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Hybrid Project Management in Industrial Innovation: Empirical Evidence from the Smart Factory Program

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Abstract— *Industrial innovation in Brazil, particularly within micro, small, medium-sized enterprises, is constrained by systemic barriers intersecting technological complexity, unequal access to innovation eco-systems, and institutional rigidity. In this regard, the governance and management of Research, Development, and Innovation projects executed under the Smart Factory program is examined in this paper. Considering on a multiple case study design with methodological triangulation (document analysis, stakeholder feedback, and KPI monitoring), three projects were analyzed to compare contrasting management approaches. Results indicate that the hybrid cases showed distinct performance patterns across several measured indicators, including rework rate, stakeholder satisfaction, phase approval time, technology readiness level, and technical integration failures. The study identifies structural tensions between institutional funding requirements, governance of emerging technologies, and power asymmetries in knowledge transfer. Based on the empirical evidence, the proposed Hybrid Project Management Framework integrates predictive governance with adaptive planning, iterative execution, real-environment validation, decentralized decision-making, and dynamic monitoring. The framework provides a context-specific management approach for projects while preserving formal governance and accountability requirements*.

Keywords— *Hybrid Project Management, Emerging Technology Governance, Technology Transfer, Innovation Policy*.

I. INTRODUCTION

Innovation is widely recognized as a fundamental engine of economic development and national competitiveness [1,2]. Countries with stronger capability to generate, diffuse, and absorb technological innovation tend to exhibit more dynamic economies with greater participation in global value chains [3,4]. However, this capability is not spontaneous: it depends on robust institutional environments, effective public policies, sustained investment in science and technology, and efficient articulation among heterogeneous players, firms, universities, research institutes, government, and civil society [5,6].

In Brazil, innovation performance remains constrained by institutional fragmentation, uneven articulation among players of the National Innovation System, and limited technological intensity [7-9]. In addition to organizational resistance to innovation, micro, small, and medium-sized organizations (MSMEs), which comprise around 90% of Brazilian industries, face further obstacles regarding their ability to access credit, resources, and technological capabilities [10-12]. The Smart Factory program, launched in 2020 by the Brazilian Industry Confederation (CNI) in partnership with an Industry 4.0 Science and Technology Institute (ICT), addresses these barriers through collaborative projects involving digital technologies and validation in real operational environments [13].

Despite its strategic relevance, the literature offers limited empirical analysis of how project management practices shape outcomes in such initiatives, and even less attention has been paid to structural and political dimensions of these processes. This literature gap is addressed in this paper by presenting empirical evidence from three Research, Development, and Innovation (RD&I) projects and proposing a Hybrid Project Management Framework (HPMF) situated within the broader political economy of industrial innovation and the governance of emerging technologies.

II. THEORETICAL APPROACH

A. Political Economy of Innovation and the Triple Helix

The innovation process cannot be understood dissociated from its political-economic structures. Freeman's [2] concept of the National System of Innovation and Lundvall's [3] demand-pull framework situate innovation within socially constructed institutional arrangements. In developing nations, these agreements are characterized by unequal power dynamics and structural limits on knowledge sharing and creation [14]. The Triple Helix model [15] theorizes the dynamic interaction among university, industry, and government, which is embodied in the Smart Factory program in the balanced configuration: CNI (government-industry nexus), an ICT (academic-technology institution), and MSMEs (industry) interact in an overlapping collaborative space. This model has been extended to the Quintuple Helix [16], which incorporates ecological environments and civil society as additional innovation drivers.

B. Technology Transfer and ICT-Industry Interaction

Technology transfer from ICTs to industry is a nonlinear process that needs both the knowledge creator's desire to transfer and the recipient's capacity to absorb [17]. The process unfolds through interacting (dual) dynamics, a supply side driven by ICT research output (technology prospecting, intellectual property protection, and commercialization) and a demand side driven by industrial needs, such as identification of technology gaps, selection of partners, negotiation, and internalization. Both dimensions are mediated by a shared culture of innovation and cooperation, without which even technically sound solutions fail to produce industrial impact [18].

In the Smart Factory framework, that process itself reveals structural asymmetries: MSMEs hold knowledge domain and operational context while ICTs hold technological expertise. Through organized communication, iterative validation, and co-design methods, good project management has to actively

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close these knowledge disparities. Stakeholder feedback documented in this study reveals that failures in this bridging function, manifested as informational deficits, late scope change disclosure, and lack of participatory governance, were the primary source of project friction across all three cases analyzed.

