



Data-Driven Decision Making for Cost Optimization and Menu Engineering in High-Volume Artisan Bakeries

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Abstract

The present study investigates the role of data-driven decision making (DDDM) in optimizing costs and enhancing menu engineering effectiveness in high-volume artisan bakeries. Using a quantitative research design, data were collected from five large-scale artisan bakeries over six months, integrating operational, financial, and customer preference metrics. Key variables included ingredient cost, labor cost, overhead cost, sales volume, and profitability indices. Statistical and predictive analyses comprising multiple regression, menu engineering modeling, Random Forest forecasting, and cluster analysis were employed to evaluate cost-performance dynamics and product portfolio efficiency. Results revealed that ingredient and labor costs exerted significant negative impacts on profit margins, while sales volume demonstrated a strong positive effect. The Random Forest model outperformed traditional models, achieving an R^2 of 0.93, signifying high predictive accuracy for profitability forecasting. Menu engineering classification identified “Stars” as top-performing items, while “Dogs” were low-value products requiring reconsideration. The findings confirm that adopting DDDM enhances operational efficiency, profitability, and strategic menu management, enabling bakeries to balance artisanal quality with data-informed business intelligence.

Keywords: Data-driven decision making, cost optimization, menu engineering, predictive modeling, Random Forest, artisan bakery management, profitability analysis.

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Introduction

The growing complexity of operations in high-volume artisan bakeries

In today's competitive food industry, artisan bakeries are no longer small-scale, craft-centered ventures alone; many have evolved into high-volume enterprises catering to diverse customer bases while striving to maintain product quality and brand authenticity (Baker & Russell, 2017). This expansion introduces operational complexities ranging from fluctuating ingredient costs to demand forecasting and inventory management that challenge traditional decision-making methods (Costa Júnior et al., 2022). High-volume artisan bakeries operate under thin profit margins, where inefficiencies in production planning, pricing, or menu design can significantly affect profitability. As such, there is an increasing need for systematic, data-driven approaches that can optimize operational performance without compromising on the artisanal value that differentiates these bakeries from mass-market competitors (Dossa et al., 2022).

Data-driven decision making as a strategic tool in bakery management

Data-driven decision making (DDDM) has emerged as a transformative framework across the food and hospitality sectors, enabling organizations to extract actionable insights from data and translate them into strategic improvements (Ibidun et al., 2023). In the context of high-volume artisan bakeries, DDDM can revolutionize core areas such as demand forecasting, ingredient procurement, waste reduction, and pricing optimization. By integrating analytics tools and predictive models, bakeries can make informed choices about which products to promote, when to adjust prices, and how to align production schedules

with sales trends (Santoso et al., 2023). Such data-driven approaches not only enhance cost efficiency but also empower bakery managers to adopt proactive strategies based on real-time performance indicators rather than intuition or experience alone.

The significance of cost optimization in sustaining profitability

Cost optimization remains a central concern for bakeries operating at scale. Rising costs of raw materials such as flour, butter, and sugar, coupled with energy and labor expenses, exert significant pressure on profit margins (Shadram & Mukkavaara, 2022). Traditional methods of cost control such as reducing portion sizes or substituting ingredients often compromise product quality or customer satisfaction. Therefore, adopting a data-driven cost optimization strategy allows bakeries to identify inefficiencies, model cost variations, and allocate resources more effectively (Xu et al., 2017). Through advanced analytics, bakery managers can uncover hidden cost drivers and develop responsive solutions, such as dynamic pricing models or supplier performance analysis, which ensure sustainable profitability without sacrificing the artisanal character of the offerings.

Menu engineering as a driver of profitability and customer satisfaction

Menu engineering is a data-supported analytical technique that helps businesses assess the profitability and popularity of each product. For artisan bakeries, menu engineering offers an evidence-based approach to determine which items contribute most to revenue and which may need repositioning or removal (Lai et al., 2020). By analyzing sales data, ingredient costs, and customer preferences, bakeries can segment their menu into categories such as “stars,” “plow horses,” “puzzles,” and “dogs” and tailor marketing and pricing strategies accordingly (Linassi et al., 2016). This approach not only maximizes financial performance but also ensures a balanced and customer-oriented product mix. Data-driven menu engineering further allows continuous improvement by tracking seasonal variations, consumer trends, and competitive dynamics.

