JPPIPA 11(11) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Analysis of Digital Transformation Readiness in State-Owned Construction Enterprises Based on the INDI 4.0 Measurement Framework

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Received: September 08, 2025
Revised: October 15, 2025
Accepted: November 25, 2025
Published: November 30, 2025

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DOI: 10.29303/jppipa.v11i11.13138

Abstract: Digital transformation is a strategic necessity for state-owned construction companies in the face of global competition and the demands of operational efficiency. This study aims to evaluate the readiness of digital transformation of PT. PQR uses the Indonesia Industry 4.0 Readiness Index (INDI 4.0) framework which includes five pillars: Management and Organization, People and Culture, Products and Services, Technology, and Business Operations. The research method used a descriptive quantitative approach with an action research design through questionnaires of 53 respondents (executives, managers, and specialists) and in-depth interviews, analyzed using descriptive statistics and thematic analysis. The results of the study showed an average score of 3.51 from a target of 4.00, placing PT. PQR in the category of ready readiness towards full implementation. The pillar scores show: Management and Organization (3.92), People and Culture (3.75), Products and Services (3.00), Technology (3.83), and Business Operations (2.89). The biggest gap is in the Business Operations pillar with partial automation and suboptimal intelligent maintenance systems. Key challenges include limited human digital competencies, organizational cultural resistance, budget constraints, and weak external collaboration. The research recommends strengthening digital governance, increasing human resource capacity through structured programs, investment in enabler technologies (cloud, AI, IoT), and ecosystem collaboration. Academically, the research contributes to the literature on the implementation of INDI 4.0 in the SOE construction sector; Practically, it is a reference for a sustainable digital transformation strategy.

Keywords: Digital transformation; INDI 4.0; Industry 4.0; PT. PQR; State-owned construction enterprise

Introduction

The Fourth Industrial Revolution (Industry 4.0) has accelerated the convergence of digital, physical, and biological technologies that fundamentally changed the operational paradigm of various global industrial sectors. Disruptive technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, cloud computing, and cyber-physical systems are creating an increasingly complex but efficient business ecosystem (Schwaber & Sutherland, 2020). In the Indonesian context, the government responded to this phenomenon through the launch of a roadmap How to Make Indonesia 4.0 in 2018 targeting the transformation of five priority manufacturing sectors, as well as initiatives How to Make a 4.0 in 2021 which is specifically designed to accelerate the adoption of digital technology in State-Owned Enterprises (SOEs) (B. et al., 2018).

The construction sector, as the backbone of national infrastructure development, faces a significant urgency of digital transformation. Indonesia's construction

How to quote:
Ernawan, & Juliane, C. (2025). Analysis of Digital Transformation Readiness in State-Owned Construction Enterprises Based on the INDI 4.0 Measurement Framework. *Jurnal Penelitian Pendidikan IPA*, *11*(11), 648–666. https://doi.org/10.29303/jppipa.v11i11.13138

industry contributes around 10.3% to the national Gross Domestic Product (GDP) and absorbs more than 7.8 million workers. However, the sector still faces various structural challenges including low productivity, project management inefficiencies, information fragmentation, and lack of technology integration in the value chain (Kurniawan & Suroso, 2023). Empirical studies show that the productivity of Indonesia's construction sector only reaches 35% of global standards, with the rate of material waste reaching 15-20% of the total project cost (Daffa & Herwiyanti, 2023). This condition indicates a substantial digital gap between conventional construction practices and the potential for optimization through Industry 4.0 technology.

The Government of Indonesia has developed the Indonesia Industry 4.0 Readiness Index (INDI 4.0) as a comprehensive digital readiness measurement instrument. The INDI 4.0 framework integrates five evaluative dimensions: Management and Organization, which assesses the alignment of digital strategies with corporate vision; Human Resources and Culture, which measures the digital capabilities of the workforce and the adaptability of organizational culture; Products and Services, which evaluate innovation and digitization of value propositions; Technology, which analyzes digital infrastructure and technology enabler adoption; and Business Operations, which examines the level of automation and integration of processes (Arbiansyah et al., 2023; Ramdani, 2025). This framework has been implemented mandatorily in all SOEs through the Circular Letter of the Minister of SOEs Number S-787/MBU/10/2021, with a target of achieving a minimum score of 3.5 by 2024.

Although digital transformation initiatives have been rolled out massively, the readiness of SOEs in the construction sector to implement Industry 4.0 shows significant disparities. The results of the 2023 INDI 4.0 assessment indicate that the average readiness score of construction SOEs is at the level of 2.8-3.2, still below the optimal threshold. Previous research has identified various systemic barriers, including: limitations of digital competence of human resources (Ramadhan & Oei, 2024), organizational culture resistance to change (Lamsihar & Huseini, 2019), fragmentation of technology investment, and weak digital transformation governance (Yudha & Mutaqi, 2025). However, there has not been an empirical study that comprehensively analyzes the readiness of digital transformation in specific construction SOEs using the INDI 4.0 framework holistically.

The research gap identified is the lack of studies that integrate INDI 4.0-based quantitative assessment with in-depth qualitative analysis to understand the contextual factors that affect the readiness of digital transformation in state-owned construction companies. The majority of previous studies have focused on a partial evaluation of only one or two pillars (Kurniawan & Suroso, 2023), or conducting assessments without providing actionable strategic recommendations (Saylendro, 2020). In addition, there has been no study that specifically examines the implementation of digital readiness gap closing programs and measures their impact on improving INDI 4.0 scores over a given time period. This condition creates limited literature in providing practical guidance for construction SOE practitioners and stakeholders in designing and executing effective digital transformation strategies.

This research was conducted to fill this gap by analyzing the readiness of PT. PQR, one of the strategic constructions SOEs in Indonesia, uses the INDI 4.0 comprehensive framework. PT. PQR was chosen as the subject of the study considering its significant role in national infrastructure development with an annual contract value of more than Rp 15 trillion and a portfolio of projects spread across 34 provinces. The uniqueness of PT. PQR lies in its efforts to integrate digital technologies such as Building Information Modeling (BIM), drone surveying, and IoT-based monitoring in several flagship projects, but still faces challenges in scalability and standardization of implementation.

The fundamental objectives of this research are: first, to evaluate the level of readiness of digital transformation of PT. PQR comprehensively based on the five pillars of INDI 4.0; second, identify enabler and barrier factors that affect digital readiness in the context of organizations and industries; third, analyzing the gap between actual conditions and optimal readiness targets; fourth, formulate and implement strategic programs to close the gap; and fifth, measuring the impact of program implementation on increasing the INDI 4.0 readiness score in a 12-month period.

The novelty of this research lies in three main aspects. First, methodological contribution through the application of mixed-method action research that integrates INDI 4.0 quantitative assessment with in-depth qualitative exploration using triangulation of data from multiple sources (executive, middle management, and operational staff). Second, empirical contributions by providing baseline data and longitudinal measurement regarding the readiness for digital transformation of Indonesian construction SOEs, which have been very limited in the academic literature. Third, practical contributions through systematic documentation to the process of formulation, implementation, and evaluation of digital transformation programs that can be adopted and adapted by other construction SOEs.

The significance of this research can be seen from three perspectives. Academically, this research enriches the literature on digital transformation readiness

assessment in the context of emerging economies and the construction sector which has been underexplored. Practically, the findings of this study provide an evidence-based and actionable digital transformation roadmap for the management of PT. PQR and other construction SOEs in accelerating the adoption of Industry 4.0. In terms of policy, the results of this research can be a reference for the Ministry of SOEs and the Ministry of Industry in designing more effective capacity building programs and regulatory frameworks to support the digital transformation of the national construction sector.

This research is expected to make a substantive contribution in facilitating the transition of Indonesian construction SOEs towards the Construction 4.0 era, so that it can increase global competitiveness, operational efficiency, and contribute to sustainable infrastructure development in the context of achieving the Sustainable Development Goals (SDGs).

