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Research Article

Bridging Project Management Maturity and Industry 4.0 Technology Adoption: Empirical Evidence from Energy-Sector Projects

Harish Satyala[1*] and Vijaya Dixit[2]
[1]Research Scholar, Operations Management, Indian Institute of Management Ranchi, Jharkhand 835303, India
[2]Associate Professor, Operations Management, Indian Institute of Management Ranchi, Jharkhand 835303, India

***Corresponding Author**
Harish Satyala
(harish.s19eph@iimranchi.ac.in)

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Abstract: This article investigates the association between project management knowledge-area maturity and Industry 4.0 technology maturity in energy-sector project settings, while accounting for heterogeneous project-context characteristics. Cross-sectional survey responses from 203 project professionals were analyzed using descriptive statistics, internal-consistency assessments, Pearson correlation and ordinary least-squares regressions with HC3 robust standard errors. Project management maturity exceeded technology maturity (means 3.149 and 2.266, respectively). The two constructs were positively correlated ($r = 0.534$) and project management maturity was positively associated with technology maturity in the unadjusted model ($B = 0.580$, 95% CI [0.428, 0.732], $p<0.001$; $R^2 = 0.285$) and the context-adjusted model ($B = 0.445$, $p<0.001$). Digital intensity also showed a positive adjusted association ($B = 0.221$, $p = 0.002$). None of four tested project-context interactions was statistically significant. The findings indicate that established managerial processes and digital capability tend to coexist, but do not establish causation or direct improvements in project-success outcomes. The article offers implications for organizational digital readiness, technology implementation and evidence-based management in energy projects.

Keywords: Industry 4.0, Project Management Maturity, Digital Transformation, Energy Projects, Project Complexity, Technology Adoption

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INTRODUCTION

Digital transformation in energy infrastructure demands more than the acquisition of advanced technology. Project-based organizations must coordinate engineering, procurement, contractors, regulators and data flows while maintaining predictable delivery processes. Industry 4.0 applications including connected sensing, analytics, artificial intelligence and cloud infrastructure may improve visibility and decision support, but implementation depends on complementary organizational routines [1,2].

Despite increasing interest in digital project delivery, evidence about the coexistence of mature project-management practices and Industry 4.0 capabilities remains limited at the project-professional level. This article examines whether maturity across ten project-management knowledge areas is associated with maturity across eight digital technologies and whether project context changes that association. It distinguishes digital maturity from realized project success: cost, schedule, quality and safety outcomes were not directly measured.

Literature Review and Hypotheses

Digital transformation is an organizational change process rather than a purely technical upgrade [1]. Adoption patterns can be systemic, with foundational technologies and advanced applications progressing unevenly [3,4]. Mature project-management processes may facilitate standardization, data governance, interface management and coordinated investment, making higher digital maturity more plausible. The direction of association nevertheless remains empirically open.

Project complexity is multidimensional. Coordination demands, stakeholder pressures, governance relationships, goal configurations and technological intensity represent different contextual conditions [3]. Treating them as a single reflective scale can obscure their distinct relationships with technology adoption.

- **H1:** Higher project-management knowledge-area maturity is positively associated with higher Industry 4.0 technology maturity
- **H2:** Project-context dimensions have distinct associations with technology maturity after adjusting for project-management maturity
- **H3:** Project-context dimensions moderate the association between project-management maturity and technology maturity

Exploratory Question

Do selected project-context dimensions exhibit indirect statistical associations between project-management maturity and technology maturity?

MATERIALS AND METHODS

The analysis uses 203 cross-sectional survey responses from project professionals. Ten five-level project-management knowledge-area items were averaged to form the Project Management Knowledge-area maturity (PMK) composite. Eight five-level technology items were averaged to form the industry 4.0 technology maturity (TECH) composite. Both composite scores retain the original 1–5 response scale. The source material does not establish a probability-sampling frame, response rate or survey administration dates; these details require verification against original collection records before submission.