C. Hybrid Project Management in Innovation Context

Project management concepts and practices have evolved from prescriptive predictive models (PMBOK [19], Stage-Gate [20]) toward recognition that innovation projects demand adaptive approaches. Agile methodologies such as Scrum [21] prioritize iterative cycles and stakeholder collaboration, while Kerzner [22] and Conforto et al. [23] advocate hybrid models balancing governance rigor with operational flexibility. Shenhar and Dvir's [24] Diamond Framework emphasizes that no single model fits all project types, adaptation to contingent conditions is structurally required. In public funded innovation programs, this tension is particularly acute: agile flexibility must coexist with accountability demands imposed by funding agencies [25].

III. Methodology

A. Case Selection and Management-Approach Classification

Utilizing methodological triangulation [27] and a qualitative multiple case study design [26], this research combines KPI monitoring, stakeholder feedback content analysis, and document analysis. Three cases – projects A, B, C – were selected from a Smart Factory project portfolio through a systematic case-selection procedure. The three cases were chosen from an initial portfolio of 20 Smart Factory projects using purposive theoretical sampling. The selection process took into account five criteria: operational stability, technical capability of the project team, comparable technological maturity (TRL 6 to 8), technological and strategic relevance, stakeholder alignment. A 1-5 scoring system was used to assess each project based on these criteria. The three projects with the highest overall scores were selected for in-depth analysis.

After case selection, the projects were classified according to their dominant management practices observed throughout the project lifecycle. Project A was categorized as predictive because it relied predominantly on upfront scope definition, formal planning, centralized decision-making, and sequential development. Project B was categorized as hybrid-emergent because of predictive governance mechanisms coexisted with iterative planning, agile practices, continuous validation, and decentralized tactical decisions. Project C was categorized as hybrid-adaptive since, at first, it followed predominantly predictive practices, but progressively incorporated iterative validation and adaptive management mechanisms in response to project uncertainties and operational feedback. Thus, the cases weren't chosen in accordance with established methodological categories; instead, they arose organically from the methodical examination of actual management practices. This distinction supports the comparative analysis while avoiding the assumption that the cases constitute statistically representative groups.

KPI monitoring was done using indicators customized to the unique features of RD&I projects and implemented through monitoring dashboards and project records. The following markers were chosen: average time to approve a phase, rework rate, time to structure a scope, final TRL, technical integration failures, and stakeholder satisfaction as assessed by NPS. The duration of the scope structuring process, expressed in months, was determined by calculating the amount of time that passed between the start of the project and the officialization of the first scope. Rework rate was calculated as the percentage of identified work items requiring correction or modification after their initial completion. Average phase approval time was calculated as the mean elapsed time, in days, between submission of a phase for approval and its formal approval. TRL evolution was assessed by recording the initial and final TRL achieved by each project according to the TRL scale adopted in the research. Sprint delivery rate was calculated as the percentage of planned sprint deliverables completed within the respective sprint cycle. Stakeholder satisfaction was assessed using the Net Promoter Score (NPS), based on stakeholder responses regarding their likelihood of recommending the project or solution. These indicators were monitored throughout the project lifecycle and consolidated at project level for comparative analysis.

The three sources of evidence were integrated at the case level through a structured cross-analysis. Documentary finding was first used to identify management practices, formal procedures, constraints, and events recorded throughout the project lifecycle. Stakeholder feedback was then analyzed using content analysis to identify recurring perceptions, implementation difficulties, and contextual factors related to those practices. KPI data was subsequently used to describe the quantitative performance of each case. The three evidence streams were compared for each project, linking documented management practices and stakeholder-reported experiences to the corresponding performance indicators. This integration allowed qualitative observations to be examined alongside quantitative evidence and supported the identification of convergent patterns across the three cases. The resulting cross-case comparison informed the characterization of the projects as predominantly predictive, hybrid-emergent, or hybrid-adaptive and supported the formulation of the proposed HPMF principles.

