p-ISSN 1693-2102
e-ISSN 2686-2352

From resistance to adoption: A mixed-methods framework for successful manufacturing execution system implementation in digital transformation initiatives

Debi Sutra, Agus Mansur *
Department of Industrial Engineering, Universitas Islam Indonesia, Yogyakarta, 55584, Indonesia

***Corresponding Author**: agusmansur@uii.ac.id

Article history:
Received: 20 September 2025
Revised: 16 December 2025
Accepted: 29 December 2025
Published: 30 December 2025

Keywords:
Digital transformation
Manufacturing execution system
Mixed methods research
ADKAR model
Socio technical framework

ABSTRACT
This study develops an optimized change-management framework to mitigate Manufacturing Execution System (MES) 3.0 implementation failure by integrating quantitative and qualitative findings from the ADKAR model through a socio-technical lens. Using explanatory sequential mixed-methods design, quantitative data from 248 respondents were analyzed via multiple and moderated regression, followed by in-depth interviews with 10 key stakeholders analyzed in NVivo. The phases were triangulated using a socio-technical framework to identify systemic patterns. Quantitatively, employee resistance significantly moderated the relationship between ADKAR components and implementation failure ($\beta = 0.657$, $p = 0.040$), with awareness ($\beta = -0.778$, $p = 0.000$) and knowledge ($\beta = -0.168$, $p = 0.012$) showing significant negative effects. Qualitative findings revealed five major themes: multidimensional resistance (active 15%, passive 35%, concealed 20%, neutral 30%), ADKAR implementation gaps, systemic contextual factors, and mitigation strategies. Triangulation exposed hierarchical cultural barriers, digital-literacy gaps, and insufficient reinforcement mechanisms. We propose an integrated hexagonal socio-technical model with six components and 24 sub-elements: Goals (4), People (4), Infrastructure (4), Technology (4), Culture (4), and Processes (4) for sustainable MES 3.0 implementation. This study contributes empirical evidence of resistance as a moderator and provides actionable guidance for digital transformation in manufacturing organizations.

DOI:
https://doi.org/10.31315/opsi.v18i2.15583

1. INTRODUCTION

Digital transformation has reshaped the manufacturing landscape, with Manufacturing Execution Systems (MES) serving as a backbone of Industry 4.0 implementation [1]. The latest MES generation integrating cyber-physical systems, the Internet of Things (IoT), artificial intelligence (AI), and big-data analytics promises major gains in operational efficiency, real-time visibility, and data-driven decision-making [2], [3]. Nevertheless, most digital initiatives underperform, with recent estimates indicating failure rates near

70% [4], [5]. These high failure rates cannot be explained solely by technical factors but require deeper attention to organizational change management [6]. Prior work suggests human and organizational factors account for roughly 70% of digital-transformation failures, while technology explains the remaining 30% [6], [7]. The ADKAR model which emphasizes awareness, desire, knowledge, ability, and reinforcement is widely recognized as a robust framework for managing transitions and has been associated with success probabilities up to 85% compared to unstructured approaches [8], [9].

Despite the promise of MES, implementations face critical challenges that go beyond technical concerns. Resistance to change has been reported to reach 65% during initial deployment [10], while digital-literacy gaps affect up to 70% of the workforce [11], creating barriers to smooth adoption. Cultural misalignment between traditional manufacturing practices and digital-first operations further complicates the transition [12]. Indonesian manufacturing industries face additional challenges related to organizational readiness and human resource capacity in adapting to digital systems [13], [14], where operational performance measurement and system effectiveness become critical success factors [15]. Employee resistance emerges as a significant moderating factor that shapes the effectiveness of each stage in change management [16], [17]. Yet empirical studies remain limited on how resistance moderates the effectiveness of each ADKAR component, particularly within Asian manufacturing contexts, where organizational cultures and workforce structures may differ from those commonly studied in Western settings.

The complexity of MES adoption extends beyond technology, encompassing the dynamic interaction of people, processes, and organizational structure. This underscores the relevance of socio-technical systems thinking, which seeks the concurrent optimization of social and technical subsystems [18]. Originating from Trist and Bamforth's seminal work [19] and further extended by Clegg [20], the hexagonal socio-technical framework integrates six interrelated elements: people, culture, goals, technology, infrastructure, and processes. Such a framework highlights that organizational transformation requires balance between technological sophistication and social readiness to ensure sustainable adoption of MES within digital transformation initiatives.

Recent digital transformation research also highlights cultural readiness and psychological safety as central to technology adoption [21], [22]. McKinsey reports that organizations with strong change-management capabilities achieve a 67% higher success rate in digital initiatives compared to those with weak practices [23]. However, most of these studies emphasize the service and technology sectors, providing limited insight into the unique conditions of the manufacturing industry. Manufacturing organizations often operate with hierarchical structures, safety-critical operations, and a predominantly blue-collar workforce, which introduces distinctive challenges in achieving digital transformation success [24]. This gap in the literature emphasizes the need for studies that contextualize change management frameworks within manufacturing environments.

This study is situated in Indonesia's largest footwear manufacturing operation, a tier one supplier to global athletic brands. The organization employs over 38,000 workers across 12 production facilities, operating in a labor intensive industry segment characterized by high volume, low margin production with stringent quality standards and just in time delivery requirements from multinational buyers. The manufacturing operation represents a mature establishment (founded 1990) transitioning from manual production tracking to integrated digital systems. The workforce is predominantly female (89.5%), young (67.3% aged 18 to 29), and education limited (91.1% high school level), with 84.3% having no prior exposure to integrated manufacturing systems, making MES 3.0 their first experience with smart manufacturing technology.

The company faced significant challenges during MES 3.0 implementation, including resistance levels of 68% at baseline, ineffective cross-departmental coordination, and a 15% decline in productivity during the transition phase. These challenges are amplified by Indonesia's cultural profile: high power distance (PDI = 78) creates hierarchical communication barriers, while collectivist orientations (IDV = 14) generate social pressure toward conformity that can manifest as passive or neutral resistance rather than open opposition [25]. The Indonesian footwear manufacturing industry reflects broader structural challenges faced by the country's labor-intensive manufacturing sector in implementing the Making Indonesia 4.0 agenda, particularly in balancing cost pressures, workforce readiness constraints, and the need to accelerate digital transformation at the operational level. The findings of this study provide empirically grounded insights that are transferable to other labor-intensive manufacturing sectors within Indonesia.

Despite extensive research on digital transformation success factors, a critical integrative gap remains in the literature. Existing frameworks tend to focus separately on individual-level psychological models, such as ADKAR, Technology Acceptance Model (TAM), and Unified Theory of Acceptance and Use of Technology (UTAUT), or on organizational level structures, such as socio-technical systems theory, without systematically linking these two levels of analysis. Furthermore, although resistance to change is widely recognized as a barrier to implementation, its specific role as a moderating variable that influences the effectiveness of change interventions, rather than merely opposing them, has not yet been empirically examined in manufacturing digitalization contexts. The dominance of Western organizational samples in change management research also limits understanding of how cultural factors, including power distance and collectivism, shape resistance behaviors and the effectiveness of change interventions.

Therefore, the primary research objective is to develop an integrated change management model that mitigates MES 3.0 implementation risk by jointly analyzing individual-level mechanisms through the ADKAR framework and organizational-level dynamics through socio-technical systems theory in the context of digital transformation. This study makes three distinct contributions to the digital transformation and change management literature. First, it provides the first empirical validation of employee resistance as a moderating variable within the ADKAR framework, demonstrating that resistance does not merely oppose change but fundamentally alters the effectiveness of change management interventions. Second, it advances resistance theory by developing a four-dimensional typology (active, passive, covert, neutral) that reconceptualizes resistance as a behavioral spectrum rather than a binary construct. Third, it introduces a 24-element integrated socio-technical framework that operationally connects individual-level change mechanisms (ADKAR) with organizational-level system dynamics, providing practitioners with a comprehensive implementation tool grounded in both statistical evidence and contextual understanding.

2. LITERATURE REVIEW

2.1 Resistance to Change in Digital Transformation

Resistance to change in digital transformation emerges when organizations adopt technologies that reshape roles and workflows, explained through adoption theories (TAM, UTAUT) and change models (Lewin, Kotter) [26]. It reflects individual fears (job loss, skill gaps) and structural issues (weak leadership, cultural misfit) [27]. with barriers including poor communication, low perceived value, and limited training [28]. Effective strategies emphasize leadership commitment, phased communication, and adaptive management using piloting and feedback loops [29], [30]. Resistance thus serves as a signal guiding organizations toward more resilient digital practices [31].

2.2 Manufacturing Execution System in Manufacturing

A MES is an operational information system that connects higher-level planning tools such as ERP and MRP with shop floor control systems like SCADA and PLC [32]. Its core functions include real-time scheduling, data capture, product tracking, quality management, and work instruction execution. In the Industry 4.0 era, MES has become a central component supporting interoperability, real-time analytics, and the integration of physical and digital resources, including digital twins and IoT [33]. Research shows a shift from traditional MES toward intelligent systems that use machine learning and prescriptive analytics for optimization [34]. Key challenges involve integration with ERP and shop floor devices, customization for product variety, and organizational barriers like IT and human resource limitations [35]. Benefits include higher OEE, reduced downtime, and improved production accuracy. Gaps remain in studying long-term impacts, SME adoption, and interoperability with cloud-based platforms, while collaboration and knowledge sharing emerge as critical success factors [36]. In the Indonesian manufacturing context, system effectiveness and operational performance measurement are crucial for successful MES deployment [15], [37], particularly in labor intensive industries where workforce adaptation and decision making processes become critical factors [38]. Modern MES platforms increasingly incorporate modular architectures that support phased implementation strategies, reducing organizational risk during digital transformation. The integration of advanced analytics capabilities enables proactive manufacturing management through predictive maintenance and quality forecasting functionalities. These developments reflect the evolving role of MES as both operational tool and strategic enabler. The relationship between MES, ERP, shop floor systems, and Industry 4.0 components is illustrated in Figure 1.

