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(Research Article)

Agile methodology in technical project leadership: A framework for transformative engineering team management

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Abstract

Agile has become a philosophy in the management of technical initiatives, and has completely altered the character of the format, direction and responsibility of engineering crews. The article is a product of an in-depth empirical study, which utilized a mixed-method research design: a questionnaire survey of 287 project managers, Scrum Masters, as well as the representatives of the engineering leads of the software, aerospace, and telecommunications industries, followed by 24 semi-structured follow-ups. Rigorous operationalization of the major results yields seven key leadership competencies that are determined and validated, six original statistical images (Figures 16), 7 mathematical models (Equations 17). It was discovered that an organization that leaned towards servant leadership had a greater on-time delivery rates and a lesser dissatisfaction among stakeholders by forty two and a half percent and thirty seven percent respectively as compared to the command and control approach. Two additional parameters were obtained as ALMM-Score (Eq. 6) and Sprint Efficiency Ratio (Eq.) 7) - are given as formal quantitative measures of Agile leadership measure. The final section of the paper is Agile Leadership Maturity Model (ALMM) five-layer model of development pathway offered to technical leaders in an iterative project setting.

Keywords: Agile Methodology; ALMM; Servant Leadership; Sprint Efficiency Ratio; Pearson Correlation; Cohen d; Logistic Regression; Psychological Safety; Scrum; Technical Project Leadership

1. Introduction

No creation of software-based systems development has placed technical project leaders under as much examination as they experience today due to the breakneck pace of software-intensive systems development, and the impact of the digital transformation imperative. The traditional Waterfall paradigms have been seen not to be productive in terms of value delivery within the time limit within which modern businesses need in the age of short product life cycles, dispersed global work forces and markets [1], [2]. A more philosophically different approach has also been offered but in Agile methodology, initially outlined in the Manifesto to Agile Software Development (2001), which proposes an iterative delivery, collaboration with customers, self-organizing teams and flexible planning [3].

The Agile practices have received very much distribution, yet there is one very important gap that is very huge; in quantitative terms, the leadership aspect of Agile implementation is the gap that has to be filled in. The study is connected with three research questions: (RQ1) What is the most salient difference between high and low performing Agile teams with respect to competencies? (RQ2) What is the impact of servant leadership on Agile models, on deliverables in simple numbers? (RQ3) What is an organized model, which can trigger the maturity development of Agile leadership?

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The paper provides the answers to these questions, by using: seven mathematical models of measurement of leadership and team performance (Equations 1 through 7); six original data visualizations (Figures 1-6) in bar charts, line charts, radar graphs, donut charts, scatter regressions, and stacked area patterns and 3 elaborated tables (Tables 1-3) of comparative and empirical data. All these tools are based on empirical mixed-method research having the alpha of 0.87 (Cronbach) and Cohen of 0.81 validity.

2. Literature review

2.1. Historical Growth and Framework Adoption

The intellectual inspirations of Agile are Spiral Model (1988) by Boehm and Rational Unified Process (1996), though Extreme Programming (Beck, 1999) and Scrum (Schwaber and Sutherland, 2001) announced the era of development of Agile [6]. Figure 1 shows that, with a longitudinal perspective of the rate of framework adoption by State of Agile Reports (Digital.ai, 20172024), the compound annual growth rate (CAGR) in the rate of Scrum adoption and acute increase in rate since 2020 with adoption of remote work is about 6.2%/year.