To strengthen analytical validity and reliability, the study combined systematic case selection, multiple sources of evidence, structured content analysis, descriptive treatment of quantitative indicators, and methodological triangulation. Findings were cross-checked across documentary, qualitative, and quantitative evidence to identify convergent patterns and inconsistencies. Additionally, as an applied methodological output, an AI-based conversational decision-support tool was developed in parallel with the empirical data collection. The tool was trained on the structured dataset from the three projects, including KPI records, stakeholder feedback, management practices, and the HPMF guidelines. It was designed to support project managers in risk identification, methodological recommendation, and scenario analysis.

Preliminary exploratory testing was conducted to examine the consistency of the tool's recommendations with the empirical evidence and management patterns identified in the three cases and with the principles underlying the proposed framework. No formal quantitative benchmark against an independent expert panel was conducted at this stage. The tool therefore remains at an early stage of development and requires further development and validation before it can be considered a robust decision-support solution for broader practical use. Future stages should include testing with broader and more diverse project datasets, systematic evaluation procedures, repeated practitioner assessments, and comparison with established decision-making practices. The tool is detailed in Section 5 as part of the HPMF applied outputs.

B. *KPI Operationalization and Measurement*

To ensure consistency and transparency in the comparative analysis, the performance indicators were operationalized according to their measurement units and their occurrence within the project management lifecycle. The selected KPIs were designed to capture dimensions related to: technological maturity; planning; execution; decision-making; stakeholder perception.

- Scope structuring time was measured in months and refers to the time required to structure and formalize the project scope before or at the beginning of execution.
- Rework rate was expressed as a percentage and represents the proportion of project activities or deliverables requiring correction or rework during execution.
- Average phase approval time was measured in days and corresponds to the average time required for formal approval of project phases or critical decision points.
- The final TRL was chosen as an indicator of the project completion's technological maturity, in accordance with the TRL scale utilized in the Smart Factory program.
- Stakeholder satisfaction was measured using the NPS, based on stakeholder feedback collected during the project lifecycle.

Technical integration failures were measured as the number of documented failures or inconsistencies identified during the integration of the developed solution with the technical or operational environment. Technical project documentation, governance records, meeting records, stakeholder feedback, and monitoring dashboards were used to collect KPI data. Measurements were consolidated for each case and subsequently compared across projects A, B, C. The indicators were analyzed jointly with qualitative evidence to support methodological triangulation and to avoid interpreting single KPI variations independently of the management practices observed in each project.

IV. Main Findings

A. *Comparative KPI Analysis*

Table I presents the comparative performance indicators across the three projects. The comparison between Project A (predominantly predictive) and Projects B and C (hybrid) shows consistent differences across the measured performance dimensions.

TABLE I. Comparative KPI performance across the three projects.

KPI	Project A (Predictive)	Project B (Hybrid)	Project C (Hybrid)
Scope structuring time (months)	4.5	3.8	5.2
Rework rate (%)	22	15	28
Avg. phase approval time (days)	45	38	50
Final TRL achieved	6	8	8
Stakeholder satisfaction (NPS)	52	81	76
Technical integration failures	7	2	3

Project A – predominantly predictive planning – obtained a rework rate of 22%, an average phase approval time of 45 days, and TRL 6 by completion, with stakeholder satisfaction measured at NPS 52. Project B, which incorporated hybrid practices, presented a rework rate of 15%, an average phase approval time of 38 days, and TRL 8 by completion, with NPS 81. Project C, characterized by a progressive transition toward hybrid-adaptive practices, presented a rework rate of 28%, an average phase approval time of 50 days, TRL 8 by completion and NPS 76.

Quantitative findings reveal varied trends across the performance metrics that were assessed. Project B presented lower scope structuring time, lower rework rate, and shorter average phase approval time than Project A. Project C, in contrast, required more time for initial scope structuring and phase approval and presented a higher rework rate, despite reaching the same final TRL as Project B. Both hybrid cases reached TRL 8, compared with TRL 6 in Project A, while stakeholder satisfaction was higher in both hybrid projects. These results should be interpreted as comparative evidence within the three cases analyzed rather than as statistically generalizable effects.

Technical integration failures also provide an important dimension for interpreting the comparative results. Project A recorded seven integration failures, Project B, two, and Project C, three. Although these differences cannot be interpreted as causal evidence given the multiple-case design, they are consistent with the qualitative evidence of more frequent iterative validation and shorter feedback cycles in the hybrid cases. Technical problems in Projects B and C may be found and fixed via repeated validation processes, closer engagement between technical teams and stakeholders, and incremental verification during execution. According to this pattern, technical inconsistencies may have been found sooner by integrating iterative validation procedures into the project governance structure, which would have lessened the persistence of integration problems throughout the development process.

