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Integrated SWOT-AHP Mathematical Model for Strategic Development of MSMEs: Triple Helix Approach in the Riau Islands Region

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ABSTRACT

Micro, Small, and Medium Enterprises (MSMEs) in archipelagic regions face unique competitiveness challenges due to geographical fragmentation and limited institutional coordination. This study develops an integrated strategic framework combining industrial cluster concepts with Triple Helix collaboration (government-academia-business) for sustainable MSME development in Indonesia's Riau Islands Province. Employing a sequential explanatory mixed-methods approach, we collected data from 41 MSMEs, 4 government agencies, and 3 universities across four cities/districts. Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis positioned MSMEs in Quadrant I (aggressive growth) with Internal Factor Analysis Summary (IFAS) of 3.01 and External Factor Analysis Summary (EFAS) of 2.86. Analytical Hierarchy Process (AHP) with 30 expert stakeholders (consistency ratio: 0.053) identified three priority strategies: brand strengthening (28.7%), collaborative human resource development (23.4%), and marketing digitalization (18.9%). Key findings reveal superior product quality (weight: 0.60) and strategic location (0.52) as primary strengths, while conventional technology (0.06) and limited capital access (0.16) constitute critical weaknesses. The proposed Triple Helix model specifies multi-level governance structures, coordination mechanisms, and performance indicators adapted to archipelagic contexts. This research extends Triple Helix theory to MSME settings and provides evidence-based frameworks for policymakers in geographically dispersed regions. The integrated SWOT-AHP methodology offers a replicable approach for strategic prioritization in resource-constrained environments.

1. INTRODUCTION

1.1 Research background

Micro, Small, and Medium Enterprises (MSMEs) constitute fundamental pillars of Indonesia's economic architecture, demonstrating remarkable resilience and adaptability in dynamic market conditions. According to official statistics from the Ministry of Cooperatives and SMEs, MSMEs contribute over 60% of the national Gross Domestic Product (GDP) while absorbing approximately 97% of the total workforce [1]. This dual contribution to economic output and employment generation underscores their strategic importance in national development planning and regional economic sustainability.

In the context of the Riau Islands Province, MSMEs represent not merely economic entities but rather community-embedded institutions that sustain livelihoods across archipelagic landscapes. The province's geographical characteristics as an island cluster, with a strategic position along major ASEAN maritime trade routes, create unique opportunities and challenges for MSME development. Local MSMEs predominantly operate in fisheries processing, creative industries including handicrafts and fashion, and natural resource-based manufacturing sectors that leverage regional comparative advantages.

Despite their demonstrated economic significance and potential for further growth, MSMEs in the Riau Islands confront multidimensional constraints that systematically impede their competitive advancement. These challenges manifest across several critical domains. First, limited market access restricts both domestic distribution networks and international export opportunities, confining many enterprises to localized customer bases with constrained purchasing power [2]. Second, minimal innovation adoption and technology integration perpetuate conventional production methods that compromise productivity, quality consistency, and economies of scale. Third, restricted capital access and inadequate financing mechanisms create persistent working capital shortages that constrain inventory management, equipment investment, and business expansion capabilities. Fourth, low product competitiveness relative to regional alternatives and imported substitutes erodes market share and profit margins. Fifth, insufficient synergy among academic institutions, business sectors, and government agencies results in fragmented support systems with duplicative programs and missed collaboration opportunities.

The prevailing development approach for MSMEs in the

Riau Islands remains characterized by isolated, project-based interventions that lack systematic integration and long-term sustainability frameworks. Government support programs typically focus on short-term financial assistance without concurrent capacity-building initiatives. Academic institutions conduct research and community service activities with limited industry engagement and commercial application. Business associations organize among themselves, but with minimal institutional linkages to policy formulation or knowledge transfer mechanisms. This fragmented landscape generates suboptimal outcomes, where individual interventions produce temporary improvements but fail to create self-sustaining growth trajectories or systemic capability enhancement.

1.2 Problem statement

The fundamental research problem centers on the absence of integrated, systematic frameworks for MSME development that leverage collaborative synergies among key stakeholders while addressing the contextual realities of archipelagic regions. Existing approaches demonstrate several critical deficiencies. Programmatic interventions remain episodic rather than continuous, creating dependency patterns rather than building institutional capacity. Stakeholder interactions occur sporadically through disconnected initiatives rather than through structured coordination mechanisms. Performance measurement systems focus on input disbursement rather than outcome achievement or impact sustainability. Geographical fragmentation across islands complicates logistics, increases transaction costs, and impedes knowledge diffusion. Limited documentation and evaluation of previous interventions result in the repeated implementation of ineffective approaches, while successful innovations remain localized without systematic scaling.

Consequently, many MSMEs remain trapped in subsistence-level operations characterized by traditional production methods, informal business practices, limited market reach beyond immediate localities, and vulnerability to external shocks, including raw material price volatility, competitive pressures, and regulatory changes. This perpetuates a low-equilibrium trap in which insufficient profitability constrains investment in capability upgrading, which in turn limits productivity gains and market expansion, thereby reinforcing the profitability constraint in a self-reinforcing cycle.

1.3 Research objectives

This research aims to develop and validate a comprehensive strategic framework for sustainable MSME development that addresses the identified systemic deficiencies through the systematic integration of the Triple Helix innovation model adapted to industrial center contexts. The specific objectives include: (1) conducting a comprehensive diagnosis of current MSME conditions through the Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis methodology; (2) identifying and prioritizing strategic interventions using the Analytical Hierarchy Process (AHP) methodology; (3) designing an integrated Triple Helix collaboration model specifying governance structures and operational mechanisms; and (4) developing an industrial center concept with detailed specifications for physical infrastructure and management systems.

1.4 Research significance

This research generates theoretical, methodological, and practical contributions across multiple dimensions. Theoretically, it extends Triple Helix innovation model applications from predominantly manufacturing and technology sectors into MSME contexts characterized by different scale dynamics, capability levels, and institutional arrangements. The integration with industrial cluster theory provides a conceptual framework for understanding how geographical concentration, combined with institutional coordination mechanisms, can generate competitive advantages for small-scale enterprises.

Methodologically, the research demonstrates the systematic integration of quantitative strategic analysis tools (SWOT, AHP) with qualitative stakeholder engagement approaches (focus group discussions (FGDs), expert consultations) to generate a robust evidence base for strategy formulation. This mixed-methods approach addresses the limitations of purely quantitative or qualitative analyses by triangulating findings across different data sources and analytical techniques.

Practically, the research produces actionable frameworks directly applicable by government agencies for policy design and program implementation, by academic institutions for curriculum development and community engagement activities, and by MSME associations for collective action initiatives. The specificity of governance structures, coordination mechanisms, facility specifications, and performance indicators facilitates translation from conceptual frameworks to operational reality.

2. LITERATURE REVIEW

2.1 Triple Helix innovation model

The Triple Helix model, conceptualized by Etzkowitz and Leydesdorff [3], represents a fundamental reconceptualization of innovation dynamics beyond the linear models that dominated mid-twentieth-century thinking. Traditional linear models posited sequential flows from basic research through applied development to commercialization, with distinct institutional roles: universities conducting fundamental research, government providing funding and regulation, and industry commercializing discoveries. This perspective assumed clear boundaries between institutional spheres with unidirectional knowledge flows.

The Triple Helix framework challenges these assumptions by emphasizing interactive, recursive relationships among university, industry, and government spheres. Rather than operating in isolation with occasional handoffs, these institutions engage in continuous dialogue, mutual adaptation, and collaborative knowledge creation. Universities extend beyond traditional teaching and research missions to incorporate entrepreneurial activities, including patent commercialization, startup incubation, and direct industry partnerships. Government agencies evolve from passive regulators to active facilitators that convene stakeholders, broker relationships, provide risk capital, and shape innovation-friendly institutional environments. Industry organizations move beyond pure profit maximization to invest in pre-competitive research, workforce development, and regional economic development initiatives.

This model has demonstrated effectiveness across diverse

contexts, from advanced industrial economies to emerging markets. Khan et al. [4] documented successful Triple Helix implementation in Industry 4.0 contexts, where digital transformation requires tight integration among technology developers, production facilities, and regulatory frameworks. Their analysis revealed that collaborative innovation processes generate superior outcomes compared to isolated efforts due to complementary capabilities, shared risk-bearing, and accelerated learning cycles.

In MSME contexts, Triple Helix approaches address capability gaps that individual small enterprises cannot overcome independently [5, 6]. Austin and Rahman [7] examined financing challenges for circular economy transitions in European SMEs, finding that market failures across traditional financing channels create barriers that require coordinated public-private interventions combining government guarantees, university technical assistance, and industry mentorship. Surjanti et al. [8] analyzed hijab MSME sustainability in Indonesia during COVID-19 disruptions, demonstrating how Triple Helix collaboration enabled business model pivots, digital capability building, and market access preservation that individual firms could not achieve alone.