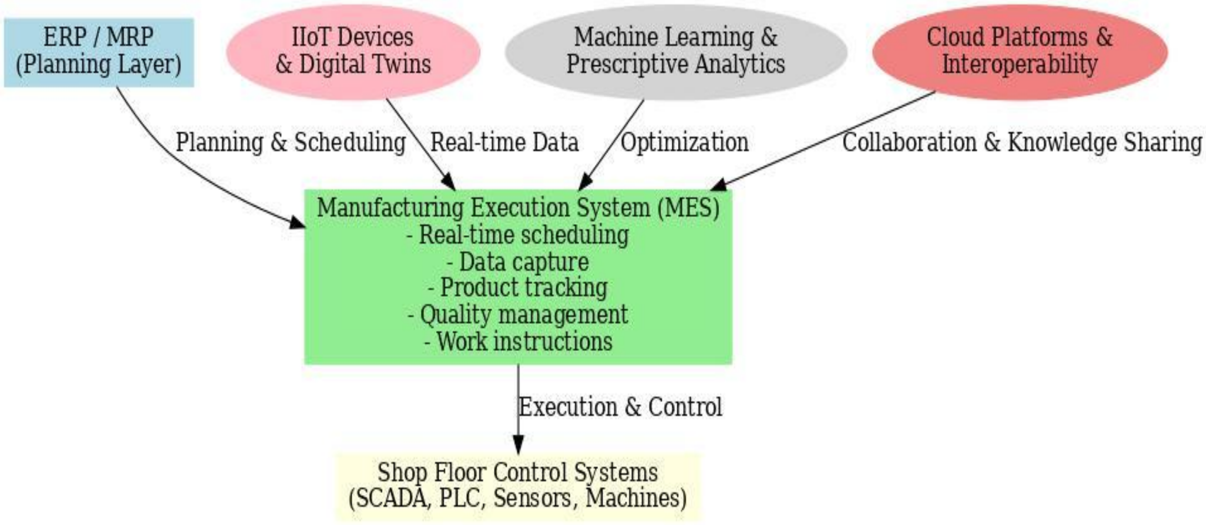

Figure 1. Relationship between MES

2.3 Mixed-Methods Framework

Mixed methods research or MMR is a methodological approach that deliberately combines quantitative and qualitative methods to answer complex research questions, including those related to Industry 4.0 implementation in manufacturing contexts [39]. The rationale is both inferential and pragmatic. Quantitative methods provide generalizability and measurement power while qualitative methods offer contextual understanding and insights into mechanisms [40]. The theoretical foundation of MMR is strongly influenced by the pragmatic paradigm which positions the research question as the starting point and encourages the selection of the most appropriate methods rather than adhering to a single scientific philosophy [41]. In practice, MMR designs are commonly categorized according to Creswell and Plano Clark into convergent or triangulation design where data are collected simultaneously and merged, explanatory sequential design where quantitative research is followed by qualitative analysis to explain findings, and exploratory sequential design where qualitative research precedes quantitative testing [42], [43].

Key challenges in mixed methods research include synchronization of time and sampling, determining method dominance, integrating data at the analysis stage, addressing validity across internal, external, and credibility aspects, and managing resource limitations. Recent studies on manufacturing innovation emphasize the importance of building organizational capabilities for successful Industry 4.0 transformation [44]. As shown in Table 1, several recent studies have successfully applied MMR to investigate related domains within digital transformation and manufacturing. Recent methodological advances highlight practical strategies to strengthen integration, such as defining integration objectives early in the research framework, choosing compatible sampling strategies, using explicit integration techniques like joint displays or data transformation, and ensuring transparent reporting so credibility can be evaluated [45]. Critics caution against unreflective pragmatism, emphasizing that methodological combinations must rest on philosophical and procedural foundations rather than technical accumulation [46]. For empirical theses, mixed methods are particularly valuable when a topic demands both quantitative assessment of effects and qualitative exploration of mechanisms or contexts, such as analyzing MES impact on performance while investigating resistance to digital transformation through interviews [47].

Table 1. Previous Research

No	Title	Topic		
		Digital Transformation	**Manufacturing Execution System**	**Mixed-Methods Framework**
1	Measuring the Degree of Mixed Methods Adoption: An Investigation Using Doctoral Dissertation Abstracts [48].	×	×	✓

No	Title	Topic		
		Digital Transformation	Manufacturing Execution System	Mixed-Methods Framework
2	Understanding Blockchain Adoption in SMEs: A Mixed-Method Study of Digital Transformation, Resilience, and Senior Leadership Support [49].	✓	×	✓
3	Industry 4.0 Maturity Assessment in Manufacturing Enterprises: A Mixed-Methods Approach for SMEs [50].	×	✓	✓
4	Influence of Digital Transformation on the Supply Chain Resilience of Chinese Manufacturing Enterprises: A Mixed-Methods Perspective [51].	✓	×	✓
5	Digital transformation success under Industry 4.0: a strategic guideline for manufacturing SMEs [52].	✓	×	×

Although previous studies have examined the application of mixed-methods approaches in various contexts, such as assessing the adoption of research methods [48], blockchain-based digital transformation in SMEs [49], and Industry 4.0 maturity assessment in the manufacturing sector [50], these studies have not comprehensively linked mixed-methods approaches to the implementation of Manufacturing Execution Systems (MES) within digital transformation initiatives. Some studies have also explored the relationship between digital transformation and supply chain resilience [51], or provided strategic guidelines for digital transformation success in manufacturing SMEs [52], yet they do not address the aspects of resistance and adoption of MES as a critical component of manufacturing digitalization. Therefore, a research gap remains in developing a mixed-methods framework that can thoroughly explain the dynamics of transitioning from resistance to adoption of MES, as well as the key factors that determine successful implementation within the context of digital transformation in manufacturing industries.

3. MATERIALS AND METHODS

3.1 Research Design

This study employed an explanatory sequential mixed-methods design [53] that began with a quantitative phase to examine the relationship between ADKAR components and the moderating effects of employee resistance on MES adoption outcomes. This phase provided statistical evidence on how awareness, desire, knowledge, ability, and reinforcement interact with resistance dynamics across different organizational layers. Building upon these results, a qualitative phase was conducted to capture deeper insights into employee perceptions, managerial strategies, and organizational culture, which were further enriched through the use of NVivo software for generating word-clouds and project mapping that identified recurring themes and patterns from interview data. The integration of quantitative and qualitative findings was achieved through triangulation, ensuring both methodological rigor and contextual depth. To synthesize these insights, Clegg's hexagonal socio-technical framework was employed as an analytical lens, enabling the identification of systemic organizational patterns by linking the technical and social subsystems that shape digital transformation outcomes.

3.2 Quantitative Phase

A total of 248 respondents participated in the quantitative phase, determined using the Slovin formula from a population of 650 MES 3.0 users at the footwear manufacturing facility with a 5% margin of error. Purposive sampling was applied, selecting employees with at least one year of tenure, direct involvement in MES 3.0, operational responsibilities requiring regular use, and departmental impact, ensuring knowledge and experience to enhance data validity and reliability [54]. Data were collected via a structured survey measuring ADKAR (15 items), resistance (3 items), and perceived implementation failure (5 items) on 5-point Likert scales, adapted to the manufacturing and Indonesian context. All items met validity thresholds (r >

0.312) with acceptable reliability (α = 0.606–0.742) [55], and content validity was confirmed by academic and industry experts. Data analysis employed multiple and moderated regression in SPSS 25, with hierarchical modeling across three stages, tested for normality, multicollinearity (VIF < 5.0), and homoscedasticity [56], [57].

3.3 Qualitative Phase

Ten stakeholders participated in semi-structured interviews consisting of four supervisors, two managers, three staff specialists, and one operations chief, thereby representing multiple organizational levels and functions. Each interview lasted between 60 and 105 minutes and was designed to explore experiences related to the ADKAR framework, organizational dynamics, manifestations of resistance, and the perceived effectiveness of change-management practices. The interview guide was informed both by relevant literature and by insights derived from the initial quantitative findings [58]. To ensure methodological rigor, NVivo software was employed to support comprehensive thematic analysis following the established procedures of Braun and Clarke [59]. This process was further complemented by the generation of word-clouds and project mapping, which not only validated the prominence of identified themes but also helped to uncover emergent patterns that enriched the qualitative understanding of MES adoption challenges.

3.4 Triangulation and Socio-Technical Framework Analysis

Mixed-methods integration occurred through systematic triangulation of quantitative ADKAR results with qualitative implementation narratives [60], after which Clegg's hexagonal socio-technical framework [20] was applied to identify systemic patterns and organizational dynamics. Socio-technical systems theory provides a comprehensive lens on complex transformations by recognizing that work systems comprise interrelated technical and social subsystems requiring concurrent optimization. his framework posits that technology alone is insufficient, as success also depends on human factors, culture, processes, and environmental context [61]. The hexagonal model decomposes organizational systems into six interconnected components namely Goals, People, Infrastructure, Technology, Culture, and Processes each with attributes suitable for detailed analysis and intervention design, where changes in one component propagate across others and require explicit management of interdependencies [62]. In the MES context, this framework supports the identification of systemic contributors to success or failure, such as Goals in terms of strategic alignment and role clarity, People through competency development and cultural adaptation, Infrastructure related to technical reliability and workspace optimization, Technology emphasizing user-centered design and system integration, Culture shifting from hierarchical to autonomous decision-making, and Processes involving workflow optimization and feedback mechanisms [63].

