The Tech-Scenario-Governance Triangle: A Synergistic Framework for AI Cross-Domain Innovation (2022-2026)

Abstract

Artificial intelligence (AI) cross-domain innovation is not driven by single-factor advancement but by the synergistic interaction of three core elements: technical feasibility, scenario relevance, and governance compliance. This review synthesizes 9 key studies (2022-2026) to propose a "Tech-Scenario-Governance (TSG) Triangle" framework, analyzing how the dynamic balance of these three elements enables AI success across healthcare, quantum science, digital commerce, cybersecurity, and finance. The framework reveals that: technical elements provide foundational capabilities (e.g., hybrid architectures, unsupervised learning), scenario elements define practical relevance (e.g., clinical diagnosis, cross-channel marketing), and governance elements ensure sustainable adoption (e.g., privacy protection, regulatory alignment). Findings demonstrate that breakdown in any single element leads to innovation failure, while tight synergistic coupling drives impactful cross-domain AI. This framework offers a holistic tool for researchers, practitioners, and policymakers to evaluate and design AI solutions that are technically robust, practically applicable, and ethically compliant.

1 Introduction

The success of AI across diverse domains depends on more than just technical sophistication— it requires alignment with real-world application scenarios and adherence to domain-specific governance norms [1][9]. For example, a technically advanced lung nodule segmentation algorithm (tech) fails if it does not integrate with clinical workflows (scenario) or violates patient data privacy (governance) [1]; similarly, a powerful federated learning tool (tech) delivers no value if it does not address cross-channel marketing needs (scenario) or comply with data regulations (governance) [3][8]. However, existing research often prioritizes technical advancement in isolation, overlooking the interdependence of tech, scenario, and governance [2][7]. This review addresses this gap by synthesizing recent literature (2022-2026) to construct the TSG Triangle framework, unpacking how the synergistic interaction of these three elements drives cross-domain AI innovation. By integrating findings from five key sectors, this paper aims to provide a comprehensive understanding of what makes AI solutions work in real-world cross-domain contexts.

2 The TSG Triangle Framework: Core Elements and Synergies

2.1 Technical Element: Foundational Capabilities Tailored to Domain Needs

The technical element of the TSG Triangle refers to AI architectures, algorithms, and infrastructures that provide the core capabilities to address domain challenges. These technical solutions are not generic but tailored to the unique data characteristics and task requirements of specific domains. In healthcare, Chang et al. [1] developed the PDU-Net algorithm— a hybrid technical solution integrating path aggregation modules and dual attention mechanisms— to address the technical challenge of processing 3D medical images with high spatial heterogeneity. This technical design ensures precise lung nodule segmentation, laying the foundation for clinical application. In quantum science, Wu et al. [2] customized unsupervised learning algorithms as the technical core to handle high-dimensional, unlabeled quantum data, overcoming the limitation of traditional supervised learning in modeling complex quantum systems. In finance, Li and Liu [9] adapted LSTM models as the technical backbone, adjusting sequence parameters to fit the volatility of financial time-series data, enabling accurate market trend prediction. For digital commerce SMEs, Yi [7] built a multi-tenant technical infrastructure with standardized APIs, providing accessible AI capabilities that address the technical resource constraints of small businesses. The technical element thus serves as the "engine" of the TSG Triangle, delivering the core capabilities needed for cross-domain innovation.

