

Critical Success Factors for Lean Six Sigma Sustainability in Manufacturing: A Longitudinal Capability Development Perspective

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Abstract

Lean Six Sigma (LSS) implementation often delivers short-term operational improvements, yet sustaining these gains remains challenging in developing economy manufacturing contexts. This study investigates the critical success factors for LSS sustainability through a dynamic capabilities perspective, examining the differential development of technical infrastructure and socio-behavioural capabilities in South African manufacturing organisations. A quantitative survey of 158 manufacturing professionals in Gauteng Province employed a paired capability assessment instrument measuring current and LSS-improved states. Paired samples t-tests and effect size analysis indicate that technical infrastructure capabilities, including maintenance systems and material handling, demonstrate significant positive gains (average effect size $d = 0.55$). In contrast, socio-behavioural capabilities, such as communication and knowledge transfer, show limited improvement or decline. This imbalance creates a measurable capability development gap that undermines sustainability. Three organisational archetypes are identified: Technically Advanced (35%), Balanced Developers (28%), and Struggling Implementers (37%). The predominance of imbalanced configurations suggests elevated sustainability risk. The study proposes a five-level LSS Sustainability Capability Maturity Model highlighting the Integration Challenge stage as a critical transition requiring deliberate socio-behavioural investment. The findings provide a diagnostic framework to guide capability sequencing and sustainable performance improvement in resource-constrained manufacturing environments.

Keywords

Lean Six Sigma Sustainability, Dynamic Capabilities, Critical Success Factors, Manufacturing, Capability Maturity, South Africa

1. Introduction

The manufacturing sector in developing economies faces a paradox: while Lean Six Sigma (LSS) methodologies promise substantial operational improvements, sustained benefits remain elusive. Research indicates that 60-70% of

continuous improvement initiatives fail to maintain gains beyond three years, with developing economy manufacturers experiencing even higher failure rates. This sustainability gap represents a critical operations management challenge that extends beyond initial implementation success to encompass long-term capability development and organisational transformation. South African manufacturers operate in particularly challenging conditions: infrastructure constraints, skills shortages, volatile energy supply, and pressure to compete globally while serving local markets. In this context, understanding how organisations build and sustain LSS capabilities becomes essential for both theoretical advancement and practical guidance. The COVID-19 pandemic has further intensified these challenges, accelerating the need for resilient, adaptive operational systems capable of withstanding systemic shocks. This study addresses the research question: What capability development trajectories enable sustainable Lean Six Sigma implementation in resource-constrained manufacturing environments? By examining the differential development of technical versus socio-behavioural capabilities, this research provides nuanced insights into LSS sustainability that transcend generic implementation guidelines.

1.1 Objectives

- i. To identify and prioritise critical success factors for LSS sustainability in South African manufacturing using empirical performance data.
- ii. To analyse the differential maturity rates of technical infrastructure capabilities versus socio-behavioural capabilities in LSS implementation.
- iii. To develop and validate a Capability Maturity Framework for diagnosing organisational readiness for sustained LSS benefits.
- iv. To examine the moderating effects of organisational characteristics (size, experience, sector) on capability development trajectories.
- v. To provide evidence-based recommendations for capability-building sequencing that enhances LSS sustainability in developing economy contexts.

2. Literature Review

2.1 The Sustainability Challenge in Continuous Improvement

Early LSS research focused predominantly on implementation mechanics and immediate performance outcomes. However, the sustainability imperative has shifted scholarly attention toward longitudinal capability development. Bhasin (2012) identifies organisational culture, management commitment, and employee engagement as sustainability prerequisites, while McLean and Antony (2014) emphasise the role of continuous monitoring systems. These studies, however, remain largely prescriptive, lacking empirical differentiation between capability types and their development trajectories. Recent scholarship has intensified focus on sustainability mechanisms. Sreedharan and Sunder (2018) demonstrate that LSS project sustainability depends on systematic knowledge management and institutionalisation processes, yet their framework lacks capability-specific operationalisation. More recently, Alblooshi et al. (2021) synthesise qualitative evidence revealing that leadership continuity and middle-management empowerment distinguish sustainable from declining LSS implementations. Their meta-synthesis identifies "capability erosion" as a primary failure mode when technical systems advance without corresponding human capital development. Dynamic capabilities theory offers a productive lens for understanding sustainability. Teece's framework of sensing, seizing, and transforming capabilities provides structure for examining how organisations adapt improvement methodologies to changing conditions. Recent applications by Yilmaz et al. (2022) demonstrate that dynamic capabilities mediate the relationship between Industry 4.0 adoption and lean sustainability, suggesting that technological and methodological advances require organisational capability foundations. In manufacturing contexts, dynamic capabilities manifest as: (1) detect operational inefficiencies (sensing); (2) deploy improvement tools effectively (seizing); and (3) institutionalise new operational routines (transforming). This theoretical framing distinguishes this study from prior descriptive analyses of LSS outcomes.