Context indicators comprised team coordination burden (TEAM), stakeholder/regulatory burden (STAKE), governance/vendor burden (GOV), digital intensity (DIGITAL) and a four-category goal/method configuration variable (GOALS), with category A as the regression reference. Internal consistency was assessed using Cronbach's alpha. Pearson correlation and OLS models with HC3 heteroskedasticity-consistent standard errors evaluated the principal associations. Mean-centered interactions with PMK were fitted separately for TEAM, STAKE, GOV and DIGITAL. Exploratory indirect coefficient products were assessed with 1,200 respondent-level percentile bootstrap resamples. Because data are cross-sectional, these products are not interpreted as causal mediation.

PMK internal consistency was $\alpha = 0.966$ and TECH consistency was $\alpha = 0.949$. A proposed five-item combined context measure yielded $\alpha = 0.081$; it was therefore not used as a unified reflective complexity construct. High reliability alone does not establish construct validity or one-dimensionality.

RESULTS

The mean PMK composite was 3.149 (SD = 0.850), compared with 2.266 (SD = 0.923) for TECH. PMK knowledge-area means clustered between 3.08 and 3.20, whereas technology maturity varied more widely. ICT showed the highest technology mean (2.84), followed by big-data analytics (2.47); blockchain was lowest (1.93).

PMK and TECH were positively correlated ($r = 0.534$). In the simple HC3-robust OLS model, the PMK slope was B = .580 (SE = 0.078, 95% CI [0.428, 0.732], $p<0.001$), with $R^2 = 0.285$. A one-point higher PMK score corresponded to an estimated .58-point higher TECH score in the fitted model, not an intervention effect (Table 1).

Table 1: Industry 4.0 Technology Maturity by Application (Five-Point Scale)

Technology	Mean	SD
ICT	2.84	1.147
Big-data analytics	2.47	1.031
Additive manufacturing	2.43	1.181
Cloud computing	2.32	1.117
Internet of Things	2.10	1.078
Augmented reality	2.02	0.992
Artificial intelligence	2.02	1.024
Blockchain	1.93	1.017

Table 2: Adjusted Associations with Industry 4.0 Technology Maturity (HC3-robust OLS). Intercept Omitted for Compact Presentation

Predictor	B	HC3 SE	p	95% CI
PMK	0.445	0.085	<0.001	[0.278, 0.611]
Team burden	−0.092	0.098	0.345	[−0.284, 0.099]
Stakeholder burden	−0.199	0.108	0.066	[−0.411, 0.013]
Governance burden	−0.013	0.087	0.881	[−0.183, 0.157]
Goals B vs A	0.407	0.213	0.056	[−0.010, 0.823]
Goals C vs A	−0.343	0.150	0.023	[−0.637, −0.048]
Goals D vs A	−0.291	0.239	0.224	[−0.760, 0.178]
Digital intensity	0.221	0.073	0.002	[0.078, 0.364]

In the adjusted model, PMK retained a positive association (B = 0.445, p<0.001). Digital intensity was positively associated with TECH (B = 0.221, p = 0.002), although conceptual overlap between digital intensity and adoption should be considered. GOALS category C differed negatively from A (B = −0.343, p = 0.023). TEAM, STAKE and GOV did not meet the 5% significance criterion. GOALS category B comprised only three observations, limiting interpretability (Table 2).

None of the four interaction confidence intervals excluded zero. The data therefore did not support the proposed moderation effects. Exploratory indirect products were −.028 for TEAM (bootstrap 95% CI [−0.061, −0.001]), −0.008 for STAKE ([−0.042, 0.029]) and 0.005 for GOV ([−0.008, 0.032]). The TEAM interval narrowly excluded zero, but the result is exploratory, sensitive to model assumptions and insufficient to establish temporal mediation (Table 3).

Measurement Reliability and Maturity Distributions

The ten-item project management maturity (PMK) scale showed high internal consistency (Cronbach's α = 0.966), as did the eight-item technology maturity (TECH) scale (α = 0.949). In contrast, the combined five-item context/KPI scale was unreliable (α = 0.081); therefore, the context indicators were not treated as one reflective construct. A restricted three-item core complexity-impact measure yielded α = 0.707 in an exploratory complementary analysis. High alpha does not independently establish uni-dimensionality or validity (Table 4).