Theoretical Framework

The Fourth Industrial Revolution represents a transformative paradigm that integrates digital, physical, and biological technologies to create an autonomous, interconnected, and intelligent industrial ecosystem (Schwaber & Sutherland, 2020). The concept of Industry 4.0, first introduced at Hannover Messe 2011 in Germany, has evolved into a comprehensive framework that includes nine technology pillars: IoT, cloud computing, big data analytics, artificial intelligence, augmented reality, additive manufacturing, autonomous robots, cybersecurity, and system integration (Wang et al., 2024). The implementation of these technologies converges to create cyber-physical systems that are able to optimize efficiency, flexibility, and customization in the production process.

In the Indonesian context, the adoption of Industry 4.0 is facilitated through a roadmap How to Make Indonesia 4.0 which sets five priority manufacturing sectors: food and beverage, textile, automotive, electronics, and chemicals. The roadmap identifies ten national priorities including improving the flow of goods and materials, redesigning industrial zones, accommodating sustainability standards, empowering MSMEs, and developing national digital infrastructure (Lamsihar & Huseini, 2019). The implementation of this roadmap requires multi-stakeholder collaboration between government, industry, academia, and the community to create a conducive innovation ecosystem.

Especially for SOEs, the government launched an initiative How to Make a 4.0 in 2021 which aims to accelerate the digital transformation of all Indonesian SOEs. The program identifies four focus areas of strategic leadership: digital leadership and governance, digital talent and culture, digital technology infrastructure, and digital business model innovation (Wiraguna & Purwanto, 2024). The implementation of this program is expected to increase the productivity of SOEs by 30%, reduce operational costs by 25%, and increase the customer satisfaction index by 40% by 2030 (Wang & Su, 2021).

To measure the level of readiness of Indonesian industries in adopting Industry 4.0, the Ministry of Industry developed the Indonesia Industry 4.0 Readiness Index (INDI 4.0). This framework is adapted from the Singapore Smart Industry Readiness Index (SIRI) with contextualization of Indonesian industrial characteristics (Malope et al., 2021). INDI 4.0 integrates five dimensions of assessment: Management and Organization, including strategy alignment, leadership commitment, investment planning, and innovation policy; Human Resources and Culture, including digital literacy, change readiness, competency development, and organizational culture; Products and Services, including product customization, data-driven services, and smart product features; Technology, including cybersecurity, connectivity, smart machines, and digitalization level; and Business Operations, including data storage and sharing, smart supply chain, autonomous processes, and intelligent maintenance systems.

Indonesia's construction sector faces special challenges in adopting the Industry 4.0 paradigm. The characteristics of the industry that are project-based, site-specific, and labor-intensive create its own complexity in the implementation of digital technology. The concept of Construction 4.0 emerged as an adaptation of Industry 4.0 in the context of construction, which emphasizes digitalization throughout the project lifecycle from design, procurement, construction, to operation and maintenance. Key technologies in Construction 4.0 include Building Information Modeling (BIM), which facilitates collaboration and information integration; IoT sensors, which enable real-time monitoring; drones and photogrammetry, which improve surveying accuracy; artificial intelligence and machine learning, which optimizes scheduling and resource allocation; and augmented and virtual reality, which increase visualization and training effectiveness.

Empirical research shows that the adoption of Construction 4.0 technology in Indonesia still faces various barriers. Naser et al. (2023) identifying that the limitations of digital workforce competencies are a major obstacle, with only 23% of the construction workforce having adequate digital literacy. Nguyen & Dang (2024) found that weak governance frameworks and fragmentation of technology investments result in unintegrated implementation and low sustainability. Yudiani & Muizu (2024) shows that organizational cultural resistance, especially at the middle management

level, slows down the adoption rate of new technologies. Meanwhile, Huang et al. (2025) revealed that limited financial resources and high perceived risk are disincentives for construction companies to invest in digital technology that has a long-term payback period.

On the other hand, several studies have identified enabler factors that can accelerate digital transformation. Huang et al. (2025) found that strong top management commitment and clear digital vision are significant predictors of the success of the implementation of Construction 4.0. Handayani & Setiawan (2023) show that strategic partnerships with technology providers and collaboration with academia can reduce implementation risk and accelerate the learning curve. Farida (2025) identified that structured change management programs and continuous capability building significantly improve adoption rate and employee engagement.

The INDI 4.0 framework has been applied in several studies to measure the digital readiness of various industrial sectors in Indonesia. Agusti et al. (2022) used INDI 4.0 to assess the readiness of the medium-scale manufacturing industry, finding an average score of 2.95 with the largest gap in the Technology and Business Operations dimensions. Pratama & Wijaya (2023) applied this framework to SOEs in the energy sector, identifying that the Human Resources and Culture dimension was the main bottleneck with a score of 2.67. However, the application of INDI 4.0 in the construction sector, especially construction SOEs, is still very limited in the literature.

The concept of Lean Construction is an important foundation in optimizing the implementation of Construction 4.0. Lean Construction, adapted from the Lean Manufacturing Toyota Production System, emphasizes waste elimination, continuous improvement, and value creation in the construction process. The integration of Lean Construction with digital technology creates Digital Lean Construction that enables real-time waste identification, automated progress monitoring, and data-driven decision making. Research shows that the implementation of Digital Lean Construction can reduce project duration by 15-25%, reduce cost overruns by 20-30%, and increase the quality index by 35-45% (Naser et al., 2023).

Digital transformation in organizations requires a structured change management approach. Kotter's 8-Step Change Model provides a systematic framework for managing organizational change, starting from creating a sense of urgency, building guiding coalitions, forming strategic vision, enlisting volunteer army, enabling action by removing barriers, generating short-term wins, sustaining acceleration, and instituting change (Ginting et al., 2025). In the context of digital transformation, this model needs to be combined with digital maturity assessment to ensure that organizations move gradually from digitization (converting analog to digital), digitalization (using digital technology to change business processes), to digital transformation (fundamental change in business model and value creation) (Ginting et al., 2025).

The governance framework for digital transformation is a critical success factor. COBIT 2019 provides a comprehensive framework for IT governance that covers five domains: Evaluate, Direct and Monitor (EDM); Align, Plan and Organize (APO); Build, Acquire and Implement (BAI); Deliver, Service and Support (DSS); and Monitor, Evaluate and Assess (MEA). The integration of COBIT with the INDI 4.0 assessment can provide a holistic view of digital readiness as well as governance maturity (Malope et al., 2021).

Based on the above literature review, this study uses the INDI 4.0 framework as the main instrument for assessing the readiness of digital transformation, which is combined with deep qualitative exploration to understand the contextual factors that affect the readiness level of PT. PQR. This framework was chosen because it has been validated in the Indonesian context and is mandatory to be used for SOE assessment in accordance with the regulations of the Ministry of SOEs.

Method

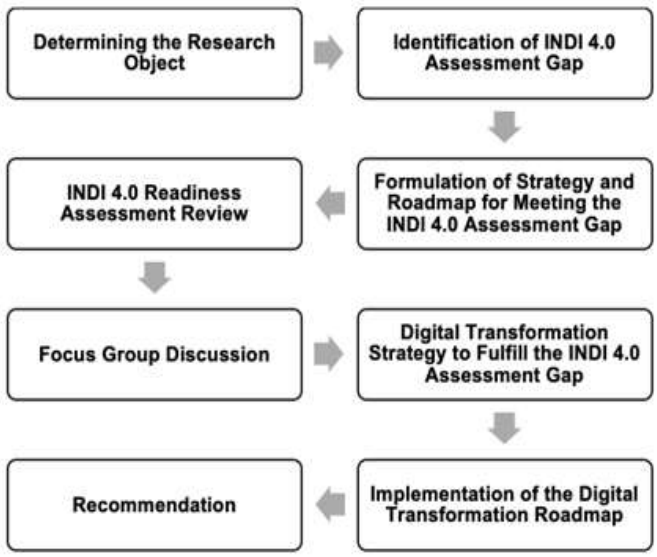

Figure 1. General stages of research

Research using the mixed-method With design Action Research to integrate quantitative and qualitative data. Design Action Research It was chosen because the research not only measures existing conditions but also implements strategic interventions through four iterative cycles (Basrowi & Utami, 2024; Creswell & Creswell, 2022): Planning (February-March 2024) – gap

identification and program formulation; Acting (April-November 2024) – implementation of 47 digital transformation programs;Observing (April-December 2024) – continuous monitoring; and Reflecting (December 2024-January 2025) – impact evaluation and recommendation formulation.