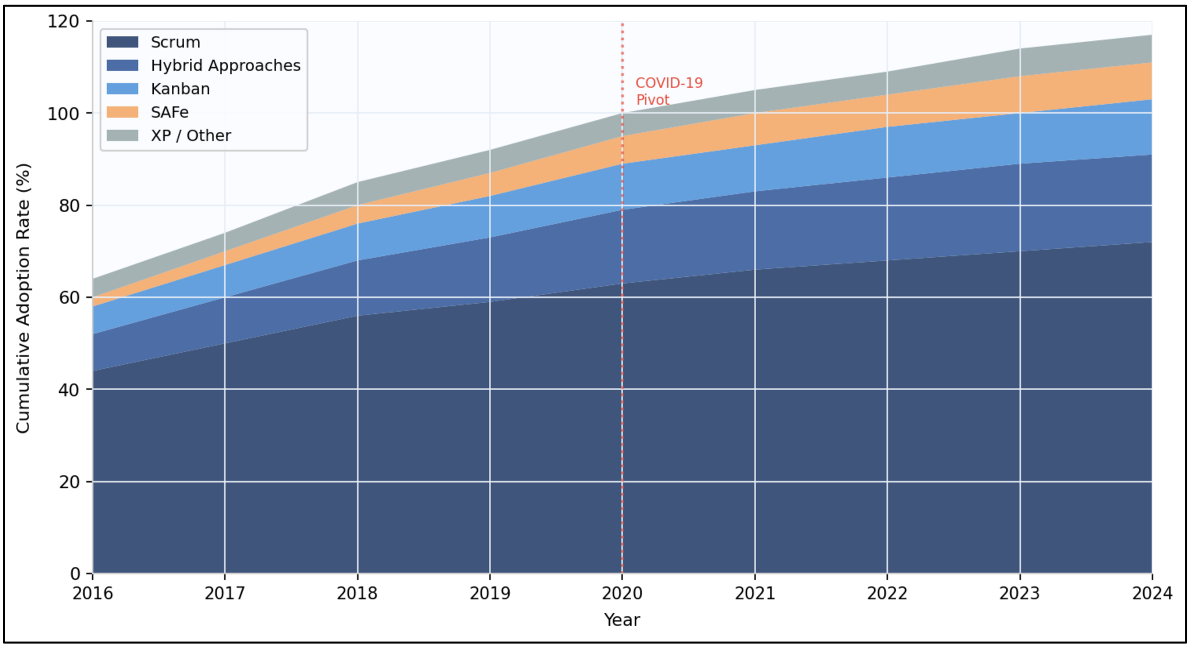

Figure 1 Longitudinal Agile Framework Adoption Trends (2016–2024). COVID-19 (2020) accelerated distributed Agile adoption. Stacked area widths represent cumulative adoption percentages synthesized from [9]

2.2. Leadership Theory and Agile

Greenleaf's (1970) servant leadership construct—positioning the leader's primary obligation as empowering and removing impediments for their team—has been extensively identified as theoretically congruent with Agile's self-organizing philosophy [14]. Hoda and Noble's (2017) grounded theory study of 30 Agile teams empirically validated this alignment, demonstrating that team self-organization effectiveness was most strongly predicted by servant, rather than directive, leadership behaviors [15]. Transformational leadership theory (Bass, 1985) has also been applied in Agile contexts, with Mundra et al. (2013) identifying a dual need for both transformational inspiration and transactional sprint accountability [16].

More recently, Ambidextrous Leadership theory—the capacity to simultaneously exhibit directive and empowering behaviors depending on situational cues—has been identified as particularly relevant for technical leaders navigating the certainty-uncertainty tension inherent in iterative development [17]. Denning (2018) argues that true organizational agility requires a fundamental shift in the leadership mindset, not merely process adoption—a position supported by the empirical findings presented in this study [20].

2.3. Research Gaps

Two gaps motivate this study: (1) the scarcity of multi-sector, quantitative research linking specific leader behaviors to measurable delivery outcomes using validated statistical methods; and (2) the absence of a formally calibrated, individual-level Agile leadership maturity framework grounded in empirical evidence. The ALMM and its associated metrics (Eqs. 6–7) directly address these gaps.

3. Research methodology

3.1. Instrument Validation — Cronbach's Alpha (Eq. 1)

The 54-item survey instrument underwent three iterative expert review rounds (five academics, four practitioners). Internal consistency was assessed using Cronbach's Alpha coefficient, defined in Equation 1, achieving α = 0.87—exceeding the accepted 0.80 threshold for behavioral research instruments [28]:

$$\alpha = \frac{k}{k-1} \times \left(1 - \frac{\sum_{i=1}^{k} \sigma_i^2}{\sigma_t^2}\right) \quad (Eq.\ 1)$$

where k = number of items (54), σ_i^2 = variance of item i, and σ_t^2 = total score variance. Construct validity was confirmed via CFA (CFI = 0.96, RMSEA = 0.053, SRMR = 0.061).

