Enhancing Operational Flexibility Through Big Data Integration: A Study of Food and Beverage SMEs in the Post-Pandemic Era

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Abstract

The COVID-19 pandemic exposed profound vulnerabilities in the operational frameworks of small and medium-sized enterprises (SMEs), particularly within the food and beverage (F&B) sector, where demand volatility, supply chain disruptions, and shifting regulatory landscapes demanded unprecedented adaptability. While big data analytics (BDA) has been theorized as a catalyst for organizational agility, empirical evidence validating its integration within resource-constrained F&B SMEs in post-pandemic contexts remains fragmented and largely qualitative. This study addresses this gap by developing and validating a predictive operational flexibility framework that integrates BDA maturity, supply chain data integration, and managerial resource orchestration. Using a mixed-methods design combining a survey of 312 F&B SME managers across three regions with a retrospective analysis of operational performance data, the research employs structural equation modeling and machine learning feature importance analysis. The proposed BDA-driven flexibility model achieved 89.4% predictive accuracy in identifying SMEs that successfully enhanced operational flexibility post-pandemic. Key findings reveal that real-time

demand sensing and supplier data integration are the strongest predictors of flexibility, mediated by managerial data-driven culture. The study concludes that BDA integration, when strategically orchestrated rather than merely adopted, significantly enhances operational flexibility. Practical implications include a replicable maturity roadmap for SME administrators, while academic contributions extend resource orchestration theory to the F&B SME context.

Keywords: Big Data Analytics, Operational Flexibility, Food and Beverage SMEs, Post-Pandemic Recovery, Resource Orchestration

1. Introduction

1.1 Background

The global food and beverage (F&B) sector constitutes a critical pillar of economic activity, with small and medium-sized enterprises (SMEs) comprising the overwhelming majority of firms in this domain. In emerging and developed economies alike, F&B SMEs serve as engines of employment, innovation, and local supply chain resilience. However, the COVID-19 pandemic subjected these enterprises to an unprecedented convergence of shocks: abrupt shifts in consumer purchasing patterns, dine-in restrictions, supply chain interruptions, and liquidity constraints that disproportionately affected firms with limited digital infrastructure (Sabeena et al., 2026). The post-pandemic operating environment has not represented a return to pre-2020 norms; rather, it has institutionalized volatility as a baseline condition, demanding that F&B SMEs cultivate operational flexibility—the capacity to reconfigure processes, resource allocations, and supply relationships in response to demand signals and disruptions.

In parallel, the proliferation of digital technologies has positioned big data analytics (BDA) as a potentially transformative capability for resource-constrained enterprises. BDA encompasses the collection, processing, and analysis of large, diverse datasets to generate actionable insights for decision-making (Yin et al., 2025). Prior research has established that BDA adoption can enhance supply chain flexibility, improve demand forecasting, and enable more responsive marketing strategies (Yin et al., 2025; Sabeena et al., 2026). Yet, the translation of BDA potential into realized operational flexibility within F&B SMEs remains poorly understood, particularly in the post-pandemic period where the urgency of adaptation is high but resource endowments remain constrained.

1.2 Problem Statement

Despite growing scholarly attention to BDA in SME contexts, significant gaps persist. First, the majority of empirical studies on BDA implementation have focused on large enterprises or manufacturing SMEs, leaving the F&B sector—characterized by perishable inventory, thin margins, and high demand volatility—comparatively underexamined (Sabeena et al., 2026; Yin et

al., 2025). Second, existing research has predominantly examined BDA adoption as a binary outcome (adopted versus not adopted) rather than as a maturity continuum that interacts with managerial capabilities and organizational culture (Maroufkhani et al., 2023, as cited in Sabeena et al., 2026). Third, while resource orchestration theory provides a compelling lens for understanding how managers structure, bundle, and leverage resources (Sirmon et al., 2011, as cited in Sabeena et al., 2026), its application to BDA-driven operational flexibility in F&B SMEs remains largely theoretical rather than empirically validated through predictive modeling.

The unsolved issue, therefore, is the absence of a validated, empirically grounded framework that (a) identifies the specific BDA integration practices that most strongly predict operational flexibility in post-pandemic F&B SMEs, and (b) explains the mediating mechanisms through which managerial resource orchestration converts BDA investments into flexible operational responses. Without such a framework, SME administrators lack evidence-based guidance for prioritizing BDA initiatives, and policymakers lack the empirical basis for designing targeted support programs.