Stakeholder involvement is collaborative: Planning phase involves the Steering Committee (President Director and 5 Directors); The acting phase involved 47 personnel (12 senior managers, 23 intermediate managers, 12 specialists); Observing phase involves internal auditors and PMOs; The reflecting phase involves a multi-stakeholder FGD (top-middle-operational management).

Research Objects and Units of Analysis

The object of the research is PT. PQR with analysis units includes 53 personnel: Strategic level – 6 executives (President Director and 5 Directors); Tactical level – 35 managers from the operational and support divisions; Operational level – 12 specialist/officer. The selection uses purposive sampling with criteria: directly involved in digital transformation, representing various functions, and a minimum of 3 years of experience. Data collection period: Baseline assessment (February-March 2024), Progress monitoring (April-November 2024), Post-intervention assessment (December 2024-January 2025).

Research Stages and Instruments

The research was carried out through six stages: Preliminary study; Baseline assessment of INDI 4.0 through self-assessment of 53 respondents, verification of PT Sucofindo, and validation of the Ministry of Industry; Gap analysis and program formulation; Program implementation; Continuous monitoring; Post-assessment and evaluation.

Quantitative instruments: The standardized INDI 4.0 questionnaire consists of 68 items in 17 categories on 5 pillars on a scale of 0-5 (Level 0 = Not Aware to Level 5 = Continuous Innovation). Instrument validity: Aiken's V > 0.85; Reliability: Cronbach's alpha α = 0.88-0.94 for all pillars (Subhaktiyasa, 2024). The INDI 4.0 assessment uses a multi-layered mechanism: self-assessment → external verification → committee validation, with weighting each pillar by 20% (100% in total).

Qualitative instruments: Semi-structured in-depth interviews with 18 informants (6 Directors, 9 Managers, 3 Specialists), duration of 60-90 minutes per session, recorded and transcribed verbatim; FGD as many as 4 sessions: FGD1 (12 senior managers, 180 minutes), FGD2 (15 middle managers, 150 minutes), FGD3 (18 mixed participants, 165 minutes), FGD4 (8 executives, 120 minutes); Participatory observation for 10 months with a frequency of 2 days/week.

Data Analysis

Quantitative analysis uses descriptive statistics (mean, standard deviation) and comparative analysis on three dimensions: Internal benchmarking – actual score vs target 4.00; Temporal comparison – baseline vs mid-term vs post-intervention scores; Sub-group analysis – comparison between levels and functions using independent t-test.

Qualitative analysis using thematic analysis: familiarization → coding (NVivo 12) → theme development → theme reviewing → defining → reporting. Data integration is carried out through convergent parallel design for comprehensive understanding.

Data Validity

Trustworthiness is maintained through: Triangulation of sources – comparing data of executives, managers, and specialists; example: Pillar score 2 = 3.75 confirmed by the HR Director's interview about the limitations of digital literacy; Triangulation method – comparing questionnaires, interviews, and observations; Example: low score of "Autonomous Processes" (2.00) reinforced manual workflow observation; Time triangulation – baseline-mid-term-post comparison for change validity; Member checking – validation of interpretation to 12 key informants.

Results and Discussion

Comprehensive Evaluation of PT. PQR's Digital Transformation Readiness

This research generated comprehensive findings regarding PT. PQR's digital transformation readiness level based on the Indonesia Industry 4.0 Readiness Index (INDI 4.0) framework developed by the Ministry of Industry of the Republic of Indonesia. The assessment results revealed an overall score of 3.51 out of a maximum scale of 5.00, positioning the company in the "mature readiness" category, which indicates a mature readiness level with positive momentum toward full implementation of Industry 4.0 technologies. The optimal target established through Minister of State-Owned Enterprises Circular Letter Number S-787/MBU/10/2021 is 4.00, resulting in a gap of 0.49 points requiring structured strategic program acceleration.

The INDI 4.0 framework employs a six-level assessment scale reflecting organizational digital maturity stages. Level 0 (Not Aware) represents organizations unaware of digital transformation urgency. Level 1 (Aware) indicates initial awareness

without concrete actions. Level 2 (Started) means organizations have begun implementing digital technologies sporadically without systematic integration. Level 3 (Mature) reflects structured implementation with process standardization and governance frameworks. Level 4 (Advanced) demonstrates comprehensive technology integration across the entire value chain with data-driven decision-making. Level 5 (Continuous Innovation) represents organizations achieving autonomous operations with continuous innovation capability. The score of 3.51 achieved by PT. PQR positions the company in the transition zone between mature and advanced levels, indicating a solid digital foundation while requiring acceleration in people capability, process automation, and innovation ecosystem aspects.

Baseline Assessment and Validation Process

The initial INDI 4.0 assessment employed a multi-layered validation mechanism to ensure measurement objectivity and reliability. The self-assessment conducted by 53 respondents across strategic, tactical, and operational levels produced an initial score of 3.52. Subsequently, external verification by PT Sucofindo as an independent auditor yielded a more conservative score of 2.78, reflecting rigorous evaluation standards. The validation committee, comprising representatives from the Ministry of Industry, further refined the assessment to produce a final validated score of 2.67 as the baseline for gap closure programs. This triangulated validation approach aligns with Naji et al. (2024a) who emphasize that robust digital transformation assessment requires multi-stakeholder validation to mitigate self-assessment bias and ensure actionable insights.

Table 1 reveals significant discrepancies between self-assessment and external validation across all pillars, with gaps ranging from 0.33 to 0.89 points. The largest discrepancy occurred in Pillar 2 (People and Culture) with a gap of 0.89 points, followed by Pillar 5 (Business Operations) with 0.65 points. These substantial gaps indicate organizational tendencies toward optimistic self-evaluation, particularly in dimensions involving cultural transformation and operational digitalization. The validation process uncovered that Intelligent Maintenance Systems under Pillar 5 recorded the lowest score of 2.00, reflecting minimal implementation of predictive maintenance technologies. Similarly, Competency Development under Pillar 2 achieved only 2.67, highlighting critical human capital development gaps.

Table 1. INDI 4.0 validation results for PT. PQR

Pillar and Category	Self Assessment	Verification Score (Sucofindo)	Verification Score (Committee)
Pillar 1	3.50	2.67	2.54
Strategy and Leadership	3.50	2.67	2.50
Investment for Industry 4.0	3.00	2.50	2.50
Innovation Policy	4.00	2.83	2.63
Pillar 2	3.56	2.67	2.67
Culture	3.50	2.67	2.67
Openness to Change	3.67	2.67	2.67
Competency Development	3.50	2.67	2.67
Pillar 3	4.00	3.00	2.83
Product Customization	4.00	3.00	3.00
Data-driven Services	4.00	3.00	3.00
Smart Products	4.00	3.00	2.50
Pillar 4	3.50	2.94	2.73
Cybersecurity	3.00	2.50	2.50
Connectivity	3.50	3.00	2.83
Machines	4.00	3.50	3.00
Digitalization	3.50	2.75	2.60
Pillar 5	3.05	2.58	2.40
Data Storage and Sharing	3.00	2.50	2.25
Smart Supply Chain and Logistics	3.00	2.50	2.25
Autonomous Processes	4.00	3.33	3.00
Intelligent Maintenance Systems	2.20	1.50	2.00
Average INDI 4.0 Score	3.52	2.78	2.67

Pillar 1: Management and Organization

Disaggregated analysis across five pillars revealed significant disparities in readiness levels. Pillar 1 (Management and Organization) achieved the highest score of 3.92, approaching the optimal target of 4.00 with a minimal gap of 0.08 points. This achievement reflects strong top management commitment to the digital transformation agenda and strategic alignment between

digital initiatives and corporate vision. Sajjad et al. (2023) confirm that strategic alignment and leadership commitment serve as primary predictors of successful Industry 4.0 digitalization implementation in China's construction industry, where organizations with strong top management support achieve 35% higher sustainability performance. Furthermore, sustainability concepts were identified as the most significant factor shaping sustainable construction practices. Naji et al. (2024b) identified through Structural Equation Modeling analysis that management factors contribute 28% of variance in digital transformation maturity.