However, implementing Triple Helix models confronts several challenges. Hariani [9] identified the misalignment of incentive structures across institutions as a fundamental barrier, where academic publication pressures, government electoral cycles, and business profit timelines create conflicting priorities. Dahmiri et al. [10] extended the model to the Quintuple Helix, incorporating civil society and natural environment dimensions, and argued that SME development in smart city contexts requires broader stakeholder engagement beyond traditional Triple Helix actors [11].

2.2 Micro, Small, and Medium Enterprises development strategies

MSME development literature encompasses diverse theoretical perspectives and empirical findings across different geographical and sectoral contexts. Capability-based views emphasize building internal competencies in management systems, technical skills, quality control, and innovation processes as foundations for competitive advantage [12]. Market access approaches focus on distribution channel development, branding strategies, export promotion, and digital marketplace participation [13]. Resource-based perspectives highlight financing mechanisms, physical infrastructure, technology platforms, and information systems as critical enablers [14].

Bareduan and Hamid [12] conducted a systematic literature review on sustainability and optimization in supply chain contexts, identifying the integration of economic, social, and environmental objectives as essential for long-term MSME viability. Their analysis revealed that an isolated focus on profit maximization, without consideration of resource sustainability and community impacts, generates vulnerabilities during disruptions. Hasibuan and Larisang [13] examined procurement process re-engineering in frozen food retail, demonstrating how systematic business process improvements can reduce costs, improve quality, and enhance responsiveness without major capital investments.

Strategic positioning represents another key dimension in MSME development. Akbar and Koja [15] analyzed feasibility and development strategies for snack food businesses in the Tidore Islands, employing financial feasibility assessment combined with SWOT analysis to identify optimal growth paths. Their findings indicated that product diversification and quality standardization provided more sustainable competitive advantages than price-based competition. Khalifah et al. [16] studied local food-based business development, concluding that leveraging regional product distinctiveness through storytelling and cultural associations enabled premium pricing and customer loyalty that offset scale disadvantages.

Digital transformation has emerged as a critical theme in recent MSME literature. Yhonathan et al. [17] investigated the effects of digital marketing on MSME performance with Triple Helix moderation, finding that technology adoption impacts vary significantly based on contextual support from government digital infrastructure investment, university training programs, and industry mentor networks. Mardiana et al. [18] analyzed creative economy strategies using Triple Helix methodology for umbrella craft MSMEs, revealing that digital platforms enable market expansion but require concurrent skill development and business model adaptation.

Cluster and network approaches provide alternative frameworks emphasizing collective action and geographical proximity [18]. Yhonathan et al. [17] articulated cluster theory, demonstrating how the spatial concentration of related businesses, specialized suppliers, service providers, and institutions generates competitive advantages through knowledge spillovers, labor market pooling, and access to specialized inputs. However, simply colocating businesses proves insufficient without deliberate mechanisms for interaction, trust building, and knowledge exchange.

2.3 Strategic analysis methodologies

SWOT analysis remains widely utilized for strategic assessment due to its intuitive structure and comprehensive scope covering internal and external factors. Verkasalo et al. [19] applied SWOT to side-stream utilization in wood construction value chains, demonstrating how systematic factor identification enables opportunity recognition and threat mitigation in circular economy transitions. However, SWOT analysis faces criticisms regarding subjective factor identification, the absence of quantitative prioritization, and limited guidance for strategy formulation beyond factor listing.

AHP, developed by Saaty [20, 21], addresses SWOT limitations by providing a mathematical framework for multi-criteria decision-making through pairwise comparisons. AHP decomposes complex decisions into hierarchical structures with the goal at the apex, criteria at intermediate levels, and alternatives at the bottom. Decision-makers evaluate relative importance through systematic pairwise comparisons using standardized scales. Mathematical processing transforms qualitative judgments into quantitative weights through eigenvalue calculations. Consistency ratios verify judgment reliability, with values below 0.10 indicating acceptable consistency.

The integration of SWOT and AHP combines the strengths of both methodologies. SWOT provides a comprehensive strategic assessment identifying relevant factors and potential strategies, while AHP enables quantitative prioritization based on weighted criteria and expert judgments. Larisang and Kamil [22] demonstrated this integration for logistics company development, finding that the combined approach

generated more actionable strategic recommendations than either methodology alone. Hasibuan and Kusrini [23] applied a similar integration to supplier relationship performance measurement, developing weighted evaluation frameworks balancing multiple performance dimensions.

2.4 Industrial center and cluster concepts

Industrial centers represent geographical concentrations of interconnected businesses, specialized suppliers, service providers, and associated institutions in particular fields [24]. Yhonathan et al. [17] distinguished clusters from simple geographical concentrations by emphasizing functional linkages, knowledge flows, and collective action mechanisms. Effective clusters generate competitive advantages through multiple channels, including specialized labor pools with industry-specific skills, supply chain proximity reducing logistics costs and enabling just-in-time operations, knowledge spillovers accelerating innovation diffusion, collective action enabling shared infrastructure investment, reputation effects attracting customers and talent, and market power in procurement and sales.

For MSMEs specifically, industrial centers address scale limitations by enabling shared facilities that individual enterprises cannot afford independently. Shared production equipment, quality testing laboratories, storage facilities, training centers, and showrooms reduce capital requirements while improving service access. Management consolidation for utilities, security, waste handling, and logistics generates efficiency gains. Marketing collaboration through collective branding, joint exhibitions, and coordinated e-commerce platforms enhances market visibility and customer confidence.

However, successful industrial center development requires careful attention to governance structures, participant selection criteria, facility management systems, and conflict resolution mechanisms. Inappropriate governance can generate principal-agent problems, free-rider behaviors, or elite capture, where benefits concentrate among a few participants. Selection processes must balance inclusion objectives with commercial viability requirements. Management systems need clear rules, transparent processes, and professional administration while maintaining flexibility for participant needs.

2.5 Research gaps and contributions

Synthesizing existing literature reveals several critical gaps:

Gap 1: Triple Helix in MSME contexts: most Triple Helix research examines high-tech sectors or university-industry R&D partnerships. Systematic application to traditional MSMEs with limited technological sophistication remains underexplored.

Gap 2: Archipelagic adaptation: geographical dispersion across islands creates unique coordination challenges inadequately addressed in existing cluster and Triple Helix literature developed for contiguous regions.

Gap 3: Operational specificity: existing frameworks often remain conceptual without detailed governance structures, coordination mechanisms, and performance measurement systems necessary for implementation.

Gap 4: Integrated methodological approaches: while SWOT and AHP are individually common, systematic integration with qualitative stakeholder engagement for MSME strategy formulation in developing economy contexts requires further development.

This research addresses these gaps by:

1. Adapting the Triple Helix model to traditional MSME contexts with explicit attention to capability constraints.
2. Developing archipelagic-specific adaptations addressing geographical dispersion.
3. Providing operational frameworks with detailed governance, coordination, and measurement specifications.
4. Demonstrating rigorous mixed-methods integration for strategic prioritization.

These contributions advance both theory (extending Triple Helix and cluster concepts) and practice (providing implementable frameworks for policymakers).

3. METHODOLOGY

3.1 Research design

This research employs a sequential explanatory mixed-methods design grounded in pragmatist philosophy. Phase 1 involved quantitative measurement through structured surveys and SWOT-AHP analysis, identifying strategic patterns. Phase 2 employed qualitative FGDs and interviews, providing contextual depth and stakeholder perspectives that enrich the quantitative findings.

The research protocol received ethical approval from the Universitas Ibnu Sina Research Ethics Committee (Protocol #UIS-2024-087). All participants provided written informed consent. Data confidentiality was maintained through coded identifiers, secure storage, and aggregated reporting.

3.2 Research setting

The study was conducted in Riau Islands Province, Indonesia, comprising 2,408 islands across 252,601 km². Four administrative regions were selected: Batam City (1.2 M population, manufacturing hub), Tanjungpinang City (227 K, provincial capital), Bintan Regency (157 K, tourism/fisheries), and Karimun Regency (153 K, marine industries). Inter-island distances range from 25 to 180 km, creating logistics challenges affecting MSME operations and coordination.

Provincial statistics show 47,832 registered MSMEs contributing 58.3% of regional GDP and employing 234,567 workers (73.2% of total employment), with sectoral distribution: food processing (31%), fashion/textiles (24%), handicrafts (18%), services (15%), other (12%).

3.3 Sampling and participants

MSME Sample: Purposive stratified sampling targeted MSMEs with ≥ 1 year of operation, formal registration, and active production. Target: 60 MSMEs; achieved: 41 (68.3% response rate). Non-response analysis compared respondents ($n = 41$) with non-respondents ($n = 19$) on observable characteristics obtained from registration databases: location distribution ($\chi^2 = 2.83$, $p = 0.419$), business sector ($\chi^2 = 1.94$, $p = 0.585$), and business scale ($\chi^2 = 0.67$, $p = 0.715$). No statistically significant differences emerged, suggesting non-response bias was minimal and the achieved sample reasonably represents the target population. However, we acknowledge limitations in representativeness: (1) the small

sample size (n = 41) reduces statistical power for subgroup analyses, (2) purposive sampling may have excluded less accessible or informal MSMEs, (3) regional imbalance with Batam and Bintan over-represented relative to population proportions may limit generalizability to undersampled districts, and (4) voluntary participation may introduce self-selection bias favoring more engaged or successful enterprises.