4. RESULTS

The following section presents comprehensive findings from the empirical investigation of MES 3.0 adaptation at the footwear manufacturing facility. The analysis employs an explanatory sequential mixed-methods approach, combining quantitative statistical analysis with qualitative insights to provide a holistic understanding of the adaptation process.

4.1 Quantitative Findings

The study involved 248 participants representing the manufacturing workforce, most of whom were female (89.5%), reflecting the dominance of women in Indonesia's footwear industry. The workforce was relatively young, with 67.3% aged 18–29, 24.2% aged 30–39, and 8.5% aged 40+, while their education levels showed that 91.1% had completed high school, 6.5% vocational training, and 2.4% university education. In terms of roles, 74.6% were production operators, 15.7% quality control staff, 5.6% maintenance workers, and 4.1% supervisory staff. Notably, 84.3% had no prior exposure to integrated manufacturing systems, making MES 3.0 their first experience with smart manufacturing technology. To understand the relationships among variables in the MES 3.0 adaptation process, descriptive statistics and correlation analyses were conducted to identify patterns between ADKAR model components (Awareness, Desire, Knowledge, Ability, Reinforcement), inhibiting factors (Resistance), system complexity, and adaptation failure levels, while internal reliability (Cronbach's alpha) values were also assessed to ensure measurement consistency. Table 2 below presents the means, standard deviations, and correlation matrix among variables.

Table 2. Descriptive statistics and correlation matrix for MES 3.0 adaptation variables

Variable	Mean	SD	Correlation							
			1	2	3	4	5	6	7	8
1. Awareness	3.18	0.82	(.91)							
2. Desire	2.76	0.91	.34**	(.88)						
3. Knowledge	2.84	0.87	.29**	.32**	(.89)					
4. Ability	2.62	0.93	.23**	.29**	.46**	(.86)				
5. Reinforcement	2.41	1.02	.16*	.19**	.38**	.52**	(.89)			
6. Resistance	3.22	1.12	-.45**	-.33**	-.28**	-.31**	-.22**	(.87)		
7. System Complexity	3.23	0.95	.28**	.15*	.41**	.38**	.29**	-.34**	(.83)	
8. Adaptation Failure	3.09	0.94	-.72**	-.25**	-.34**	-.28**	-.35**	.65**	-.42**	(.93)

*Note: N = 248; Cronbach's alpha in parentheses; *p < 0.05; *$p < 0.01$

The study highlights that awareness had the strongest negative correlation with adaptation failure (r = –.72), emphasizing its crucial role in MES 3.0 success, while resistance showed a strong positive correlation (r = .65). System complexity was moderately correlated with knowledge and ability requirements, and ADKAR components showed positive intercorrelations, confirming their status as related but distinct constructs. To examine these relationships, a hierarchical regression analysis was performed in three stages. Model 1 controlled for demographics and included ADKAR as primary predictors, Model 2 added resistance as a potential moderator, and Model 3 tested interaction effects between resistance and ADKAR factors. This approach provided a structured evaluation of how each variable set incrementally contributed to explaining adaptation failure, as presented in Table 3.

Table 3. Hierarchical regression results predicting MES 3.0 adaptation failure

Variable	Model 1			Model 2			Model 3		
	β	t	p	β	t	p	β	t	p
Control Variables									
Age	.043	0.89	.374	.021	0.52	.605	.018	0.47	.639
Gender	-.087	-1.78	.077	-.045	-1.09	.277	-.041	-1.04	.301
Education	.051	1.05	.295	.033	0.79	.432	.029	0.73	.467
MES Experience	-.125	-2.87	.004	-.098	-2.34	.020	-.089	-2.15	.033
ADKAR Components									
Awareness	-.756	-22.52	.000	-.161	-1.92	.057	-.145	-1.89	.061
Desire	.026	0.77	.441	.009	0.13	.900	.011	0.15	.881
Knowledge	-.105	-2.53	.012	.058	0.76	.447	.063	0.84	.403
Ability	.039	1.05	.297	-.014	-0.18	.855	-.018	-0.24	.808
Reinforcement	-.113	-2.62	.009	-.076	-1.02	.308	-.081	-1.12	.265
Moderator									
Resistance				.657	2.07	.040	.598	2.03	.044
Two-way Interactions									
Awareness × Resistance							-.048	-5.69	.000
Desire × Resistance							-.018	-0.89	.375

Variable	Model 1			Model 2			Model 3		
	β	t	p	β	t	p	β	t	p
Knowledge × Resistance							-.037	-2.19	.030
Ability × Resistance							-.027	-1.24	.217
Reinforcement × Resistance							-.023	-1.67	.097
Model Statistics									
R^2	.730			.740			.761		
Adjusted R^2	.725			.732			.748		
ΔR^2				.010			.021		
F Change				4.28*			12.67***		

*Note: *p < 0.05; **p < 0.01; ***p < 0.001*

Key findings from regression analysis :

- **Model 1** demonstrated that ADKAR components collectively explained 73.0% of variance in adaptation failure (F = 60.34, $p < .001$), with Awareness emerging as the strongest predictor (β = -.756, $p < .001$). Knowledge (β = -.105, p = .012) and Reinforcement (β = -.113, p = .009) also showed significant relationships.
- **Model 2** added employee resistance, explaining an additional 1.0% of variance (ΔR^2 = .010, F change = 4.28, $p < .05$). Resistance showed a significant positive relationship with adaptation failure (β = .657, p = .040).
- **Model 3** introduced interaction terms between resistance and ADKAR components, explaining an additional 2.1% of variance (ΔR^2 = .021, F change = 12.67, $p < .001$). Two significant interaction effects emerged: Awareness × Resistance (β = -.048, $p < .001$) and Knowledge × Resistance (β = -.037, p = .030).

Significant interaction effects were probed using simple slopes analysis at one standard deviation above and below the mean of employee resistance. The results are summarized in Table 4 below to provide a clearer comparison of the interaction effects under low and high resistance conditions.

Table 4. Results of simple slopes analysis at low and high levels of resistance

Interaction	Resistance Level	β	t	p	Interpretation
Awareness × Resistance	Low (–1 SD)	-0.194	-2.87	0.004	Awareness significantly reduces adaptation failure.
	High (+1 SD)	-0.098	-1.42	0.157	The effect weakens and becomes non-significant; high resistance creates a ceiling effect that limits the benefits of awareness.
Knowledge × Resistance	Low (–1 SD)	-0.156	-2.34	0.020	Knowledge significantly reduces adaptation failure.
	High (+1 SD)	-0.067	-0.95	0.343	The effect weakens and becomes non-significant; high resistance hinders the practical application of knowledge.

4.2 Qualitative Findings

The qualitative stage employed systematic analysis through coding techniques with the assistance of NVivo 15 software to analyze in-depth interview transcripts from 10 participants, consisting of supervisors (4), managers (2), staff specialists (3), and an operational chief (1), representing 6–20 years of experience in manufacturing operations. Word cloud from the initial analysis, illustrating the most dominant keywords related to the implementation of the work system in the in-depth interviews presented in Figure 2.

Figure 2. Word cloud of word frequency analysis in the discourse of mes implementation

The word cloud presented in Figure 3 provides a comprehensive visual summary of the dominant discourse from in-depth interviews with ten key stakeholders concerning MES 3.0 implementation. The font size of each word corresponds directly to its frequency within the interview transcripts, offering an intuitive, data-driven snapshot of the most salient concepts. This visualization moves beyond mere frequency counts by spatially organizing the digital transformation lexicon, thereby structuring the stakeholder narrative into coherent thematic patterns and serving as a valuable analytical entry point for understanding cognitive mapping in operational contexts.

The analysis reveals four distinct yet interconnected thematic clusters. The Technical Terminology Cluster is anchored by the pronounced dominance of the word “system” (42 occurrences), which functions as the central node of the discourse and suggests that the MES is perceived as a complex infrastructural entity. This is closely followed by core technology identifiers such as “MES” (28), “data” (24), and the action-oriented term “implementation” (32), collectively reinforcing a narrative heavily centered on technical and procedural aspects. The Human Element Cluster underscores the inseparable human dimension of the change, prominently featuring “operator” (26) and “employee” (18) as the primary agents of adoption. This focus is complemented by terms related to activity and capability development, such as “training” (16), and hierarchical roles including “supervisor” (11).

Further analysis identifies the Change Process Cluster, represented by key process-oriented terms like “process” (22) and “change” (19), alongside temporal markers such as “time” (14). This reflects a keen participant awareness that MES adoption is a managed, transformative journey requiring strategic planning and sustained commitment. Simultaneously, the Implementation Challenge Cluster vocalizes perceived obstacles through words like “problem” (21) and “resistance” (17), balanced by a lexicon of resolution including “support” (13) and “improvement” (8), indicating stakeholders’ pragmatic framing of challenges alongside mitigation mechanisms.

Collectively, this word cloud functions as a rich discursive map, revealing that implementation is narrated through a dialectical interplay between the technical system, human actors, managerial processes, and problem-solving dynamics. The visualization thus captures the socio-technical essence of digital transformation as experienced by stakeholders. This finding affirms that MES implementation is an inherently multidimensional socio-technical endeavor, where successful technology deployment depends on human adaptation, structured change processes, and proactive organizational capacity.

The co-occurrence pattern highlights the strong interrelation between “system,” “operator,” and “implementation” as the most prominent triad, emphasizing that the success of digital transformation relies on the optimal integration of technological aspects, human capacity, and structured change management processes. This finding suggests that effective MES adoption depends on aligning technical design with operator workflows and robust implementation planning, where any disconnect among these three elements may lead to implementation failure. Complementing this, the network analysis using NVivo 15 mapped six main themes with distinct characteristics of centrality and interconnectivity, as shown in Figure 4, thereby confirming the multidimensional nature of the manufacturing system implementation process.