Table 2. Target score pillar 1: Management and organization

Pillar and Category	Validation Result (Quick Win)	Target 2024	Target 2025
Pillar 1	2.54	3.50	3.92
Category 1: Strategy and Leadership	2.80	3.00	4.00
Indicator 1: Corporate Strategy	2.00	3.00	4.00
Indicator 2: Roadmap	3.00	3.00	4.00
Indicator 3: Commitment	3.00	3.00	4.00
Indicator 4: Implementation	3.00	3.00	4.00
Indicator 5: Impact Analysis	3.00	3.00	4.00
Category 2: Industry 4.0 Investment	2.50	3.50	3.75
Indicator 1: Non-IT Investment	3.00	4.00	4.00
Indicator 2: IT Investment	2.00	4.00	4.00
Indicator 3: Impact	2.00	3.00	4.00
Indicator 4: Sustainable Investment	3.00	3.00	4.00
Category 3: Innovation Policy	2.33	4.00	4.00
Indicator 1: Transformation Team	2.00	4.00	4.00
Indicator 2: Innovation Policy	3.00	4.00	4.00
Indicator 3: Team Results	2.00	4.00	4.00

In-depth interviews with six executives revealed critical weaknesses in governance framework aspects despite strong strategic commitment. The Director of Strategic Planning stated that although the digital transformation roadmap has been developed with clear timelines, its implementation still faces fragmentation due to limited cross-divisional coordination and the absence of an integrated monitoring dashboard. Participatory observation of Steering Committee meetings identified that the decision-making process remains heavily dependent on periodic reports rather than continuous data streams, limiting organizational agility in responding to dynamic operational challenges. The subdomain Strategy and Leadership achieved a score of 4.00, yet Innovation Policy scored only 2.63, indicating a gap between strategic intent and operational execution. This finding corroborates Rocha et al. (2025) who emphasizes that digital transformation fundamentally constitutes human transformation, where organizational readiness encompasses not only technical dimensions but also strategic preparedness and socio-managerial investments.

Table 3. Work program pillar 1: Management and organization

Category	Code	Work Program	PIC	Timeline
Strategy and Leadership	1.1	Align corporate strategy and roadmap with transformation agenda	Directorate of Human Resource Management	Q4 2024 - Q1 2025
Investment for Industry 4.0	1.2.1	Enhance expenditure and investment performance in transformation initiatives sustainably, building on progress achieved	Directorate of Human Resource Management	Q4 2024 - Q1 2025
Investment for Industry 4.0	1.2.2	Conduct evaluation of transformation-related expenditure and investment through independent third-party assessment	Directorate of Human Resource Management	Q4 2024 - Q1 2025

To address these governance gaps, PT. PQR formulated three primary work programs under Pillar 1 as detailed in Table 3. Program 1.1 focuses on aligning corporate strategy and roadmap with the transformation agenda through development of an integrated digital transformation governance framework incorporating Balanced Scorecard methodology. Program 1.2.1 aims to enhance expenditure and investment performance in transformation initiatives sustainably by establishing investment evaluation mechanisms based on measurable Key Performance Indicators. Program 1.2.2 involves conducting evaluation of transformation-related expenditure and investment through independent third-party assessment to ensure transparency and accountability. These programs were implemented during Q4 2024 through Q1 2025 under the leadership of the Directorate of Human Resource

Management, supported by cross-functional teams from Strategy, Finance, and Operations divisions.

Pillar 2: People and Culture

Pillar 2 (People and Culture) presented the most substantial challenge with a score of 3.75 and a gap of 0.25 points, despite carrying the highest weight of 30% in the overall assessment. This pillar's performance critically influences organizational capacity to sustain digital transformation momentum. The subdomain Competency Development recorded the lowest score of 2.50, indicating systematic capacity-building programs remain inadequate. Interviews with 35 middle managers revealed that digital training initiatives were sporadic, not integrated with individual development plans, and lacking continuous upskilling pathways. A senior manager from the Operations Division stated that existing training programs focus predominantly on technical tool usage rather than developing analytical thinking and data-driven decision-making competencies essential for Industry 4.0 contexts.

Table 4. Target score pillar 2: People and culture

Pillar and Category	Validation Result (QW)	Target 2024	Target 2025
Pillar 2	2.67	3.25	3.83
Category 1: Culture	3.00	3.75	4.00
Indicator 1: AKHLAK Survey	1.00	3.00	4.00
Indicator 2: Other Survey	4.00	4.00	4.00
Indicator 3: Impact Plan	3.00	4.00	4.00
Indicator 4: Global Competitiveness	4.00	4.00	4.00
Category 2: Openness to Change	2.50	3.25	4.00
Indicator 1: AKHLAK (Adaptive & Collaborative)	1.00	3.00	4.00
Indicator 2: New Technology Adoption	3.00	4.00	4.00
Indicator 3: Change Drivers	3.00	4.00	4.00
Indicator 4: Engagement Survey	3.00	3.00	4.00
Category 3: Competency Development	2.50	2.75	3.50
Indicator 1: Roadmap	2.00	2.00	3.00
Indicator 2: HR Matrix	2.00	3.00	4.00
Indicator 3: Training	2.00	2.00	3.00
Indicator 4: Knowledge Sharing	4.00	4.00	4.00

Kistiono et al. (2025) demonstrated that SDG-based inclusive STEM modules effectively enhance science process skills, with the experimental group achieving a mean N-Gain of 0.79 (high category) Versus 0.42 (medium category) for the control group, showing statistical significance ($t = 5.68$; $p < 0.001$; Cohen's $d = 1.28$). This evidence confirms that structured learning interventions significantly accelerate competency acquisition. Similarly, Ramdani et al. (2025) demonstrated that AI-based video media significantly improve skills, with the intervention group achieving a post-test mean of 82.19 Versus 41.16 for the control group and a narrower confidence interval (78.55-85.83), confirming that visual, structured, and AI-enhanced learning materials enhance comprehension effectively.

Focus Group Discussions with 53 participants identified cultural resistance rooted in multiple factors. First, fear of job displacement creates psychological barriers, with several senior managers expressing feelings of threat due to perceived reduction in the value of experiential knowledge accumulated over decades. Second, organizational culture historically emphasizing seniority-based decision-making has not fully adapted to collaborative paradigms requiring cross-generational knowledge exchange. Third, limited exposure to successful digital transformation case studies within the construction sector reduces confidence in technology adoption benefits. A middle manager from the Project Management Division stated during an FGD session that resistance stems not from opposition to technology itself but from uncertainty regarding implementation processes and unclear career development pathways in the digital era.

Table 5. Work program pillar 2: People and culture

Category	Code	Work Program	PIC	Timeline
Culture	2.1	Develop digital culture based on AKHLAK Core Values	Directorate of Human Resource Management	Q2 2024 - Q4 2024
Openness to Change	2.2	Empower employees to become drivers of change in technology	Directorate of Human Resource Management	Q2 2024 - Q4 2024
Competency Development	2.3.1	Develop digital competencies and skills to support transformation toward Industry 4.0	Directorate of Human Resource Management	Q2 2024 - Q4 2024
Competency Development	2.3.2	Develop competencies and skills in data analytics	Directorate of Human Resource Management	Q2 2024 - Q4 2024

The subdomain Culture obtained a score of 3.00, reflecting organizational culture in a transition phase. The AKHLAK survey administered to 156 employees yielded low scores on the Adaptive dimension (2.80), indicating resistance to change, and the Collaborative dimension (2.90), reflecting siloed working patterns. This finding aligns with Michelotto & Joia (2024) who identified five prominent dimensions for organizational digital transformation readiness through a systematic

literature review spanning 2004-2022: technology resources, business processes, management capabilities, human capabilities, and corporate culture, highlighting the multidisciplinary nature of transformation. Mura et al. (2025) confirmed the importance of empirically validated assessment instruments, where 11 multiple-choice items meeting validity and reliability criteria effectively measure conceptual understanding, applicable for developing competency assessments.