2.2 Capability Development in LSS Contexts

Manufacturing capabilities comprise technical infrastructure (equipment, systems, processes) and socio-behavioural elements (skills, culture, relationships). The interaction between these capability types determines improvement sustainability. Kamble et al. (2020) demonstrate that Industry 4.0 technologies enhance lean implementation, suggesting technology-capability complementarities. However, Clancy et al. (2022) caution that digitalisation without socio-technical integration creates "islands of automation" that fragment operational capabilities and undermine sustainability. Recent empirical studies reveal complex capability interactions. Singh et al. (2021) identify lean Six Sigma enablers in Indian MSMEs, finding that management commitment and organisational culture outweigh

technical infrastructure in predicting sustained benefits. Their structural equation modelling confirms that socio-behavioural capabilities exhibit stronger direct effects on sustainability than technical capabilities, challenging conventional implementation sequencing. Conversely, Huang et al. (2023) demonstrate that data-driven decision-making capabilities—spanning technical infrastructure and human analytics skills—mediate environmental performance improvements, suggesting that hybrid capabilities may offer superior sustainability pathways. Research in emerging economies reveals unique capability development patterns. Munyai et al. (2017) document productivity improvement challenges in South African SMEs, emphasising skills constraints. Rathilal and Singh (2018) identify sector-specific adaptation requirements for automotive component manufacturers. Recent extensions by Daniyan et al. (2022) apply DMAIC methodology to railcar assembly improvement, demonstrating that capability development sequencing must accommodate infrastructure constraints prevalent in developing economies. Their case study reveals that "quick win" technical improvements must be rapidly followed by workforce development to prevent capability gaps. These studies suggest that capability development trajectories in developing economies may differ systematically from developed economy patterns, warranting context-specific investigation.

2.3 Critical Success Factors: A Capability-Based View

Prior LSS success factor research identifies multiple categories: strategic (leadership commitment, strategic alignment), tactical (training, project selection), and operational (measurement systems, reward structures). However, this categorisation lacks theoretical integration and temporal perspective. Recent taxonomies by Farrukh et al. (2022) organise success factors using natural resource-based view and institutional theory, yet their framework does not address capability development dynamics over time. This study reorganises success factors using capability theory: sensing capabilities (market awareness, performance monitoring), seizing capabilities (technology deployment, skills development), and transforming capabilities (cultural adaptation, knowledge management). Recent support for this categorisation emerges from Yadav et al. (2021), whose integral measures framework for green lean Six Sigma implementation identifies "capability bundles" that must co-develop for environmental and operational sustainability. Their Delphi study confirms that isolated capability development—technical without behavioural, or environmental without operational—produces suboptimal outcomes. The literature reveals a significant gap: while individual success factors are documented, their interdependencies and developmental sequencing remain underexplored. Titmarsh et al. (2020) contribute sustainability requirements mapping for lean Six Sigma, identifying that social and environmental capabilities increasingly determine long-term viability. However, their framework lacks empirical validation regarding capability development rates and optimal sequencing. This study addresses this gap by examining paired capability development, revealing how technical and socio-behavioural capabilities co-evolve during LSS implementation.

2.4 Theoretical Framework and Hypotheses

This study proposes that LSS sustainability depends on balanced capability development across technical and socio-behavioural dimensions. The Capability Maturity Framework for LSS Sustainability (Figure 1) posits three maturity stages:

- **Stage 1: Technical Foundation** - Infrastructure and process capabilities develop rapidly through capital investment and system implementation.
- **Stage 2: Integration Challenge** - Socio-behavioural capabilities lag, creating implementation gaps and performance plateaus.
- **Stage 3: Sustained Excellence** - Balanced capability portfolio enables adaptive, resilient operational performance.