B. *Stakeholder Feedback Analysis*

Table II synthetizes key themes and findings obtained from stakeholder feedback. Rigid scope, management failures, bureaucratic flows, budget inflexibility, and communication deficits, were the primary sources of friction, rather than technical challenges, therefore highlighting the political-organizational nature of innovation management barriers.

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TABLE II. Synthesis of stakeholder feedback across the three projects.

Project	Theme	Key Findings
A	Rigid scope definition	Excessive planning locked tasks for over a month; validation teams received insufficient prior notice.
A	Decision-making delays	Approvals for critical steps took 12+ days on average, disrupting development rhythm.
B	Bureaucratic decision flows	Technical teams lacked autonomy; supplier delays due to internal approval chains.
B	Lack of progress visibility	Partner companies had no clear milestones; data contributions went unacknowledged.
C	Budget inflexibility	Improvement opportunities went unexploited due to frozen budget structures.
C	Documentation overload	Teams spent more time adjusting compliance reports than doing technical development.

Power asymmetries could be clearly identified in feedback patterns: MSMEs frequently reported informational deficits, not knowing their own project's status, receiving late notice of critical changes, or discovering scope alterations only in the final month. These evidences are consistent with issues of technology transfer processes that reproduce knowledge hierarchies between ICTs and industrial partners [17,18].

V. Hybrid Project Management Framework

Relying on empirical evidence and theoretical foundations, HPMF is structured around five guiding principles and six operational phases. These principles work as follows:

(1) Continuous Adaptation, progressive elaboration as a structural response to uncertainty;
(2) Structured Interactivity, advancement through short, systematically evaluated functional increments;
(3) Real-Environment Validation, continuous verification in industrial settings as a prerequisite for technical adherence;
(4) Agile Governance, decentralized tactical decision-making incompatible with bureaucratic delays; and
(5) Evidence-based control through indicators that reflect the real solution behavior over the course of development cycles, known as dynamic indicator monitoring.

Fig. 1 exhibits the full HPMF workflow, which integrates predictive and agile practices across four sequential periods organized around TRL progression from 6 to 8: Initiation and Planning; Development; Monitoring; Finalization. Table III details the six operational phases of the HPMF with their key practices and tools.

The proposed framework extends the literature on hybrid project management in three main dimensions. First, it gives contextual empirical evidence on hybrid management practices in industrial RD&I projects within a developing economy and under formal institutional accountability needs, a context less represented in the hybrid project management literature, which has been predominantly developed in software and technology-intensive environments [22,24]. Second, it incorporates TRL as a structural reference for differentiating management practices based on technological maturity, therefore connecting technological uncertainty with methodological choices. Third, it proposes an integrated governance logic that combines decentralized tactical decision-making, iterative planning, and continuous validation with formal controls and accountability mechanisms. In this sense, the contribution of the HPMF lies not in replacing established project management approaches, but in integrating them into a context-specific governance model for industrial innovation projects.

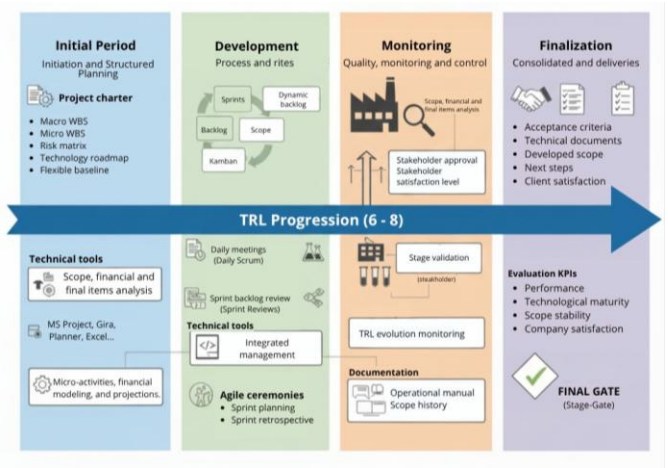


Fig. 1. Overview of the HPMF phases, tools, and TRL progression.