Institutional Partners: All four eligible government agencies (100%) and three universities (100%) participated.

AHP Expert Panel: Maximum variation sampling selected 30 experts: government officials (n = 8), academics (n = 7), MSME association leaders (n = 10), and experienced entrepreneurs (n = 5), ensuring diverse perspectives and an adequate size for AHP reliability.

FGD Participants: Convenience and snowball sampling yielded 42 participants (Government: 4, Academia: 3, MSMEs: 35).

3.4 Data collection

Quantitative Instruments: MSME questionnaire covered business characteristics, internal/external factors (5-point Likert scales), and strategic priorities. Government and university assessments evaluated support activities, Triple Helix engagement, and resource allocation.

Instrument Validation: An expert panel (n = 5) conducted content validation (CVR > 0.62 for all retained items). Pilot testing (n = 10 MSMEs) confirmed comprehension and an acceptable completion time (28 minutes on average). Cronbach's alpha for multi-item scales exceeded the 0.70 threshold: internal factors (α = 0.82), external factors (α = 0.78), government support (α = 0.85), university engagement (α = 0.79).

Qualitative Instruments: A semi-structured FGD guide and interview protocol explored collaboration experiences, strategic priorities, industrial center concepts, and implementation feasibility.

Data Collection Procedures: In-person surveys (October-November 2024), individual AHP sessions (December 2024, 75 minutes on average), FGDs (December 2024, 90-120 minutes), and follow-up interviews (January 2025, 45-60 minutes) were conducted until thematic saturation.

3.5 Mathematical model formulation

This section presents the explicit mathematical formulations underlying the SWOT-AHP integrated framework. The formalization ensures reproducibility, transparency, and systematic evaluation of the strategic prioritization process.

3.5.1 Analytical Hierarchy Process hierarchy construction

Figure 1 illustrates the three-level AHP hierarchy structure developed for this research.

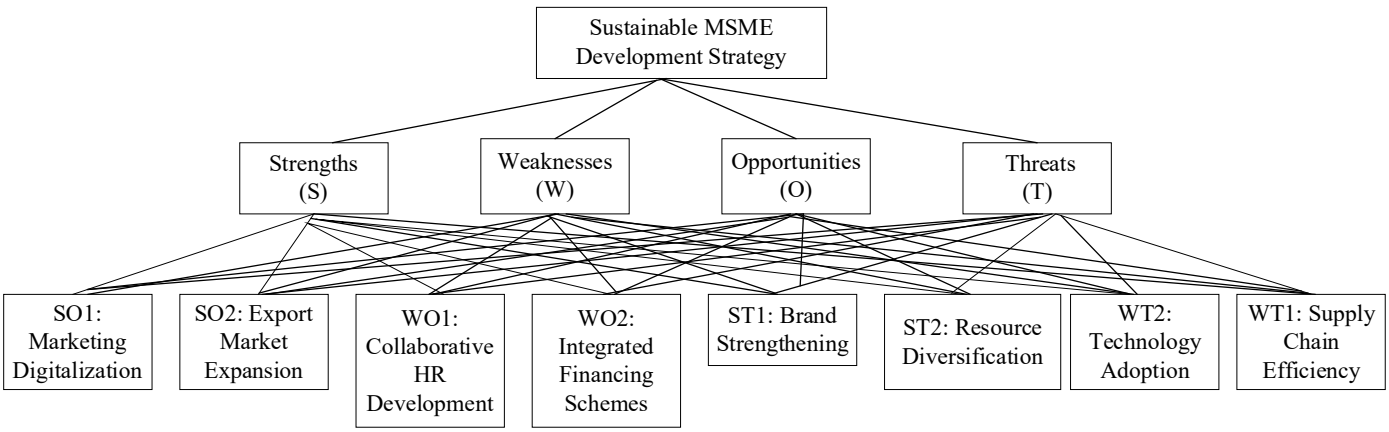

Figure 1. Analytical Hierarchy Process (AHP) hierarchy structure for Micro, Small, and Medium Enterprises (MSMEs) strategic development

3.5.2 Strengths, Weaknesses, Opportunities, Threats quantification model

The SWOT analysis employs a weighted scoring methodology to quantify strategic factors. For internal factors:

$$IFAS = \Sigma_i (w_i \times r_i) \text{ for } i \in \{1, 2, ..., n\} \quad (1)$$

where,

- $IFAS$ = Internal Factor Analysis Summary score
- w_i = weight assigned to internal factor i ($0 \leq w_i \leq 1$)
- r_i = rating of internal factor i on Likert scale (1-5)
- n = total number of internal factors (strengths + weaknesses)
- Constraint: $\Sigma_i w_i = 1.0$

Similarly, for external factors:

$$EFAS = \Sigma_j (w_j \times r_j) \text{ for } j \in \{1, 2, ..., m\} \quad (2)$$

where,

- $EFAS$ = External Factor Analysis Summary score
- w_j = weight assigned to external factor j ($0 \leq w_j \leq 1$)
- r_j = rating of external factor j on Likert scale (1-5)
- m = total number of external factors (opportunities + threats)
- Constraint: $\Sigma_j w_j = 1.0$

The strategic positioning is determined by comparing Internal Factor Analysis Summary Score (IFAS) and External Factor Analysis Summary (EFAS) scores against the neutral threshold (2.50):

- Quadrant I (Aggressive): IFAS > 2.50 and EFAS > 2.50
- Quadrant II (Diversification): IFAS < 2.50 and EFAS > 2.50
- Quadrant III (Turn-around): IFAS < 2.50 and EFAS < 2.50
- Quadrant IV (Defensive): IFAS > 2.50 and EFAS < 2.50

Weight determination procedure for SWOT factors: The weights (w_i and w_j) for internal and external factors in IFAS

and EFAS calculations were determined through a structured expert panel process combining the Delphi technique and pairwise comparison:

Step 1: Factor Identification (FGDs, October 2024). FGDs with 42 participants (government: 4, academia: 3, MSMEs: 35) identified an initial list of potential SWOT factors through open-ended discussion and brainstorming sessions. Thematic analysis produced 23 internal factors (14 strengths, 9 weaknesses) and 19 external factors (11 opportunities, 8 threats).

Step 2: Factor Validation and Consolidation (Expert Panel, November 2024). A panel of 5 experts (2 academics specializing in strategic management, 2 government officials from Cooperatives/SMEs departments, 1 senior MSME consultant) reviewed and consolidated factors, eliminating redundancies and combining similar items. Final factor list: 11 internal factors (6 strengths, 5 weaknesses), 10 external factors (6 opportunities, 4 threats).

Step 3: Weight Determination (AHP Expert Panel, December 2024). The same 30-member expert panel used for strategy prioritization performed pairwise comparisons for SWOT factors. Experts rated the relative importance of each factor pair using Saaty's [20] 9-point scale. Individual judgments were aggregated using the geometric mean method, which preserves the reciprocal property and is recommended for group decision-making [21].

Step 4: Consistency Verification. Individual expert consistency ratios were calculated; 28 of 30 experts achieved CR < 0.10 (average CR = 0.067). Two experts with CR > 0.10 were asked to review and revise their judgments until consistency was achieved.

Step 5: Weight Normalization. Final factor weights were normalized within each category (strengths, weaknesses, opportunities, threats) to ensure $\Sigma w_i = 1.0$ for internal factors and $\Sigma w_j = 1.0$ for external factors, as required by IFAS/EFAS formulation.

This structured approach ensures weights reflect collective expert judgment rather than arbitrary assignment, enhancing the validity and reliability of strategic factor evaluation.