2.2 Scenario Element: Practical Relevance Aligned with Domain Contexts

The scenario element ensures that technical capabilities are translated into practical value by aligning with real-world application contexts, user needs, and workflow requirements. This element answers the question: "Does the AI solution solve a problem that matters in the domain’s actual scenario?" In healthcare, the core scenario is clinical diagnosis—PDU-Net’s technical design is directly aligned with this scenario by generating segmentation results compatible with radiologists’ workflow, enabling integration into daily clinical practice [1]. In digital commerce, key scenarios include cross-channel marketing and creator monetization—Yi [3][8] designed federated learning frameworks and zero-knowledge verification tools that fit these scenarios, enabling retailers to collaborate across channels and creators to monetize without disrupting user experience. In cybersecurity, the critical scenario is microservice vulnerability management—Zhou [4][5] developed M-VP2 (multi-agent reinforcement learning) and hybrid SAST-DAST-SCA-IAST frameworks that align with the scenario of balancing security, operations, and cost, addressing the day-to-day challenges of IT and business teams. In finance, core scenarios include portfolio optimization (for investors) and ESG improvement (for SMEs)—Li and Liu’s [9] LSTM models fit the investment scenario by providing actionable market predictions, while Liu [6] highlighted the need for AI tools that fit the SME ESG scenario by offering low-resource, high-impact optimization strategies. The scenario element acts as the "compass" of the TSG Triangle, ensuring technical capabilities are directed toward practical domain needs.

2.3 Governance Element: Sustainable Adoption Through Compliance and Ethics

The governance element ensures that AI innovations are adopted sustainably by aligning with domain-specific regulations, ethical norms, and stakeholder expectations. This element mitigates risks and builds trust, enabling long-term cross-domain application. In healthcare, governance revolves around patient data privacy (e.g., HIPAA, GDPR)—PDU-Net's technical design incorporates anonymization features, and its scenario integration complies with clinical data governance norms, ensuring sustainable adoption in medical institutions [1]. In digital commerce, governance focuses on user privacy protection and data sharing regulations—Yi's [3][8] frameworks integrate differential privacy, federated learning, and zero-knowledge verification, which are core governance-compliant technologies that enable cross-channel collaboration without violating privacy laws. In cybersecurity, governance includes industry security standards (e.g., ISO 27001) and organizational risk management policies—Zhou's [5] hybrid framework aligns with these governance requirements by prioritizing vulnerabilities based on regulatory risk thresholds [5]. In finance, governance encompasses financial regulations and ESG disclosure standards—Liu [6] emphasized that AI-driven ESG tools must comply with these governance norms to help SMEs improve ratings while meeting regulatory obligations. The governance element serves as the "foundation" of the TSG Triangle, ensuring that technical and scenario alignment does not come at the cost of compliance or ethics.

2.4 Synergistic Coupling: How the TSG Triangle Drives Innovation

The TSG Triangle's power lies in the synergistic coupling of its three elements— no single element can drive successful cross-domain AI alone. For example:

- In digital commerce [3][8], Yi's frameworks achieve TSG synergy: federated learning (tech) fits cross-channel marketing (scenario) while complying with privacy regulations (governance), creating compliant and practical collaboration tools.
- In cybersecurity [4][5], Zhou's solutions demonstrate synergy: multi-agent reinforcement learning (tech) aligns with vulnerability patch planning (scenario) and complies with security standards (governance), delivering actionable risk-cost balance.
- In healthcare [1], PDU-Net exemplifies synergy: hybrid architectures (tech) integrate with clinical diagnosis (scenario) and comply with data privacy (governance), improving diagnostic accuracy sustainably.

Breakdown in any element leads to failure: a technically advanced AI model that ignores scenario needs (e.g., a quantum science model not fitting research workflows) or violates governance norms (e.g., a digital commerce tool that compromises privacy) will not be adopted [2][3].

3 TSG Triangle Application Across Domains

3.1 Healthcare: Tech (PDU-Net Hybrid Architectures) → Scenario (Clinical Lung Nodule Diagnosis) → Governance (Patient Data Privacy)

The TSG synergy here is tight: PDU-Net's technical design (path aggregation + dual attention) addresses the scenario need for precise, workflow-compatible segmentation, while governance-compliant data anonymization ensures trust and regulatory adherence [1]. This synergy enables PDU-Net to deliver clinical value without compromising ethics or compliance.

3.2 Quantum Science: Tech (Customized Unsupervised Learning) → Scenario (Quantum System Modeling) → Governance (Intellectual Property Protection)

Wu et al.'s [2] solution achieves TSG alignment: unsupervised learning (tech) fits the scenario of modeling unlabeled quantum data, while governance considerations (e.g., data access controls) support cross-institutional collaboration without violating intellectual property norms. This synergy accelerates quantum research while mitigating governance risks.