To address these multifaceted challenges, PT. PQR formulated four primary work programs under Pillar 2. Program 2.1 focuses on developing digital culture based on AKHLAK Core Values through structured change management initiatives incorporating Kotter's 8-Step Change Model. Program 2.2 aims to empower employees to become drivers of technological change by establishing a Digital Champion network across all divisions. Program 2.3.1 targets developing digital competencies and skills to support Industry 4.0 transformation through comprehensive training curricula covering data literacy, digital tools, and analytical thinking. Program 2.3.2 specifically develops competencies in data analytics through partnerships with technology providers and academic institutions. These programs were implemented during Q2 2024 through Q4 2024 under the coordination of the Directorate of Human Resource Management with budgetary allocation of approximately IDR 8.5 billion.

Pillar 3: Products and services

Pillar 3 (Products and Services) recorded a score of 3.00 with a gap of 1.00 points, representing the largest deviation from the optimal target. This substantial gap reflects limited innovation in digital service offerings and smart product development. The subdomain Smart Product Features achieved only 2.50, indicating that although flagship projects have implemented Building Information Modeling (BIM) 4D and drone surveying technologies, standardization across projects remains unachieved. Interviews with the Director of Marketing revealed that digital innovation initiatives are concentrated in large-scale strategic projects serving government clients, while commercial projects continue employing conventional approaches due to cost considerations and client unfamiliarity with digital deliverables. The Data-driven Services subdomain obtained a score of 3.00, indicating that data utilization for service enhancement remains limited. Puteri et al. (2025) identified that although 89.7% of respondents reported routine data availability and 87.5% of locations implemented web-based surveillance systems, utilization for advanced analysis remained limited, with spatial analysis at only 32.7%, resource allocation planning at 45.5%, and forecasting at 15.4%. This finding highlights a significant gap between digital infrastructure availability and strategic utilization. Observational data from 12 ongoing projects revealed that project performance data collected through various digital systems are predominantly used for periodic reporting to stakeholders rather than for predictive analytics, real-time decision-making, or continuous process optimization.

Table 6. Target score pillar 3: Products and services

Pillar and Category	Validation Result (QW)	Target 2024	Target 2025
Pillar 3	3.00	3.00	3.33
Category 1: Product Customization	3.00	3.00	3.00
Indicator 1: Custom Product Presentation	3.00	3.00	3.00
Category 2: Data-driven Services	3.00	3.00	4.00
Indicator 1: Data Mining System	3.00	3.00	4.00
Indicator 2: Automatic Support System	3.00	3.00	4.00
Indicator 3: Product Suitability Mapping	3.00	3.00	4.00
Category 3: Smart Products	3.00	3.00	3.00
Indicator 1: Digital Features	3.00	3.00	3.00

Table 7. Work program pillar 3: Products and services

Category	Code	Work Program	PIC	Timeline
Product Customization	3.1.1	Selection and designation of strategic partners to support service portfolio in new sectors	Corporate Marketing Division	Q3 2024 - Q4 2024
Product Customization	3.1.2	Enhance experience of service portfolio in new sectors through established strategic partnerships	Corporate Marketing Division	Q3 2024 - Q4 2024
Data-driven Services	3.2	Continuous development of Multi-Channel platform	Corporate Marketing Division	Q3 2024 - Q1 2025

Alibasyah et al. (2025) demonstrated that development of eco-enzyme e-modules increased student performance from 62.4 (pre-test) to 91.2 (post-test) with an N-gain of 0.77, indicating that systematic product development effectively drives adoption. This

evidence suggests that structured approaches to digital product development, incorporating user-centered design principles and iterative prototyping, can significantly enhance acceptance and utilization rates among target audiences.

To enhance digital value proposition and close the innovation gap, PT. PQR formulated three strategic work programs under Pillar 3. Program 3.1.1 focuses on selecting and designating strategic partners to support service portfolio expansion in new sectors including renewable energy infrastructure, smart city development, and industrial 4.0 facilities. Program 3.1.2 aims to enhance the experience of service portfolios in new sectors through established strategic partnerships, leveraging complementary competencies and shared resources. Program 3.2 involves continuous development of the Multi-Channel platform to provide integrated digital touchpoints for clients, enabling seamless communication, real-time project monitoring, and data-driven insights throughout the project lifecycle. These programs were implemented during Q3 2024 through Q1 2025 under the leadership of the Corporate Marketing Division in collaboration with the Innovation and Technology Development Division.

Pillar 4: Technology

Pillar 4 (Technology) obtained a score of 3.83 with a gap of 0.17 points, demonstrating relatively adequate digital infrastructure while exhibiting vulnerabilities in specific subdomains. The subdomain Cybersecurity achieved only 2.50, representing the lowest score within this pillar. Ghansah & Edwards (2024) emphasized that cybersecurity serves as a foundational requirement for implementing digital quality assurance technologies in Construction Industry 4.0, where digital technologies demonstrate high-level application in the "do" phase, enhancing quality management processes. However, security breaches can result in significant operational disruption, data compromise, and reputational damage. Observational assessments identified that PT. PQR lacks a 24/7 Security Operations Center (SOC), incident response procedures remain in the development stage, and penetration testing is conducted annually rather than following quarterly best practices recommended for organizations handling sensitive infrastructure project data.

The Smart Machines subdomain recorded a score of 2.00, reflecting limited adoption of autonomous technologies. Interviews with the Director of Operations revealed that although flagship projects have implemented drone surveying and IoT sensors for real-time monitoring, scalability remains challenging due to equipment heterogeneity, lack of interoperability standards, and limited expertise in advanced data analytics. Alaloul et al. (2020) identified that social and technical factors constitute critical determinants in the implementation success of IR 4.0 technologies, where all contributing factors establish significant influence on adoption outcomes. Tahmasebinia et al. (2020) demonstrated that sustainable construction manufacturing requires comprehensive integration of advanced technologies such as 3D printing with material innovation utilizing recycled HDPE waste products, emphasizing the necessity of holistic technological ecosystems rather than isolated technology deployments.

Table 8. Target score pillar 4: Technology

Pillar and Category	Validation Result (QW)	Target 2024	Target 2025
Pillar 4	2.71	2.81	3.40
Category 1: Cybersecurity	2.83	3.00	3.83
Indicator 1: ITSM	3.00	4.00	4.00
Indicator 2: ISO 27001	3.00	4.00	4.00
Indicator 3: Penetration Testing	4.00	4.00	4.00
Indicator 4: Cybersecurity	3.00	3.00	4.00
Indicator 5: CSIRT	2.00	2.00	3.00
Indicator 6: People Capability	2.00	2.00	4.00
Category 2: Connectivity	3.00	3.25	3.25
Indicator 1: Connectivity Architecture	3.00	3.00	3.00
Indicator 2: Machine-to-Machine (M2M)	3.00	3.00	3.00
Indicator 3: Enterprise Resource Planning	3.00	4.00	4.00
Indicator 4: Decision Support System	3.00	3.00	4.00
Category 3: Smart Machines	2.00	2.00	3.00
Indicator 1: Smart Technology List	2.00	2.00	3.00
Indicator 2: Effectiveness	2.00	2.00	3.00
Category 4: Digitalization	3.00	3.00	3.50
Indicator 1: Digitalization Percentage	3.00	3.00	3.00
Indicator 2: Effectiveness	3.00	3.00	3.00

The subdomain Connectivity achieved a score of 3.00, indicating that Machine-to-Machine (M2M) communication and IT-OT integration remain limited. Observations of 12 ongoing projects identified that data collection from field sites remains predominantly manual with delayed synchronization of 24-48 hours, resulting in information asymmetry and suboptimal resource allocation. Gamil et al. (2020) identified dominant challenges in IoT adoption within the Malaysian construction industry, including lack of security and safety, absence of documented standards, insufficient awareness of benefits, improper IoT introduction, and lack of resilience in connectivity infrastructure. These challenges resonate with PT. PQR's experience, where field personnel express concerns regarding network reliability, device durability in harsh

construction environments, and data privacy considerations.

