the high-performing categories (Star and Cash Cow).

Overall, the classification shows that Dog and Question Mark products accounted for the majority of the portfolio before optimization, whereas Star and Cash Cow products represented only a small proportion of the active SKUs. These classification results served as the basis for the subsequent product portfolio optimization.

3.1.3. Product Portfolio Optimization

Based on the Modified BCG Matrix classification, the product portfolio optimization strategy was implemented to improve the allocation of limited vending machine capacity by prioritizing high-performing products and rationalizing underperforming Stock Keeping Units (SKUs). Rather than treating all products equally, the optimization process translated the portfolio classification into operational decisions regarding facing allocation, replenishment priority, product rotation, replacement, and delisting. These strategies were implemented during the intervention period in April 2026 with the objective of increasing product availability for high-demand products while reducing the shelf space occupied by products with persistently low sales performance.

The implementation resulted in a substantial restructuring of the product portfolio. The total number of active SKUs was reduced from 253 during the baseline period to 146 following portfolio optimizations, representing a 42.3% reduction in the overall product assortment. This rationalization was achieved primarily through the removal of consistently underperforming products classified as Dogs, while retaining high-performing products and selectively maintaining products with future growth potential. At the same time, additional facing capacity and replenishment priority were allocated to Star products to improve product availability and reduce stock-out occurrences during daily operations.

Table 9. Product Portfolio Before and After Optimization

Portfolio Indicator	Baseline	After Optimization	Change
Total Active SKUs	253	146	-107
SKU Reduction	–	–	42.3%
Portfolio Strategy	Conventional	Modified BCG Matrix	Implemented

Following implementation, the number of active SKUs decreased from 253 to 146, representing a 42.3% reduction in the product assortment. The optimized portfolio was subsequently used to evaluate changes in consumer purchase behavior and sales performance. Consequently, the optimized portfolio provided greater opportunities for high-demand products to remain available between replenishment cycles while reducing the operational burden associated with maintaining slow-moving inventory. This strategic reallocation established the operational mechanism through which the Modified BCG Matrix was expected to influence consumer purchasing behavior and improve sales performance, which are evaluated in the subsequent sections.

3.1.4. Consumer Purchase Behavior

To evaluate the behavioral impact of the Modified BCG Matrix-based product portfolio optimization strategy, consumer purchase behavior was analyzed by comparing actual transaction records before and after the intervention. Rather than relying on self-reported survey responses, this study employed automatically recorded transaction data generated by the vending machine management system, allowing behavioral changes to be assessed under real operational conditions. The comparison focused on average daily transaction volume and average daily sales revenue, which represent the intensity of purchasing activity following the implementation of the optimized product portfolio.

Table 10. Changes in Consumer Purchase Behavior Before and After Portfolio Optimization

Consumer Behavior Indicator	Before Optimization	After Optimization	Change	Interpretation
Average Daily Transactions	498.58	640.84	+28.53%	Higher purchasing activity after portfolio optimization
Average Daily Sales Revenue (IDR)	2,869,832	3,506,705	+22.19%	Increased daily sales performance
Observation Days	212	61	–	Based on actual operating days
Valid Transactions	105,700	39,091	–	Successful payment and successful dispense only

Note: April 2026 was treated as the implementation (wash-in) period and was therefore excluded from the before-and-after comparison.

The results demonstrate a substantial improvement in consumer purchasing activity after the intervention. As presented in Table 10, the average number of daily transactions increased from 498.58 transactions per day during the baseline period to 640.84 transactions per day following portfolio optimization, representing an increase of 28.53%. Similarly, the average daily sales revenue increased from IDR 2,869,832 to IDR 3,506,705, equivalent to an improvement of 22.19%. These findings indicate that optimizing the product portfolio did not reduce purchasing opportunities despite decreasing the number of active SKUs from 253 to 146. Instead, reallocating limited vending machine capacity toward higher-performing products increased product availability and encouraged greater purchasing activity among consumers.

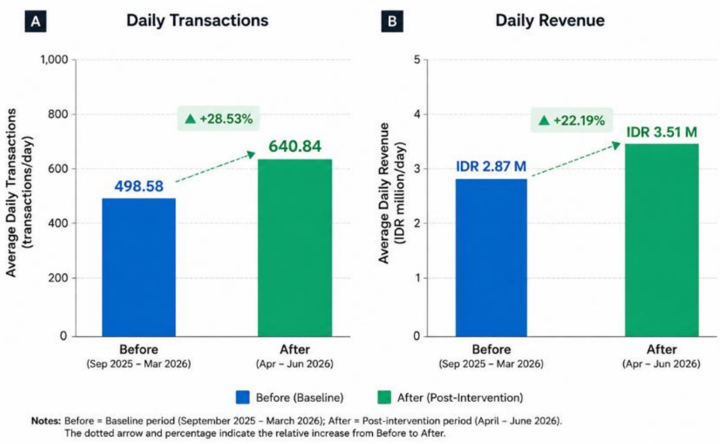

Figure 5. Changes in Average Daily Transactions and Daily Sales Revenue Before and After Portfolio Optimization