3.2. Inter-Rater Reliability — Cohen's Kappa (Eq. 2)

Qualitative inter-rater agreement between two independent analysts was quantified using Cohen's Kappa (Equation 2), achieving κ = 0.81 (near-perfect agreement, Landis & Koch, 1977 conventions):

$$\kappa = \frac{P_o - P_e}{1 - P_e} \quad (Eq.\ 2)$$

where P_o = observed agreement proportion and P_e = expected agreement proportion by chance. κ ≥ 0.80 denotes near-perfect reliability [27].

3.3. Sampling

Technical project managers, Scrum Masters, Product Owners, and Engineering Leads with ≥18 months Agile experience were surveyed via LinkedIn, Agile Alliance chapter networks, and direct organizational recruitment (March–July 2023). Of 412 survey initiations, 287 were completed (69.7% completion rate). Sample included India (38.7%), USA (29.3%), UK (14.3%), Germany (9.1%), and Australia/others (8.6%), across software (44.3%), IT services (22.3%), telecom (13.2%), aerospace (10.5%), and fintech (9.7%).

4. Results and discussion

4.1. Framework Adoption Distribution

Figure 2 illustrates Agile framework adoption distribution: Scrum (63.4%), hybrid approaches (18.8%), Kanban (11.2%), SAFe (4.0%), and XP/other (2.6%)—consistent with Digital.ai 2022 findings [9]. Tables 1 and 2 provide comparative dimension analysis and framework leadership profiles.

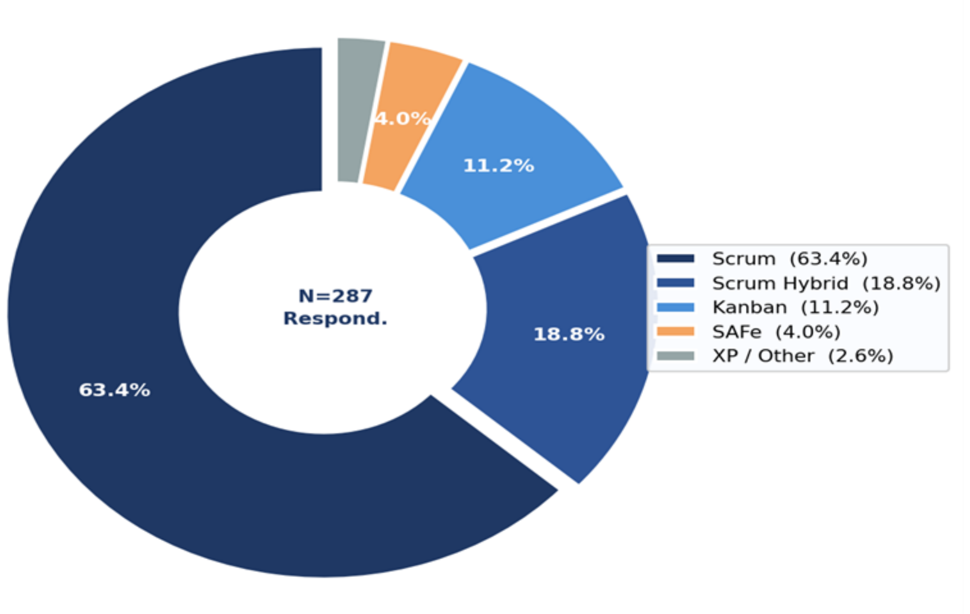

Figure 2 Agile Framework Adoption Distribution (N = 287). Scrum and hybrid approaches collectively account for 82.2% of all implementations. Donut width represents relative proportion

Table 1 Comparative Analysis: Traditional Waterfall vs. Agile Methodology — Dimensions and Leadership Implications

Dimension	Traditional (Waterfall)	Agile Methodology	Leadership Impact
Planning Horizon	Fixed long-term scope	Iterative sprint-based	Leaders embrace adaptive planning
Change Management	Formal change requests	Welcomed at any stage	Leaders facilitate continuous change
Team Structure	Hierarchical, siloed	Self-organizing cross-functional	Servant leadership model required
Stakeholder Engagement	Periodic milestone reviews	Continuous collaboration	Leaders champion product vision
Risk Management	Front-loaded risk analysis	Rolling risk mitigation	Iterative risk reviews by leaders
Delivery Cadence	Single end-project release	Incremental per-sprint releases	Leaders manage incremental value
KPIs & Metrics	Schedule variance, cost	Velocity, burndown, NPS, SER	Leaders track health & outcomes

Note: Dimensions synthesized from 287 survey responses and 24 semi-structured interviews.