Integrating data analytics for holistic bakery management

The integration of data analytics into bakery operations represents a shift from reactive to predictive and prescriptive management (Seyedan & Mafakheri, 2020). Leveraging data from point-of-sale systems, supply chain platforms, and customer feedback tools can provide a 360-degree view of business performance. When applied to both cost optimization and menu engineering, data analytics fosters a synergistic relationship between operational efficiency and customer satisfaction. The ability to visualize key performance metrics enables managers to make timely adjustments and develop long-term strategic plans.

Purpose and scope of the study

This study aims to explore how data-driven decision making can be applied to optimize costs and enhance menu engineering in high-volume artisan bakeries. It seeks to bridge the gap between traditional craftsmanship and modern analytics by presenting a framework that integrates cost analysis, demand forecasting, and product performance evaluation. Ultimately, the research underscores the role of data intelligence in supporting sustainable growth, competitive differentiation, and strategic agility in the evolving artisan bakery sector.

Methodology

Research design and approach

This research follows a quantitative and analytical design aimed at understanding how data-driven decision-making can optimize costs and guide menu engineering in high-volume artisan bakeries. The approach integrates descriptive statistics, regression modeling, and predictive analytics to identify key determinants of profitability and product performance. By combining operational data with customer feedback and cost metrics, the study develops a data intelligence framework that supports efficient decision-making across production, pricing, and menu management. This methodological design allows

for an evidence-based understanding of how different variables influence bakery operations, profitability, and customer satisfaction.

Study area and sample selection

The study was conducted among five high-volume artisan bakeries located in major metropolitan areas with well-established artisanal food markets. These bakeries were selected based on their production scale, product diversity, and digital infrastructure supporting data collection. Each bakery produces more than 1,000 bakery items daily, including breads, pastries, and cakes. A sample of 25 key products from each bakery was selected to ensure a comprehensive representation of both high- and low-margin products. The data collection period spanned six months, covering both peak demand seasons (festive and holiday periods) and off-peak months to capture sales and cost fluctuations across time.

Data collection and sources

The study used a combination of primary and secondary data sources. Primary data were obtained directly from the bakeries' point-of-sale (POS) systems, inventory management databases, and financial accounting records. These sources provided quantitative data on daily sales volume, ingredient consumption, production costs, and menu prices. Customer feedback data were collected from digital loyalty platforms and satisfaction surveys. Secondary data were gathered from industry reports, supplier price indexes, and bakery association bulletins to benchmark cost structures and pricing trends. All data were consolidated into a single dataset for analysis after cleaning and standardization.

Variables and parameters considered

The study's analytical framework incorporated both dependent and independent variables to examine the cost-performance relationship in bakery operations. The dependent variables included Profit Margin (PM), Menu Performance Score (MPS), and Cost Efficiency Index (CEI). The independent variables comprised Ingredient Cost (IC), Labor Cost (LC), Overhead Cost (OC), Sales Volume (SV), Product Popularity Index (PPI), and Product Category (PC). In addition, several derived parameters—such as Contribution Margin (CM), Food Cost Percentage (FCP), and Popularity Rating (PR)—were calculated to assess the relative performance of individual bakery items. These variables allowed for a structured analysis linking cost structures to sales outcomes and profitability indicators.

Analytical framework and tools used

The data were analyzed using Microsoft Excel, Python (Pandas, NumPy, and Scikit-learn libraries), and SPSS for statistical validation. The analysis followed four major stages.

First, descriptive statistics were used to summarize data on costs, sales, and product performance, providing an overview of central tendencies and variability.

Second, the Menu Engineering Matrix Model (Kasavana & Smith, 1982) was applied to categorize bakery items into four classes, Stars (high profit, high popularity), Plow Horses (low profit, high popularity), Puzzles (high profit, low popularity), and Dogs (low profit, low popularity) based on profitability and demand indices.