3.3 Digital Commerce: Tech (PETs + Multi-Tenant Infrastructure) → Scenario (Cross-Channel Collaboration/SME Adoption) → Governance (Privacy Regulations)

Yi's [3][7][8] frameworks create multi-layered TSG synergy: privacy-enhancing technologies (PETs) and multi-tenant infrastructure (tech) fit the scenarios of cross-channel marketing and SME resource constraints, while compliance with GDPR/CCPA (governance) ensures sustainable adoption. This synergy balances business value, user privacy, and inclusive access.

3.4 Cybersecurity: Tech (MARL + Hybrid Security Frameworks) → Scenario (Microservice Vulnerability Management) → Governance (Industry Security Standards)

Zhou's [4][5] solutions demonstrate TSG alignment: multi-agent reinforcement learning (MARL) and hybrid testing frameworks (tech) address the scenario of balancing security, operations, and cost, while compliance with ISO 27001 (governance) ensures organizational acceptance. This synergy delivers actionable cybersecurity value that fits real-world constraints.

3.5 Finance: Tech (LSTM Models + ESG-AI Tools) → Scenario (Portfolio Optimization/SME ESG Improvement) → Governance (Financial Regulations/ESG Disclosure)

The finance TSG synergy involves: LSTM models (tech) fitting portfolio optimization (scenario) while complying with financial data regulations (governance) [9]; and ESG-AI tools (tech) addressing SME resource constraints (scenario) while aligning with ESG disclosure norms (governance) [6]. This dual synergy drives both investment efficiency and sustainable finance adoption.

4 Practical Implications of the TSG Triangle

4.1 For Researchers

Design AI solutions with TSG synergy in mind: start by mapping domain-specific scenario needs and governance requirements, then develop technical capabilities that align with both— rather than prioritizing technical novelty in isolation. For example, when developing medical AI, integrate clinical workflow (scenario) and data privacy (governance) into technical design [1]; when building quantum AI, align with research scenarios and intellectual property governance [2].

4.2 For Practitioners

Use the TSG Triangle as an evaluation tool for cross-domain AI adoption: assess whether a solution has strong technical capabilities, fits core business scenarios, and complies with relevant regulations. Reject solutions that excel in one element but fail in others (e.g., a technically advanced tool that disrupts workflows or violates privacy [3][8]). For SMEs, prioritize TSG-aligned solutions like Yi's [7] multi-tenant infrastructure, which balances tech accessibility, scenario fit, and governance compliance.

4.3 For Policymakers

Develop cross-domain governance frameworks that facilitate TSG synergy: for example, standardize data formats (to reduce technical-scenario misalignment [2][9]) and create flexible privacy regulations (to enable PETs in digital commerce and healthcare [3][1]). Fund TSG-aligned AI initiatives that address high-impact scenarios (e.g., medical diagnosis [1], SME ESG improvement [6]) while complying with ethical norms.

5 Future Directions and Conclusion

Future research should focus on: first, quantifying TSG synergy (e.g., developing metrics to measure technical-scenario-governance alignment); second, exploring TSG dynamics in emerging domains (e.g., climate science, smart cities); third, building AI tools that automate TSG alignment (e.g., scenario-aware technical design platforms). Additionally, case studies of TSG failure (e.g., AI solutions rejected due to scenario misfit or governance violations) could provide critical insights for avoiding common pitfalls.

This review introduces the TSG Triangle framework, synthesizing 9 recent studies to demonstrate that AI cross-domain innovation is driven by the synergistic interaction of technical feasibility, scenario relevance, and governance compliance. The framework reveals that successful AI solutions are not just technically advanced but also practically

applicable and ethically compliant— with breakdown in any element leading to adoption failure. By adopting the TSG Triangle, researchers, practitioners, and policymakers can accelerate the development and adoption of impactful, sustainable cross-domain AI solutions, unlocking AI's full potential across healthcare, quantum science, digital commerce, cybersecurity, finance, and beyond.

References

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