TABLE III. HPMF phases and key practices.

Phase	Key Practices and Tools
1. Initiation & Structured Planning	Functional block scoping; TRL mapping; directional base document; macro risk matrix; technology roadmap aligned to TRL 3-4.
2. Adaptive Planning	Hybrid macro-schedule (predictive milestones + agile sprints); layered planning; iterative planning meetings.
3. Integrated Technical Execution	Sprint cycles (2-4 weeks); Kanban boards; daily stand-ups; tools: LoRaWAN, MQTT, SQL, Node-RED.
4. Real-Environment Validation	UAT protocols; industrial integration tests; performance dashboards; non-conformity records.
5. Governance & Decision-Making	Decentralized tactical authority; data-driven deliberative meetings; simplified decision flow.
6. Monitoring, Control and Closure	Weekly KPI dashboards; continuous risk reassessment; Stage-Gate closure review; technology transfer documentation.

A. AI-Supported Decision Tool as HPMF Applied Output

As an applied output of the proposed HPMF, an AI-based conversational decision-support tool was developed using the structured dataset from the three projects, including KPI records, stakeholder feedback, management practices, and HPMF guidelines. The tool supports risk identification, methodological recommendation, and scenario analysis across the HPMF phases. Preliminary exploratory testing indicated consistency between its recommendations and the empirical evidence underlying the framework. However, no formal quantitative benchmark against an independent expert panel was conducted. The tool therefore remains exploratory and requires broader datasets, systematic evaluation, repeated practitioner assessment, and comparison with established decision-making practices before broader application. This result reflects a tangible overlap between innovation governance and AI deployment, while also bringing up concerns regarding algorithmic accountability in publicly

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funded RD&I programs. This is a governance dimension that merits more research as AI decision-support tools become more common in innovation management.

VI. Discussion

A. Innovation Policy Implications

The observed differences between predictive and hybrid project management suggest that publicly funded innovation programs may benefit from greater methodological flexibility. Stakeholder feedback also revealed informational asymmetries affecting MSMEs, indicating the relevance of transparency, participatory governance, and capacity-building mechanisms. Institutional provisions could include adaptive governance, periodic methodological reviews linked to project maturity and uncertainty, and approval processes that allow adjusts without compromising accountability. The HPMF's policy consequence is not to supplant official governance structures, but rather to make them adaptable enough to handle the iterative and ambiguous character of industrial RD&I projects.

B. Technology Governance and Socioecological Dimensions

The HPMF can also be interpreted through the Quintuple Helix perspective, recognizing that innovation projects are embedded in broader institutional and societal contexts. This study, however, did not directly gauge social ecological or environmental consequences. The socioecological dimension should be understood as a conceptual and governance-oriented implication rather than an empirically validated outcome. Future research should incorporate explicit environmental and socioecological indicators into the HPMF.

C. Convergence with Project Management Theory

The research findings are consistent with key project management theories. In actuality, the HPMF operationalizes Shenhar and Dvir's [24] contingency perspective by relating project characteristics and technical maturity to methodological decisions, complements Stage-Gate by continuous micro-validation [20], and applies progressive elaboration from PMBOK [19].

VII. Conclusions

Based on the findings from industrial RD&I projects, this study showed that hybrid project management methods were linked to better performance results. The comparison of three Smart Factory projects indicated differentiated performance patterns across the measured indicators, including rework rate, stakeholder satisfaction, phase approval time, TRL, scope structuring time, and technical integration failures. The proposed HPMF, based on findings from the three project cases, integrates predictive governance with adaptive planning, iterative execution, real-environment validation, decentralized decision-making, and continuous monitoring. Its main contribution is to connect project features and technological maturity with differentiated management practices while maintaining formal governance and accountability requirements.

Publicly financed RD&I programs may gain from more adaptable governance structures and more methodological flexibility, according to the research. Albeit, the socioecological dimension of the proposed HPMF remains a conceptual and governance-oriented implication, as environmental outcomes were not directly measured. The main limitations are the following: the small number of purposively selected cases, which limits generalizability; inability to establish causal effects; the exploratory stage of the AI-based decision-support tool, which though was not formally benchmarked against an independent expert panel. Future research should expand the empirical base, further validate the AI tool, and incorporate explicit environmental and socioecological indicators.

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