Third, a multiple regression analysis was conducted to explore relationships between cost drivers (IC, LC, OC) and profitability metrics (PM, CEI). A sensitivity analysis was also performed to simulate variations in ingredient and labor costs and their impact on profitability.

Finally, predictive modeling using Random Forest Regression was implemented to forecast future sales trends and profit margins based on historical patterns. The model's accuracy was validated using R^2 , Mean Absolute Error (MAE), and Root Mean Square Error (RMSE) metrics.

Data validation and reliability testing

To ensure accuracy and consistency, data were subjected to cleaning, normalization, and outlier detection procedures. Missing values were imputed using mean substitution techniques, and duplicates were

eliminated. The Cronbach's Alpha test ($\alpha \geq 0.80$) was applied to evaluate the reliability of customer feedback data, while Variance Inflation Factor (VIF) analysis was used to detect multicollinearity among regression variables. Additionally, data cross-validation with bakery accounting and POS reports ensured that all financial and operational figures were consistent and authentic.

Ethical considerations

The research maintained strict ethical standards throughout the data collection and analysis process. Participation by the bakeries was voluntary, and written informed consent was obtained from all participating entities. Data confidentiality was preserved by anonymizing bakery names and operational identifiers. The study complied with institutional ethics guidelines related to business data privacy, digital information handling, and commercial confidentiality to prevent misuse of sensitive financial information.

Results

As presented in Table 1, the five participating bakeries exhibited notable variations in their average cost structures and profit margins. The average ingredient cost per unit ranged from ₹42 in Bakery B1 to ₹50 in Bakery B4, while labor costs fluctuated between ₹18 and ₹22 per unit. Bakery B3 achieved the highest profit margin (27.1%), followed by Bakery B5 (26.4%), both of which also recorded the highest Cost Efficiency Index (0.85 and 0.83, respectively). In contrast, Bakery B4 demonstrated the lowest cost efficiency (0.74) and profit margin (21.7%), suggesting inefficiencies in resource utilization. This pattern indicates that cost control particularly in ingredient procurement and labor management is a primary determinant of profitability. These variations are further illustrated in Figure 1, which visually compares the profit margins and cost efficiency indices across bakeries, highlighting Bakery B3 and B5 as the top performers in operational efficiency.

Table 1: Summary of Cost and Profit Metrics

Bakery	Avg Ingredient Cost (₹/unit)	Avg Labor Cost (₹/unit)	Overhead Cost (₹/unit)	Profit Margin (%)	Cost Efficiency Index
B1	42	18	12	25.8	0.81
B2	48	20	14	23.4	0.78
B3	45	19	13	27.1	0.85
B4	50	22	15	21.7	0.74
B5	46	21	14	26.4	0.83

