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DEVELOPMENT OF A QUALITY ASSURANCE FRAMEWORK FOR SIMULATOR DEVELOPMENT: INTEGRATION OF CUTTING-EDGE THEORIES AND BEST PRACTICES (SYSTEMATIC LITERATURE REVIEW 2020–2025)

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Abstract

This study presents a Quality Assurance (QA) framework for simulator development, integrating the theories of Total Quality Management (TQM), ISO 25010, Capability Maturity Model Integration (CMMI), and Agile Quality Assurance. A systematic literature review (SLR) was conducted on peer-reviewed publications and internationally accredited standards in Scopus from 2020 to 2025. The results of the review indicate that QA for simulator development must be multidimensional: user-oriented design, continuous improvement, software reliability, verification and validation (V&V), and data-driven feedback. The proposed QA framework was validated through benchmarking of best practices and the latest industry standards, with the aim of improving the reliability and effectiveness of next-generation simulators.

Keywords: ***Quality assurance, simulator, software quality, TQM, ISO 25010, CMMI, Agile, systematic literature review.***

INTRODUCTION

Simulators are critical components in aerospace, military, and industrial training, as they support safe learning, cost efficiency, and high flexibility (Corey, 2023; Banica et al., 2022). The complexity of simulator development—integrating hardware, software, and human factors—demands a robust QA framework to ensure that the system is reliable, safe, user-friendly, and defect-free (ISO/IEC 25010:2011; Banica et al., 2022; Malik et al., 2024). However, many projects fail due to QA processes being conducted only at the final stages of development (Pagano et al., 2022). A comprehensive QA framework must incorporate classical theories (TQM), software quality standards (ISO 25010/25040), process maturity (CMMI), and the agile QA and V&V paradigm to ensure that each phase and component of the simulator meets global standards and industry best practices (Juran & Godfrey, 1999; Khoshraftar et al., 2022; Corey, 2023).

METHOD

The research methodology uses a Systematic Literature Review (SLR) based on the PRISMA protocol (Moher et al., 2009), conducted on the Scopus, IEEE Xplore, and ScienceDirect databases (2020–2025). Keywords used were: "quality assurance AND simulator," "ISO 25010 AND simulator," "CMMI AND simulation," "agile QA AND simulation," "V&V AND hardware-in-the-loop," and "TQM AND training systems." Selection criteria included: (a) Scopus Q1–Q3 journals, IEEE Proceeding, Elsevier, Springer, or Nature; (b) articles discussing QA frameworks and measurable outcomes; (c) empirical studies/industrial practices; (d) peer-reviewed/indexed articles. Two independent reviewers conducted the selection and data extraction, and the results were summarized in the SLR table.

SLR Table 1. QA Framework in Simulator Development (2020–2025)

No	Theory / Standard	Focus & Application	Key Findings	References
1	TQM (Deming, Juran)	Quality culture, continuous improvement, user satisfaction	Reduction in errors, increased stakeholder satisfaction, preventive processes	Khoshraftar et al. (2022); Banica et al. (2022)
2	ISO 25010/25040	Software quality, 8 key elements, V&V	Reliability, maintainability, security, functional completeness, quality audit	ISO/IEC 25010:2011; Coster et al. (2023); Banica et al. (2022)
3	CMMI	Process maturity, traceability, risk control	Consistency in QA, risk prediction, significant defect reduction	Nidheesh et al. (2021); Paulk et al. (1993)
4	Agile QA	Iterative, feedback loop, quality built-in	Faster validation cycles, early bug detection, increased user satisfaction	Pagano et al. (2022); Corey (2023)
5	V&V Framework	Validation & verification of model/SW/HW-in-the-loop	System test accuracy, compliance, fail-safe operations	Malik et al. (2024); Sargent (2013)

RESULTS AND DISCUSSION

The results from the SLR of publications in Scopus and other internationally reputable journals confirm that effective QA requires the synergy of multiple approaches. TQM underpins all project activities by promoting a culture of continuous improvement, error prevention, and a focus on end-user satisfaction (Khoshraftar et al., 2022; Banica et al., 2022). ISO 25010 provides measurable software quality audit parameters, which are periodically evaluated (Coster et al., 2023). CMMI emphasizes the maturity level of the development process and risk reduction, with empirical evidence showing a reduction in defects by up to 35% in high-reliability simulator projects (Nidheesh et al., 2021). The Agile QA paradigm supports fast validation and built-in quality integrated into the development cycle, enabling early detection of bugs/errors (Pagano et al., 2022; Corey, 2023). The V&V framework serves as the foundation for validating hardware-in-the-loop, simulation models, and software, ensuring that the simulation's viability is not only based on features but also its robustness to scenario changes (Malik et al., 2024). Studies by Banica et al. (2022) and Coster et al. (2023) emphasize the importance of test automation, digital twin technology, and industry benchmarks for developing modern, data-driven simulators. The microservices approach, continuous integration, and KPI-based business process QA further enhance the effectiveness and efficiency of complex simulator projects.

Proposed QA Framework

1. Pre-Development QA Planning: Review of ISO standards, risk assessments, and TQM training for the development team.
2. Agile QA Modular: Implementation of unit testing, integration, system acceptance, and user story-based feedback in an iterative manner.
3. ISO 25010 and CMMI Checkpoint Audits: Regular quality measurement, maintainability evaluation, and process maturity audits.
4. V&V Automation & Digital Twin: Automated verification and validation for models, hardware-in-the-loop, and simulation edge-case scenarios.
5. Benchmarking & Continuous Improvement: Assessment using empirical data and benchmarks from global simulator industries.

CONCLUSION

The QA framework integrating the theories of TQM, ISO 25010, CMMI, Agile, and V&V has proven to be an outstanding approach, as demonstrated in reputable Scopus literature, for developing reliable, safe simulators that meet international standards. It is recommended that the simulator industry adopt a comprehensive QA pattern, emphasizing continuous improvement, regular audits, and real user feedback as the foundation for global competitiveness.

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