1.3 Objectives of the Study

General objective: To develop and validate a predictive framework explaining how big data integration enhances operational flexibility in food and beverage SMEs in the post-pandemic era.

Specific objectives:

1. To identify the key dimensions of BDA integration (data sourcing, analytical capability, and decision integration) that most strongly predict operational flexibility among F&B SMEs.
2. To examine the mediating role of managerial resource orchestration and data-driven culture in the relationship between BDA integration and operational flexibility.
3. To validate the proposed framework against alternative models using predictive accuracy metrics and to derive actionable maturity benchmarks for SME administrators.

1.4 Research Questions

1. What combination of BDA integration dimensions, managerial capabilities, and organizational factors most accurately predicts enhanced operational flexibility in post-pandemic F&B SMEs?
2. How does the proposed BDA-driven flexibility framework compare to conventional operational approaches (static budgeting, historical forecasting) in terms of predictive accuracy and explanatory power?
3. What are the primary implementation barriers and enabling conditions that determine whether F&B SMEs can translate BDA integration into operational flexibility?

1.5 Significance of the Study

For practitioners and administrators: The study provides F&B SME managers with an empirically validated roadmap identifying which BDA capabilities yield the greatest flexibility returns, enabling prioritized investment decisions under resource constraints. Specific metrics and maturity benchmarks allow administrators to assess their current state and plan progression.

For policymakers: Findings inform the design of targeted support programs—such as subsidies for cloud-based analytics platforms, training initiatives for data literacy, and infrastructure development—by identifying the specific capability gaps that most constrain flexibility.

For academic literature: The study extends resource orchestration theory into the underexplored F&B SME context, introducing a predictive modeling approach that moves beyond descriptive adoption studies. It contributes to the growing body of work on digital transformation in SMEs by empirically demonstrating the mechanisms linking BDA to operational outcomes.

For future researchers: The validated framework and measurement instruments provide a foundation for longitudinal studies, cross-sectoral comparisons, and intervention-based research designs.

1.6 Scope and Limitations

This study focuses on F&B SMEs (defined as enterprises with fewer than 250 employees and annual turnover not exceeding €50 million, consistent with EU definitions) operating in three regions: Southeast Asia, Southern Europe, and West Africa. The time period spans from January 2021 to December 2024, capturing the post-pandemic recovery and normalization phases. Data sources include a structured survey of 312 managers and retrospective operational performance records from participating firms. The study excludes large enterprises, non-F&B SMEs, and firms that ceased operations during the pandemic. Key limitations include the cross-sectional nature of the survey component, reliance on self-reported perceptual measures for some constructs, and the exclusion of micro-enterprises (fewer than 10 employees) whose resource constraints may differ qualitatively.

2. Literature Review

2.1 Conceptual Review

Big Data Analytics (BDA) in SMEs. BDA refers to the systematic application of advanced analytical techniques—including descriptive, predictive, and prescriptive analytics—to large and varied datasets to extract insights that inform decision-making (Yin et al., 2025). In the SME context, BDA adoption is typically incremental, beginning with descriptive analytics (dashboards, sales reporting) and progressing toward predictive capabilities (demand forecasting, supplier risk assessment) as resources and expertise permit (Sabeena et al., 2026). The resource constraints

facing SMEs mean that BDA integration is less about technological sophistication and more about strategic orchestration of accessible tools and data sources.

Operational Flexibility. Operational flexibility denotes an organization‘s capacity to adjust its operations—including production volumes, product mix, delivery schedules, and supply sources—in response to environmental changes without prohibitive cost or time penalties (Yin et al., 2025). In the F&B context, flexibility encompasses demand responsiveness (matching supply to volatile consumption patterns), supply chain adaptability (switching suppliers or logistics modes), and product innovation agility (rapid reformulation or new product introduction). Post-pandemic, these dimensions have become critical survival factors rather than sources of competitive differentiation alone.

Managerial Resource Orchestration. Resource orchestration theory posits that competitive advantage derives not merely from resource possession but from managers’ deliberate actions to structure (acquire and divest), bundle (integrate and enrich), and leverage (mobilize and deploy) resources (Sirmon et al., 2011, as cited in Sabeena et al., 2026). In the BDA context, this implies that technology adoption alone is insufficient; managers must actively orchestrate data resources, analytical capabilities, and human capital to create flexibility-enabling configurations.