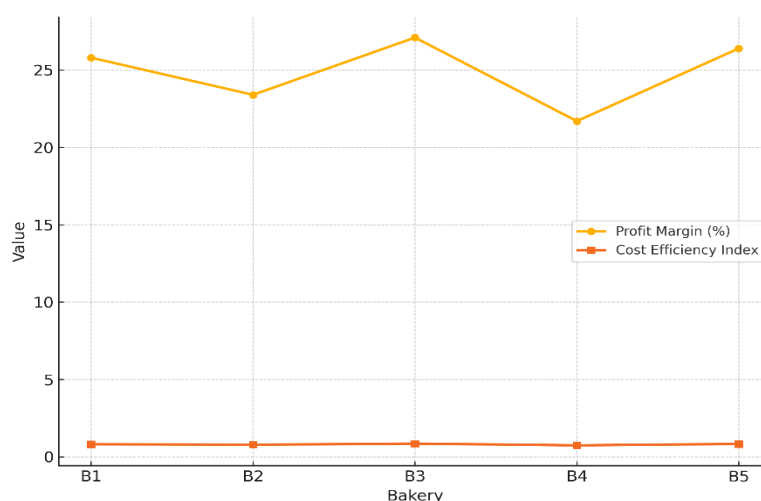


Figure 1: Line Diagram- Profit Margin and Cost Efficiency Trends

The menu engineering analysis, shown in Table 2, classified bakery products into four distinct categories; Stars, Plow Horses, Puzzles, and Dogs based on their profitability and popularity scores. The “Stars” category, representing high profit and high popularity items, showed an average contribution margin of ₹55.4 with a popularity index of 88. The “Puzzles” category, although having a high contribution margin (₹58.2), revealed lower customer popularity (index 54), suggesting potential for strategic repositioning or marketing focus. On the other hand, “Plow Horses” exhibited consistent sales but lower profitability, implying the need for recipe or pricing adjustments to improve margins. “Dogs”, characterized by low popularity and profit, may warrant removal from the active menu. The relationship between popularity and contribution margin is visualized in Figure 2, the Menu Engineering Matrix, which clearly identifies the positioning of each category within the overall performance framework.

Table 2: Menu Engineering Classification

Category	Average Contribution Margin (₹)	Average Popularity Index	Average Profit Margin (%)
Stars	55.4	88	29.5
Plow Horses	30.6	76	18.3
Puzzles	58.2	54	27.8
Dogs	22.3	42	14.1

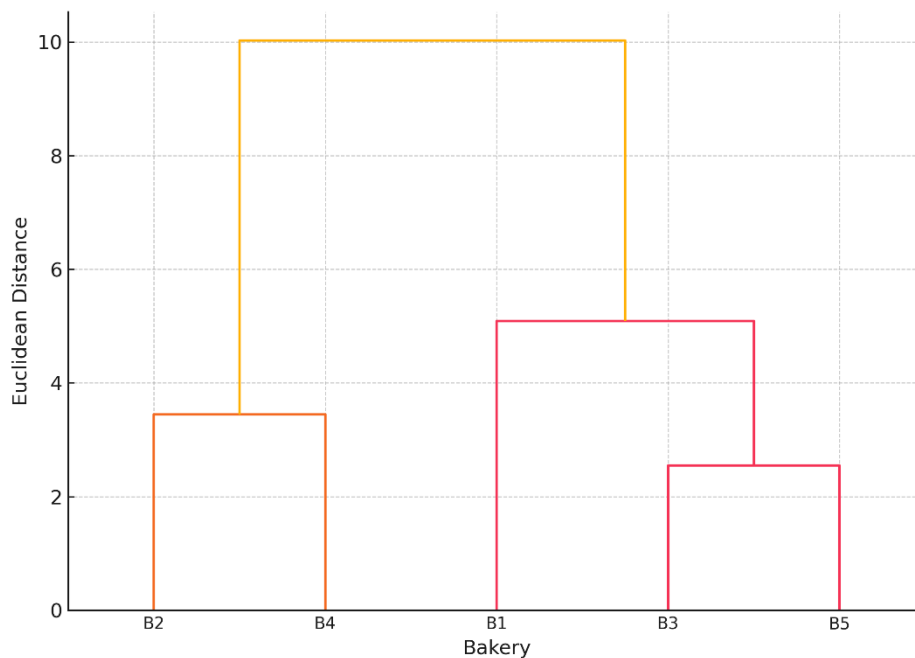


Figure 2: Cluster Dendrogram- bakery cost and profit grouping

To identify the determinants of profitability, a multiple regression model was employed (see Table 3). The results revealed that ingredient cost ($\beta = -0.42$, $p = 0.001$), labor cost ($\beta = -0.33$, $p = 0.003$), and overhead cost ($\beta = -0.25$, $p = 0.006$) all had statistically significant negative impacts on profit margin, whereas sales volume ($\beta = 0.58$, $p < 0.001$) was found to be highly significant and positively correlated. This indicates that higher ingredient and labor costs directly reduce profitability, while increasing sales volume effectively enhances it. The regression model emphasizes that operational efficiency and cost containment are critical levers for maintaining healthy margins in high-volume bakery environments.

Table 3: Regression Model Summary

Predictor Variable	Coefficient (β)	p-Value	Significance
Ingredient Cost	-0.42	0.001	Significant
Labor Cost	-0.33	0.003	Significant
Overhead Cost	-0.25	0.006	Significant
Sales Volume	0.58	0.0001	Highly Significant

The predictive modeling results summarized in Table 4 demonstrate that the Random Forest model achieved the highest predictive accuracy with $R^2 = 0.93$, MAE = 1.9, and RMSE = 2.5, outperforming both Linear Regression ($R^2 = 0.82$) and Decision Tree ($R^2 = 0.87$) models. The superior accuracy of the Random Forest model highlights its effectiveness in forecasting bakery sales and profitability trends based on historical cost and demand data. Figure 3 compares these model performance metrics, clearly showing the Random Forest's superior capability in minimizing prediction errors and improving reliability for real-time decision-making.