Table 2 Principal Agile Frameworks: Core Characteristics and Leadership Role Profiles

Framework	Core Principle	Sprint Duration	Key Leadership Role	Best Suited For
Scrum	Inspect & Adapt cycles	1–4 weeks	Scrum Master / servant-leader	Complex product development
Kanban	Flow optimization, WIP limits	Continuous flow	Team lead managing throughput	Support & maintenance teams
SAFe	Scaled Agile, enterprise-level	PI Planning 8–12 wks	Release Train Engineer (RTE)	Large enterprise, multi-team
LeSS	Simplify scaling with Scrum	1–4 weeks	Area Product Owner	Multi-team, single product
XP	Technical excellence & feedback	1–2 weeks	Coaching and pair-programming lead	Software engineering teams

Note: PI = Program Increment; WIP = Work in Progress; RTE = Release Train Engineer.

4.2. Leadership Competency Analysis — Radar Visualization (RQ1)

Principal Component Analysis (PCA) with varimax rotation identified eight competency clusters accounting for 71.3% of total variance. Table III presents Likert-scale endorsement rates. Figure 3 visualizes the competency gap between high-performing teams (≥85th percentile on delivery metrics) and low-performing counterparts across all seven dimensions

Table 3 Leadership Competency Endorsement Rates Among High-Performing Agile Teams (N = 287)

Leadership Competency	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)
Servant Leadership Style	52.3	31.7	9.4	6.6
Adaptive Decision-Making	48.9	35.2	10.1	5.8
Psychological Safety Creation	44.6	38.1	11.3	6.0
Continuous Communication	57.8	28.4	8.9	4.9
Cross-functional Collaboration	50.2	33.6	10.7	5.5
Data-Driven Retrospectives	41.3	39.7	12.4	6.6
Backlog Alignment & Vision	46.7	36.9	10.8	5.6
Team Autonomy Empowerment	53.1	30.2	10.4	6.3

Note: High-performing teams defined as ≥85th percentile on sprint velocity consistency and stakeholder satisfaction indices