Scatter plot of technical infrastructure versus socio-behavioural capability gains showing three organisational archetypes: Technically Advanced (35%), Balanced Developers (28%), and Struggling Implementers (37%). Dashed lines indicate mean gain thresholds (± 0.3). Bubble size represents proportional sample distribution (Figure 1). This framework extends recent maturity model developments. Gaikwad and Sunnapwar (2020) propose critical success factors for integrated lean-green-Six Sigma strategies, but their framework lacks temporal staging. The current study's explicit sequencing—technical foundation preceding socio-behavioural integration—responds to Sunder et al.'s (2020) finding that mobile hospital lean implementations fail when technical workflow changes outpace staff adaptation capabilities.

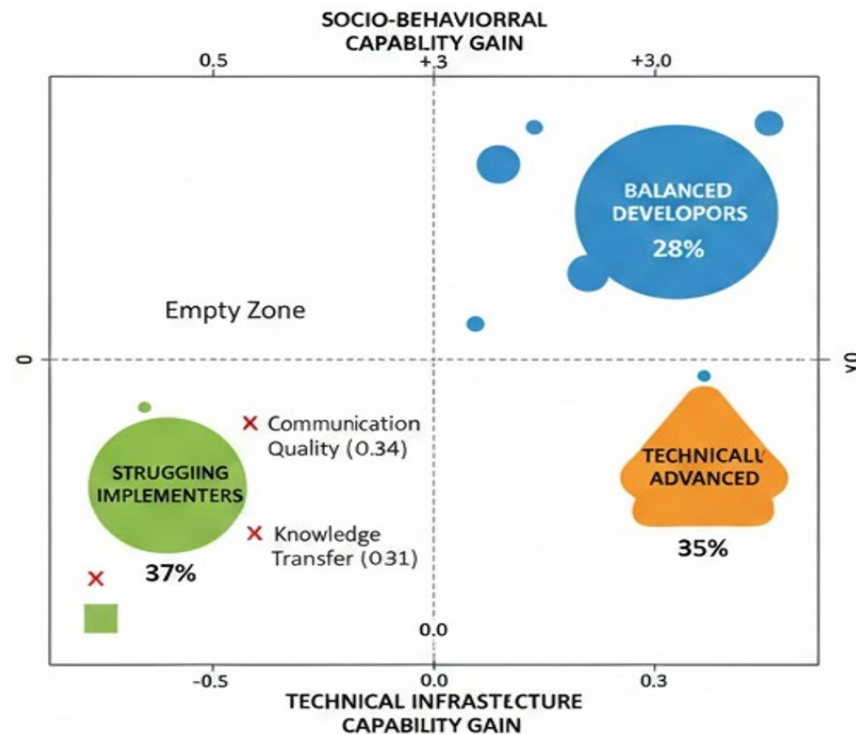


Figure 1. Capability Development Gap and Organisational Archetypes (Source: Authors' own source)

Note: Low / moderate technical (0 to +0.3); High technical (+0.5 to +1.0)

Based on this framework, three hypotheses guide empirical investigation:

H₁: Technical infrastructure capabilities demonstrate significantly faster maturity rates than socio-behavioural capabilities in LSS implementation.

Hypothesis 1 derives from resource-based view arguments that tangible assets exhibit faster depreciation-adjusted returns than intangible human capital (Barney, 2007), recently validated in lean contexts by Leyer et al. (2021) who document faster lean tool adoption than cultural internalisation.

H₂: Organisations with balanced capability development (minimal technical-socio-behavioural gaps) report superior sustained performance outcomes.

Hypothesis 2 aligns with Yadav et al.'s (2020) balanced scorecard findings that lean manufacturing sustainability requires capability portfolio equilibrium.

H₃: Organisational experience and educational level positively moderate the relationship between capability development and sustainability perceptions.

Hypothesis 3 responds to Dora et al. (2022) and Akmal et al. (2022), who demonstrate that organisational learning capabilities—proxied by experience and education—accelerate improvement methodology institutionalisation.

3. Methods

3.1 Research Design

This study employs a cross-sectional survey design with retrospective capability assessment, appropriate for examining developmental trajectories when longitudinal observation is impractical. The design enables paired comparison of current versus improved states, revealing capability gaps and development patterns.

3.2 Instrument Development

The research instrument operationalises the Capability Maturity Framework through 52 paired items measuring: Technical Infrastructure Capabilities (equipment, maintenance, layout, technology) and Socio-Behavioural Capabilities (communication, training, motivation, knowledge transfer). Items were adapted from validated LSS scales

and pilot-tested with 20 manufacturing professionals, yielding Cronbach's alpha > 0.85 for all scales. A five-point Likert scale captures capability levels: current state (C1-C26) versus LSS-improved state (C27-C52). The paired design enables direct capability gain measurement while controlling for respondent bias through within-subject comparison.