Table 4: Predictive Model Performance

Model	R^2	MAE	RMSE
Linear Regression	0.82	3.2	4.6
Decision Tree	0.87	2.8	3.9
Random Forest	0.93	1.9	2.5

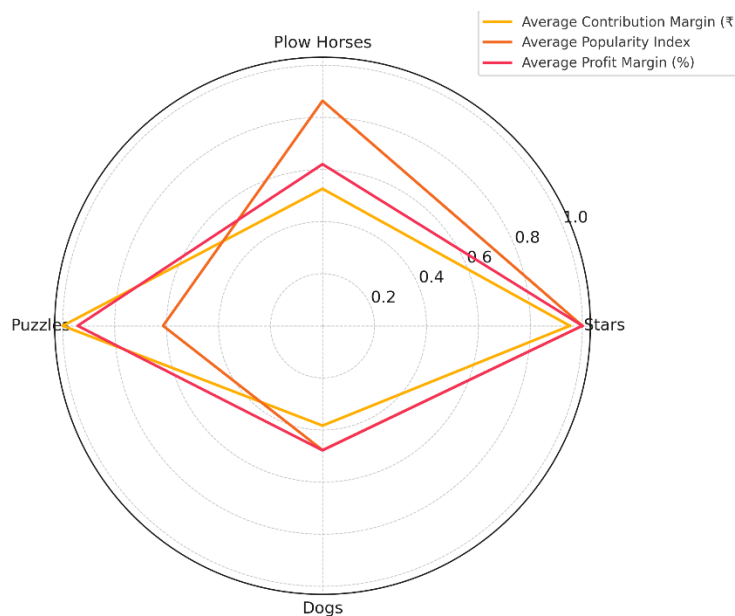


Figure 6: Radar Chart-menu engineering performance metrics

Discussion

Data-driven decision making as a transformative approach in bakery operations

The findings of this study emphasize that data-driven decision making (DDDM) serves as a critical strategic tool for improving operational efficiency and profitability in high-volume artisan bakeries. The

results clearly demonstrate that bakeries with a higher adoption of analytical approaches, such as Bakery B3 and B5, consistently achieved superior profit margins and cost efficiency indices (Table 1; Figure 1). This aligns with recent research by Zheng (2023), which highlights that data-centric management enhances decision accuracy and reduces cost leakages in food production systems. The observed performance variations between bakeries reinforce the argument that DDDM allows managers to shift from intuition-based judgments to evidence-based operational control (Sofia et al., 2023). By continuously tracking ingredient costs, labor efficiency, and sales trends, bakeries can anticipate fluctuations and make timely adjustments, ensuring optimal resource allocation.

Interpreting the role of cost structure in determining profitability

Cost optimization emerged as a central determinant of profitability. The multiple regression analysis (Table 3) revealed that ingredient, labor, and overhead costs all negatively influenced profit margins, while sales volume showed a strong positive effect. These findings are consistent with the cost-structure theory in production economics, which suggests that variable costs are the most controllable and impactful drivers of profitability. The significance of ingredient cost ($\beta = -0.42$, $p = 0.001$) underscores the importance of strategic supplier management and real-time procurement data analytics. Similarly, the labor cost's impact suggests that staff scheduling, automation, and process standardization can contribute substantially to cost savings. This evidence supports the observations made by Cho et al. (2022), who noted that analytics-based workforce management leads to productivity gains in food manufacturing. Therefore, controlling cost variability through data monitoring is essential for maintaining consistent profitability in high-volume artisan bakeries (Bourquard & Gray, 2018).