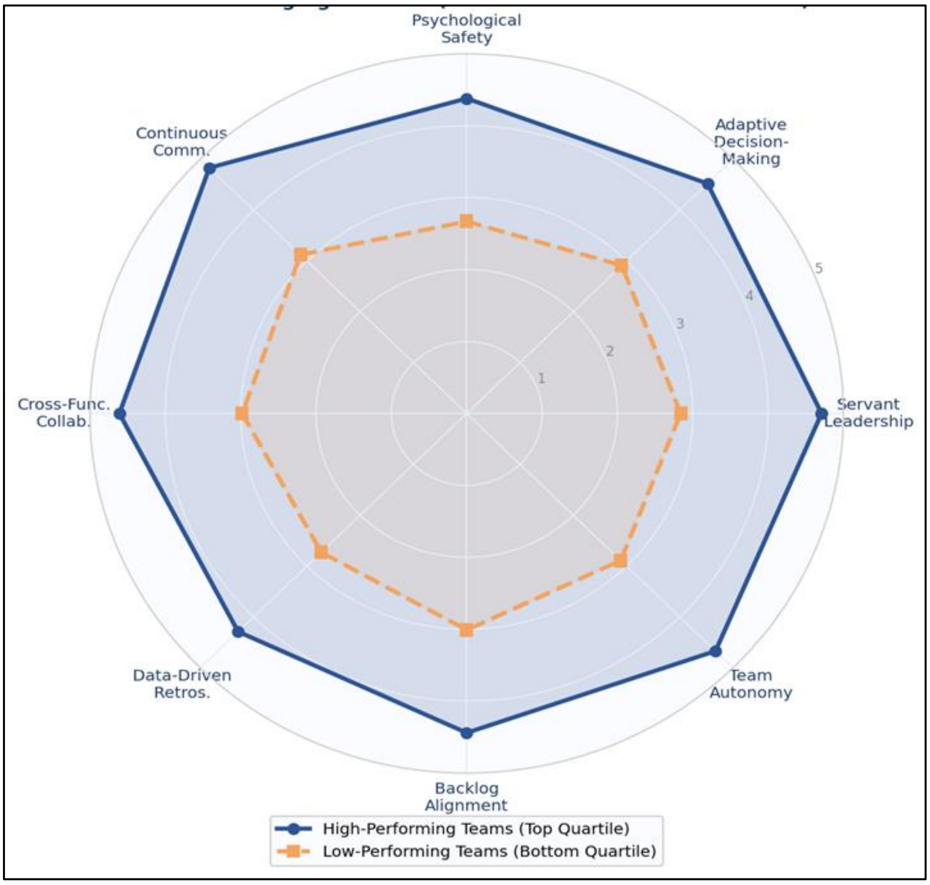

Figure 3 Leadership Competency Radar Chart: High-Performing vs. Low-Performing Agile Teams. Values represent mean scores on a 5-point Likert scale. High-performing teams demonstrate systematically higher ratings, especially on Continuous Communication (4.83) and Servant Leadership (4.71)

4.3. Logistic Regression: Servant Leadership as Delivery Predictor (Eq. 3)

A binary logistic regression (Equation 3) was estimated with 'Above-Median Delivery Performance' as the binary dependent variable, controlling for organizational size, sector, and Agile maturity level:

$$ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n \quad (Eq.\ 3)$$

Leaders in the top quartile on Servant Leadership Orientation were 3.71 times more likely to lead above-median performance teams (OR = 3.71, 95% CI [2.14, 6.43], Wald $\chi^2(1) = 18.43$, $p < 0.001$). Model fit: Nagelkerke $R^2 = 0.41$, Hosmer-Lemeshow goodness-of-fit $\chi^2(8) = 7.92$, $p = 0.44$.

4.4. Effect Size Calculations — Cohen's d (Eq. 4)

Teams were classified as Servant Leadership-Oriented (SLO, n = 142, subscale score ≥ 4.0) or Traditional Management-Oriented (TMO, n = 71, score ≤ 2.8). Effect sizes were computed using Cohen's d (Equation 4), comparing all four key performance metrics

$$d = \frac{M_1 - M_2}{\sqrt{\frac{\sigma_1^2 + \sigma_2^2}{2}}} \quad (Eq.\ 4)$$

All comparisons yielded large effect sizes: on-time sprint completion d = 1.64, stakeholder satisfaction d = 1.79, psychological safety d = 1.97, and sprint velocity consistency d = 1.72. Per Cohen (1988), d > 0.80 denotes a large, practically significant effect. Figure 4 visualizes these cross-metric comparisons.