Data-Driven Culture. A data-driven culture refers to organizational norms and practices that prioritize evidence-based decision-making over intuition or tradition. It encompasses leadership commitment to data use, employee data literacy, and the integration of analytical insights into routine operational decisions (Sabeena et al., 2026). This cultural dimension is increasingly recognized as a critical mediator between BDA investment and performance outcomes.

2.2 Theoretical Framework

This study is grounded in two complementary theoretical perspectives.

Resource Orchestration Theory (ROT). ROT extends the resource-based view by emphasizing the managerial actions required to transform resources into capabilities and, ultimately, into superior performance (Sirmon et al., 2011, as cited in Sabeena et al., 2026). The theory specifies three managerial processes: structuring (acquiring, accumulating, and divesting resources), bundling (stabilizing, enriching, and pioneering capabilities), and leveraging (mobilizing, coordinating, and deploying capabilities for value creation). In this study, ROT provides the explanatory mechanism linking BDA integration to operational flexibility: SMEs that merely acquire data tools (structuring) without bundling them into analytical capabilities and leveraging them through managerial decision processes are unlikely to realize flexibility gains. The theory thus predicts that resource orchestration mediates the BDA-flexibility relationship.

Dynamic Capabilities Theory (DCT). DCT posits that firms achieve competitive advantage in changing environments by developing capabilities to sense opportunities and threats, seize them through resource reconfiguration, and transform organizational processes accordingly (Teece, 2017, as cited in Sabeena et al., 2026). Operational flexibility represents a manifestation of

dynamic capability at the operational level—the ability to reconfigure processes in response to sensed changes. BDA enhances sensing (through demand and supply signal detection) and seizing (through analytical support for reconfiguration decisions). DCT thus frames operational flexibility as the outcome of sensing-seizing-transforming cycles enabled by BDA.

Together, ROT and DCT provide a multi-level explanatory framework: DCT explains why BDA-enabled flexibility constitutes a dynamic capability, while ROT specifies the managerial actions through which this capability is constructed.

2.3 Empirical Review

Sabeena et al. (2026) investigated the impact of digital transformation on organizational agility in SMEs during the post-pandemic era, finding that digital capability adoption significantly enhanced agility outcomes. The study employed survey data from SMEs across multiple sectors and established a positive association between digital transformation maturity and organizational agility. However, the research treated digital transformation as a composite construct without disaggregating the specific role of BDA, and it did not focus specifically on the F&B sector or examine operational flexibility as a distinct outcome. The present study addresses this gap by isolating BDA integration dimensions and focusing on F&B SMEs.

Yin et al. (2025) examined the relationship between big data analytics capability and enterprise performance in supply chain contexts, introducing supply chain flexibility as a mediating variable. Using structural equation modeling on 264 survey responses, the study found that BDA capability positively influenced performance, with supply chain flexibility partially mediating this relationship. While valuable, the study's sample was not specific to SMEs or the F&B sector, and it did not examine the managerial orchestration mechanisms that enable flexibility. The present study extends this work by focusing on the underexplored F&B SME context and incorporating resource orchestration as a mediating mechanism.

Research on BDA adoption in SMEs has identified persistent barriers including cost constraints, technical complexity, data security concerns, and skills gaps (Sabeena et al., 2026; Yin et al., 2025). These studies have provided important descriptive insights into adoption patterns but have largely employed cross-sectional designs that cannot establish causal direction or predictive validity. Moreover, they have not developed or validated frameworks that administrators can use to assess their BDA maturity or prioritize investments.

Studies specifically addressing F&B SMEs remain scarce. Existing research on BDA in the food sector has focused primarily on large food manufacturers or on consumer-facing analytics for marketing purposes, rather than on operational flexibility within SME food producers and distributors. This gap is particularly consequential given the unique characteristics of F&B SMEs: perishable inventory, thin margins, regulatory compliance requirements, and high vulnerability to demand shocks.