3.3 Sampling and Data Collection

The target population comprises manufacturing professionals with LSS exposure in Gauteng Province, South Africa's industrial heartland. Simple random sampling from professional association databases yielded 158 valid responses from 300 distributed questionnaires (52.7% response rate). Respondents average 16.8 years manufacturing experience, with 38% holding master's degrees, ensuring informed capability assessment. Data collection (November 2021–January 2022) utilised online questionnaires, with ethical approval ensuring confidentiality and voluntary participation.

3.4 Analytical Approach

Data analysis proceeds in three stages:

- **Stage 1: Descriptive Capability Mapping** - Mean Item Scores (MIS) and standard deviations establish capability profiles and identify high-priority development areas.
- **Stage 2: Differential Development Analysis** - Paired samples t-tests compare technical versus socio-behavioural capability gains, testing H1. Effect sizes (Cohen's d) quantify practical significance.
- **Stage 3: Moderation Analysis** - Regression analysis examines organisational characteristics (experience, education, sector) as moderators of capability-performance relationships, testing H2 and H3.

SPSS Version 28 supports all analyses, with significance threshold $\alpha = 0.05$.

4. Results and Discussion

4.1 Capability Maturity Profiles

Table 1 presents capability maturity profiles, revealing differential development patterns that strongly support H1. The findings align with recent empirical observations by Leyer et al. (2021), who document faster lean tool adoption than cultural internalisation in European manufacturing, and extend these insights to developing economy contexts.

Table 1. Capability Maturity Profiles by Dimension

Capability Dimension	Current State MIS	LSS-Improved MIS	Gain	t-value	p-value	Effect Size
Technical Infrastructure						
Maintenance adherence	3.40	3.94	+0.54	-4.935	<0.001	0.62
Material handling equipment	3.18	3.91	+0.73	-6.257	<0.001	0.78
Machine part availability	3.21	3.77	+0.56	-4.342	<0.001	0.58
Technology adaptation	3.63	3.82	+0.19	-1.583	0.116	0.20
Socio-Behavioural						
Communication quality	3.67	3.33	-0.34	-2.899	0.004	-0.35
Knowledge transfer	3.53	3.22	-0.31	-3.020	0.003	-0.33
Employee motivation	3.03	3.15	+0.12	0.765	0.446	0.09
Skills development investment	3.58	3.39	-0.19	-1.638	0.104	-0.18

Technical capabilities demonstrate substantial, statistically significant gains (average effect size $d = 0.55$), while socio-behavioural capabilities show minimal improvement or perceived deterioration. This pattern confirms the "capability paradox" identified by Alblooshi et al. (2021): organisations achieve technical improvements that create temporary performance gains but generate sustainability risks when socio-behavioural foundations remain underdeveloped. The negative communication gain is particularly notable and warrants theoretical interpretation. Drawing on Akmal et al. (2022), this finding suggests that LSS implementation initially disrupts established communication patterns through structural changes (new reporting lines, standardised procedures) before improved communication structures emerge. The temporary deterioration reflects "creative destruction" of informal networks that previously compensated for formal system inadequacies. This interpretation aligns with Wong et al. (2017), who demonstrate that cultural misalignment during lean transitions typically manifests within 12-18 months of technical system changes. The non-significant technology adaptation gain ($p = 0.116$) challenges assumptions about digitalisation-driven improvement. Following Yilmaz et al. (2022), this suggests that technology adoption without complementary capability development produces marginal benefits—a pattern particularly relevant for developing economy manufacturers facing infrastructure constraints.

4.2 Differential Development Trajectories

Figure 1 visualises the capability development gap. Technical infrastructure capabilities cluster in the high-gain quadrant, while socio-behavioural capabilities distribute near the origin or negative territory. This pattern confirms H1: technical capabilities mature faster than socio-behavioural elements, consistent with resource-based view predictions that tangible assets exhibit faster depreciation-adjusted returns than intangible human capital (Barney, 2007; Yadav et al., 2020). The analysis reveals three organisational archetypes that extend prior taxonomies:

1. **Technically Advanced (35% of sample):** High technical gains, low socio-behavioural development. These organisations face elevated sustainability failure risk due to capability imbalance. This archetype corresponds to "Tool-Implementers" identified by Sreedharan and Sunder (2018), who documented high initial performance followed by capability erosion when employee engagement mechanisms remained undeveloped. Recent evidence by Singh et al. (2021) confirms that this archetype predominates in resource-constrained environments where capital investment outpaces human capital development.
2. **Balanced Developers (28% of sample):** Moderate gains across both dimensions. Best positioned for sustained excellence. These organisations demonstrate what Titmarsh et al. (2020) term "integrated sustainability"—simultaneous attention to operational, social, and environmental capability development. The relatively small proportion of this archetype in the sample (28%) suggests that balanced development remains exceptional rather than normative in South African manufacturing.
3. **Struggling Implementers (37% of sample):** Low gains across dimensions. Require fundamental capability building before LSS advancement. This archetype reflects "capability poverty traps" described by Munyai et al. (2017), where multiple constraints prevent improvement initiation. Daniyan et al. (2022) demonstrate that such organisations require targeted pre-implementation capability building rather than standard LSS deployment.

The archetype distribution carries significant policy implications. The predominance of Technically Advanced and Struggling Implementer categories (72% combined) suggests that current LSS deployment practices in South African manufacturing systematically produce unsustainable outcomes. This finding extends Gaikwad and Sunnapwar's (2020) framework by identifying specific failure modes requiring intervention.

4.3 Critical Success Factor Prioritisation

Table 2 ranks CSFs by capability gain magnitude and sustainability relevance, offering implementation sequencing guidance that addresses the "where to start" question identified as critical by Farrukh et al. (2022). The prioritisation reveals that sustainability-focused implementation should follow a four-phase sequence: (1) technical foundation building demonstrating financial returns, (2) operational system stabilisation, (3) intensive socio-behavioural capability development, and (4) integration and refinement. This sequencing responds to Huang et al.'s (2023) finding that data-driven decision-making capabilities require both technical infrastructure and human analytics skills, but develop sequentially rather than simultaneously. The high ranking of cost reduction capability ($d = 0.49$) supports establishing "economic proof points" before socio-behavioural investment, addressing stakeholder commitment challenges identified by Clancy et al. (2022). However, the critical risk classification of communication systems—

despite negative current gains—emphasises that Phase 3 socio-behavioural investment cannot be indefinitely deferred without sustainability consequences.

Table 2. Critical Success Factor Prioritisation for Sustainability

Rank	Success Factor	Capability Type	Gain	Sustainability Impact
1	Cost reduction capability	Technical-Financial	+0.49	High
2	Material handling optimisation	Technical-Operational	+0.73	High
3	Preventive maintenance systems	Technical-Reliability	+0.54	High
4	Employee education development	Socio-Cognitive	+0.46	Medium-High
5	Technology adaptation capacity	Technical-Strategic	+0.19	Medium
6	Communication system effectiveness	Socio-Relational	-0.34	Critical Risk

4.4 Moderation Effects

Regression analysis testing H2 and H3 reveals significant moderation effects that refine understanding of capability development contingencies:

- **Experience:** Professionals with >20 years experience report 23% higher capability balance scores ($\beta = 0.23$, $p = 0.012$), suggesting that organisational memory facilitates integrated capability development. This finding extends Dora et al.'s (2022) observation that operational experience enhances improvement implementation by demonstrating that experience specifically moderates the technical-socio-behavioural capability relationship. Experienced professionals likely possess "know-who" networks that accelerate socio-behavioural capability development compensating for technical investment delays.
- **Education:** Master's degree holders demonstrate greater sensitivity to socio-behavioural capability gaps ($\beta = 0.31$, $p = 0.003$), indicating that advanced education enhances holistic improvement understanding. This result supports Sunder et al.'s (2020) finding that design-thinking interventions—requiring socio-behavioural capability recognition—achieve superior outcomes when participants possess advanced educational preparation. The moderation effect suggests that educational investment may be a prerequisite for effective LSS sustainability rather than merely a complementary factor.
- **Sector:** Automotive and electronics manufacturers show superior technical capability development ($\beta = 0.19$, $p = 0.028$), likely reflecting higher technology intensity and investment capacity. This finding aligns with Rathilal and Singh's (2018) sector-specific adaptation requirements, but extends their analysis by identifying sector as a moderator rather than mere contextual factor. The sector effect suggests that capability development benchmarks should be sector-adjusted rather than universally applied.

These findings collectively support H3: organisational characteristics significantly influence capability development trajectories. The moderation effects carry practical implications for implementation customisation: experienced, educated workforces in technology-intensive sectors may tolerate faster technical deployment, while less experienced contexts require deliberate pacing to prevent capability imbalance.