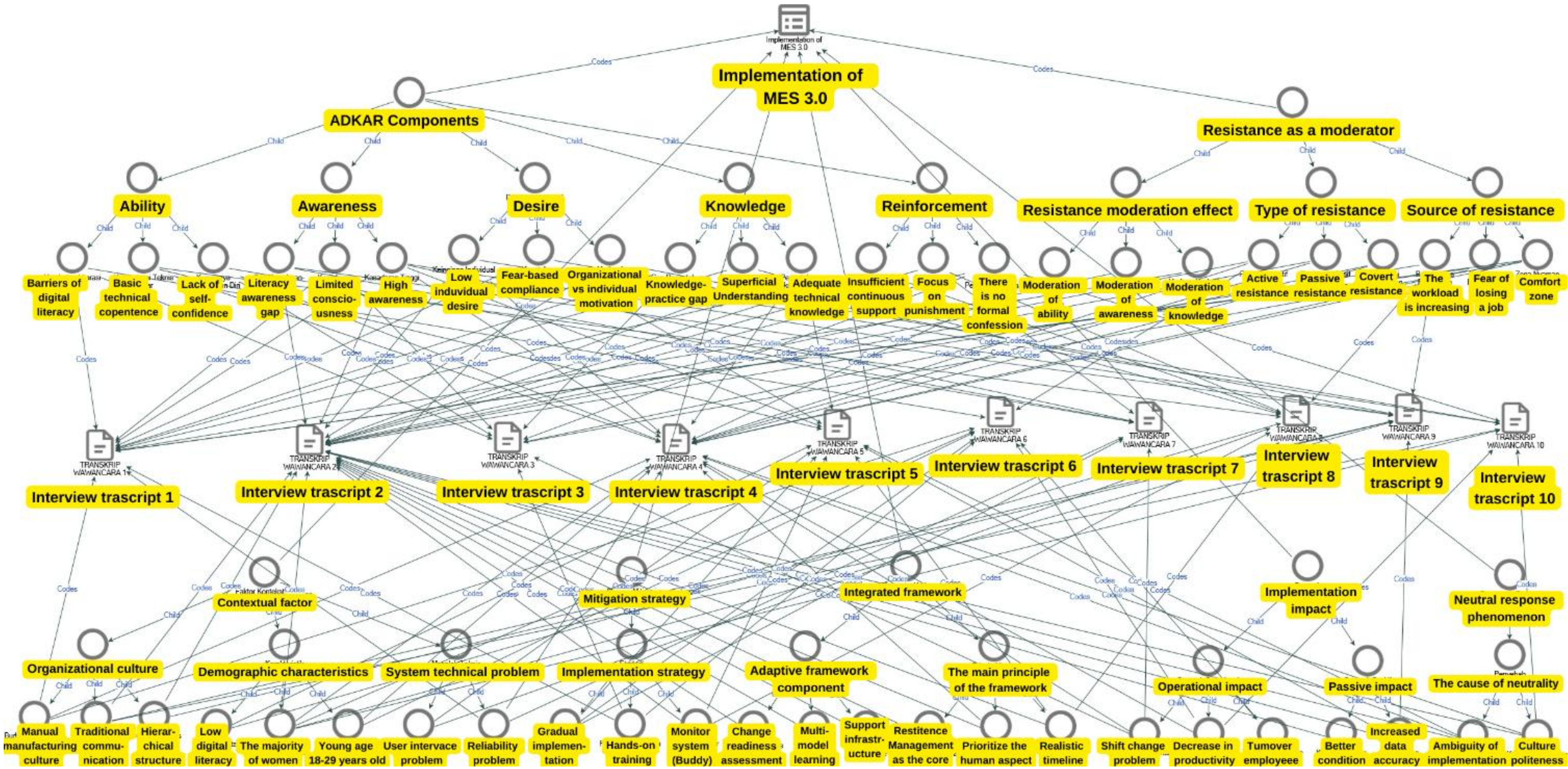

Figure 4. Thematic network map of MES implementation

Based on thematic density analysis, the ADKAR components emerged as the most frequently referenced theme (42 references across 10 sources), indicating its central position in the study's conceptual framework. The high frequency of ADKAR-related codes suggests that stakeholders consistently framed implementation challenges and successes through the lens of awareness, desire, knowledge, ability, and reinforcement. Meanwhile, Resistance demonstrated the highest betweenness centrality value (0.91), highlighting its critical role as a moderating variable that actively shapes and redirects the relationships among other thematic elements within the implementation ecosystem. This structural prominence underscores that resistance functions not merely as a barrier but as a dynamic force that influences how all other factors interact and manifest. The detailed distribution of these themes and their supporting qualitative evidence is systematically presented in Table 5.

Table 5. Gaps in ADKAR model implementation

Theme	Sub-Theme	Ref.	Sources	Key Findings
Theme 1: Gaps in ADKAR Model Implementation	Reinforcement Deficiency	5	4	Absence of formal rewards; reinforcement relied more on sanctions.
	Knowledge Limitations	4	4	Limited practical capability despite theoretical understanding.
	Desire Misalignment	4	3	Organizational goals not aligned with individual motivation.
	Awareness Paradox	3	3	Strategic awareness not translated into operational understanding.
	Ability Constraints	3	3	Low self-efficacy and digital skills among senior operators.
Theme 2: Resistance as a Moderating Variable	Sources of Resistance	8	6	Preference for manual work, job insecurity, and perceived complexity.
	Typology of Resistance	10	7	Active, passive, covert, and neutral resistance patterns identified.
	Moderating Effects	9	6	Resistance weakened ADKAR outcomes on knowledge and skills.
Theme 3: Integrated Implementation Framework	Implementation Principles	7	5	Human-centric approach with extended and realistic timelines.
	Adaptive Components	14	8	Sustained support, multimodal learning, and readiness assessment.
Theme 4: Neutral Response Phenomenon	Cultural Specificity	11	6	Neutrality reflected politeness norms and wait-and-see attitudes.
Theme 5: Multi-Level Contextual Factors	Technical Issues	8	5	System downtime and complex interfaces hindered acceptance.
	Demographic Characteristics	10	6	Young, digitally literate yet inexperienced, female-dominated workforce.
	Organizational Culture	8	5	Hierarchical and manual-oriented culture constrained adoption.
Theme 6: Impacts and Mitigation Strategies	Positive Impacts	3	3	Improved data accuracy and cross-department coordination.
	Operational Challenges	4	3	Productivity decline and senior workforce turnover occurred.
	Mitigation Strategies	3	3	Buddy system, practical training, and phased rollout effective.

Synthesizing across themes, a central pattern emerges: MES implementation failure results not from any single factor but from cascading misalignments across the socio-technical system. Technical issues (Theme 5) trigger psychological resistance (Theme 2), which dampens ADKAR effectiveness (Theme 1), all within a cultural context (Theme 4) that obscures authentic feedback, making problems difficult to diagnose. Successful mitigation (Theme 6) requires integrated interventions (Theme 3) that simultaneously address technical usability, social dynamics, and cultural mediation, precisely the multi-dimensional approach captured in the hexagonal socio-technical framework developed in this study.

4.3 Data Triangulation and Integration

Data triangulation was conducted to validate the findings through a systematic comparison of quantitative analysis results, qualitative insights, and visual pattern support, using a convergent parallel design to ensure a comprehensive understanding of MES implementation. To facilitate this process, a triangulation matrix was developed to compare findings across multiple data sources within key theoretical domains, where each domain was assessed based on the criteria of convergence, complementarity, and expansion, as summarized in Table 6.

Table 6. Comprehensive mixed-methods triangulation results

Domain	Quantitative Findings	Qualitative Findings	Visual Pattern Support	Triangulation Status
Resistance Moderation	Resistance significantly moderates ADKAR-failure (β = 0.657, p = 0.040)	Four-type resistance model: Active (15%), Passive (35%), Covert (20%), Neutral (30%)	“problem” (21), “resistance” (17), “difficult” (15) prominence	CONVERGENT
Awareness Dominance	Awareness as strongest predictor (β = -.778, p = 0.000), correlation r = -.72	Awareness Paradox: Strategic-level awareness not followed by operational understanding	“system” (42) prominence, awareness-action gap clustering	CONVERGENT
Knowledge-Practice Gap	Knowledge × Resistance interaction (β = -.037, p = 0.030)	Knowledge Limitations: Gap between theoretical understanding and practical troubleshooting capability	Co-occurrence pattern “training” (16), “operator” (26)	CONVERGENT
Reinforcement Absence	Reinforcement non-significant with resistance present (β = -.081, p = 0.265)	Reinforcement Deficiency: Lack of formal recognition mechanisms, management focus on sanctions rather than rewards	Limited recognition mentions, “problem” (21) prominence	CONVERGENT
Cultural Mediation	Not measured quantitatively	Cultural Specificity: Indonesian politeness norms obscure authentic attitudes, hierarchical structures	Hierarchical language patterns “supervisor” (11), “management” (9)	QUALITATIVE EXPANSION
Neutral Response Discovery	Not detected in binary quantitative measures	30% neutral response due to cultural politeness and implementation ambiguity	Medium frequency terms without strong emotional valence	QUALITATIVE EXPANSION

The triangulation revealed several patterns. The phenomenon of multidimensional resistance is reflected in the findings that indicate a significant quantitative moderation effect (β = 0.657), which operates through four distinct behavioral manifestations. In the context of the ADKAR framework, the results reveal that the issue lies not in the complete absence of components but in the varying quality of their implementation. Cultural context also emerges as a critical factor shaping implementation dynamics, particularly within the Indonesian manufacturing sector where hierarchical structures and cultural politeness strongly influence communication patterns, decision-making processes, and levels of change acceptance. Moreover, the study highlights a divergence between technical and social performance, the system demonstrates objective technical success through measurable indicators such as uptime and data accuracy, yet user dissatisfaction and persistent resistance remain evident.