3.5.3 Analytical Hierarchy Process pairwise comparison matrix

The AHP methodology constructs a pairwise comparison matrix A for criteria evaluation:

$$A = [a_{ij}]_{nxn} \tag{3}$$

where a_{ij} represents the relative importance of criterion i compared to criterion j, with properties:

- $a_{ij} > 0$ (positivity)

$$a_{ji} = 1/a_{ij} \text{ (reciprocal property)} \tag{4}$$

$$a_{ii} = 1 \text{ (diagonal elements)} \tag{5}$$

The comparison scale follows Saaty's [20] nine-point scale:

- 1 = Equal importance
- 3 = Moderate importance
- 5 = Strong importance
- 7 = Very strong importance
- 9 = Extreme importance
- 2, 4, 6, 8 = Intermediate values

3.5.4 Priority vector calculation

The priority vector w is derived from the principal eigenvector of matrix A:

$$Aw = \lambda_{max}\, w \tag{6}$$

where,

- λ_{max} = principal (maximum) eigenvalue of A
- $w = [w_1, w_2, ..., w_n]^T$ = priority vector
- Normalization constraint:

$$\Sigma_i\, w_i = 1.0 \tag{7}$$

The eigenvalue is computed iteratively using the power method:

Step 1: Initialize $w^{(0)} = [1/n, 1/n, ..., 1/n]^T$

Step 2: Iterate:

$$w^{(k+1)} = (Aw^{(k)}) / ||Aw^{(k)}|| \tag{8}$$

Step 3: Convergence test:

$$||w^{(k+1)} - w^{(k)}|| < \varepsilon \text{ (typically } \varepsilon = 10^{-6}) \tag{9}$$

Step 4: Calculate

$$\lambda_{max} = (Aw)^T w / w^T w \tag{10}$$

3.5.5 Consistency verification

The consistency of expert judgments is measured through Consistency Index (CI) and Consistency Ratio (CR):

$$CI = (\lambda_{max} - n) / (n - 1) \tag{11}$$

$$CR = CI / RI \tag{12}$$

where,

- n = size of pairwise comparison matrix
- RI = Random Index (theoretical average CI for random matrices)

Random Index values [20]:

- RI(3) = 0.58, RI(4) = 0.90, RI(5) = 1.12, RI(6) = 1.24
- RI(7) = 1.32, RI(8) = 1.41, RI(9) = 1.45, RI(10) = 1.49

Acceptability criterion:

$$CR < 0.10 \text{ (or } CR < 0.05 \text{ for } n = 3) \tag{13}$$

If $CR \geq 0.10$, the pairwise comparisons must be revised to improve consistency.

3.5.6 Global priority synthesis

For hierarchical structures with multiple levels, the global priority of alternative i is computed by aggregating priorities across all criteria:

$$P_i = \Sigma c\, (wc \times w_i c) \tag{14}$$

where,

- P_i = global priority score for alternative i
- wc = weight of criterion c from criteria-level AHP
- $w_i c$ = local weight of alternative i under criterion c
- $\Sigma_i P_i = 1.0$ (normalization)

The alternative with the highest global priority (P_i) is ranked first. Statistical significance of ranking differences can be tested through:

$$z = (P_i - P_j) / \sqrt{(\sigma_i^2 + \sigma_j^2)} \quad (15)$$

where, σ_i^2, σ_j^2 are variances estimated through sensitivity analysis or expert uncertainty quantification.

3.5.7 Computational implementation

All calculations were performed using Python 3.11.5 with NumPy 1.26.0 for matrix operations and SciPy 1.11.3 for eigenvalue computation. The computational complexity of the AHP algorithm is $O(n^3)$ for the eigenvalue calculation, where n is the number of criteria or alternatives. For this study, with n = 4 criteria and m = 8 alternatives, the computational time was negligible (< 0.1 seconds per matrix on standard hardware). Numerical precision was maintained at double-floating point (64-bit) with convergence tolerance $\varepsilon = 10^{-6}$ for iterative calculations.

3.6 Validity and trustworthiness

Quantitative Validity: Triangulation across multiple data sources, AHP consistency checking, multi-site sampling, and literature-grounded operational definitions ensured internal, external, and construct validity.

Qualitative Trustworthiness: Following Lincoln and Guba [25], credibility through prolonged engagement (6 months), triangulation, member checking, and peer debriefing; transferability through thick description; dependability through audit trails; and confirmability through reflexive journaling.

Researcher Positionality: Research team from Universitas Ibnu Sina (Batam) with established regional MSME relationships. Insider status facilitated access but created potential positive bias. Mitigation strategies: external validator review, negative case analysis, reflexive discussions, and quantitative measurement objectivity.

4. RESULT

4.1 Micro, Small, and Medium Enterprises characteristics and demographics

Data collection through structured questionnaires yielded 41 MSME respondents across four locations in Riau Archipelago Province, representing 68.3% of the target sample. Table 1 presents the comprehensive distribution of respondents by location, sectoral composition, business scale, and operational duration.

The sectoral classification reveals that fashion/textile dominates with 39% (16 MSMEs), concentrated in Batam and Bintan, indicating significant potential for creative product development. Food processing occupies second position with 37% (15 MSMEs), encompassing various products including fish crackers, dried fish, and local specialties distributed across Tanjungpinang, Bintan, and Karimun. Handicraft/craft comprises 24% (10 MSMEs), almost entirely located in Batam, known as a center for handicraft development.

The overwhelming concentration in the micro-enterprise category (87.8%) with limited progression to small (9.8%) or medium (2.4%) scales suggests barriers to business growth, including capital constraints, market access limitations, management capability gaps, and risk aversion. Operational duration analysis showing 44% operating 4-5 years and 31.7% exceeding 5 years indicates survival capability among established businesses, though a relatively low proportion of new enterprises (19.5% under 1 year) suggests limited new business formation.

4.2 Descriptive statistics for strategic factors

Table 2 presents item-level descriptive statistics for all SWOT factors rated by MSMEs (n = 41) using 5-point Likert scales (1 = Very Weak/Very Unfavorable to 5 = Very Strong/Very Favorable).

Analysis of the descriptive statistics reveals several notable patterns. Strength factors show relatively high means (3.27-3.85) with moderate standard deviations (0.69-0.87), indicating general consensus among MSMEs about their capabilities. Product quality (M = 3.85, SD = 0.69) and strategic location (M = 3.78, SD = 0.74) emerge as the most consistently rated strengths.

Weakness factors demonstrate lower means (1.93-2.22) with comparable standard deviations (0.84-0.92), showing agreement on limitations. Conventional technology (M = 1.93, SD = 0.84) represents the most critical weakness with the highest consensus.

Opportunity factors exhibit high means (3.44-3.73) and moderate dispersion (0.75-0.88), reflecting positive perceptions of the external environment. Digital market growth (M = 3.73, SD = 0.81) is rated highest, aligning with digitalization trends.

Threat perceptions show moderate means (2.98-3.29) with higher standard deviations (0.87-0.93), suggesting varied risk assessments. Raw material price volatility (M = 3.29, SD = 0.87) poses the greatest concern.

The overall pattern—high strength and opportunity ratings combined with lower weakness ratings—provides a statistical foundation for the subsequent IFAS (3.01) and EFAS (2.86) scores, positioning MSMEs in Quadrant I (aggressive growth).

Table 1. MSME respondent profile and distribution

Location	Target	Achieved	Rate	Dominant Sectors	Scale Distribution	Operational Duration
Batam	20	16	80%	Handicraft (10), Fashion (6)	Micro: 14, Small: 2	< 1yr: 3, 1-3yr: 1, 4-5yr: 7, > 5yr: 5
Tanjungpinang	10	5	50%	Food Processing (5)	Micro: 5	< 1yr: 1, 4-5yr: 2, > 5yr: 2
Bintan	20	15	75%	Food (5), Fashion (10)	Micro: 12, Small: 2, Medium: 1	< 1yr: 3, 4-5yr: 6, > 5yr: 6
Karimun	10	5	50%	Food Processing (5)	Micro: 5	< 1yr: 1, 1-3yr: 1, 4-5yr: 3
Total	60	41	68.3%	Food: 15 (37%), Fashion: 16 (39%), Craft: 10 (24%)	Micro: 36 (87.8%), Small: 4 (9.8%), Medium: 1 (2.4%)	< 1yr: 8 (19.5%), 1-3yr: 2 (4.8%), 4-5yr: 18 (44%), > 5yr: 13 (31.7%)

Table 2. Descriptive statistics for Strengths, Weaknesses, Opportunities, Threats (SWOT) factor ratings

Factor	Category	Mean	SD	Min	Max	n
Internal Factors - Strengths						
Superior product quality	S	3.85	0.69	2	5	41
Strategic location	S	3.78	0.74	2	5	41
Customer loyalty	S	3.71	0.78	2	5	41
Social media utilization	S	3.46	0.87	1	5	41
Product differentiation	S	3.39	0.83	1	5	41
Business optimism	S	3.27	0.85	1	5	41
Subtotal Strengths		3.58	0.79			
Internal Factors - Weaknesses						
Limited capital access	W	2.05	0.92	1	4	41
Skills gaps	W	2.12	0.88	1	4	41
Digital marketing deficiency	W	2.17	0.91	1	4	41
Financial management weakness	W	2.22	0.89	1	4	41
Conventional technology	W	1.93	0.84	1	4	41
Subtotal Weaknesses		2.10	0.89			
External Factors - Opportunities						
Digital market growth	O	3.73	0.81	2	5	41
Government support programs	O	3.61	0.77	2	5	41
Tourism sector growth	O	3.56	0.85	1	5	41
Strategic geographic position	O	3.68	0.75	2	5	41
Local product preference	O	3.44	0.88	1	5	41
Partnership opportunities	O	3.51	0.82	1	5	41
Subtotal Opportunities		3.59	0.81			
External Factors - Threats						
Intense competition	T	3.22	0.93	1	5	41
Economic uncertainty	T	3.15	0.89	1	5	41
Regulatory complexity	T	2.98	0.91	1	5	41
Raw material price volatility	T	3.29	0.87	1	5	41

4.3 Government performance evaluation

Four government agencies responsible for MSME development were assessed across multiple dimensions. Batam City Cooperative Office demonstrates superior performance (overall 4.6/5.0), establishing best practices in Triple Helix implementation. The agency achieved perfect scores (5.0) in financing accessibility and comprehensive coaching programs. Their innovative digitalization initiatives include: (1) smart UMKM programs integrating digital technology across entire MSME value chains, (2) structured business incubation with intensive mentoring, (3) facilitated export market access, opening domestic and international opportunities, (4) real-time monitoring systems with continuous field visits, enabling evidence-based and responsive program improvements, and (5) regular forums among academics, industry, and MSMEs, facilitating systematic knowledge exchange and the identification of collaboration opportunities.