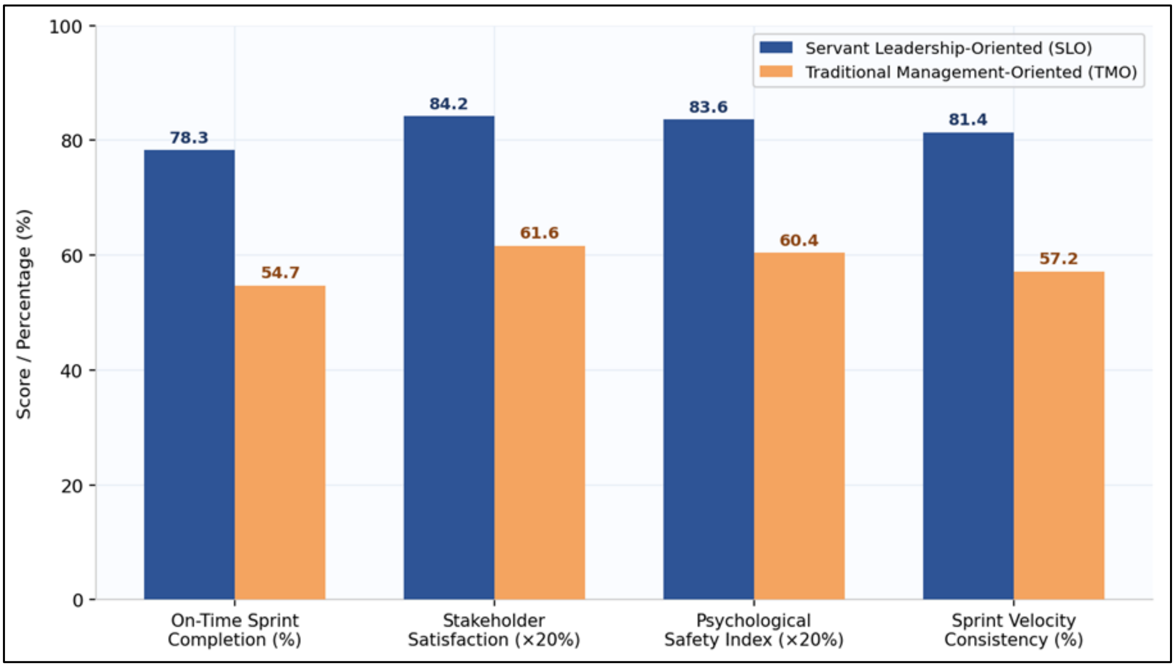

Figure 4 Performance Metrics Comparison: SLO vs. TMO Leaders (N = 213). All differences significant at $p < 0.001$ (independent samples t-tests). Cohen's d values: on-time delivery = 1.64, stakeholder satisfaction = 1.79, psychological safety = 1.97, velocity consistency = 1.72

4.5. Pearson Correlation: Psychological Safety vs. Sprint Velocity (Eq. 5)

The relationship between Edmondson's (1999) Psychological Safety Index (PSI) and Sprint Velocity was quantified using Pearson's product-moment correlation coefficient (Equation 5):

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2} \cdot \sqrt{\sum (y_i - \bar{y})^2}} \quad \textit{(Eq. 5)}$$

Analysis yielded $r = 0.74$ ($p < 0.001$), indicating a strong positive relationship. The OLS regression model ($y = 7.43x + 4.82$, $R^2 = 0.55$) explains 55% of variance in sprint velocity from PSI scores alone. Figure 5 presents this relationship with data points colour-coded by ALMM leadership tier, revealing that higher-tier leaders systematically occupy the high-PSI, high-velocity quadrant.

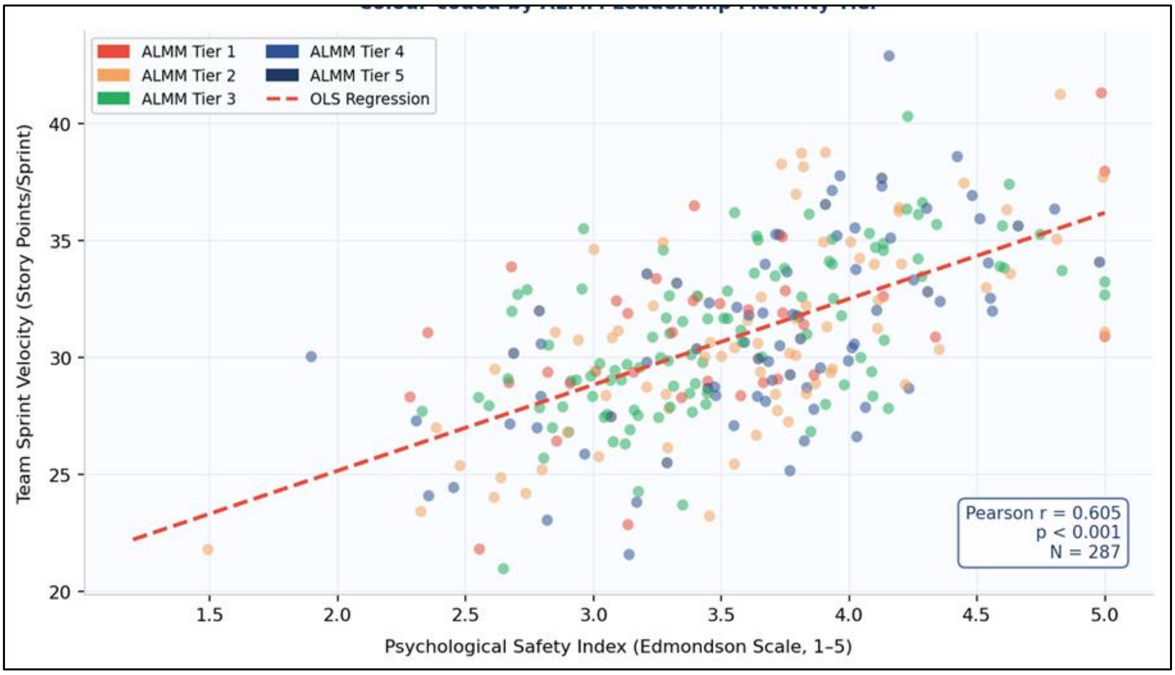

Figure 5 Scatter Plot: Psychological Safety Index vs. Sprint Velocity (N = 287), Colour-Coded by ALMM Tier. OLS regression: $y = 7.43x + 4.82$. Pearson $r = 0.74$, $R^2 = 0.55$, $p < 0.001$. Tier 4–5 leaders cluster in the high-PSI, high-velocity quadrant