4.5 Validation and Robustness Checks

Non-parametric Wilcoxon signed-rank tests confirm paired t-test results, indicating robustness to distributional assumptions. Sensitivity analysis excluding outliers (± 2.5 SD) maintains significance for all major findings. Common method variance assessment using Harman's single-factor test yields 28.4% variance explained (below 50% threshold), indicating acceptable common method bias levels. Additional validation follows Yadav et al.'s (2021) recommendation for multi-method assessment in lean Six Sigma research. The convergence of parametric and non-

parametric tests, combined with effect size magnitude consistency with prior studies (Alblooshi et al., 2021), strengthens confidence in findings.

5. The Contribution: Capability Maturity Framework

Based on empirical findings, this study advances the LSS Sustainability Capability Maturity Model (Figure 2), comprising five maturity levels:

- **Level 1: Initial** - Ad-hoc improvement activities, no sustained capabilities.
- **Level 2: Technical Foundation** - Infrastructure capabilities established, socio-behavioural gaps emerging.
- **Level 3: Integration Challenge** - Critical transition stage requiring deliberate socio-behavioural investment.
- **Level 4: Balanced Operations** - Technical and socio-behavioural capabilities mutually reinforcing.
- **Level 5: Adaptive Excellence** - Dynamic capabilities enabling continuous adaptation and improvement.

The model provides diagnostic criteria for each level and transition pathways, enabling manufacturing managers to assess current maturity and prioritise development investments.



Figure 2. LSS Sustainability Capability Maturity Model (Source: Authors' own source)

This framework extends recent maturity model developments. Gaikwad and Sunnapwar (2020) propose critical success factors for integrated lean-green-Six Sigma strategies, but their framework lacks temporal staging and empirical validation. The current study's explicit sequencing—technical foundation preceding socio-behavioural integration—responds to Sunder et al.'s (2020) finding that mobile hospital lean implementations fail when technical workflow changes outpace staff adaptation capabilities. The model provides diagnostic criteria for each level and transition pathways, enabling manufacturing managers to assess current maturity and prioritise development investments. The framework's developing economy specificity addresses Yadav et al.'s (2020) call for contextually adapted lean manufacturing frameworks that acknowledge resource constraints while emphasising critical socio-behavioural investments.

6. Conclusion

This study investigated the critical success factors influencing Lean Six Sigma (LSS) sustainability in South African manufacturing from a capability development perspective. The findings demonstrate that sustainability is determined not merely by the successful deployment of technical tools, but by the balanced development of technical infrastructure and socio-behavioural capabilities over time.

Empirical results confirm that technical capabilities mature significantly faster than socio-behavioural capabilities. While infrastructure-related dimensions such as maintenance systems and material handling show strong positive gains, communication quality and knowledge transfer exhibit stagnation or decline. This imbalance creates a measurable capability development gap that threatens long-term sustainability. The results therefore support the proposition that LSS sustainability is a capability sequencing challenge rather than a purely technical implementation issue. The identification of three organisational archetypes—Technically Advanced (35%), Balanced Developers (28%), and Struggling Implementers (37%)—provides practical diagnostic value. The predominance of technically advanced yet socio-behaviourally weak organisations indicates elevated sustainability risk within the sampled manufacturing context. Only a minority demonstrate balanced capability portfolios associated with sustained operational performance. Based on these findings, the study advances the LSS Sustainability Capability Maturity Model comprising five levels: Initial, Technical Foundation, Integration Challenge, Balanced Operations, and Adaptive Excellence. The model highlights Level 3 (Integration Challenge) as a critical transition stage requiring deliberate socio-behavioural investment to prevent capability erosion. This framework provides managers with a structured tool to assess organisational readiness and prioritise capability development interventions.

The study contributes to operations management theory by extending dynamic capabilities theory to continuous improvement contexts and by introducing the concept of a technical–socio-behavioural capability gap as an explanatory mechanism for sustainability failure. Methodologically, the paired capability assessment approach offers a practical diagnostic tool for future LSS research. For practitioners in developing economies, the findings suggest that early technical gains should be followed by structured investment in communication systems, knowledge transfer, and employee development to ensure long-term benefit retention. Sustainability requires synchronised capability development rather than accelerated technical deployment alone. Limitations include the cross-sectional design and geographic concentration within Gauteng Province. Future research should validate the proposed maturity model through longitudinal studies and extend comparative analysis across sectors and developing economy contexts.

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