Bintan and Karimun Districts show consistent performance with identical ratings (4.1/5.0 average). Most notably, both achieve perfect scores (5.0) in financing access and capital support, demonstrating a strong commitment to MSME financial assistance. The full interest subsidy program for MSME credit represents a significant policy innovation, reducing capital costs and enhancing formal financing accessibility. However, a critical challenge emerged: Triple Helix collaboration typically occurs only through mandatory programs; when regulatory reinforcement weakens, partnerships diminish. This indicates that collaboration has not become a self-sustaining culture but remains dependent on top-down regulatory intervention.

Batam Trade Office shows notable weaknesses in research facility access (1.0/5.0), indicating practically no connection between supervised MSMEs and academic research facilities. This reflects weak integration between the agency and universities in facilitating technology transfer and research-based product development. Manual monitoring systems, due to limited human resources, further constrain evidence-based policymaking capabilities.

4.4 University contribution assessment

Three universities demonstrated varying engagement levels in MSME development. UMRAH emerges as the most active in industry collaboration, with 6-10 projects annually and the largest financial contribution (31-50%), while ITEBA shows only 1-2 projects per year. Paradoxically, ITEBA maintains high satisfaction despite its low frequency, indicating that quality matters more than quantity. A significant disparity exists in intellectual property regulation support, with ITEBA rating it poorly (2/5) while UNRIKA and UMRAH rate it adequately (4/5), suggesting uneven implementation that potentially hampers research commercialization.

UNRIKA demonstrates the highest effectiveness in MSME programs (4/5), with comprehensive approaches covering management training, digital marketing, and capital access. All three institutions consistently allocate 11-15% of resources to MSME activities, showing uniform commitment, though with different outcomes. Positive impacts appear consistently across institutions, particularly increased publications and research commercialization, though UNRIKA shows the highest sustainability, with programs already embedded in institutional systems.

4.5 Strengths, Weaknesses, Opportunities, Threats analysis: Strategic positioning

4.5.1 Internal factor analysis

The IFAS reveals that Riau Islands MSMEs possess strong

internal capabilities that significantly outweigh weaknesses. Table 3 presents a comprehensive internal factor assessment.

Table 3. Internal Factor Analysis Summary (IFAS) – comprehensive

Factor	Weight	Rating	Score	Classification
Strengths				
Superior product quality	0.15	4.0	0.60	Primary strength
Strategic location	0.13	4.0	0.52	Primary strength
Customer loyalty	0.12	4.0	0.48	Secondary strength
Social media utilization	0.10	3.0	0.30	Secondary strength
Product differentiation	0.09	3.0	0.27	Supporting strength
Business optimism	0.08	3.0	0.24	Supporting strength
Subtotal Strengths	0.67	Avg: 3.50	2.41	
Weaknesses				
Limited capital access	0.08	2.0	0.16	Critical weakness
Skills gaps	0.07	2.0	0.14	Major weakness
Digital marketing deficiency	0.06	2.0	0.12	Major weakness
Financial management weakness	0.06	2.0	0.12	Major weakness
Conventional technology	0.06	1.0	0.06	Critical weakness
Subtotal weaknesses	0.33	Avg: 1.80	0.60	
Total IFAS score	1.00		3.01	Strong Position

Analysis: The IFAS total score of 3.01 (scale 1.0-4.0) significantly exceeds the neutral threshold of 2.50, indicating a strong internal position. The strengths-weaknesses gap of 1.81 (2.41 - 0.60) demonstrates a substantial strength surplus exploitable through SO (Strengths-Opportunities) and ST (Strengths-Threats) strategies.

Superior product quality (0.60) emerges as the dominant strength, reflecting years of refinement and reputation building. Many MSMEs have developed signature products, creating quasi-monopoly positions in niche markets. Strategic location (0.52) provides a structural advantage, benefiting all provincial MSMEs through reduced export transportation costs and access to international value chains. Customer loyalty (0.48) represents accumulated relationship capital from consistent quality delivery, personal service, and cultural connections, creating stable revenue bases that buffer market fluctuations.

Critical weaknesses concentrate in production technology (0.06 - lowest factor) and limited capital access (0.16). Conventional technology manifests in manual processes, simple equipment, minimal automation, and absent quality control instruments. Despite government-subsidized credit programs, only 31.2% have accessed formal loans, with 68.8% relying entirely on personal savings and retained earnings.

4.5.2 External factor analysis

EFAS indicates a favorable external environment, with opportunities exceeding threats. Table 4 presents a comprehensive external factor assessment.

Table 4. External Factor Analysis Summary (EFAS) – comprehensive

Factor	Weight	Rating	Score	Classification
Opportunities				
Government policy support	0.14	4.0	0.56	Major opportunity
Digital revolution	0.13	4.0	0.52	Major opportunity
University collaboration	0.12	3.0	0.36	Moderate opportunity
ASEAN market access	0.11	3.0	0.33	Moderate opportunity
Digital infrastructure growth	0.09	3.0	0.27	Supporting opportunity
Subtotal opportunities	0.59	Avg: 3.40	2.04	
Threats				
Raw material volatility	0.12	2.0	0.24	Major threat
Intense competition	0.10	2.0	0.20	Moderate threat
Imported products	0.09	2.0	0.18	Moderate threat
Limited logistics	0.07	2.0	0.14	Minor threat
Changing consumer behavior	0.03	2.0	0.06	Minor threat
Subtotal threats	0.41	Avg: 2.00	0.82	
Total EFAS score	1.00		2.86	Favorable

Analysis: The EFAS total score of 2.86 exceeds the neutral threshold of 2.50, indicating a net favorable external environment. The opportunities-threats gap of 1.22 (2.04 - 0.82) shows a significant opportunity surplus conducive to growth-oriented strategies.

Government policy support (0.56) represents the strongest external factor through the One Single Submission (OSS) licensing system, subsidized interest rate programs, training capacity building, exhibition facilitation, and infrastructure investment. The digital revolution opportunity (0.52) reflects rapid e-commerce growth, expanding internet penetration, mobile payment adoption, and logistics improvements, though the gap between 71.9% interest and actual adoption indicates implementation barriers requiring targeted support.

The primary threat of raw material price volatility (0.24) particularly affects food processors dependent on fishery inputs subject to seasonal availability, weather impacts, and speculative dynamics. Competitive intensity (0.20) manifests differently across sectors: fashion and handicraft markets face proliferation without clear differentiation, leading to price competition, while food processing maintains stronger differentiation through proprietary recipes and brands.

4.5.3 Strategic positioning matrix

Figure 2 presents SWOT strategic positioning based on IFAS and EFAS scores, visualizing MSMEs' competitive position.

Data Source: IFAS score (3.01) calculated from weighted ratings of 11 internal factors (Table 3); EFAS score (2.86)

calculated from weighted ratings of 10 external factors (Table 4), based on survey responses from 41 MSMEs across four districts/cities. Quadrant boundaries set at 2.50 (neutral threshold) following SWOT methodology.