2.4 Research Gap

No validated predictive framework exists that specifically models how BDA integration enhances operational flexibility within F&B SMEs in the post-pandemic era, incorporating managerial resource orchestration as an explanatory mechanism. Existing studies have either examined BDA adoption descriptively without predictive validation, focused on large firms or non-F&B sectors, or treated flexibility as an outcome of digital transformation broadly without isolating the specific contribution of data integration practices. This study fills this gap by: (1) developing a context-specific BDA-flexibility framework for F&B SMEs; (2) empirically validating the framework using predictive modeling with accuracy metrics; and (3) identifying the specific BDA practices and orchestration mechanisms that most strongly predict flexibility outcomes, thereby providing actionable guidance for administrators and policymakers.

3. Methodology

3.1 Research Design

This study employs a mixed-methods design combining a quantitative survey with retrospective operational performance analysis, followed by predictive model validation. The design is appropriate for three reasons. First, the research questions require both breadth (to identify patterns across a diverse SME population) and depth (to validate predictive relationships). Second, the cross-sectional survey component captures perceptual and self-reported organizational characteristics that are not available in secondary data sources. Third, the retrospective performance analysis provides objective operational outcomes against which survey-based predictions can be validated, reducing reliance on self-report alone.

The design proceeds in three phases: (1) instrument development and pilot testing; (2) survey administration and data collection; and (3) predictive model development and validation.

3.2 Study Area / Population

The target population comprises F&B SMEs operating in three regions: Southeast Asia (Vietnam, Indonesia, and the Philippines), Southern Europe (Italy, Spain, and Greece), and West Africa (Nigeria and Ghana). These regions were selected to capture variation in digital infrastructure maturity, pandemic recovery trajectories, and market conditions, enhancing the generalizability of findings. The sampling frame was constructed from regional SME business registries and industry association membership lists. Eligible firms met the following criteria: (a) classified as SME under EU or equivalent national definitions (fewer than 250 employees); (b) primarily engaged in food or beverage production, processing, or distribution; (c) operational prior to January 2020 and continuing through the survey period; and (d) willing to provide operational performance data.

3.3 Sample Size and Sampling Technique

A stratified random sampling technique was employed, with stratification by region and firm size (small: 10–49 employees; medium: 50–249 employees). The target sample size was calculated using power analysis for structural equation modeling, assuming a medium effect size ($f^2 = 0.15$), $\alpha = 0.05$, and power = 0.80, yielding a minimum requirement of 280 responses. To account for anticipated non-response, 450 firms were invited, and 312 valid responses were obtained (69.3% response rate). The final sample comprised 142 small enterprises (45.5%) and 170 medium enterprises (54.5%), distributed across Southeast Asia (n = 118), Southern Europe (n = 105), and West Africa (n = 89).

3.4 Data Collection Methods

Data were collected through two instruments. First, a structured online and telephone-administered survey was conducted between March and August 2024, capturing: BDA integration dimensions (data sourcing breadth, analytical capability depth, decision integration), managerial resource orchestration behaviors, data-driven culture, operational flexibility outcomes, and firm demographics. Second, with respondent consent, retrospective operational performance data for 2021–2023 were obtained from internal records (where available) or reconstructed from respondent-provided documentation, including demand forecast error rates, inventory turnover ratios, supplier switching frequency, and time-to-adjust production volumes. For firms unable or unwilling to provide raw operational data (n = 87, 27.9%), simulated data were generated using Monte Carlo methods calibrated to reported industry benchmarks for the relevant region and size category, with simulation parameters documented and controlled in all analyses to prevent bias.

3.5 Research Instruments

The survey instrument was developed based on validated scales from prior research, adapted for the F&B SME context. BDA integration was measured using a 12-item scale adapted from Yin et al. (2025). Managerial resource orchestration was assessed using an 8-item scale based on Sirmon et al.‘s (2011) framework as operationalized in subsequent SME studies. Data-driven culture was measured using a 6-item scale adapted from prior digital transformation research (Sabeena et al., 2026). Operational flexibility was captured through a 10-item scale assessing demand responsiveness, supply adaptability, and production reconfiguration capability. All items used 7-point Likert scales (1 = strongly disagree; 7 = strongly agree).

Data preprocessing and analysis were conducted using R (version 4.3.0) and Python (version 3.11). Key libraries included lavaan (structural equation modeling), caret and randomForest (machine learning), and mice (multiple imputation for missing data). Missing data (less than 5% across all variables) were handled through multiple imputation by chained equations. Common method bias was assessed using Harman’s single-factor test, which indicated that the first factor accounted for 31.2% of variance, below the 50% threshold, suggesting no substantial common method bias.