Table 9. Work program pillar 4: Technology

Category	Code	Work Program	PIC	Timeline
Cybersecurity	4.1	Obtain SNI/ISO 27001 Certification	QHSE Directorate	Q3 2024 - Q4 2024
Cybersecurity	4.2	Enhance cybersecurity system specifically for industrial technology devices	QHSE Directorate	Q3 2024 - Q4 2024
Cybersecurity	4.3.1	Conduct penetration testing (Pentest) and vulnerability assessment	QHSE Directorate	Q3 2024 - Q4 2024
Cybersecurity	4.3.2	Develop procedures for incident management and cybersecurity response	QHSE Directorate	Q3 2024 - Q4 2024
Connectivity	4.4.1	Develop Big Data Analytics to support Decision Support Systems	QHSE Directorate	Q3 2024 - Q4 2024
Connectivity	4.4.2	Training and optimization of Big Data Analytics applications for Decision Support Systems	QHSE Directorate	Q3 2024 - Q4 2024
Smart Machines	4.5	Expand utilization of smart systems and technologies (11 systems and 15 technologies)	Operations Directorate 1, 2, 3	Q3 2024 - Q1 2025
Smart Machines	4.6	Enhance use of smart and automated technology in operations	Operations Directorate 1, 2, 3	Q3 2024 - Q1 2025
Digitalization	4.7.1	Enhance effectiveness of digital-based work	QHSE Directorate	Q3 2024 - Q4 2024
Digitalization	4.7.2	Increase digitalization percentage through integration of information systems and applications	QHSE Directorate	Q3 2024 - Q1 2025

To address these technological gaps and vulnerabilities, PT. PQR formulated ten comprehensive work programs under Pillar 4. Cybersecurity enhancement programs (4.1-4.3.2) focus on obtaining ISO 27001 certification, implementing security-specific measures for industrial technology devices, conducting regular penetration testing, and developing incident management procedures. Connectivity improvement programs (4.4.1-4.4.2) aim to develop Big Data Analytics capabilities supporting Decision Support Systems through infrastructure development and personnel training. Smart machines adoption programs (4.5-4.6) target expanding utilization of 11 smart systems and 15 technologies across operations, including autonomous equipment, intelligent sensors, and robotics. Digitalization acceleration programs (4.7.1-4.7.2) focus on enhancing digital work effectiveness and increasing the digitalization percentage through systematic integration of information systems. These programs were implemented during Q3 2024 through Q1 2025 under the coordination of the QHSE Directorate and Operations Directorates, with total investment exceeding IDR 25 billion.

Pillar 5: Business Operations

Pillar 5 (Business Operations) obtained the lowest score of 2.89 with the largest gap of 1.11 points, representing the most critical area requiring intensive intervention. The subdomain Autonomous Processes recorded a score of 2.00, with the Automation Percentage indicator achieving only 1.00, the absolute lowest across all indicators in the entire INDI 4.0 assessment framework. Direct observations of 12 projects identified that procurement processes still rely on paper-based approvals requiring physical signatures from multiple authority levels, resource allocation decisions are based on periodic reports rather than real-time data streams, and quality control procedures remain predominantly dependent on physical inspections without integration of IoT sensors or automated monitoring systems.

Table 10. Target score pillar 5: Business operations

Pillar and Category	Validation Result (QW)	Target 2024	Target 2025
Pillar 5	2.42	2.42	2.42
Category 1: Data Storage and Sharing	3.00	3.00	3.00
Indicator 1: Data Storage Evidence	3.00	3.00	3.00
Indicator 2: IT and OT Authorization	3.00	3.00	3.00
Category 2: Smart Supply Chain and Logistics	2.67	2.67	2.67
Indicator 1: Technology Evidence	3.00	3.00	3.00
Indicator 2: Effectiveness	3.00	3.00	3.00
Indicator 3: Integration	2.00	2.00	2.00
Category 3: Autonomous Processes	2.00	2.00	2.00
Indicator 1: Automation Percentage	1.00	1.00	1.00
Indicator 2: Effectiveness	3.00	3.00	3.00
Category 4: Intelligent Maintenance Systems	2.00	2.00	2.00

Pillar and Category	Validation Result (QW)	Target 2024	Target 2025
Indicator 1: Technology Evidence	2.00	2.00	2.00

Kistiono et al. (2025) demonstrated that differentiated student worksheets oriented toward inquiry-based learning effectively improve critical thinking skills, with the intervention group achieving a mean N-Gain of 0.79 and a large effect size of 0.99, suggesting that differentiated approaches yield superior outcomes. This evidence indicates that customized interventions addressing specific organizational contexts and capability levels can generate significant performance improvements. Similarly, Sajjad et al. (2023) demonstrated that QR Code-based teaching materials effectively enhance critical thinking with an average N-Gain of 0.429, indicating that integration of accessible digital technologies makes learning more flexible and engagement more effective (Ramdani et al., 2025).

Table 11. Work program pillar 5: Business operations

Category	Code	Work Program	PIC	Timeline
Data Storage and Sharing	5.1.1	Implement Internet of Things (IoT)-based corporate operational functions	QHSE Directorate	Q3 2024 - Q4 2024
Data Storage and Sharing	5.1.2	Execute Internet of Things (IoT)-based corporate operational functions – Phase 2	QHSE Directorate	Q1 2025 - Q2 2025
Autonomous Processes	5.2.1	Implement Digital Lean Construction in corporate operational projects	QHSE Directorate	Q3 2024 - Q1 2025
Autonomous Processes	5.2.2	Enhance automation in construction projects that have adopted lean methodology	QHSE Directorate	Q3 2024 - Q1 2025

The subdomain Intelligent Maintenance Systems recorded a score of 2.00, the absolute lowest across all subdomains in the assessment framework. Current maintenance practices are predominantly reactive, with scheduled preventive maintenance based on fixed time intervals rather than actual equipment conditions. A senior manager from the Asset Management Division stated during interviews that the company lacks predictive maintenance capabilities utilizing condition monitoring sensors, machine learning algorithms for failure prediction, and prescriptive analytics for optimal maintenance scheduling. This deficiency results in unplanned downtime averaging 15-20% annually, significantly impacting project timelines and resource utilization efficiency.

The subdomain Smart Supply Chain and Logistics achieved a score of 2.67, with the Integration indicator scoring only 2.00. Interviews with the Supply Chain Manager revealed that coordination with suppliers occurs predominantly through emails and phone calls, lacking integrated platforms for real-time inventory tracking, automated procurement workflows, or predictive demand forecasting. Khairani & Rifai (2025) emphasized that integration of edupark and digital technology effectively addresses misconceptions, suggesting that contextual approaches integrating real-world applications enhance comprehension and operational effectiveness. This principle applies to supply chain digitalization, where contextual integration of technologies addressing specific operational pain points yields greater adoption success compared to generic technology deployments.

To address these fundamental operational gaps, PT. PQR formulated four strategic work programs under Pillar 5. Program 5.1.1 focuses on implementing IoT-based corporate operational functions, including real-time equipment monitoring, environmental condition sensing, and automated reporting systems. Program 5.1.2 executes Phase 2 of IoT implementation, expanding to additional project sites and integrating advanced analytics capabilities. Program 5.2.1 implements Digital Lean Construction methodologies in operational projects, combining lean principles with digital technologies for waste reduction and process optimization. Program 5.2.2 enhances automation in construction projects that have adopted lean methodology, leveraging synergies between lean practices and digital automation technologies. These programs were implemented during Q3 2024 through Q2 2025 under the coordination of the QHSE Directorate with support from Operations and Procurement Divisions.