The observed improvements suggest that the Modified BCG Matrix-based optimization strategy influenced consumer purchasing behavior by reshaping the available product assortment rather than merely reducing the number of products offered. The elimination of consistently underperforming SKUs created additional capacity for high-demand products, thereby improving product availability and reducing the likelihood of stock-out events. Consequently, consumers were more likely to encounter preferred products at the point of purchase, resulting in increased transaction frequency and higher daily sales revenue. These findings provide behavioral evidence that portfolio optimization can enhance consumer purchasing activity while simultaneously improving operational efficiency, thereby establishing the behavioral mechanism through which the intervention contributed to improved sales performance.

3.1.5. Interrupted Time Series Analysis

To determine whether the observed improvements in consumer purchasing activity were attributable to the implementation of the Modified BCG Matrix-based product portfolio optimization strategy rather than natural temporal variation, an Interrupted Time Series (ITS) analysis with segmented regression was conducted. The intervention was defined as the implementation of the portfolio optimization strategy in April 2026, while April itself was treated as a wash-in period and excluded from the estimation to minimize potential implementation bias. Consequently, the baseline period consisted of September 2025–March 2026, whereas the post-intervention period covered May–June 2026.

Figure 6 illustrates the daily transaction volume before and after the portfolio optimization intervention. During the baseline period, transaction volume exhibited a relatively stable upward trend, followed by an immediate increase after the implementation period. Although normal day-to-day fluctuations remained evident, transaction levels consistently remained higher during the post-intervention period despite the reduction in the number of active Stock Keeping Units (SKUs) from 253 to 146. The upward shift in the segmented regression line suggests an immediate improvement in consumer purchasing activity following portfolio optimization.

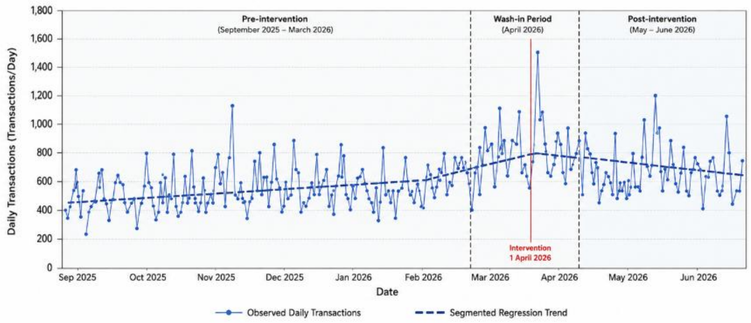

Figure 6. Interrupted Time Series of Daily Transactions Before and After Portfolio Optimization

To verify whether the observed changes were statistically significant, segmented regression models were estimated using Ordinary Least Squares (OLS), Generalized Least Squares with autoregressive correction (GLSAR), and Newey–West Heteroskedasticity and Autocorrelation Consistent (HAC) estimation. Diagnostic testing identified the presence of autocorrelation and heteroskedasticity; therefore, the Newey–West HAC estimator was adopted as the primary model for statistical inference because it provides robust standard errors while preserving unbiased coefficient estimates.

The segmented regression results, presented in Table 11, confirm that the portfolio optimization strategy produced a statistically significant immediate improvement in consumer purchasing activity. The intervention increased daily transaction volume by approximately 187 transactions ($p = 0.030$) and daily sales revenue by approximately IDR 1.08 million ($p = 0.023$). Although the estimated post-intervention trend changes were not statistically significant, the positive level changes indicate that the intervention generated an immediate operational improvement beyond the underlying baseline trend.

Table 11. Interrupted Time Series Results Using Segmented Regression

Outcome	Model	Level Change (β)	p-value	Trend Change (β)	p-value
Daily Transactions	Newey–West HAC	187.27.00	0.030	-1.62	0.074
Daily Revenue (IDR)	Newey–West HAC	1,081,245	0.023	-8,291	0,109
Average Transaction Value (IDR)	Newey–West HAC	133.60	0,225	02.26	0.054

Note: Newey–West HAC estimates are reported because diagnostic testing identified autocorrelation and heteroscedasticity in the residuals. This estimator provides robust standard errors for statistical inference.

Overall, the ITS findings complement the descriptive analysis presented in the previous section, where average daily transaction volume increased by 28.53% and average daily sales revenue increased by 22.19% following portfolio optimization. These results provide robust empirical evidence that the Modified BCG Matrix-based portfolio optimization strategy effectively improved consumer purchasing behavior and sales performance within the vending machine network.