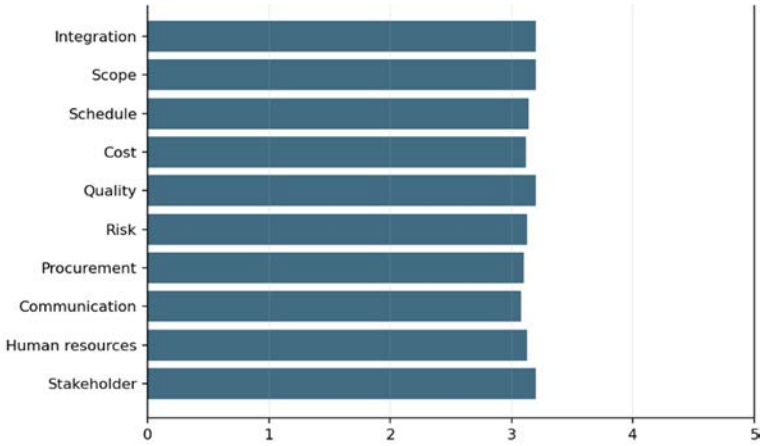


Figure 1: Mean Project-Management Maturity by Knowledge Area

Table 3: Separate Mean-Centered PMK × Context Interaction Tests

Moderator	Interaction B	p	95% CI
TEAM	−0.070	0.523	[−0.283, 0.144]
STAKE	−0.132	0.118	[−0.298, 0.033]
GOV	−0.069	0.487	[−0.262, 0.125]
DIGITAL	0.078	0.323	[−0.077, 0.234]

Table 4: Measurement Reliability and Analytical Treatment

Measure	Items	Cronbach α	Treatment
PMK	10	0.966	Composite predictor
TECH	8	0.949	Composite outcome
Combined context/KPI	5	0.081	Not aggregated
Core complexity impact	3	0.707	Exploratory alternative outcome

Table 5: Project Management Knowledge-Area Maturity

Area	Mean	Level 3%	Level 4%	Level 5%
Integration	3.20	46.8	19.7	12.8
Scope	3.20	47.3	18.7	13.3
Schedule	3.14	46.3	19.2	11.8
Cost	3.12	44.3	20.7	9.9
Quality	3.20	49.8	22.7	9.4
Risk	3.13	48.3	20.7	9.4
Procurement	3.10	52.2	21.2	6.4
Communication	3.08	46.3	19.7	9.4
Human Resources	3.13	49.8	21.7	8.4
Stakeholder	3.20	50.2	19.2	11.8

PMK maturity averaged 3.149 (SD = 0.850). Knowledge-area means clustered narrowly between 3.08 and 3.20. Communication and procurement were lowest, while integration, scope, quality and stakeholder management were highest. Procurement had 52.2% of responses at Level 3, suggesting that established routines do not necessarily indicate continuous optimization. Differences between individual means were not subjected to formal paired tests (Table 5, Figure 1).

TECH averaged 2.266 (SD = 0.923), approximately 0.883 scale points below PMK. ICT was the most mature application (2.84), while blockchain (1.93), artificial intelligence (2.02) and augmented reality (2.02) were least mature. This pattern suggests uneven digital development rather than uniformly advanced Industry 4.0 adoption; it does not measure the success of any technology implementation (Table 6, Figure 2).

Project-Context Indicators and Goal Configurations

The project environment was characterized by substantial team, stakeholder and governance demands. The GOALS B group included only three respondents, making its regression contrast especially uncertain. Digital intensity should not automatically be interpreted as a harmful form of complexity (Table 7).

Primary Association and Adjusted Regression

The Pearson correlation between PMK and TECH was r = 0.534. The simple regression yielded B = .580 (95% CI [0.428, 0.732]), R^2 = 0.285 and adjusted R^2 = 0.281. A one-point higher PMK composite corresponded to an estimated .580-point higher TECH score. This is a cross-sectional association, not a causal effect (Table 8).