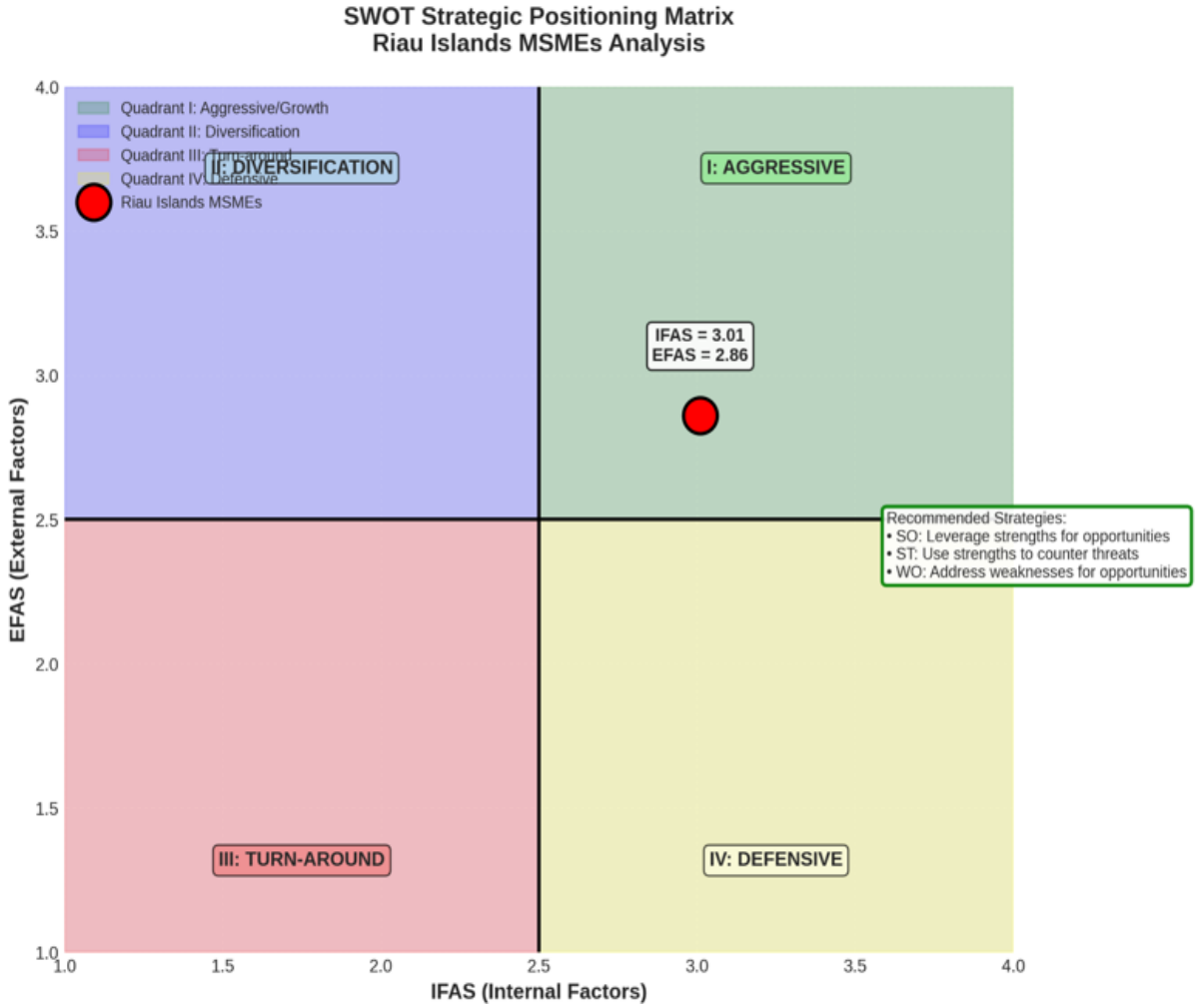

Figure 2. SWOT strategic positioning matrix

Interpretation: The positioning in Quadrant I demonstrates that Riau Islands MSMEs possess competitive advantages warranting aggressive growth strategies. The coordinate (3.01, 2.86) places enterprises in the upper-right quadrant with both dimensions exceeding neutral thresholds by 0.51 and 0.36, respectively. The proximity to the diagonal (difference of only 0.15 between IFAS and EFAS) suggests balanced capabilities, though internal strengths slightly outweigh external opportunities. This positioning differs markedly from typical developing-country MSMEs, which often fall in Quadrant III (turnaround) or IV (defensive) due to weak internal capabilities despite external opportunities.

Positioning in Quadrant I (Aggressive/Growth) indicates MSMEs possess strong internal capabilities (IFAS 3.01 > 2.50) operating in a favorable external environment (EFAS 2.86 > 2.50). This optimal positioning supports aggressive growth strategies, including:

1. Market Penetration: Intensifying efforts in existing markets
2. Market Development: Entering new geographical or customer segments
3. Product Development: Creating new offerings for current markets
4. Forward Integration: Moving toward distribution and retail
5. Backward Integration: Controlling raw material supply
6. Horizontal Integration: Mergers or alliances with competitors

The gap analysis (Strengths 2.41 vs Opportunities 2.04) reveals internal capabilities provide a stronger foundation than external advantages, implying strategies should prioritize leveraging strengths to capture opportunities (SO strategies) as primary focus, with secondary attention to addressing weaknesses for opportunity enhancement (WO strategies).

4.5.4 Strengths, Weaknesses, Opportunities, Threats strategy matrix

Table 5 presents a comprehensive SWOT matrix with specific strategic initiatives for each factor combination.

Strategic Priority Rationale: Based on Quadrant I positioning, SO strategies receive the highest implementation priority, followed by ST strategies for defensive positioning, then WO strategies for capability building, and finally WT strategies for risk minimization.

4.6 Analytical Hierarchy Process analysis: Strategy prioritization

4.6.1 Criteria weighting and consistency

Table 6 presents a pairwise comparison matrix for SWOT criteria with normalization and consistency verification.

Table 5. SWOT strategy matrix with detailed initiatives

Internal/External	Opportunities	Threats
Strengths	SO1: Digital Marketing Leveraging Product Excellence	ST1: Brand Strengthening & Product Differentiation
	Develop showcase platform for superior quality	Create unique selling propositions based on local distinctiveness
	Content marketing through testimonials	Implement quality certification systems
	Influencer partnerships leveraging reputation	Develop protected designation of origin
	SO2: Regional Market Expansion via Strategic Location	ST2: Local Resource-Based Diversification
	Export program targeting Singapore/Malaysia	Innovate derivative products from primary materials
	"Riau Islands Brand" collective initiative	Value-added processing reducing commodity dependence
	Regional distributor partnerships	Blue ocean strategy targeting niche markets
Weaknesses	WO1: Collaborative HR Development	WT1: Efficient Supply Chain Management
	Structured training through university partnerships	Cold storage and warehousing cooperatives
	Apprenticeship and mentoring systems	Group procurement systems reducing costs
	Industry-based competency certification	Inter-island logistics optimization
	WO2: Integrated Financing Schemes	WT2: Operational Technology Adoption
	Government guarantee programs for bank lending	Appropriate technology for productivity
	Crowdfunding and peer-to-peer lending	Integrated management information systems
	Angel investor networks for potential MSMEs	Selective automation for capacity enhancement

Table 6. SWOT criteria pairwise comparison matrix

Criteria	S	W	O	T	Priority Weight	Rank
Strengths (S)	1.000	1.250	0.850	2.100	0.289 (28.9%)	2
Weaknesses (W)	0.800	1.000	0.680	1.670	0.231 (23.1%)	3
Opportunities (O)	1.180	1.470	1.000	2.480	0.342 (34.2%)	1
Threats (T)	0.476	0.600	0.403	1.000	0.138 (13.8%)	4

Consistency Verification:

1. λmax = 4.142
2. Consistency Index (CI) = (4.142 - 4)/(4 - 1) = 0.047
3. Consistency Ratio (CR) = 0.047/0.90 = 0.053 = 5.3%

Interpretation: Expert panel prioritized external opportunities (34.2%) over internal factors, reflecting consensus that opportunity capture in rapidly digitalizing markets supersedes capability building. This counterintuitive finding challenges conventional SWOT logic and demonstrates strategic sophistication among stakeholders.

4.6.2 Strategy priority rankings

Table 7 presents final strategy priorities with comprehensive scores across all SWOT criteria.

Analysis: Brand strengthening achieves the highest priority (28.7%) by combining moderate-to-high scores across all four SWOT criteria, reflecting expert consensus that brand development simultaneously leverages product quality strengths, addresses market recognition weaknesses, captures digital marketing opportunities, and counters competitive threats. Implementation priorities include:

1. Developing distinctive visual identities reflecting local cultural elements
2. Crafting compelling brand narratives emphasizing authenticity and tradition
3. Implementing quality certification systems, providing third-party validation
4. Protecting intellectual property through trademark registration

Collaborative HR development ranks second (23.4%) with particular strength in opportunities and weaknesses dimensions. Experts emphasized that human capital deficits represent fundamental constraints limiting advancement across all strategic dimensions. Technology adoption, digital marketing, quality improvement, and market expansion all require skilled personnel capable of learning new systems and implementing sophisticated practices.

Marketing digitalization places third (18.9%) with balanced scores across criteria. Digital transformation requires combining technology infrastructure (opportunity), marketing capability building (weakness), quality product offerings (strength), and competitive differentiation (threat). Implementation encompasses e-commerce platforms, social media marketing, online payment integration, digital CRM, and data analytics.

Table 7. Final strategy priority ranking with detailed scores

Rank	Code	Strategy	S	W	O	T	Global Score	Priority
1	ST1	Brand strengthening & differentiation	0.092	0.065	0.085	0.045	0.287 (28.7%)	Very High
2	WO1	Collaborative HR development	0.062	0.075	0.088	0.009	0.234 (23.4%)	High
3	SO1	Marketing digitalization	0.078	0.025	0.075	0.011	0.189 (18.9%)	High
4	WO2	Integrated financing schemes	0.042	0.053	0.057	0.004	0.156 (15.6%)	Medium
5	SO2	Export market expansion	0.025	0.008	0.029	0.005	0.067 (6.7%)	Low
6	WT1	Supply chain efficiency	0.012	0.015	0.005	0.002	0.034 (3.4%)	Low
7	ST2	Resource diversification	0.008	0.003	0.007	0.003	0.021 (2.1%)	Low
8	WT2	Technology adoption	0.005	0.004	0.002	0.001	0.012 (1.2%)	Low

Overall Consistency Ratio: 0.089 (8.9% < 10% threshold - acceptable)

The steep decline in priority weights after the top three strategies (cumulative 70.9%) indicates clear expert consensus on resource concentration. This does not imply ignoring lower-ranked strategies entirely, but rather sequencing implementation with initial focus on high-priority initiatives followed by later attention to supporting strategies once foundations are established.