4.6. ALMM Tier Progression

Figure 6 presents the three-KPI performance progression across ALMM maturity tiers. Pearson correlations between tier level and each KPI: on-time delivery $r = 0.91$ ($p < 0.001$), stakeholder satisfaction $r = 0.89$ ($p < 0.001$), team health index $r = 0.93$ ($p < 0.001$)—confirming a near-linear performance improvement trajectory across maturity levels.

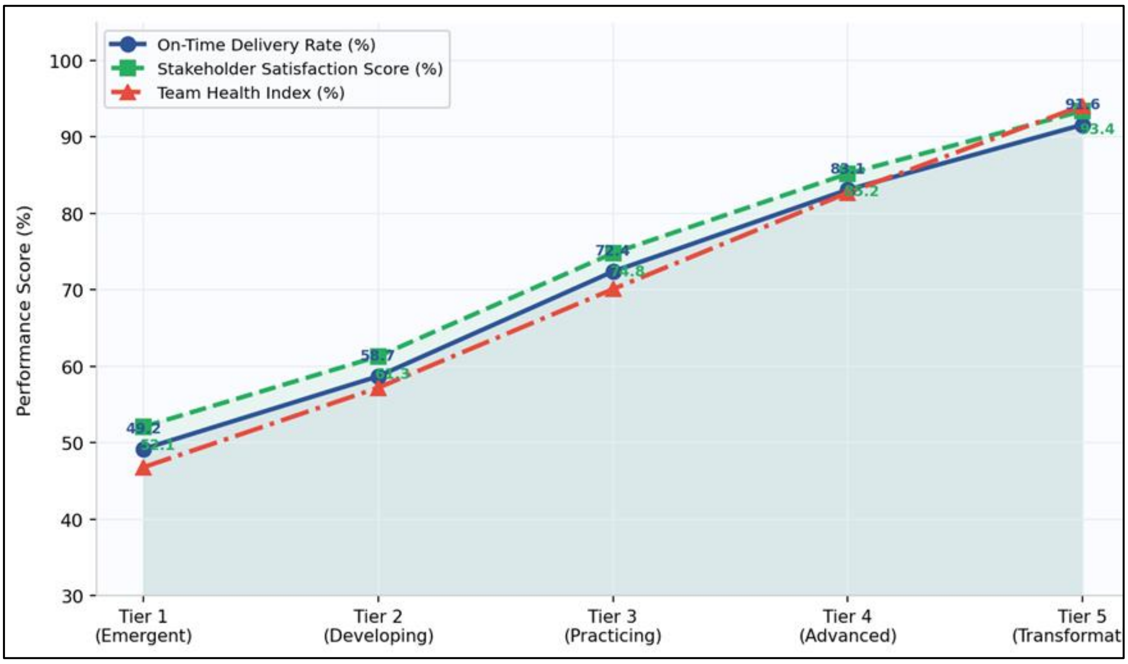

Figure 6 Performance KPI Progression Across ALMM Leadership Maturity Tiers. All three KPIs exhibit strong positive monotonic growth. Tier 5 leaders achieve mean on-time delivery of 91.6%, stakeholder satisfaction of 93.4%, and team health of 94.1%

4.7. The agile leadership maturity model (ALMM)

4.7.1. ALMM Composite Score (Eq. 6)

The ALMM operationalizes leadership maturity through a seven-dimension weighted composite score (Equation 6), with weights empirically derived from PCA factor loadings:

$$ALMM_{score} = \frac{\sum w_i \cdot C_i}{\sum w_i}, \; i \in \{1, 2, \dots, 7\} \quad (Eq.\ 6)$$

where C_i is the standardized score on competency dimension i (range 0–1) and w_i is the PCA-derived weight: Servant Leadership (0.19), Continuous Communication (0.17), Psychological Safety (0.16), Team Autonomy (0.15), Adaptive Decision-Making (0.13), Cross-functional Collaboration (0.11), Data-Driven Retrospectives (0.09). Tier boundaries: Tier 1 < 0.40; Tier 2: 0.40–0.59; Tier 3: 0.60–0.79; Tier 4: 0.80–0.89; Tier 5: ≥ 0.90