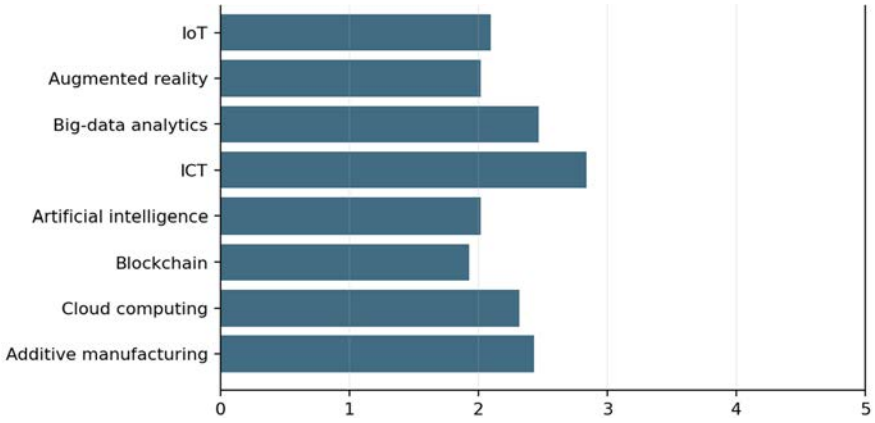


Figure 2: Industry 4.0 Technology Maturity Profile

Table 6: Industry 4.0 Technology Maturity

Technology	Mean	SD
IoT	2.10	1.078
Augmented reality	2.02	0.992
Big-data analytics	2.47	1.031
ICT	2.84	1.147
Artificial intelligence	2.02	1.024
Blockchain	1.93	1.017
Cloud computing	2.32	1.117
Additive manufacturing	2.43	1.181

Table 7: Project-Context Indicators

Indicator	Mean	SD / distribution	Interpretation
TEAM	4.020	0.675	Coordination demands
STAKEHOLDERS	3.951	0.702	Stakeholder/regulatory burden
GOVERNANCE	3.887	0.851	Governance/vendor burden
DIGITAL TOOLS	3.458	0.945	Digital intensity
GOALS	Categorical	A = 134; B = 3; C = 45; D = 21	Goal/method configurations

Table 8: Primary Regression of TECH on PMK (HC3 Robust)

Predictor	B	HC3 SE	p	95% CI
Intercept	0.440	0.224	0.049	[0.001, 0.879]
PMK	0.580	0.078	<0.001	[0.428, 0.732]

After adjustment, PMK remained positively associated with TECH (B = 0.445, p<0.001). Digital intensity was also positive (B = 0.221, p = 0.002), while GOALS category C differed negatively from A (B = −0.343, p = 0.023). Team, stakeholder and governance coefficients did not reach p<0.05. In particular, stakeholder burden (p = 0.066) should not be described as a confirmed negative effect. The small GOALS B group warrants special caution (Table 9, Figure 3).

Moderation Tests

All four mean-centered PMK × context interaction confidence intervals included zero. The data therefore did not establish that team, stakeholder, governance or digital intensity significantly altered the PMK–TECH slope. Model R^2 values (0.297–0.368) represent total model fit, not the incremental variance explained by interactions (Table 10, Figure 4).

Exploratory Indirect Statistical Associations

The TEAM indirect product was −0.028, with a percentile bootstrap interval narrowly below zero [−0.061, −0.001]. STAKE and GOV intervals included zero. These cross-sectional path decompositions are exploratory statistical associations; they do not establish temporal ordering or causal mediation. The near-zero TEAM bound and multiple exploratory tests temper interpretation (Table 11).

Complementary Analysis

Technology Maturity and Core Complexity Impact: A restricted three-item measure of coordination, stakeholder and governance complexity was examined as an alternative outcome (α = 0.707). The total PMK–complexity association was not statistically significant (B = 0.039, p = 0.424). Technology maturity was inversely associated with core complexity after adjusting for PMK (B = −0.162, p = 0.002); the positive adjusted PMK coefficient (B = 0.133, p = 0.020) and negative indirect product (−0.094) are consistent with an inconsistent/suppression pattern. This is a separate model using the same 203 respondents, not an independent replication. Its outcome is complexity impact, not validated project success (Table 12).