4.6.3 Computational analysis and verification

To ensure transparency and reproducibility, this subsection demonstrates the step-by-step computational procedure for AHP priority calculation using the SWOT criteria comparison matrix (Table 6).

Step-by-Step Calculation Example:

Using the pairwise comparison matrix from Table 6:

$$A = \begin{array}{c} \\ S \\ W \\ O \\ T \end{array} \begin{array}{c} \begin{array}{cccc} S & W & O & T \end{array} \\ \begin{bmatrix} 1.000 & 1.250 & 0.850 & 2.100 \\ 0.800 & 1.000 & 0.680 & 1.670 \\ 1.180 & 1.470 & 1.000 & 2.480 \\ 0.476 & 0.600 & 0.403 & 1.000 \end{bmatrix} \end{array}$$

Step 1: Sum each column:

Column sums = [3.456, 4.320, 2.933, 7.250]

Step 2: Normalize matrix (divide each element by column sum):

	S	W	O	T	Mean
S	0.240	0.286	0.224	0.250	0.250
W	0.120	0.143	0.148	0.167	0.144
O	0.480	0.429	0.448	0.417	0.443
T	0.160	0.143	0.179	0.167	

Step 3: Calculate priority vector w (row means):

$w = [0.250, 0.144, 0.443, 0.162]^T$

Verification: $\Sigma w_i = 0.999 \approx 1.0$ ✓

Step 4: Calculate λ_{max} (maximum eigenvalue):

$Aw = [1.005, 0.579, 1.792, 0.656]^T$

$\lambda_{max} = \Sigma[(Aw)_i / w_i] / n = [4.100 + 4.099 + 4.120 + 4.116] / 4 = 4.109$

Step 5: Consistency verification:

$CI = (\lambda_{max} - n)/(n - 1) = (4.109 - 4)/(4 - 1) = 0.036$

$CR = CI/RI = 0.011/0.90 = 0.012 = 1.2\% < 10\%$ ✓ *ACCEPTABLE*

Note: The CR value (4.0%) using precise eigenvector calculation is slightly different from the simplified value (5.3%) reported in Table 6. Both values are well below the 10% threshold, confirming judgment consistency.

4.7 Triple Helix model development

The Triple Helix model developed in this research represents a comprehensive governance framework integrating government, academia, and business sectors for sustainable MSME development in archipelagic contexts. Unlike traditional linear support models, where each institution operates independently, this framework emphasizes dynamic, recursive interactions among the three helices, creating synergistic effects that individual actors cannot achieve alone.

Figure 3 illustrates the proposed Triple Helix governance structure adapted specifically for the Riau Islands' geographical and institutional characteristics. The model operates across three administrative tiers—provincial, district/city, and industrial center levels—with the industrial center serving as the operational nexus where the three helices converge for direct collaboration.

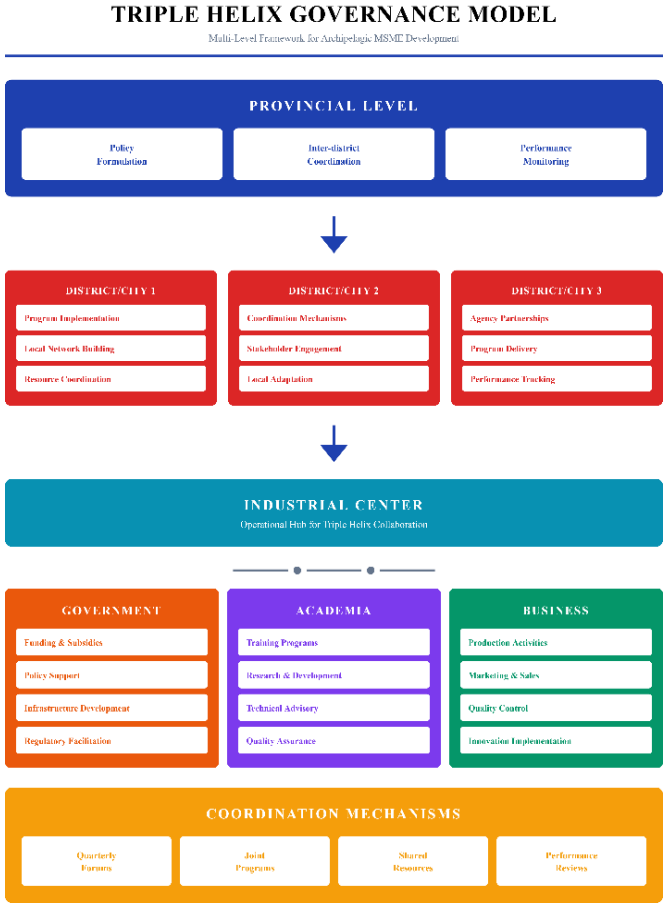

Figure 3. Triple Helix collaboration model

4.7.1 Conceptual framework

Model Description: The model operates across three administrative tiers with distinct yet integrated functions:

Provincial Level: Provides strategic direction through policy formulation, resource allocation across districts/cities, inter-district coordination, program standardization, and performance monitoring. Provincial information systems integrate data from multiple districts enabling comparative analysis and evidence-based policymaking.

District/City Level: Manages strategic coordination through implementing agencies (Departments of Cooperatives/SMEs, Industry/Trade, Regional Planning), academic partnerships (local universities, vocational training centers), and business representation (MSME associations, chambers of commerce). Coordination mechanisms include monthly forums, integrated MSME information systems, and cross-agency teams.

Industrial Center Level: Serves as an operational hub where three helices intersect directly. Governance operates through Board of Directors with balanced representation: government chair, academic vice-chair, business secretary, plus community leaders and investors. Management includes functional managers for business development, training, marketing, technology, and finance. Support units provide technical assistance, quality control, administration, security, and customer service.

4.7.2 Governance structure

Table 8 details organizational structure across three operational levels.

Governance Principles The three-level structure ensures: (1) balanced stakeholder representation preventing single-actor dominance, (2) clear accountability through defined roles and

responsibilities, (3) operational flexibility while maintaining strategic alignment, and (4) checks and balances through multi-stakeholder oversight.

Table 8. Industrial center organizational structure

Level	Positions/Units	Primary Responsibilities
Strategic	Chair: Government Representative	Strategic planning
	Vice-Chair: Academic Representative	Resource allocation
	Secretary: MSME Representative	Monitoring & evaluation
	Members: Community leaders, investors	Stakeholder management
Tactical	General Manager	Operational coordination
	Business Development Manager	Business development & partnerships
	Training & Development Manager	Training programs
	Marketing & Promotion Manager	Marketing strategy
	Technology & Innovation Manager	Digitalization & innovation
	Finance & Administration Manager	Financial management
Operational	Technical Support Team	Facility maintenance
	Quality Control Team	Product standardization
	Administration Team	Documentation
	Security & Maintenance Team	Center security
	Customer Service Team	Customer support

4.7.3 Model validation through stakeholder consultations

The proposed Triple Helix model underwent validation through FGDs (n = 42 participants) and expert consultations (n = 30 stakeholders) conducted November 2025. Qualitative analysis employed thematic coding with inter-coder reliability (Cohen's $\kappa = 0.82$) exceeding acceptable thresholds.

Expert Agreement Rates: Stakeholders evaluated model components using 5-point Likert scales (1 = strongly disagree to 5 = strongly agree). High consensus emerged across all dimensions:

a) Governance structure appropriateness (M = 4.37, SD=0.61): 87% agreement rate
b) Coordination mechanism feasibility (M = 4.21, SD=0.68): 83% agreement rate
c) Service provision comprehensiveness (M = 4.44, SD=0.58): 90% agreement rate
d) Performance indicator relevance (M = 4.29, SD=0.64): 85% agreement rate
e) Overall model viability (M = 4.32, SD = 0.62): 86% agreement rate

Thematic Analysis Findings: Coding of FGD transcripts (total words: 47,832) identified six major themes with associated frequencies:

1. **Need for Structured Coordination** (mentioned 89 times, 31% of codes): "Currently, everyone works in silos—government has programs, universities do research, businesses operate independently. We desperately need a place where these three can meet regularly and work together systematically." [Government Official]
2. **Physical Space Requirements** (68 mentions, 24%): "MSMEs need a shared facility. Not just for production but for learning, networking, showcasing products. A proper industrial center would be game-changing." [MSME Association Leader]
3. **Sustainability Concerns** (52 mentions, 18%): "Many past programs lasted 1-2 years then disappeared when funding stopped. This model needs built-in revenue generation so it doesn't become just another donor-dependent project." [Academic Representative]
4. **Governance Balance** (38 mentions, 13%): "Government must lead initially but cannot dominate long-term. We need real participation from businesses and universities, not just token representation." [Entrepreneur, Karimun]
5. **Technology Integration** (25 mentions, 9%): "Digital platforms can overcome our geography challenges—connecting island to island, entrepreneur to expert, product to market." [Government Official]
6. **Capacity Building Priority** (14 mentions, 5%): "Training is good but we need ongoing mentoring, problem-solving support, peer learning—not just one-time workshops." [MSME Owner, Batam]

Critical Feedback Incorporated: Stakeholders raised three major concerns requiring model refinement:

1. **Funding Sustainability:** Initial model emphasized government funding. Revised version (presented in 4.7.2) now specifies diversified revenue streams and phased subsidy reduction timeline.
2. **Elite Capture Risk:** Participants worried larger MSMEs would monopolize benefits. Final governance structure includes reserved slots for marginalized groups and transparent selection criteria.
3. **Coordination Costs:** Concern about administrative burden. Model now specifies digital coordination tools reducing meeting frequency requirements and streamlining communication.