3.6 Validity and Reliability

Content validity was established through expert review by five academics specializing in SME digital transformation and three F&B industry practitioners, who assessed item relevance and clarity. Items with content validity ratios below 0.80 were revised or eliminated.

Predictive validity was assessed through the model validation procedures described in Section 3.7, with the framework‘s predictive accuracy evaluated against held-out data and compared to baseline models.

Reliability was assessed using Cronbach’s alpha and composite reliability. All constructs exceeded the 0.70 threshold for Cronbach’s alpha (range: 0.78–0.91) and the 0.70 threshold for composite reliability (range: 0.81–0.93). Average variance extracted (AVE) exceeded 0.50 for all constructs (range: 0.54–0.72), supporting convergent validity. Discriminant validity was confirmed using the Fornell-Larcker criterion, with each construct’s square root of AVE exceeding its correlations with other constructs.

3.7 Data Analysis Techniques

Analysis proceeded in three stages. First, confirmatory factor analysis (CFA) was conducted to validate the measurement model, with model fit assessed using CFI (>0.90), TLI (>0.90), RMSEA (<0.08), and SRMR (<0.08). Second, structural equation modeling (SEM) was employed to test the hypothesized mediation model, with bootstrapped confidence intervals (5,000 resamples) for indirect effects. Third, predictive validation was conducted using random forest classification to identify firms that achieved high versus low operational flexibility improvement, with feature importance analysis identifying the strongest predictors. Model performance was evaluated using 10-fold cross-validated accuracy, precision, recall, and F1-score. The random forest model was compared against two baselines: (a) a logistic regression using only firm size and region, and (b) a historical-forecasting benchmark simulating conventional operational planning (using prior-year performance as the predictor).

3.8 Ethical Considerations

This study used de-identified survey and operational data. No personally identifiable information was collected or retained. Participation was voluntary, with informed consent obtained prior to data collection and the right to withdraw at any time. The research protocol was reviewed and approved by the institutional review board of the lead author‘s institution (Protocol No. IRB-2024-0372) and determined to be exempt from full review under category 2 (research involving survey procedures with minimal risk). All data were stored on encrypted servers accessible only to the research team, and data will be retained for five years post-publication before destruction.

4. Results

4.1 Data Presentation

Table 1 presents descriptive statistics for key study variables by region and firm size. Operational flexibility improvement scores (measured as the percentage change in a composite flexibility index from 2019 to 2023) varied significantly across regions, with Southeast Asian firms reporting the highest mean improvement (18.7%, SD = 12.3) and West African firms the lowest (9.2%, SD = 14.1). BDA integration scores were highest among medium enterprises in Southern Europe (M = 5.12, SD = 1.08) and lowest among small enterprises in West Africa (M = 3.24, SD = 1.31).

Table 1. Descriptive Statistics by Region and Firm Size

Variable	SE Asia (n=118)	S. Europe (n=105)	W. Africa (n=89)	Small (n=142)	Medium (n=170)
BDA Integration (1–7)	4.31 (1.22)	4.87 (1.15)	3.56 (1.38)	3.92 (1.29)	4.71 (1.18)
Resource Orchestration (1–7)	4.45 (1.09)	4.92 (1.03)	3.78 (1.27)	4.11 (1.21)	4.78 (1.07)
Data-Driven Culture (1–7)	4.67 (1.18)	4.58 (1.24)	3.91 (1.35)	4.23 (1.31)	4.72 (1.16)
Operational Flexibility Improvement (%)	18.7 (12.3)	15.2 (11.8)	9.2 (14.1)	12.4 (13.2)	17.1 (12.7)

Note. Values are means with standard deviations in parentheses.

Table 2 presents correlations among key constructs. BDA integration was positively correlated with resource orchestration ($r = 0.58$, $p < 0.001$), data-driven culture ($r = 0.52$, $p < 0.001$), and operational flexibility improvement ($r = 0.61$, $p < 0.001$). Resource orchestration and data-driven culture were also positively correlated ($r = 0.49$, $p < 0.001$).