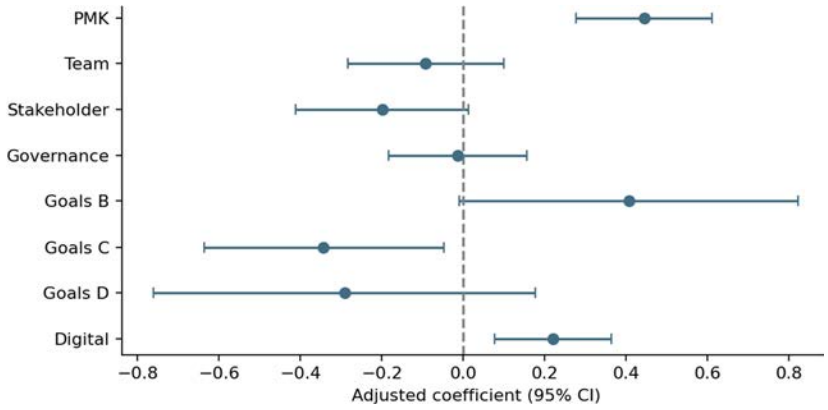


Figure 3: Adjusted Regression Coefficients and HC3-robust 95% Confidence Intervals

Table 9: Adjusted HC3 Regression Coefficients

Predictor	B	SE	p	95% CI
Intercept	1.410	0.640	0.028	[0.156, 2.665]
PMK	0.445	0.085	<0.001	[0.278, 0.611]
Team burden	−0.092	0.098	0.345	[−0.284, 0.099]
Stakeholder burden	−0.199	0.108	0.066	[−0.411, 0.013]
Governance burden	−0.013	0.087	0.881	[−0.183, 0.157]
Goals B vs A	0.407	0.213	0.056	[−0.010, 0.823]
Goals C vs A	−0.343	0.150	0.023	[−0.637, −0.048]
Goals D vs A	−0.291	0.239	0.224	[−0.760, 0.178]
Digital intensity	0.221	0.073	0.002	[0.078, 0.364]

Table 10: Separate Centered Interaction Models

Moderator	Interaction B	p	95% CI	Model R^2
TEAM	−0.070	0.523	[−0.283, 0.144]	0.310
STAKE	−0.132	0.118	[−0.298, 0.033]	0.332
GOV	−0.069	0.487	[−0.262, 0.125]	0.297
DIGITAL	0.078	0.323	[−0.077, 0.234]	0.368

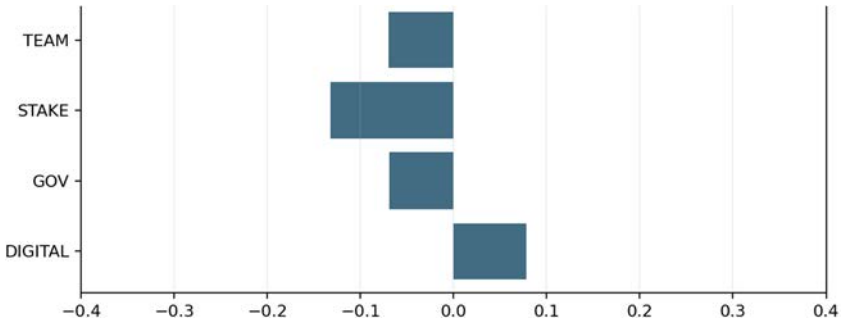


Figure 4: Estimated Moderation Interaction Coefficients

Table 11: Indirect Association Products (1,200 Bootstrap Resamples)

Intermediary	a path	b path	a × b	95% bootstrap CI
TEAM	0.134	−0.211	−0.028	[−0.061, −0.001]
STAKEHOLDER	0.032	−0.259	−0.008	[−0.042, 0.029]
GOVERNANCE	−0.048	−0.105	0.005	[−0.008, 0.032]