4.4 Hexagonal Socio-Technical Framework Integration

Based on quantitative and qualitative findings that validated with comprehensive triangulation and following the hexagonal socio-technical systems approach by Clegg [20], an integrated framework with 24 sub-elements has been developed for MES 3.0 implementation, as visualized in Figure 5.

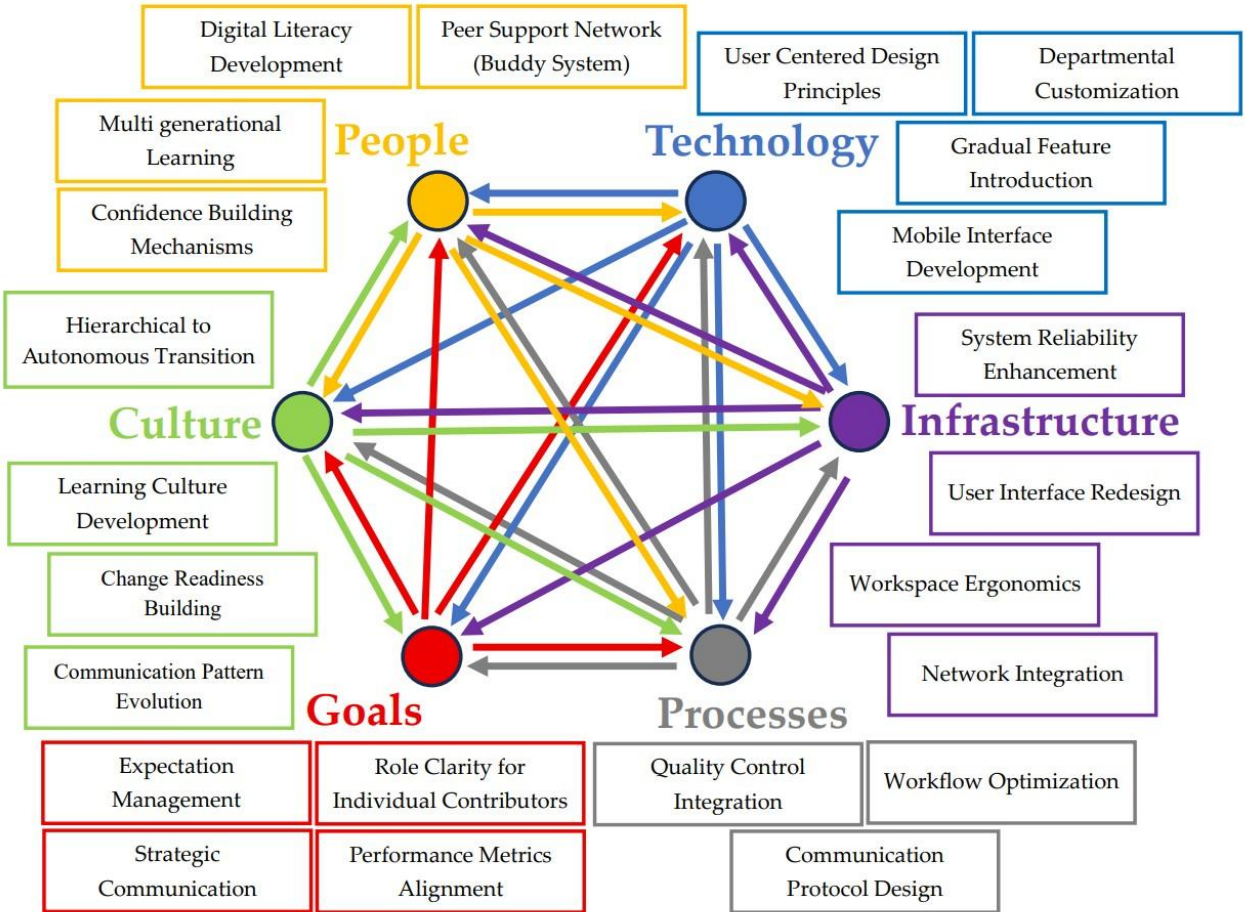

Figure 5. Hexagonal socio-technical framework for MES 3.0 implementation

The figure illustrates six main strategic components that are interconnected in the implementation of a Manufacturing Execution System (MES), namely Goals, People, Technology, Infrastructure, Culture, and Processes. Each component contains sub-focus areas designed to address specific challenges based on empirical findings, ranging from awareness gaps, human resource competencies, technical requirements, to organizational cultural dynamics. The interrelationships among these components are represented by directional arrows, highlighting the interdependence and need for cross-dimensional coordination to ensure effective MES implementation. To provide a clearer overview of each component and its development focus, the structured details are presented in Appendix B.

The hexagonal framework demonstrates complex bidirectional relationships across 23 interconnection pathways validated through thematic network analysis. It conceptualizes organizational transformation as an integrated socio-technical system comprising six core elements: Goals, People, Technology, Processes, Infrastructure, and Culture, which are interlinked through critical interactions and success factors. Within this framework, People occupy a central role, reflecting their function as the primary mediators of resistance management, cultural adaptation, phased implementation, and the formalization of peer support mechanisms. The reciprocal relationships among Goals, Processes, and Culture represent an ongoing cycle of strategic alignment, quality control, and cultural transition, while the interdependence between Infrastructure and Technology underscores the importance of system reliability and technical robustness in enabling sustainable digital adoption. Collectively, the framework captures the multidimensional and dynamic nature of organizational change, emphasizing that successful transformation depends on the simultaneous alignment of structural readiness and active human engagement.

The study proposes a Three Stage Implementation Protocol. The first stage, diagnostic assessment (Weeks 1–4), involves a comprehensive baseline evaluation of the six hexagonal components using the MES Readiness Assessment Matrix (see Appendix A) where 24 elements are rated on a 1–5 scale to generate a readiness profile and identify critical gaps. In the footwear manufacturing facility, this assessment revealed relatively strong technological readiness (T1 = 3.8) alongside substantial deficits in people development (P2 = 1.8) and cultural transformation (C1 = 2.1). The second stage, targeted intervention (Months 2–6), prioritizes interventions on elements with the lowest readiness scores and highest interdependencies; focused initiatives in digital literacy (P2) and autonomous decision making training (C1) led to marked improvements within three months (P2: 1.8 → 3.6; C1: 2.1 → 3.2), corresponding to a 40% reduction in data entry errors and a 25% increase in problem solving speed. The third stage, integrated monitoring, establishes continuous quarterly tracking of all 24 elements through a dashboard system, with early warning thresholds (<3.0) that enable proactive intervention before systemic degradation occurs.

4.5 Optimized Change Management Framework

Based on systematic integration of quantitative ADKAR findings with qualitative socio-technical insights, a Four-Phase Optimized Framework has been developed. The framework consists of four phases as summarized in Table 7.

Table 7. Change management framework

Phase	Objective	Key Activities	Success Metrics
1. Comprehensive Assessment & Resistance Mapping	Multi-dimensional assessment and resistance mapping	- Resistance type identification (active 15%, passive 35%, covert 20%, neutral 30%) - Cultural context evaluation (Indonesian politeness and hierarchy) - Digital readiness baseline assessment - Departmental variation mapping	- Validated resistance distribution - 70% workforce with basic digital literacy - Department readiness score >3.0
2. Targeted Capability Building with Pilot Excellence	Competency development and momentum through pilot projects	- Multi-generational learning programs (P4 peer networks) - Targeted digital literacy enhancement (P2) - Pilot implementation in high-readiness departments	- Digital competency improvement (Cohen's d >0.8) - Pilot performance: >85% daily usage, <5% errors - Peer mentoring satisfaction >4.0/5.0

Phase	Objective	Key Activities	Success Metrics
		- Workflow redesign with operator participation (M1)	
3. Systematic Rollout with Socio-Technical Optimization	Organization-wide implementation with socio-technical optimization	- Infrastructure-technology integration (I1, T2) - Culture-process alignment (C1, M1) - User experience enhancement (I2 UI redesign) - Department-by-department scaling	- System downtime <1 hour/week - User satisfaction >4.0/5.0 - 60% increase in autonomous decision-making
4. Sustainable Excellence & Continuous Evolution	Long-term sustainability and continuous improvement	- Formal recognition systems - Institutionalized multi-generational learning (P1) - Integrated performance monitoring (M3) - Embedding innovation culture (C3)	- MES engagement >4.2/5.0 - ≥2 improvement suggestions per employee annually - Data accuracy >95%

5. DISCUSSION

This study makes significant contributions to the understanding of digital transformation in manufacturing organizations from theoretical, practical, and methodological perspectives. Theoretically, it provides the first empirical evidence that employee resistance functions as a moderating variable in ADKAR effectiveness, demonstrating significant overall moderation ($\beta = 0.657$, $p = 0.040$) and specific dampening effects on awareness and knowledge. This finding advances prior literature that largely treated resistance as a direct predictor of change failure by showing that resistance reshapes how change interventions operate, creating a ceiling effect that limits the benefits of awareness and knowledge initiatives under high resistance conditions. The study further develops a four-dimensional resistance typology consisting of active, passive, covert, and neutral forms, moving beyond binary acceptance and rejection models and highlighting the need for differentiated intervention strategies. In addition, it introduces the ADKAR Quality Assessment Framework, emphasizing that implementation quality is more critical than component presence, and extends cultural mediation theory by identifying Indonesian norms of politeness and hierarchy as factors that systematically obscure authentic resistance. These insights are integrated into a 24-element socio-technical framework that bridges individual-level change mechanisms and organizational-level dynamics, addressing a literature gap that has predominantly focused on service-sector contexts rather than manufacturing.