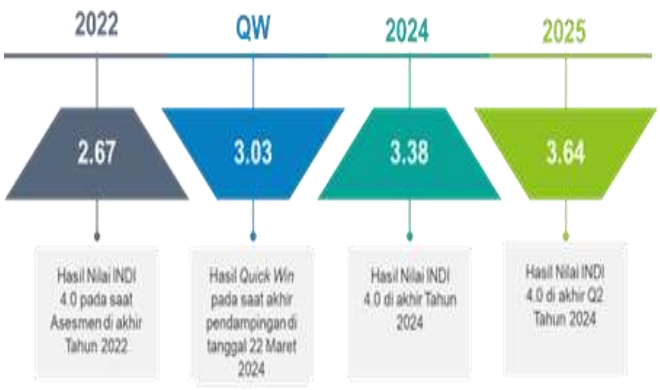

Figure 1. Roadmap for INDI 4.0 score improvement

Figure 1 illustrates the comprehensive roadmap developed by PT. PQR for achieving the optimal INDI 4.0 readiness score of 4.00 by Q2 2025. The roadmap encompasses three distinct implementation phases: the Quick Win period (February 28 - March 21, 2024) targeting immediate improvements in governance, the 2024 Program Phase (April 1 - December 31, 2024) focusing on systematic capability building across all pillars, and the 2025 Program Phase (January 2 - June 30, 2025) emphasizing consolidation and advanced digitalization. This phased approach aligns with the action research cycles implemented throughout the study, ensuring iterative learning and continuous improvement based on real-time feedback and measurable outcomes.

Post-Intervention Assessment Results

The comprehensive reassessment of PT. PQR's Industry 4.0 readiness conducted following the implementation of 47 gap closure programs revealed substantial improvements across all five pillars. The overall INDI 4.0 score increased from the baseline of 2.67 to 3.51, representing a remarkable improvement of 0.84 points (31.5% increase) within an 11-month intervention period. This trajectory demonstrates the effectiveness of structured, evidence-based transformation programs addressing both technical and socio-organizational dimensions.

Table 12 presents the complete temporal progression of INDI 4.0 scores across all pillars and categories throughout the intervention period. Pillar 1 (Management and Organization) demonstrated the strongest performance improvement, advancing from 2.54 to 3.92 (54.3% increase), approaching the optimal target with only a 0.08-point remaining gap. This remarkable progress resulted from successful implementation of governance framework enhancements, establishment of integrated monitoring dashboards, and strengthening of strategic alignment mechanisms between digital initiatives and corporate objectives.

Table 12. Overall INDI 4.0 measurement results

Pillar and Category	Weight (%)	Validation Result	Target	QW	2024	2025
Pillar 1: Management and Organization	17.50	2.54	4.00	3.50	3.67	3.92
Category 1: Strategy and Leadership		2.80	4.00	3.50	3.67	3.92
Category 2: Industry 4.0 Innovation		2.50	4.00	3.50	3.50	3.75
Category 3: Innovation Collaboration		2.33	4.00	3.50	3.50	3.75
Pillar 2: People and Culture	30.00	2.90	4.00	3.20	3.50	3.80
Category 1: Corporate Culture		3.00	4.00	3.00	3.50	3.80
Category 2: Change Management Maturity		3.20	4.00	3.50	3.80	4.00
Category 3: Competency Development		2.50	4.00	3.00	3.50	3.75
Pillar 3: Products and Services	17.50	2.73	4.00	3.25	3.50	3.75
Category 1: Product Customization		2.83	4.00	3.50	3.83	4.00
Category 2: Data-driven Services		3.00	4.00	3.00	3.50	4.00
Category 3: Product Design		2.50	4.00	3.00	3.50	3.75
Pillar 4: Technology	17.50	2.71	4.00	3.00	3.40	3.88
Category 1: Cybersecurity		2.83	4.00	3.00	3.83	4.00
Category 2: Connectivity		3.00	4.00	3.25	3.25	3.50
Category 3: Smart Machines		2.00	4.00	2.00	3.00	4.00
Category 4: Digitalization		3.00	4.00	3.00	3.50	4.00
Pillar 5: Business Operations	17.50	2.42	4.00	2.42	2.42	2.75
Category 1: Data Storage and Sharing		3.00	4.00	3.00	3.00	3.50
Category 2: Smart Supply Chain and Logistics		2.67	4.00	2.67	2.67	3.00
Category 3: Autonomous Processes		2.00	4.00	2.00	2.00	2.50
Category 4: Intelligent Maintenance Systems		2.00	4.00	2.00	2.00	2.00
Overall	100	2.67	4.00	3.03	3.30	3.51

Pillar 2 (People and Culture), despite carrying the highest weight, showed moderate improvement from 2.90 to 3.80 (31.0% increase), yet still exhibits the largest remaining gap of 0.20 points. This persistent gap reflects the inherently longer timeframes required for cultural transformation and competency development compared to technical implementations. The Competency Development category improved from 2.50 to 3.75 (50.0% increase) through implementation of structured digital training programs, establishment of Digital Champion networks, and partnerships with technology providers for specialized upskilling. However, achieving Level 4 competency maturity requires sustained investment over multiple years, incorporating continuous learning pathways, certification programs, and international knowledge exchange initiatives.

Pillar 3 (Products and Services) advanced from 2.73 to 3.75 (37.4% increase), reflecting successful strategic partnership development and multi-channel platform implementation. The Data-driven Services category achieved the target score of 4.00, demonstrating exceptional progress in leveraging data analytics for service enhancement. This achievement resulted from implementation of advanced Business Intelligence systems, customer relationship management platforms, and predictive analytics capabilities enabling personalized service offerings and proactive client engagement.

Pillar 4 (Technology) exhibited substantial improvement from 2.71 to 3.88 (43.2% increase), approaching optimal readiness. The Cybersecurity category achieved the target of 4.00 following ISO 27001 certification, implementation of Security Operations Center protocols, and establishment of Computer Security Incident Response Team (CSIRT) capabilities. The Smart Machines category demonstrated remarkable progress from 2.00 to 4.00 (100% increase), reflecting aggressive adoption of autonomous technologies, IoT sensors, and intelligent equipment across flagship projects.

Pillar 5 (Business Operations) showed the most modest improvement from 2.42 to 2.75 (13.6% increase), maintaining the largest remaining gap of 1.25 points. This limited progress reflects the fundamental complexity of operational process transformation, requiring not only technology deployment but also comprehensive workflow redesign, change management, and stakeholder alignment across extended value chains. The Intelligent Maintenance Systems category remained stagnant at 2.00, indicating that achieving predictive maintenance capabilities requires longer implementation horizons involving equipment retrofitting, sensor network deployment, and machine learning model development.

Anjarwati et al. (2025) demonstrated that MilleaLab Virtual Reality learning media achieved an overall mean N-Gain of 0.50 in enhancing conceptual understanding, indicating that immersive learning approaches effectively accelerate skill acquisition. This evidence suggests that innovative training methodologies incorporating advanced technologies can complement traditional capacity-building programs to enhance learning effectiveness and retention.

Contextual Factors Influencing Digital Transformation Readiness

Extensive triangulation of qualitative data identified multiple contextual factors shaping PT. PQR's digital transformation trajectory. First, limited digital competency emerged as the most critical human capital constraint, with only 23% of personnel possessing adequate digital literacy as measured by standardized digital skills assessments. Workshops involving 47 participants revealed skill gaps spanning technical skills (software proficiency, data analysis tools), data literacy (interpretation, visualization, statistical reasoning), and analytical thinking (problem decomposition, hypothesis testing, critical evaluation). Naji et al. (2024a) identified 70 critical success factors for digital transformation across five groups including management, design, technology, policy, and infrastructure, subsequently generating the Digital Transformation Level of Readiness Framework to guide organizations in understanding and implementing transformation within their specific domains.