3.1.6. Robustness Checks

To assess the robustness of the Interrupted Time Series (ITS) estimates, residual diagnostic tests were conducted to evaluate whether the assumptions underlying the segmented regression model were satisfied. Residual autocorrelation was examined using the Durbin–Watson statistic and the Ljung–Box test, while heteroskedasticity was assessed using the Breusch–Pagan test.

The diagnostic results, summarized in Table 12, indicate the presence of both autocorrelation and heteroskedasticity in the regression residuals. These findings suggest that the assumptions required for conventional Ordinary Least Squares (OLS) estimation were violated. Consequently, the Newey–West Heteroskedasticity and Autocorrelation Consistent (HAC) estimator was adopted as the final estimation method because it provides robust standard errors while preserving unbiased regression coefficient estimates.

Table 12. Diagnostic Tests of the Interrupted Time Series Model

Diagnostic Test	Purpose	Result	Decision
Durbin–Watson	Detect first-order autocorrelation	Autocorrelation detected	HAC estimation applied
Ljung–Box Test	Detect residual serial correlation	Significant	HAC estimation applied
Breusch–Pagan Test	Detect heteroscedasticity	Significant	HAC estimation applied
Newey–West HAC	Robust covariance estimation	Adopted as final model	Final inference based on HAC

Note: Final statistical inference was based on the Newey–West HAC estimator because residual diagnostics indicated violations of classical regression assumptions.

Overall, the robustness checks confirm that the reported intervention effects are not sensitive to violations of classical regression assumptions. Therefore, the statistical conclusions regarding the effectiveness of the Modified BCG Matrix-based portfolio optimization strategy can be considered reliable.

3.2. Discussion

3.2.1. Product Portfolio Optimization Improves Sales Performance

The results demonstrate that optimizing the product portfolio using the Modified BCG Matrix improved sales performance despite a substantial reduction in the number of active Stock Keeping Units (SKUs). Rather than expanding product variety, the optimization strategy concentrated limited vending machine capacity on products with stronger sales performance and higher growth potential. This finding suggests that effective assortment management depends more on allocating space to high-performing products than on maximizing the number of products offered, particularly in retail environments with severe space constraints.

One explanation for this improvement is that removing consistently low-performing products increased the availability and shelf exposure of high-demand products. Previous studies have shown that effective assortment optimization and shelf-space allocation improve product availability and operational efficiency by reducing stock-out risk and utilizing limited retail capacity more effectively (Czerniachowska et al., 2022; Marinelli et al., 2021). Similarly, García-Vidal et al. (2023) argued that portfolio management should prioritize products that contribute the greatest value rather than maintaining a large number of low-performing items. The present findings extend this perspective by demonstrating that the same principle can be successfully implemented at the Stock Keeping Unit (SKU) level using internal transaction data rather than conventional market share indicators.

The findings also support the application of the Modified BCG Matrix as a practical decision-support tool for automated retail operations. Unlike the conventional BCG Matrix, which evaluates Strategic Business Units (SBUs), the proposed framework replaces Relative Market Share and Market Growth Rate with Relative Sales Performance (RSP) and Sales Growth Trend (SGT), enabling portfolio optimization using operational transaction records. This adaptation provides managers with an evidence-based approach for determining facing allocation, replenishment priorities, product rotation, replacement, and product delisting in vending machine environments where external market share information is generally unavailable.

3.2.2. Consumer Purchase Behavior Following Portfolio Optimization

The observed increase in daily transaction volume indicates that portfolio optimization influenced consumer purchasing behavior beyond improving operational performance alone. Although the number of available Stock Keeping Units (SKUs) decreased substantially, consumers completed more purchase transactions during the post-intervention period. This finding suggests that improving the availability and visibility of high-performing products may have reduced purchase barriers and enabled consumers to identify preferred products more efficiently.

These findings are consistent with previous studies showing that product assortment and retail presentation influence consumer purchasing decisions in automated retail environments. Marinelli et al. (2021) reported that product arrangement and planogram design affect purchasing behavior by improving product accessibility and reducing consumer decision time. Similarly, Perfetti et al. (2025) demonstrated that the assortment displayed in vending machines shapes consumers' product choices by modifying the immediate purchasing environment. Rather than increasing product variety, the present study indicates that optimizing product composition can generate more favorable purchasing outcomes through better alignment between product availability and consumer demand.