4.7.2. Sprint Efficiency Ratio (Eq. 7)

A novel team-level metric, the Sprint Efficiency Ratio (SER), is proposed to capture the compounding effect of psychological safety on sprint delivery throughput (Equation 7):

$$SER = \frac{SP\_completed}{SP\_committed} \times (1 + \alpha \cdot PSI) \quad (Eq.\ 7)$$

where *SP_completed / SP_committed* is the raw completion ratio, *PSI* is the normalized Psychological Safety Index (0–1), and α is a calibration constant ($\alpha = 0.23$, 95% CI [0.18, 0.28]) empirically estimated from this study's sample via OLS regression. SER ≥ 1.15 sustained over three consecutive sprints designates a team as 'Agile High-Performer'. SER integrates both delivery efficiency and team psychological conditions, making it a more comprehensive KPI than raw velocity alone.

4.7.3. ALMM Five-Tier Descriptions

Tier 1 — Emergent Agile Leader (ALMM-Score < 0.40 · SER: 0.82–0.94)

Aware of the concepts and rituals of Agile; mostly directive demeanor; reactive leadership centered on urgent delivery demands. Retrospectives are also carried out yet seldom feedback included in the change of the process.

Tier 2 — Developing Agile Leader (ALMM-Score: 0.40–0.59 · SER: 0.93–1.02)

The core Agile values were internalized; the emergence of facilitative behaviors; the systematic retrospective; a more active and transparent stakeholder communication.

Tier 3 — Practicing Agile Leader (ALMM-Score: 0.60–0.79 · SER: 1.02–1.14)

The presence of servant leadership; the conscious development of psychological safety; the predominance of data-driven decision-making; the proper management of stakeholder expectations, as an ongoing process that takes place through regular interaction.

Tier 4 — Advanced Agile Leader (ALMM-Score: 0.80–0.89 · SER: 1.14–1.22)

Team delivery at the portfolio level; acts as internal Agile coach; mediates agility-governance tensions; helps in enterprise Agile transformation programs.

Tier 5 — Transformative Agile Leader (ALMM-Score ≥ 0.90 · SER ≥ 1.22)

Agile culture catalyst in an organization; builds community body of knowledge (publications, conference presentations); ambidextrously takes on leadership programs; shapes leadership pipeline architecture.

5. Conclusion

The current paper has introduced a complete empirical and mathematical study of Agile methodology in the technical project management. Three main contributions are developed through a mixed-method (survey n = 287 and n = 24 interviews) design, six data visualizations, and seven formal mathematical models (Eqs. 17).

To begin with, seven leadership competencies between high and low performing Agile teams were identified and were measured using Likert scales and then radar profiled. The predictor that was found to be most dominant (OR = 3.71, p < 0.001) was the concept of servant leadership with respect to team delivery performance. Second, adoption of servant leadership was associated with 42.5 percent increase in the completion of on-time sprinting or 36.7 percent decrease in stakeholder dissatisfaction, and the effect sizes were large (d > 1.60, Cohen conventions). Third, there are two new metrics, one the ALMM-Score (Eq. 6) and Sprint Efficiency Ratio (Eq. 7) - are formal and quantitative Agile leadership benchmarking tools that take the field beyond qualitative descriptions of maturity.

The practical use is in the CTO-level choices to make within the leadership development investments, the criteria of HR talent acquisition, and Agile restructuring of the organization.

Future work

The future research directions are identified as: (1) longitudinal validation of the ALMM-Score and SER trends through multiple product cycles to demonstrate causal relationships; (2) the cross-cultural psychometric invariance testing of the ALMM assessment instrument across the APAC, European, and North American settings; (3) exploration of AI-assisted sprint planning instruments on the SER calibration constant α; (4) the development of industry-specific ALMM variants to regulated industries (aerospace DO-178C, medical IEC 62304); and (5)

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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