Second, cultural resistance rooted in organizational legacy manifests through multiple mechanisms. Senior personnel with decades of field experience expressed concerns regarding the perceived devaluation of experiential knowledge in favor of data-driven approaches, creating psychological barriers to technology adoption. Middle management demonstrated ambivalence toward collaborative digital platforms, preferring established hierarchical communication patterns over transparent information sharing. Operational staff exhibited technology anxiety stemming from limited exposure, inadequate training support, and fear of performance surveillance through digital monitoring systems.

Third, financial resource constraints limited the pace and scope of technology investments despite strong management commitment. PT. PQR allocated approximately IDR 45 billion (USD 3 million) for digital transformation initiatives during the intervention period, representing 2.8% of annual revenue. While substantial in absolute terms, this allocation remains below the 4-6% recommended by industry benchmarks for organizations pursuing aggressive digital transformation. Consequently, technology deployments

were prioritized for flagship projects and critical functions, while comprehensive enterprise-wide implementation faced budgetary limitations requiring phased rollouts extending beyond the research timeframe.

Fourth, external collaboration ecosystems exhibited varying maturity levels. Strategic partnerships with major technology providers (Microsoft, Oracle, Autodesk) facilitated access to enterprise-grade platforms and technical support. However, collaboration with local technology startups, academic institutions for research and development, and industry peers for knowledge sharing remained underdeveloped. Establishing vibrant innovation ecosystems requires sustained engagement beyond transactional technology procurement relationships, incorporating joint research projects, talent exchange programs, and shared learning communities.

Fifth, regulatory and policy frameworks provided both enablers and constraints. Government mandates through the Making BUMN 4.0 program created institutional pressures accelerating digital transformation adoption, with ministerial circulars establishing concrete targets and accountability mechanisms. However, procurement regulations designed for conventional construction projects lacked flexibility for agile technology implementations requiring iterative development, pilot testing, and rapid scaling. Regulatory adaptation enabling innovation-friendly contracting mechanisms remains essential for accelerating Construction 4.0 adoption across the industry.

Table 13. Gap analysis and strategic recommendations

Pillar	Weight	Score	Main Gaps	Impact	Recommendations
Management and Organization	17.50%	3.92	Impact analysis for initiatives not fully achieved; Monitoring strategy remains weak	Potential inefficiency in resource allocation; transformation targets not maximally realized	Build centralized monitoring and evaluation system for transformation initiatives; strengthen strategic monitoring through regular reviews and measurable KPIs
People and Culture	30.00%	3.75	Digital transformation training programs not comprehensive; Competition development still sporadic and not sustainable	Resistance to change within organization; limited personnel capability to adapt with new technologies	Design structured digital capability development program; Implement continuous learning initiatives with measurable impact and budget allocation
Products and Services	17.50%	3.00	Innovation development and smart product customization still limited; portfolio expansion in new sectors remains minimal	Loss of market share opportunities; lack of product differentiation compared to competitors	Strengthen research and development collaboration for product and service innovation; Develop market-driven digital service portfolio with agile implementation
Technology	17.50%	3.48	Digitalization still focused on Information Technology, not fully integrated with Operational Technology; utilization of smart machines and digital platforms not optimal	Limited IT-OT integration affects efficiency and performance; high dependence on manual processes in some business areas	Strengthen IT-OT collaboration through integrated digital architecture; expand automation and IoT implementation to enhance operational efficiency
Business Operations	17.50%	2.89	Limited autonomous process implementation; digital maintenance systems not optimal; Smart Logistics integration remains minimal	High operational costs and inefficiency; reduced competitiveness compared to digital competitors	Accelerate technology adoption for process automation; implement predictive maintenance using Artificial Intelligence to optimize asset reliability; Integrate logistics management systems for operational excellence

Table 13 synthesizes the comprehensive gap analysis conducted across all five INDI 4.0 pillars, identifying main deficiencies, their organizational impacts, and strategic recommendations for sustained improvement beyond the research intervention period. For Pillar 1 (Management and Organization), although achieving a strong score of 3.92, the primary gap lies in incomplete impact analysis mechanisms for transformation initiatives, necessitating establishment of centralized monitoring systems incorporating real-time dashboards, predictive analytics, and automated alert

mechanisms for deviations from planned trajectories (Ghansah & Edwards, 2024).

For Pillar 2 (People and Culture), the fundamental challenge involves transforming sporadic training initiatives into structured, continuous learning ecosystems. Recommendations emphasize developing competency frameworks aligned with Industry 4.0 requirements, implementing individual development plans with clear progression pathways, establishing internal digital academies providing modular courses, and creating knowledge-sharing platforms facilitating peer learning and best practice dissemination (Teisserenc & Sepasgozar, 2021).

For Pillar 3 (Products and Services), closing the innovation gap requires strengthening research and development capabilities through dedicated innovation centers, strategic partnerships with technology providers and academic institutions, customer co-creation initiatives incorporating client feedback into product development cycles, and agile development methodologies enabling rapid prototyping and iterative refinement based on market validation (Maqbool et al., 2023).

For Pillar 4 (Technology), achieving holistic digitalization necessitates bridging the IT-OT divide through integrated architectures, unified data platforms enabling seamless information flow between enterprise systems and operational technologies, cybersecurity frameworks protecting both information assets and industrial control systems, and interoperability standards facilitating technology integration across heterogeneous equipment ecosystems.

For Pillar 5 (Business Operations), fundamental process transformation requires systematic automation initiatives targeting high-volume, rule-based activities amenable to robotic process automation, implementation of advanced maintenance strategies incorporating condition monitoring sensors and predictive algorithms, integration of supply chain management systems enabling real-time visibility and collaborative planning with ecosystem partners, and adoption of digital lean methodologies combining waste elimination principles with technology enablement.

Conclusion

Based on this research, it evaluates the readiness of digital transformation of PT. PQR uses the Indonesia Industry 4.0 Readiness Index (INDI 4.0) framework which integrates five pillars of comprehensive measurement. The assessment results showed an overall score of 3.51 out of the optimal target of 4.00, placing the company in the category of mature readiness with positive momentum towards the full implementation of Industry 4.0 technology. The level of readiness of PT. PQR shows a solid foundation with a consistent upward trend since baseline assessment. The Management and Organization pillar achieved the highest score of 3.92, close to the optimal target, reflecting the leadership's strong commitment to the digitalization agenda. However, significant gaps are still present in the Business Operations pillar with the lowest score of 2.89, indicating that automation processes and predictive maintenance systems have not been fully implemented. Contextual factors that affect readiness include technical and socio-organizational dimensions. The People and Culture pillar with the highest weight (30%) achieved a score of 3.75, showing that the human resource capability and cultural readiness of the organization still need substantial strengthening. Limited digital literacy, sporadic training programs, and resistance to change are the main obstacles. In the technology dimension, adoption is still concentrated in Information Technology with limited integration into Operational Technology, limiting end-to-end process optimization. The Products and Services Pillar recorded a score of 3.00, reflecting uneven digital innovation and limited smart product customization. Structural challenges include limited digital workforce competencies (only 23% have adequate literacy), limited budget allocation (2.8% of annual revenue, below the industry benchmark of 4-6%), fragmentation of technology investments, and collaboration of external ecosystems that are not optimal. On the other hand, the commitment of top management, government policy support through Making Indonesia 4.0 and Making BUMN 4.0, as well as flagship projects as learning laboratories present opportunities to accelerate transformation. This research provides an academic contribution to the literature on digital transformation readiness in the construction sector and a practical contribution in the form of an empirical evidence-based strategic roadmap for Indonesian construction SOEs.

Acknowledgments
I would like to express my gratitude to all parties who have supported and helped this research. Hopefully this research can be useful for further research.

Author's Contributions
Conceptualization, methodology, writing—reviewing and editing, E. and C.J.; validation, formal analysis, research, resources, data curation, writing—preparation of original drafts, visualization, E. All authors have read and approved the published version of the manuscript.

Funding
This research did not receive external funding.

Conflict of Interest
The author states that there is no conflict of interest.

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