The findings also suggest that modifying the available product assortment functions as a form of choice architecture, whereby changes in the retail environment influence purchasing decisions without directly altering consumer preferences. By increasing the visibility and availability of high-performing products, the optimization strategy guided purchasing behavior toward products with higher demand while preserving consumers' freedom of choice. This interpretation is consistent with the principles of behavioral decision-making, where environmental cues influence observable purchasing behavior without restricting available options.

Unlike previous studies that primarily examined planograms or recommendation systems, this study demonstrates that data-driven portfolio optimization based on transaction records can also influence consumer purchasing behavior. The integration of the Modified BCG Matrix with Interrupted Time Series (ITS) analysis provides empirical evidence that operational assortment decisions can produce measurable behavioral changes while simultaneously improving sales performance in vending machine operations.

3.2.3. Theoretical and Managerial Implications

This study contributes to the literature on product portfolio management by extending the application of the traditional Boston Consulting Group (BCG) Matrix from the Strategic Business Unit (SBU) level to the Stock Keeping Unit (SKU) level in automated retail environments. By replacing Relative Market Share with Relative Sales Performance (RSP) and Market Growth Rate with Sales Growth Trend (SGT), the proposed Modified BCG Matrix enables product portfolio evaluation using internal transaction data rather than external market share information. This adaptation addresses an important practical limitation of the conventional BCG Matrix, particularly in vending machine operations where product-level market share data are generally unavailable but transaction records are continuously generated (García-Vidal et al., 2023).

Beyond portfolio classification, this study demonstrates that product portfolio optimization can serve as a data-driven managerial intervention capable of improving both consumer purchase behavior and sales performance. The integration of the Modified BCG Matrix with Interrupted Time Series (ITS) analysis provides an evidence-based framework that links product portfolio decisions with measurable operational outcomes. These findings reinforce the growing importance of transaction analytics and business intelligence in supporting managerial decision making, enabling organizations to shift from intuition-based decisions toward evidence-based operational management (Power & Heavin, 2017; Kumoro & Rachmat, 2022).

From a managerial perspective, the proposed framework offers a practical decision-support tool for vending machine operators managing limited retail space. Rather than maximizing the number of available products, managers should prioritize products with stronger sales performance and higher growth potential while systematically identifying products requiring rotation, replacement, or delisting. Because the framework relies exclusively on routinely collected transaction data, it can be implemented continuously without requiring additional consumer surveys or external market share information. Consequently, the approach provides a scalable and cost-effective solution for improving product assortment decisions and operational efficiency (Czerniachowska et al., 2022; Marinelli et al., 2021).

Although this study focuses on smart vending machines, the proposed analytical framework may also be applicable to other technology-enabled retail formats characterized by limited selling space and digital transaction records, such as unattended convenience stores, micro-markets, and smart retail kiosks. Future research may extend the framework by integrating demand forecasting, machine learning, or real-time inventory optimization to further enhance retail decision making and operational performance (Ding et al., 2021; Nemoto & Hiraishi, 2024).

4. CONCLUSION

This study proposed and evaluated a Modified Boston Consulting Group (BCG) Matrix for product portfolio optimization in smart vending machine operations using internal transaction data. By replacing Relative Market Share with Relative Sales Performance (RSP) and Market Growth Rate with Sales Growth Trend (SGT), the proposed framework enabled Stock Keeping Unit (SKU)-level portfolio classification without requiring external market share information. The integration of the Modified BCG Matrix with Interrupted Time Series (ITS) analysis provided a systematic approach for assessing the operational impact of portfolio optimization.

The findings demonstrate that portfolio optimization successfully reduced the active product assortment while improving consumer purchase behavior and overall sales performance. Following the implementation of the optimized portfolio, daily transaction volume and daily sales revenue increased, and the segmented regression analysis confirmed statistically significant immediate intervention effects. These results indicate that data-driven portfolio optimization can improve retail performance even when the total number of available products is substantially reduced.

The study contributes to the literature by extending the application of the BCG Matrix from the Strategic Business Unit (SBU) level to the Stock Keeping Unit (SKU) level in automated retail environments. In addition, the integration of portfolio classification with transaction-based behavioral analysis and Interrupted Time Series (ITS) evaluation provides an evidence-based framework for supporting operational decision making in data-rich retail systems.

From a practical perspective, the proposed framework offers a scalable decision-support approach for vending machine operators seeking to optimize limited shelf capacity through transaction-based product portfolio management. Because the framework relies exclusively on routinely collected operational data, it can be implemented continuously without requiring external market share information or additional consumer surveys.

This study is subject to several limitations. The analysis was conducted using transaction data from a single vending machine network operating within one geographical region and evaluated consumer behavior over a relatively short post-intervention period. Future research may validate the proposed framework across different retail environments, extend the observation period, and integrate demand forecasting, machine learning, or real-time inventory optimization to further improve portfolio decision making and retail performance.

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