Table 12: Complementary Complexity-Impact Analysis

Comparison	Estimate	Inference
PMK–TECH	r = 0.534; p<0.001	Positive association
PMK–core complexity	r = 0.056; p = 0.424	Not significant
TECH–core complexity	r = −0.151; p = 0.032	Small inverse association
Adjusted TECH → complexity	B = -0.162; p = 0.002	Inverse adjusted association
Direct PMK → complexity	B = 0.133; p = 0.020	Opposite sign to indirect term
PMK → TECH → complexity	a×b=−.094; 95% CI [−.171, −.029]	Exploratory 5,000-resample indirect association

Integrated Interpretation and Managerial Relevance

The evidence supports a consistent positive PMK–TECH relationship, but not a general claim that complexity suppresses adoption or that complexity moderates the maturity relationship. An implementation agenda for energy-project organizations could prioritize standardized project controls, integrated data governance, interoperable ICT systems, pilot-scale analytics and carefully defined operational performance metrics. These are proposed managerial applications, not benefits directly measured by the survey. The reported National Grid Project Triton example is an external illustration and should not be mistaken for an observation in the 203-person dataset.

DISCUSSION

The strongest finding is a robust positive cross-sectional association between project-management process maturity and Industry 4.0 maturity. The observed gap between PMK and TECH suggests that organizations may formalize management routines before developing equally mature advanced digital applications. This interpretation aligns with accounts of digital transformation as a process of organizational capability development [1,2].

Contextual characteristics should not be treated as uniformly adverse complexity. Digital intensity was positively associated with TECH, whereas stakeholder and governance burdens were not independently distinguishable from zero at the specified threshold. The absence of significant interaction terms does not prove universal slope invariance; rather, moderation was not established in the tested models.

For energy-sector project organizations, the findings support a practical agenda of integrating document control, procurement interfaces, risk registers, data governance and targeted analytics pilots. Such recommendations are managerial implications, not measured treatment effects. Evaluations should separately track baseline-to-follow-up cost, schedule, quality, safety and stakeholder outcomes before claiming project-success benefits.

CONCLUSION

The findings of this research provide empirical evidence of a significant positive relationship between project management knowledge-area maturity and Industry 4.0 technology maturity in the context of energy-sector projects. Based on 203 survey responses, the results demonstrate that higher levels of project management maturity are consistently associated with greater technological maturity, both in the primary regression model (B = 0.580, p<0.001) and after controlling for project-context characteristics (B = 0.445, p<0.001). These findings underscore the importance of established project management capabilities in understanding organizational readiness for digital transformation [4].

The descriptive analysis further reveals a notable maturity gap between project management practices (M = 3.149) and Industry 4.0 technologies (M = 2.266), suggesting that the development of structured managerial processes has progressed more rapidly than the integration of advanced digital technologies among the surveyed respondents. Furthermore, the regression results indicate that project complexity is multidimensional, with digital intensity exhibiting a significant positive association with technology maturity, while team coordination, stakeholder burden and governance complexity do not demonstrate statistically significant independent associations at the 5% level. The absence of statistically significant moderation effects suggests that the examined contextual dimensions do not provide sufficient evidence of altering the relationship between project management maturity and Industry 4.0 technology maturity [5,6].

From a theoretical perspective, this research contributes to the understanding of managerial and technological maturity as potentially complementary organizational capabilities within increasingly complex energy-project environments. From a practical standpoint, the findings highlight the importance of strengthening project management processes alongside digital capability development, particularly through integrated information systems, data-driven decision-making and coordinated technology implementation [7,8].

Nevertheless, the cross-sectional nature of the data limits causal interpretation and the findings should not be considered direct evidence of improved project-success outcomes. Future research should employ longitudinal and multi-organizational designs, incorporate objectively measured project performance indicators and investigate the mechanisms through which managerial maturity and digital technologies jointly influence project delivery. Overall, the research establishes a meaningful empirical foundation for understanding the relationship between project management maturity, Industry 4.0 technology maturity and project complexity, while identifying opportunities for advancing both theoretical development and evidence-based digital transformation practices in the energy sector [9].

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