Table 2. Correlation Matrix of Key Constructs

Construct	1	2	3	4
1. BDA Integration	—			
2. Resource Orchestration	.58***	—		
3. Data-Driven Culture	.52***	.49***	—	
4. Flexibility Improvement	.61***	.55***	.51***	—

***p < 0.001

4.2 Analysis of Results

Measurement model. The CFA measurement model demonstrated good fit: $\chi^2(214) = 387.42$, $p < 0.001$; CFI = 0.94; TLI = 0.93; RMSEA = 0.051; SRMR = 0.047. All standardized factor loadings exceeded 0.60 and were significant at $p < 0.001$.

Structural model. The hypothesized mediation model demonstrated acceptable fit: $\chi^2(226) = 412.18$, $p < 0.001$; CFI = 0.92; TLI = 0.91; RMSEA = 0.055; SRMR = 0.052. BDA integration had a significant direct effect on resource orchestration ($\beta = 0.54$, $p < 0.001$) and on data-driven culture ($\beta = 0.48$, $p < 0.001$). Resource orchestration ($\beta = 0.31$, $p < 0.001$) and data-driven culture ($\beta = 0.27$, $p < 0.001$) each significantly predicted operational flexibility improvement. The direct effect of BDA integration on flexibility improvement, controlling for mediators, was reduced but remained significant ($\beta = 0.22$, $p = 0.003$), indicating partial mediation. The total indirect effect was significant ($\beta = 0.28$, 95% CI [0.19, 0.38]), supporting the hypothesized mediation pathways.

Predictive validation. The random forest classifier achieved 89.4% accuracy (95% CI [85.7%, 92.4%]) in predicting whether firms achieved high versus low operational flexibility improvement (median split), with precision = 0.87, recall = 0.91, and F1 = 0.89. This substantially exceeded the performance of the logistic regression baseline (accuracy = 67.2%) and the historical-forecasting benchmark (accuracy = 58.5%). Feature importance analysis (permutation-based) identified the following top predictors, in descending order: (1) real-time demand sensing capability (importance = 0.187); (2) supplier data integration (importance = 0.162); (3) managerial resource orchestration score (importance = 0.148); (4) data-driven culture (importance = 0.131); (5) firm size (importance = 0.094); and (6) region (importance = 0.072).

5. Discussion

5.1 Interpretation

Finding 1: BDA integration significantly predicts operational flexibility, but through orchestration mechanisms. The finding that BDA integration's direct effect on flexibility was substantially reduced when resource orchestration and data-driven culture were included as mediators (β from 0.61 to 0.22) provides empirical support for resource orchestration theory's central proposition: resources alone do not confer advantage; managerial actions to bundle and leverage resources are essential (Sirmon et al., 2011, as cited in Sabeena et al., 2026). This finding answers Research Question 1 by identifying that the combination of BDA integration, orchestration behaviors, and cultural factors collectively predicts flexibility, with orchestration serving as the critical converting mechanism. It aligns with Yin et al.'s (2025) finding that supply chain flexibility mediates the BDA-performance relationship, but extends that work by specifying the managerial and cultural mechanisms through which flexibility is achieved.

Finding 2: Real-time demand sensing and supplier data integration are the strongest BDA predictors. The feature importance analysis revealed that real-time demand sensing and supplier data integration outranked general BDA capability measures in predicting flexibility outcomes. This finding is consistent with the F&B sector's defining characteristics: perishable inventory and demand volatility make demand sensing particularly consequential, while supply disruptions during and after the pandemic elevated the importance of supplier visibility. It answers Research Question 2 by demonstrating that the proposed framework, incorporating specific BDA practices, achieves 89.4% accuracy—substantially exceeding conventional approaches (67.2% and 58.5%). The magnitude of this improvement suggests that the framework captures meaningful variance that traditional planning methods miss.

Finding 3: Data-driven culture is a necessary complementary condition. The significant mediation effect of data-driven culture indicates that BDA tools are insufficient without organizational norms that prioritize evidence-based decision-making. This finding extends Sabeena et al.'s (2026) work on digital transformation and agility by isolating culture as a distinct mediating mechanism rather than treating it as part of a composite digital maturity construct. It also provides empirical grounding for the resource orchestration perspective's emphasis on "leveraging" as a distinct managerial process: without a culture that encourages data use, orchestration efforts are unlikely to translate into operational flexibility.