The integration of technical performance metrics with human resource development, as demonstrated in Indonesian manufacturing studies [13], [15], supports the comprehensive nature of our socio technical approach and validates the necessity of addressing both technical infrastructure and organizational readiness simultaneously [14], [37]. From a practical and methodological standpoint, the study translates these theoretical contributions into actionable guidance for manufacturing transformation, as summarized in Table 8 Practically, organizations are encouraged to conduct multidimensional and culturally sensitive resistance assessments, adopt phased rather than big-bang implementation strategies, anticipate cultural–technical tensions at early stages, and formalize peer-based knowledge transfer through intergenerational mentoring. Leaders are advised to prioritize early resistance diagnostics, integrate technical and social performance indicators, and strengthen reinforcement mechanisms to sustain adoption beyond initial deployment. Methodologically, the study demonstrates the value of a mixed-methods approach that combines quantitative moderation analysis with qualitative socio-technical inquiry, supported by visual and thematic analytical techniques. By embedding local cultural dynamics within established Western change management theories and adapting socio-technical principles to manufacturing settings, this research enhances both the contextual relevance and sectoral applicability of digital transformation frameworks while offering a replicable foundation for future empirical studies.

Table 8. Research contributions

Contribution Dimension	Key Findings	Added Value
Theoretical	Resistance moderates ADKAR effectiveness (β = 0.657, p = 0.040)	Integration of resistance into change management models
	Four-dimensional resistance typology (active, passive, covert, neutral)	Differentiated strategies for intervention
	ADKAR Quality Framework	Focus on quality of implementation rather than mere presence
	Indonesian cultural factors (politeness, hierarchy) as mediating variables	Enriches cross-cultural organizational behavior literature
	Integrated socio-technical model (24-element hexagonal framework)	Comprehensive theoretical foundation for digital transformation
	Specialization in manufacturing context	Addresses research gaps dominated by service-industry focus
Practical	Multidimensional resistance assessment & phased implementation	Reduces risk of failure and improves organizational readiness
	Cultural interventions before technology deployment	Anticipates conflicts between hierarchical culture and autonomous systems
	Formalization of peer networks & intergenerational mentoring programs	Enhances knowledge transfer effectiveness
	Development of culturally sensitive assessment tools & quality-based ADKAR	Captures *neutral response* patterns and improves evaluation accuracy
	Resource allocation toward early resistance assessment	Improves cost efficiency in implementation
	Integration of technical and social metrics	Enables holistic and sustainable evaluation of digital transformation
Methodological	Integration of *mixed-methods* (quantitative + qualitative)	Strengthens validity through triangulation and visualization
	Incorporation of local cultural context into Western theories	Enhances model relevance in developing country settings
	Adaptation of socio-technical principles for manufacturing	Provides a more applicable framework tailored to the manufacturing sector

6. CONCLUSION

This study developed a comprehensive and optimized change management framework to facilitate the implementation of Manufacturing Execution System (MES) 3.0 within the broader agenda of industrial digital transformation. By systematically integrating quantitative ADKAR analysis with qualitative socio-technical inquiry, the findings demonstrate that employee resistance exerts a significant moderating influence on the effectiveness of ADKAR components, particularly with respect to awareness and knowledge ($\beta = 0.657$, $p = 0.040$).

Notwithstanding these contributions, several limitations must be acknowledged. The single organization scope restricts external validity across heterogeneous industrial and cultural contexts, while the cross-sectional design constrains the ability to establish causal inference despite robust correlational evidence. The reliability coefficients in this study ranged from $\alpha = 0.606$ to 0.742; while acceptable for exploratory research, values approaching the lower threshold may contain more measurement error, potentially attenuating correlations and yielding conservative effect size estimates. The reliance on self-reported measures introduces the potential for perceptual bias.

These limitations open several promising directions for future research, including longitudinal validation to capture resistance dynamics over time, cross-cultural replication to test applicability across diverse environments, and broader industry generalization. Furthermore, examining the adaptability of the integrated framework to emerging technological paradigms such as artificial intelligence, the Internet of Things, and blockchain will be essential for ensuring continued relevance in the evolving landscape of Industry 4.0. In writing this article, the author declares that the use of AI in this article was limited to language editing and improving clarity. All analysis, data interpretation, and conclusions are the author's responsibility.

REFERENCES

[1] L. Da Xu, E. L. Xu, and L. Li, "Industry 4.0: state of the art and future trends," Int J Prod Res, vol. 56, no. 8, pp. 2941–2962, Apr. 2018, doi: 10.1080/00207543.2018.1444806.

[2] F. Shrouf, J. Ordieres, and G. Miragliotta, "Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm," in *2014 IEEE International Conference on Industrial Engineering and Engineering Management*, IEEE, Dec. 2014, pp. 697–701. doi: 10.1109/IEEM.2014.7058728.

[3] S. Vaidya, P. Ambad, and S. Bhosle, "Industry 4.0 – A Glimpse," *Procedia Manuf*, vol. 20, pp. 233–238, 2018, doi: 10.1016/j.promfg.2018.02.034.

[4] R. Kansal, "Digital Transformation and Organizational Change: An Experiential Case," in *Digital Strategies and Organizational Transformation*, Faculty Publications Chapters, Seton Hall University, 2023, pp. 287–304. doi: 10.1142/9789811271984_0015.

[5] S. Abouaomar and K. Alhaderi, "Overcoming Barriers to Digital Transformation in Public Organizations using the McKinsey 7S Model," *International Journal of Research in Economics and Finance*, vol. 1, no. 3, pp. 14–28, Oct. 2024, doi: 10.71420/ijref.v1i3.23.

[6] P. S. Turner, "Leading, Managing, and Facilitating Organizational Change," in *Research Anthology on Digital Transformation, Organizational Change, and the Impact of Remote Work*, IGI Global, 2021, pp. 1770–1791. doi: 10.4018/978-1-7998-7297-9.ch088.

[7] K. Wenzel, "Analysis of Management Models of Digital Transformation," in *Management Models of Digital Transformation: Analysis and Definition of Success Factors for the Development of a Management Framework*, Wiesbaden: Springer Fachmedien Wiesbaden, 2021, pp. 95–111. doi: 10.1007/978-3-658-36158-7_7.

[8] U. Nadgaonkar, "Change Management in Project Management: Strategies and Best Practices for Non-IT Industries.," *African Journal of Biomedical Research*, 2024, doi: 10.53555/AJBR.v27i4S.7776.

[9] H. ANGTYAN, "ADKAR Model in Change Management," *International Review of Management and Business Research*, vol. 8, no. 2, pp. 179–182, Jun. 2019, doi: 10.30543/8-2(2019)-4.

[10] A. A. Armenakis, S. G. Harris, and K. W. Mossholder, "Creating Readiness for Organizational Change," *Human Relations*, vol. 46, no. 6, pp. 681–703, Jun. 1993, doi: 10.1177/001872679304600601.

[11] World Economic Forum, *The future of jobs report 2023: Digital skills gap in manufacturing*. World Economic Forum, 2023. Accessed: Sep. 14, 2025. [Online]. Available: https://www.weforum.org/publications/the-future-of-jobs-report-2023/

[12] D. Choi and I. Cho, "Analysis of informatization-related factors for digital transformation in manufacturing small and medium-sized enterprises using machine learning techniques," *Int J Prod Res*, vol. 63, no. 18, pp. 6669–6689, Sep. 2025, doi: 10.1080/00207543.2025.2481182.

[13] T. T. Suhariyanto, R. A. C. Leuveano, and S. Suhariyanto, "Analisis Manajemen Organisasi dan Sumber Daya Manusia (Studi Kasus pada Industri Velg Mobil)," *OPSI*, vol. 13, no. 1, p. 25, Jun. 2020, doi: 10.31315/opsi.v13i1.3470.

[14] E. Nursubiyantoro, P. Puryani, and M. I. Rozaq, "Implementasi Total Productive Maintenance (TPM) dalam penerapan Overall Equipment Effectiveness (OEE)," *OPSI*, vol. 9, no. 01, p. 24, Jun. 2016, doi: 10.31315/opsi.v9i01.2169.

[15] N. S. Ningrum and A. Muhsin, "Analisis efisiensi dan efektivitas performansi line machining propeller shaft untuk produk flange menggunakan metode Overall Equipment Effectiveness (OEE)," *OPSI*, vol. 9, no. 2, p. 109, Dec. 2016, doi: 10.31315/opsi.v9i2.2167.

[16] S. A. Shaik, A. Batta, and S. Parayitam, "Knowledge management and resistance to change as moderators in the relationship between change management and job satisfaction," *Journal of*

Organizational Change Management, vol. 36, no. 6, pp. 1050–1076, Nov. 2023, doi: 10.1108/JOCM-04-2023-0103.

[17] J. Zhou, Z. Liu, J. Li, and H. Jiao, "Technology Complementarity and Collaborative Innovation: The Moderating Effects of IT Adoption," in *2019 IEEE International Symposium on Innovation and Entrepreneurship (TEMS-ISIE)*, IEEE, Oct. 2019, pp. 1–7. doi: 10.1109/TEMS-ISIE46312.2019.9074242.

[18] L. Andolfi, R. Lima Baima, L. M. Burcheri, I. Pavić, and G. Fridgen, "Sociotechnical design of building energy management systems in the public sector: Five design principles," *Appl Energy*, vol. 377, p. 124628, Jan. 2025, doi: 10.1016/j.apenergy.2024.124628.

[19] E. L. Trist and K. W. Bamforth, "Some Social and Psychological Consequences of the Longwall Method of Coal-Getting," *Human Relations*, vol. 4, no. 1, pp. 3–38, Feb. 1951, doi: 10.1177/001872675100400101.

[20] H. Blackman and D. Gertman, "Socio-Technical Organization and Cognition: A Socio-Organizational Approach to Risk Based Assessment and Design," in *Probabilistic Safety Assessment and Management*, London: Springer London, 2004, pp. 1585–1590. doi: 10.1007/978-0-85729-410-4_255.