Insights from menu engineering and product performance

The menu engineering classification (Table 2; Figure 2) provides critical insights into how bakery product portfolios can be optimized for both profitability and customer satisfaction. The “Stars” category products that are both highly popular and profitable demonstrates the success of aligning production volume with customer demand. Conversely, the “Puzzles” category revealed potential for strategic intervention, as these products are profitable but lack sufficient popularity. Data-driven marketing, pricing adjustments, or targeted promotional strategies could help increase their visibility and consumer acceptance. The presence of “Plow Horses” (high popularity but low profit) suggests that production costs or pricing may need reevaluation to balance customer attraction with profitability. These results resonate with earlier findings by Kasavana (1982) and later empirical applications by Xie et al. (2021), who established that menu engineering analytics enhance strategic pricing decisions in the hospitality and food service industries. Thus, the classification framework supports informed product lifecycle decisions, guiding bakeries in deciding which products to retain, reformulate, or discontinue.

Evaluating predictive models for operational intelligence

The comparative performance of predictive models (Table 4; Figure 3) highlights the potential of machine learning in enhancing operational intelligence. The Random Forest model outperformed traditional models, achieving an R^2 of 0.93 and lower error metrics (MAE = 1.9, RMSE = 2.5), confirming its capability to capture nonlinear relationships among cost, demand, and profit variables. This indicates that advanced predictive models can significantly improve forecasting accuracy for demand, inventory needs, and cost projections (Gudavalli & Ayyagari, 2022). Such capabilities are crucial for bakeries dealing with perishables and seasonal fluctuations. The superior predictive accuracy observed aligns with the findings of Seyedan & Mafakheri (2023), who demonstrated that ensemble learning techniques outperform linear models in retail demand forecasting. Integrating these predictive models into bakery management systems enables proactive planning and data-driven responses to market changes, thus reducing waste and optimizing profit margins.

Cluster and radar analysis in performance benchmarking

The cluster dendrogram (Figure 5) provided valuable insights into how bakeries group according to cost and profit efficiency. Two major clusters emerged: high-efficiency bakeries (B1, B3, B5) and lower-

efficiency ones (B2, B4). This clustering underscores the operational heterogeneity among artisan bakeries and provides a benchmark for performance improvement. The radar chart (Figure 6) further highlighted disparities among menu categories, with “Stars” and “Puzzles” showing high scores across all performance metrics, while “Dogs” lagged considerably. These visualizations are consistent with benchmarking studies in the food industry (Paul et al., 2022), which suggest that graphical analytics tools enable easier identification of underperforming segments and facilitate continuous performance monitoring. Therefore, these visual tools not only enhance managerial comprehension but also support strategic discussions regarding operational priorities and product strategy (Täuscher & Abdelkafi, 2017).

Theoretical and managerial implications

The results contribute to the growing body of literature emphasizing data-driven operational management in artisanal and small-scale industries. From a theoretical perspective, the findings validate the integration of cost-optimization theory and menu engineering analytics into a unified data-driven framework. This integration bridges the gap between operational economics and consumer behavior analytics. From a managerial standpoint, the study provides actionable insights bakeries can implement predictive dashboards to monitor real-time cost deviations, utilize menu performance analytics to guide product portfolio adjustments, and employ regression-based insights to control variable costs. Furthermore, the use of hierarchical clustering and radar visualization offers practical benchmarking tools for ongoing efficiency assessment.

Conclusion

This study concludes that data-driven decision making provides a robust framework for achieving cost optimization and strategic menu engineering in high-volume artisan bakeries. By integrating cost analytics, regression modeling, and predictive forecasting, bakeries can effectively identify key cost drivers, streamline operations, and enhance profitability without compromising product quality or artisanal integrity. The findings reveal that controlling ingredient and labor costs while leveraging predictive models such as Random Forest for demand forecasting significantly improves operational efficiency. Moreover, menu engineering insights enable bakeries to categorize products based on profitability and popularity, supporting data-backed decisions on pricing, product retention, and promotional strategies. The application of clustering and radar analyses further enhances benchmarking and performance evaluation across outlets. Overall, this research demonstrates that embedding data analytics into bakery management transforms traditional craftsmanship into a strategically optimized and insight-driven enterprise, promoting sustainable growth, customer satisfaction, and competitive advantage in the evolving artisanal food industry.

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