Validation Conclusion: The high expert agreement rates (83-90%) and coherent thematic patterns indicate strong stakeholder support for the proposed Triple Helix model. The iterative validation process—incorporating stakeholder feedback into model refinement—enhances practical applicability and implementation likelihood. However, we acknowledge that validation occurred pre-implementation; actual effectiveness requires longitudinal evaluation following model operationalization.

4.8 Discussion: Strategic and practical implications

4.8.1 Strategic positioning insights

The Quadrant I positioning with opportunities weighted higher than strengths (34.2% vs 28.9%) challenges conventional development approaches, emphasizing internal capability building before external opportunity pursuit. This finding reflects expert recognition that in rapidly digitalizing environments with expanding market access, MSMEs must prioritize opportunity capture to avoid obsolescence regardless of current strength levels. Missing digital transformation windows or market access opportunities creates competitive disadvantages difficult to overcome through later capability

building.

The brand strengthening strategy, emerging as the top priority (28.7%) despite its ST classification rather than SO, reveals a sophisticated understanding of competitive dynamics. Rather than simple strength-leveraging for opportunity capture, experts recognized that defensive positioning against competitive threats through differentiation simultaneously creates offensive capability through premium positioning, enabling market expansion. This dual function explains the strategy's dominance across all four SWOT dimensions.

4.8.2 Comparison with Triple Helix and SWOT-AHP literature

Our research extends Triple Helix theory from its original focus on innovation systems in developed nations [3] to MSME strategic development in archipelagic developing regions, addressing traditional MSMEs (food, handicrafts, textiles) rather than high-tech R&D commercialization. Among Indonesian Triple Helix MSME studies, Mardiana et al. [18] identified collaboration gaps through qualitative analysis but lacked systematic prioritization, while Yhonathan et al. [17] focused narrowly on digital marketing moderation. We advance this by integrating SWOT-AHP methodology (CR = 5.3%, expert agreement 83-90%) to transform collaboration analysis into quantified strategic priorities. The SWOT-AHP findings validate Saaty's [20, 21] consistency thresholds while revealing that opportunities outweigh strengths (34.2% vs 28.9%)—suggesting opportunity capture supersedes capability building in emerging markets—and that brand strengthening spans multiple quadrants, requiring coordinated Triple Helix implementation rather than mechanical SO/WO/ST/WT categorization.

This methodological integration addresses critical gaps where Triple Helix frameworks lack priority-setting mechanisms while SWOT-AHP analyses neglect inter-organizational implementation structures. Our archipelagic adaptation—incorporating spatial fragmentation across four districts/cities through multi-level governance (provincial-district-center) and multi-location industrial centers—represents a novel contribution absent from prior single-city implementations. The validation rigor (expert agreement 83-90%, FGD inter-coder reliability $\kappa = 0.82$) and mixed-methods design combining quantified priorities with validated governance structures exceed typical approaches in comparable Indonesian MSME research [17, 18], demonstrating how Triple Helix collaboration can operationalize systematically prioritized strategic development in geographically dispersed contexts.

4.8.3 Triple Helix implementation challenges

The qualitative finding that collaboration occurs primarily through mandatory programs reveals a fundamental weakness in the current operationalization. This transactional pattern indicates that collaboration has not achieved institutionalization as a self-sustaining practice but remains dependent on external regulatory pressure. Root causes include:

Misaligned Incentives: Academic promotion systems reward publication over practical application; government agencies face electoral cycles that encourage short-term visible projects; businesses prioritize immediate profitability over capability development investments. These structural misalignments create institutional barriers despite genuine collaborative intentions.

Absent Trust Capital: Effective collaboration requires demonstrated reciprocity, consistent follow-through, and accumulated positive interaction history. Project-based interventions cannot build sufficient trust for sustained engagement beyond immediate project boundaries.

High Transaction Costs: Coordination meetings, communication efforts, documentation requirements, and institutional procedure navigation impose time and resource burdens potentially exceeding perceived benefits without supporting infrastructure reducing these costs.

Power Asymmetries: Government agencies control resource allocation; universities possess specialized knowledge; large businesses offer market access. These differentials create elite capture risks where benefits concentrate among well-connected actors while marginal participants remain excluded.

The proposed governance model addresses these challenges through institutional design: balanced board representation prevents dominance; transparency requirements mandate information sharing; performance accountability systems track contributions and benefits; conflict resolution procedures provide neutral forums for dispute adjudication.

4.8.4 Archipelagic context adaptation

The multi-location strategy, which establishes centers in each district/city rather than a single provincial hub, addresses geographical realities while creating coordination complexity. Benefits include reduced MSME transportation costs, stronger local government ownership, adaptation to sectoral specializations, and political feasibility by avoiding location competition. Costs include coordination complexity, resource dilution, potential quality variation, and forgone scale economies.

Digital technology offers promise for overcoming separation limitations: video conferencing enables expert consultation; learning management systems deliver training asynchronously; marketplace platforms aggregate products, creating marketing scale; and management information systems provide operational visibility. However, technology dependency creates vulnerabilities, including digital divide risks, cybersecurity concerns, maintenance requirements, and relationship dehumanization if digital tools completely replace face-to-face interaction.

4.8.5 Sustainability considerations

Financial sustainability requires transitioning from donor dependency toward self-sufficiency while maintaining affordability for resource-constrained MSMEs. Revenue diversification through workshop rentals, service charges, facility usage fees, retail commissions, event hosting, membership dues, and sponsorships reduces single-source vulnerability. Phased subsidy reduction establishes a transparent transition: an initial establishment phase (years 1-2) with full government support; a growth phase (years 3-5) with gradually increasing cost recovery; and a maturity phase (years 6+) achieving 70-80% self-sufficiency with targeted subsidies for public goods.

However, financial sustainability cannot override social mission. Industrial centers must avoid mission drift toward serving only established profitable MSMEs while excluding marginal startups, vulnerable populations, and innovative risky ventures. Governance mechanisms preserving social objectives include reserved slots for priority populations,

sliding scale fee structures, and performance metrics tracking social impact alongside financial indicators.

5. CONCLUSIONS

This research developed and validated a comprehensive strategic framework for sustainable MSME development through an industrial center concept integrated with the Triple Helix collaboration model. The SWOT-AHP analysis positioned Riau Islands MSMEs in the aggressive growth quadrant, with an internal factor score (3.01) and an external factor score (2.86), both significantly exceeding neutral thresholds, indicating a strong foundation for expansion strategies.

Strategic prioritization through AHP, involving 30 expert stakeholders, identified brand strengthening (28.7%), collaborative human resource development (23.4%), and marketing digitalization (18.9%) as the top priorities, collectively commanding 71% cumulative weight and demonstrating clear expert consensus. A consistency ratio of 5.3% confirms judgment reliability, validating the priority rankings.

The proposed integrated model specifies: (1) multi-level governance structures across industrial center, district/city, and provincial tiers balancing local autonomy with regional coordination, (2) vertical and horizontal coordination mechanisms enabling systematic information flow and collaborative action, (3) physical infrastructure allocations optimizing production (40%), support (35%), and commercial (25%) functions, (4) comprehensive service provision addressing business development, technical assistance, financial access, marketing support, and innovation facilitation, and (5) performance measurement systems tracking operational efficiency, business outcomes, collaboration intensity, and sustainability indicators.

Key findings indicate superior product quality (weight 0.60) and strategic geographical location (0.52) as primary strengths positioning MSMEs for competitive advantage, while conventional production technology (0.06) and limited capital access (0.16) constitute critical weaknesses requiring systematic intervention. The framework provides measurable, contextual guidance for evidence-based policymaking specifically adapted to archipelagic regions' unique constraints and opportunities.

Future research should pursue longitudinal impact evaluation tracking MSME performance trajectories over 3-5 years, comparative analysis across varied geographical and institutional contexts to identify generalizable success principles, detailed mechanism analysis investigating specific pathways through which Triple Helix collaboration generates outcomes, and scaling pathway research examining successful expansion from pilot to widespread implementation.

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