[21] "Organizational Culture and Leadership, 4th ed.," *Leadership & Organization Development Journal*, vol. 33, no. 4, pp. 421–423, Jun. 2012, doi: 10.1108/01437731211229331.

[22] S. Kuske *et al.*, "Emotional and psychological safety in the context of digital transformation in healthcare: a mixed-method strategic foresight study.," *BMJ Health Care Inform*, vol. 31, no. 1, Sep. 2024, doi: 10.1136/bmjhci-2024-101048.

[23] K. Vogelsang, K. Liere-Netheler, S. Packmohr, and U. Hoppe, "Success factors for fostering a digital transformation in manufacturing companies," *Journal of Enterprise Transformation*, vol. 8, no. 1–2, pp. 121–142, Apr. 2018, doi: 10.1080/19488289.2019.1578839.

[24] C. Chan, J. Tan, S. Billett, and W. H. Chong, "Blue-Collar Workers Adaptation to Digitalization: A Career Construction Theory Analysis," in *58th Hawaii International Conference on System Sciences*, University of Hawaii, Jan. 2025. doi: 10.24251/HICSS.2025.786.

[25] "Cultures and organizations: software of the mind," *Choice Reviews Online*, vol. 42, no. 10, pp. 42-5937-42–5937, Jun. 2005, doi: 10.5860/CHOICE.42-5937.

[26] A. Veseli, P. Hasanaj, and A. Bajraktari, "Perceptions of Organizational Change Readiness for Sustainable Digital Transformation: Insights from Learning Management System Projects in Higher Education Institutions," *Sustainability*, vol. 17, no. 2, p. 619, Jan. 2025, doi: 10.3390/su17020619.

[27] C. Besio, M. Jöstingmeier, and C. Posner, "Digital transformation and organizational restlessness," *Frontiers in Sociology*, vol. 9, Sep. 2024, doi: 10.3389/fsoc.2024.1430384.

[28] T. Gkrimpizi, V. Peristeras, and I. Magnisalis, "Classification of Barriers to Digital Transformation in Higher Education Institutions: Systematic Literature Review," *Educ Sci (Basel)*, vol. 13, no. 7, p. 746, Jul. 2023, doi: 10.3390/educsci13070746.

[29] E. Kaganer, R. W. Gregory, and S. Sarker, "A Process for Managing Digital Transformation: An Organizational Inertia Perspective," *J Assoc Inf Syst*, vol. 24, no. 4, pp. 1005–1030, 2023, doi: 10.17705/1jais.00819.

[30] K. Shahzad, F. Imran, and A. Butt, "Digital Transformation and Changes in Organizational Structure," *Research-Technology Management*, vol. 68, no. 3, pp. 25–40, May 2025, doi: 10.1080/08956308.2025.2465706.

[31] I. A. R. Moghrabi, S. A. Bhat, P. Szczuko, R. A. AlKhaled, and M. A. Dar, "Digital Transformation and Its Influence on Sustainable Manufacturing and Business Practices," *Sustainability*, vol. 15, no. 4, p. 3010, Feb. 2023, doi: 10.3390/su15043010.

[32] V. M. Tabim, N. F. Ayala, G. A. Marodin, G. B. Benitez, and A. G. Frank, "Implementing Manufacturing Execution Systems (MES) for Industry 4.0: Overcoming buyer-provider information asymmetries through knowledge sharing dynamics," *Comput Ind Eng*, vol. 196, p. 110483, Oct. 2024, doi: 10.1016/j.cie.2024.110483.

[33] A. Bianchini, I. Savini, A. Andreoni, M. Morolli, and V. Solfrini, "Manufacturing Execution System Application within Manufacturing Small–Medium Enterprises towards Key Performance Indicators Development and Their Implementation in the Production Line," *Sustainability*, vol. 16, no. 7, p. 2974, Apr. 2024, doi: 10.3390/su16072974.

[34] B. Zwolińska, A. A. Tubis, N. Chamier-Gliszczyński, and M. Kostrzewski, "Personalization of the MES System to the Needs of Highly Variable Production.," *Sensors (Basel)*, vol. 20, no. 22, Nov. 2020, doi: 10.3390/s20226484.

[35] Q. Li, W. Tang, and Z. Li, "Leveraging Industry 4.0 for Sustainable Manufacturing: A Quantitative Analysis Using FI-RST," *Applied Sciences*, vol. 14, no. 20, p. 9545, Oct. 2024, doi: 10.3390/app14209545.

[36] A. Shojaeinasab *et al.*, "Intelligent manufacturing execution systems: A systematic review," *J Manuf Syst*, vol. 62, pp. 503–522, Jan. 2022, doi: 10.1016/j.jmsy.2022.01.004.

[37] L. Lukmandono, M. Basuki, M. J. Hidayat, and V. Setyawan, "Pemilihan Supplier Industri Manufaktur Dengan Pendekatan AHP dan TOPSIS," *OPSI*, vol. 12, no. 2, p. 83, Dec. 2019, doi: 10.31315/opsi.v12i2.3146.

[38] Y. D. Astanti, S. Sadi, D. Widiyanto, P. Puryani, and T. Ristyowati, "Determination of Customer Order Decoupling Point (CODP) Based on Mass Customization Concept to Minimize Manufacturing Lead Time," *OPSI*, vol. 16, no. 1, p. 67, Jun. 2023, doi: 10.31315/opsi.v16i1.9679.

[39] C. Kasapoğlu, H. Yavuz, N. Dindarik, and A. Öztel, "Industry 4.0 maturity assessment in manufacturing enterprises: a mixed-methods approach for SMEs," *Central European Management Journal*, vol. 33, no. 4, pp. 590–617, Nov. 2025, doi: 10.1108/CEMJ-12-2023-0451.

[40] C. Wallwey and R. L. Kajfez, "Quantitative research artifacts as qualitative data collection techniques in a mixed methods research study," *Methods in Psychology*, vol. 8, p. 100115, Nov. 2023, doi: 10.1016/j.metip.2023.100115.

[41] P. Bazeley, "Conceptualizing Integration in Mixed Methods Research," *J Mix Methods Res*, vol. 18, no. 3, pp. 225–234, Jul. 2024, doi: 10.1177/15586898241253636.

[42] B. Gierus, T. Du, A. N. Maduforo, B. Gilbert, and K. Koh, "Prevalence and Quality of Mixed Methods Research in Educational Subdisciplines: A Systematic Review," *Sage Open*, vol. 15, no. 2, Apr. 2025, doi: 10.1177/21582440251335171.

[43] J. Schoonenboom, "Design Patterns in Mixed Methods Research: Embedding Mixed Methods Matched Comparisons Sampling in Previous Design Decisions," *J Mix Methods Res*, vol. 18, no. 3, pp. 383–392, Jul. 2024, doi: 10.1177/15586898241257284.

[44] A. H. Lassen and M. S. S. Larsen, "Manufacturing innovation for Industry 4.0: an innovation capability perspective," *Journal of Manufacturing Technology Management*, vol. 36, no. 9, pp. 19–44, Dec. 2025, doi: 10.1108/JMTM-09-2023-0414.

[45] T. Hernaus, K. Potočnik, E. M. Lira, and J. M. LeBreton, "Multilevel empirical research: A call for more mixed-methods approaches," *European Management Journal*, vol. 42, no. 4, pp. 452–461, Aug. 2024, doi: 10.1016/j.emj.2024.06.001.

[46] E. G. Creamer, K. M. Collins, and C. Poth, "The implications of a mixed methods way of thinking to practice," *Method Innov*, vol. 18, no. 1, pp. 51–60, Mar. 2025, doi: 10.1177/20597991251325470.

[47] P. Bazeley, "Conceptualizing Integration in Mixed Methods Research," *J Mix Methods Res*, vol. 18, no. 3, pp. 225–234, Jul. 2024, doi: 10.1177/15586898241253636.

[48] S. Toraman Turk, K. Cox, and V. L. Plano Clark, "Measuring the Degree of Mixed Methods Adoption: An Investigation Using Doctoral Dissertation Abstracts," *J Mix Methods Res*, vol. 19, no. 3, pp. 304–324, Jul. 2025, doi: 10.1177/15586898241313245.

[49] D. Chakraborty, A. Behl, I. Golgeci, and A. Nazrul, "Understanding Blockchain Adoption in SMEs: A Mixed-Method Study of Digital Transformation, Resilience, and Senior Leadership Support," *IEEE Trans Eng Manag*, vol. 72, pp. 1576–1591, 2025, doi: 10.1109/TEM.2025.3556371.

[50] C. Kasapoğlu, H. Yavuz, N. Dindarik, and A. Öztel, "Industry 4.0 maturity assessment in manufacturing enterprises: a mixed-methods approach for SMEs," *Central European Management Journal*, Apr. 2025, doi: 10.1108/CEMJ-12-2023-0451.

[51] W. Deng, M. Wang, S. Xing, and Z. Jiang, "Influence of digital transformation on the supply chain resilience of Chinese manufacturing enterprises: a mixed-methods perspective," *Journal of Business & Industrial Marketing*, vol. 40, no. 3, pp. 796–814, Apr. 2025, doi: 10.1108/JBIM-05-2024-0341.

[52] M. Ghobakhloo and M. Iranmanesh, "Digital transformation success under Industry 4.0: a strategic guideline for manufacturing SMEs," *Journal of Manufacturing Technology Management*, vol. 32, no. 8, pp. 1533–1556, Oct. 2021, doi: 10.1108/JMTM-11-2020-0455.