5.2 Implications

Academic implications. This study makes three contributions to theory. First, it extends resource orchestration theory into the F&B SME context, demonstrating that the structuring-bundling-leveraging framework is applicable to BDA-driven flexibility and specifying the particular importance of bundling (integrating demand and supplier data) over mere structuring (acquiring tools). Second, it integrates resource orchestration and dynamic capabilities perspectives,

positioning BDA-enabled flexibility as a dynamic capability whose construction is explained by managerial orchestration actions. Third, it introduces a predictive validation approach to the SME digital transformation literature, moving beyond descriptive association studies to establish the predictive accuracy of a theoretically grounded framework.

Practical implications. For SME administrators, the findings yield several actionable recommendations. First, prioritize real-time demand sensing and supplier data integration over broad BDA platform investments; these specific capabilities account for the largest predictive contribution to flexibility. Second, invest in managerial training for resource orchestration—specifically, developing capabilities to translate data insights into operational reconfiguration decisions. Third, cultivate data-driven culture through leadership commitment, employee data literacy programs, and the integration of dashboards into routine decision meetings. Administrators should monitor leading indicators such as demand forecast accuracy, supplier on-time delivery visibility, and the proportion of operational decisions supported by data analysis. Based on the maturity patterns observed, SMEs beginning from a low BDA base can expect to see measurable flexibility improvements within 9–12 months of consistent implementation. For policymakers, the findings support targeted interventions: subsidies for cloud-based demand sensing tools, supplier data-sharing infrastructure development, and training programs focused on analytical decision-making rather than general digital literacy.

5.3 Limitations

1. **Cross-sectional survey design.** The survey component captured perceptions and self-reported practices at a single point in time, limiting causal inference. While retrospective operational data provided some temporal anchoring, the associations reported should be interpreted as consistent with, rather than definitively establishing, causal relationships.

2. **Simulated operational data for a subset of firms.** For 27.9% of respondents, operational performance data were simulated due to unavailability of raw records. Although simulation parameters were calibrated to industry benchmarks and controlled in analyses, this introduces potential measurement error and limits the precision of the flexibility improvement estimates for this subset.

3. **Generalizability across the full SME population.** The sample was stratified by region and size but excluded micro-enterprises and firms that ceased operations during the pandemic. Findings may not generalize to the smallest F&B enterprises or to failed firms, whose experiences may differ systematically.

4. **Reliance on single-informant reports.** Each firm was represented by one respondent (typically the owner or senior manager), introducing potential common-method variance and limiting the capture of organizational heterogeneity. The Harman test suggested no substantial bias, but multi-informant designs would strengthen future research.

5.4 Future Research Directions

1. **Longitudinal panel design.** Future studies should track the same firms over multiple years to establish temporal precedence and examine how BDA integration and orchestration capabilities evolve as firms progress through maturity stages.
2. **Comparative analysis across SME sub-sectors.** Research should compare F&B SMEs with other perishable-inventory sectors (e.g., fresh produce, pharmaceuticals) and with non-perishable sectors to identify sector-specific versus generalizable flexibility mechanisms.
3. **Intervention-based research.** Experimental or quasi-experimental designs testing specific BDA interventions (e.g., demand sensing tool deployment with accompanying orchestration training) would provide stronger evidence of causal effects and yield more precise estimates of implementation timelines.
4. **Extension to micro-enterprises and informal firms.** Given the prevalence of micro-enterprises in the F&B sector globally, research examining how BDA integration can be adapted for firms with fewer than 10 employees would address a significant gap in the SME literature.

6. Conclusion

This study developed and validated a predictive framework demonstrating that big data integration significantly enhances operational flexibility in post-pandemic food and beverage SMEs, with the proposed model achieving 89.4% predictive accuracy. The central contribution is the empirical demonstration that BDA's effect on flexibility is substantially mediated by managerial resource orchestration and data-driven culture—technology alone is insufficient; the capacity to bundle data resources into analytical capabilities and leverage them through evidence-based decision processes is what converts BDA investment into operational adaptability. For administrators, the practical takeaway is clear: prioritize demand sensing and supplier integration, invest in orchestration skills alongside tools, and cultivate a culture where data informs routine operational decisions. As F&B SMEs continue to navigate an environment characterized by persistent volatility, the ability to systematically transform data into flexible action will distinguish firms that merely survive from those that thrive.

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