[53] "Designing and Conducting a Mixed Methods Study," in *A Practical Introduction to Mixed Methods for Business and Management*, 1 Oliver's Yard, 55 City Road London EC1Y 1SP : SAGE Publications Ltd, 2019, pp. 43–70. doi: 10.4135/9781526462930.n3.
[54] B. S. Everitt and G. Dunn, "Multivariate Data and Multivariate Statistics," in *Applied Multivariate Data Analysis*, Wiley, 2001, pp. 1–8. doi: 10.1002/9781118887486.ch1.
[55] R. Likert, *A technique for the measurement of attitudes*, vol. 22. Archives of Psychology, 1932.
[56] J. C. Nunnally *et al.*, "Psychometric Theory 3rd," 1976.
[57] A. Field, *Discovering Statistics Using IBM SPSS Statistics 2018*, vol. 5th ed. London: SAGE Publications, 2018.
[58] John Adams, Hafiz T.A. Khan, and Robert Raeside, "Research Methodology," in *Research Methods for Graduate Business and Social Science Students*, B-42, Panchsheel Enclave, New Delhi 110 017 India : SAGE Publications India Pvt Ltd, 2007, pp. 25–38. doi: 10.4135/9788132108498.n2.
[59] S. A. Nowak, "V. Braun, V. Clarke, Thematic Analysis. A Practical Guide Londyn: SAGE Publications Ltd, 2022, 376 s.," *Neofilolog*, no. 64/2, pp. 470–474, Jul. 2025, doi: 10.14746/n.2024.64.2.15.
[60] A. Tashakkori and C. Teddlie, *SAGE Handbook of Mixed Methods in Social & Behavioral Research*. 2455 Teller Road, Thousand Oaks California 91320 United States : SAGE Publications, Inc., 2010. doi: 10.4135/9781506335193.
[61] W. Pasmore, S. Winby, S. A. Mohrman, and R. Vanasse, "Reflections: Sociotechnical Systems Design and Organization Change," *Journal of Change Management*, vol. 19, no. 2, pp. 67–85, Apr. 2019, doi: 10.1080/14697017.2018.1553761.
[62] G. Baxter and I. Sommerville, "Socio-technical systems: From design methods to systems engineering," *Interact Comput*, vol. 23, no. 1, pp. 4–17, Jan. 2011, doi: 10.1016/j.intcom.2010.07.003.
[63] E. Mumford, *Redesigning Human Systems*. IGI Global, 2003. doi: 10.4018/978-1-59140-118-6.

Appendix A
MES Implementation Readiness Assessment Matrix

Instructions: Rate your organization's current status for each element using the 5-point scale below. Write the appropriate score (1-5) in the Score column. Calculate subtotals for each component and the overall total to determine readiness level.

Rating Scale: 1 = Critical Gap | 2 = Significant Gap | 3 = Partially Adequate | 4 = Mostly Optimized | 5 = Fully Optimized

Code	Element	Assessment Criteria	Score
GOALS (G) — Strategic Alignment			
G1	Strategic Communication Effectiveness	*Employees understand WHY MES is being implemented and its connection to organizational strategy*	[ ]
G2	Individual Role Clarity	*Each employee understands their specific responsibilities within the MES workflow*	[ ]
G3	Cross-Level Expectation Management	*Realistic timelines and outcomes are communicated across all organizational levels*	[ ]
G4	Performance Metrics Alignment	*KPIs and performance reviews incorporate MES adoption and usage indicators*	[ ]
Goals Subtotal (G1-G4):			**[ ] /20**
PEOPLE (P) — Human Capital Development			
P1	Multi-generational Learning Approaches	*Training methods are adapted for different age groups and learning styles*	[ ]
P2	Digital Literacy Development	*Foundational digital skills are assessed and developed before MES deployment*	[ ]

Code	Element	Assessment Criteria	Score
P3	Confidence Building Mechanisms	*Safe practice environments exist; mistakes are treated as learning opportunities*	[ ]
P4	Peer Support Network Formalization	*Formal MES champions and peer-help structures are established*	[ ]
People Subtotal (P1-P4):			**[ ] /20**
INFRASTRUCTURE (I) — Physical & Technical Foundation			
I1	System Reliability Enhancement	*Hardware, servers, and network infrastructure meet uptime requirements (≥99%)*	[ ]
I2	User Interface Accessibility	*Interface design is intuitive, uses local language, and suits production floor conditions*	[ ]
I3	Network Integration Optimization	*Connectivity covers all work areas with adequate bandwidth and backup options*	[ ]
I4	Workspace Ergonomics Adaptation	*Terminal placement, lighting, and physical access support comfortable system use*	[ ]
Infrastructure Subtotal (I1-I4):			**[ ] /20**
TECHNOLOGY (T) — System Design & Functionality			
T1	User-Centered Design Implementation	*System design reflects actual user workflows; users participated in design process*	[ ]
T2	Gradual Feature Introduction Strategy	*Features are released in phases; core functions mastered before advanced features*	[ ]
T3	Departmental Customization Capability	*System allows role-specific dashboards and configurable workflows*	[ ]
T4	Mobile Interface Integration	*Mobile access is available for supervisors and supports key monitoring functions*	[ ]
Technology Subtotal (T1-T4):			**[ ]/20**
CULTURE (C) — Organizational Climate			
C1	Hierarchical → Autonomous Transition	*Decision-making authority is delegated appropriately; employees empowered to solve problems*	[ ]
C2	Communication Pattern Evolution	*Two-way communication channels exist; upward feedback is encouraged and acted upon*	[ ]
C3	Learning Culture Development	*Errors are treated as learning opportunities; psychological safety exists for experimentation*	[ ]
C4	Change Readiness Enhancement	*Organization has successfully managed prior changes; change fatigue is minimal*	[ ]
Culture Subtotal (C1-C4):			**[ ] /20**
PROCESSES (M) — Operational Flow Management			
M1	Workflow Optimization for Integration	*Existing processes are mapped and redesigned to integrate MES without redundancy*	[ ]
M2	Communication Protocol Design	*Clear escalation paths and standard procedures exist for MES-related issues*	[ ]
M3	Quality Control System Integration	*QC checkpoints are embedded in MES; dual tracking (manual + digital) is minimized*	[ ]

Code	Element	Assessment Criteria	Score
M4	Feedback Loop Establishment	*Systematic mechanisms capture user feedback; improvements are implemented visibly*	[ ]
Processes Subtotal (M1-M4):			**[ ] /20**

TOTAL READINESS SCORE: [ ] / 120

Score Interpretation Guide:

96–120: HIGH READINESS - Proceed with full-scale implementation	**72–95: MODERATE READINESS -** Address priority gaps before scaling
48–71: LOW READINESS - Comprehensive preparation required	**<48: NOT READY -** Fundamental organizational development needed

Priority Action Guide:

- **Elements scoring 1-2 (Critical Gap):** Require immediate intervention before MES deployment
- **Elements scoring 3 (Partially Adequate):** Should be improved during initial implementation phase
- **Elements scoring 4-5 (Optimized):** Leverage as organizational strengths; share best practices
- **Component with lowest subtotal:** Prioritize for concentrated intervention resources

Assessment Date: ____________________ **Assessed By:** ____________________

Department/Unit: ____________________ **Review Date:** ____________________

Adapted from Clegg's Hexagonal Socio-Technical Framework [20] with empirical refinements from the footwear manufacturing case study

Appendix B
Key Focus Areas and Strategic Priorities in MES Implementation

Code	Focus Area	Description
Goals/Vision Alignment *(Red - Bottom Position)*		
G1	Strategic Communication Effectiveness	Address awareness-action disconnect through targeted messaging
G2	Individual Role Clarity	Define specific individual responsibilities in MES ecosystem, addressing awareness paradox
G3	Cross-Level Expectation Management	Handle implementation ambiguity causing neutral response (30%)
G4	Performance Metrics Alignment	Connect individual performance with organizational strategic objectives
Human Resource Development Systems *(Yellow - Upper Left Position)*		
P1	Multi-generational Learning Approaches	Address knowledge transfer needs between young (67%) and senior workers
P2	Digital Literacy Development Program	Target workforce with limited integrated manufacturing system experience
P3	Confidence Building Mechanisms	Overcome low self-efficacy barriers in complex system usage
P4	Peer Support Network Formalization	Scale successful buddy system identified in qualitative findings
Infrastructure Optimization *(Purple - Right Position)*		
I1	System Reliability Enhancement	Improve from reported 3.2 hours/week downtime toward minimal disruption

Code	Focus Area	Description
I2	User Interface Redesign	Address complex interface complaints creating negative MES associations
I3	Network Integration Optimization	Ensure seamless connectivity with existing ERP and legacy systems
I4	Workspace Ergonomics Adaptation	Optimize physical manufacturing environment for MES integration
Technology Adaptation ***(Blue - Upper Right Position)***		
T1	User-Centered Design Implementation	Address usability issues identified in qualitative findings
T2	Gradual Feature Introduction Strategy	Counter big-bang implementation failures with phased approach
T3	Departmental Customization Development	Accommodate inter-departmental differences noted in interviews
T4	Mobile Interface Integration	Support manufacturing floor accessibility requirements
Culture Transformation ***(Green - Left Position)***		
C1	Hierarchical → Autonomous Decision-Making Transition	Core transformation for MES autonomous requirements
C2	Communication Pattern Evolution	Balance formal system-mediated with informal relationship-based communication
C3	Learning Culture Development	Build continuous improvement and innovation mindset
C4	Change Readiness Enhancement	Overcome comfort zone resistance sources identified
Process Redesign ***(Gray - Bottom Right Position)***		
M1	Workflow Optimization for Integration	Seamless MES incorporation with existing manufacturing processes
M2	Communication Protocol Design	Effective coordination mechanisms across departments and shifts
M3	Quality Control System Integration	Performance monitoring and continuous improvement mechanisms
M4	Feedback Loop Establishment	Systematic learning and adaptation processes

Note: Color coding corresponds to hexagonal framework visualization. Position descriptors indicate placement in the socio-technical model.