REDiX[1] Model using multi-agentic AI

Kweonwoo Sohn[a*], Sangwha Yoon[a], mikyeong Yang[a],

[a] *MIRAE-EN Co., Ltd., Disruptive engineering, D403 Daedeok Biz Center, Daejeon, Korea*

**Corresponding author: kweonwoo.sohn@mirae-en.co.kr*

***Keywords: Reverse engineering (RE), RE-based Digital Transformation (REDiX), NQA, CGI(D)**

1. Introduction

From the 1970s to the 1980s, the aging and obsolescence of parts and components in operating nuclear power plants increased dramatically. This phenomenon was driven by several factors, including a limited supplier market of specific parts, small supply of various types of products, and the high costs of maintaining nuclear quality assurance (NQA) programs[1]. Ultimately, this situation led to the exploration of reverse engine-eering (RE) approaches to restore the designs of these aging parts and components. For these reasons, RE [2, 3] has become a crucial field for addressing aging and obsolescence issues, particularly in nuclear power plants.

This paper proposes an infrastructure for building a REDiX (RE-based digital transformation) platform model based on MBSE [4] , and presents a demonstration performance of a pilot multi-agent AI to support subprocesses for REDiX.

This multi agent includes the preparation of technical specification for RE[5, 6], quality grade reclassification based on simple causal effects, and CFSI discrimination and determination.

2. Basic element for REDiX platform

The platform should be composed of,

1) Infra structure for Quality Assurance
2) Technical element of strategy, plan and procedure for REDiX (Figure 2)
3) Resources such as tools, equipment, qualified engineers etc.,
4) Assurance through CGI dedication and part quality initiative (PQI) collaboration,
5) Procurement engineering (PE), quality class re-classification, equipment qualification(EQ) and verification and validation, which is the topics of this paper.

2.1 QA, technical strategy, plan and procedure

According to the 10CFR50 Appendix B, 18 items for quality assurance of engineering activities, internal QAM, QAP and supplementing procedure has been established for reasonable assurance of items/parts based on RE. See Figure 1 for REDiX model.

2.2 Resource management

All the tools, equipment, design and analysis tools, and qualified personnel is managed to gain integrity of REDiX implementation.

2.3 Technical elements for REDiX platform

REDiX is being established with a help of technical specific elements of field engineering such as PE, CFSI discrimination, re-classification of quality class of parts/devices which belong to mother equipment.

Figure 1 shows the REDiX which consists of technical subprocess(es) and technical elements described above. Additionally, it needs to collect licensee's appropriate information and to consider the early engagement of regulation for eliminating the contingency in REDiX implementation.

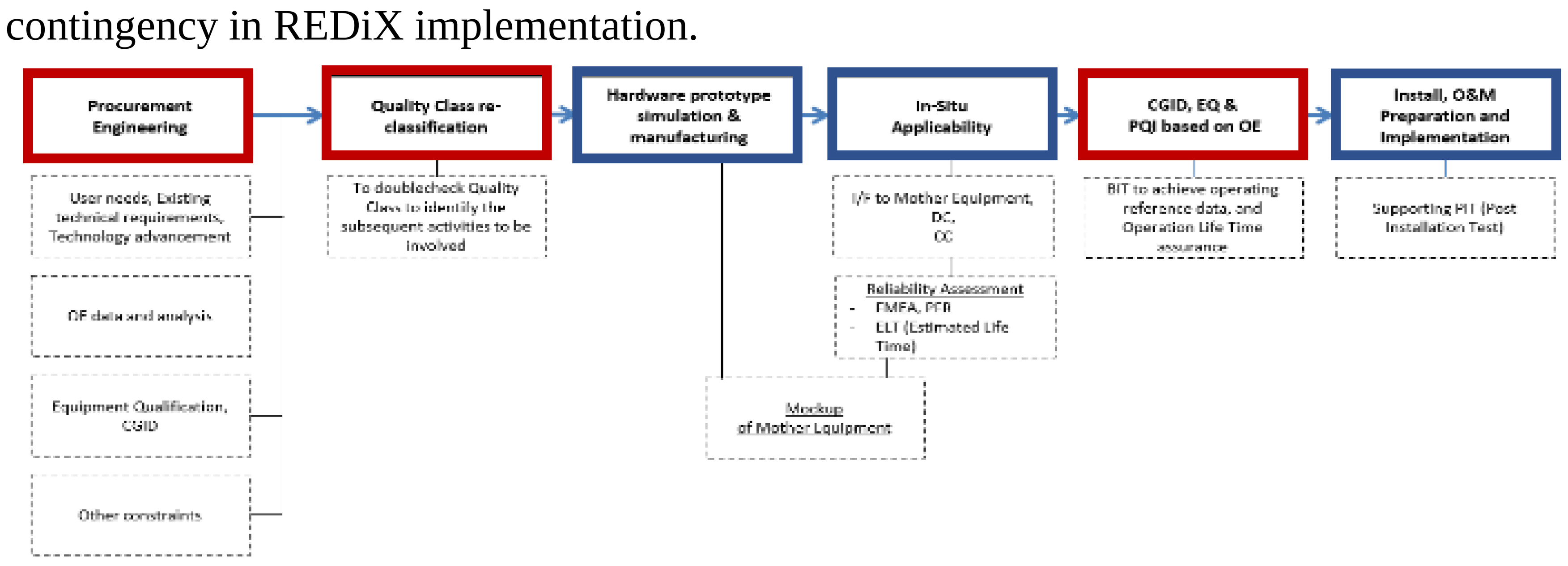


Figure 1 REDiX model for RE

(NOTE) Red boxes in Figure 1 are implemented using agentic AI prototype. Blue boxes in Figure 1 will be implemented in future

3. Agentic AI supporting REDiX

Currently technical subprocess(es) have been underway using agentic AI approaches, which has been prototyped. The followings are the typical examples of agentic AI for each of subprocess, which is based on quality and technical infra of organization as in Figure 2.

3.1 Agent AI for PE

The proposed agentic AI for PE, a core implementation of the REDiX model, automates technical specification writing for design and procurement to enhance engineering efficiency. The system follows a three-stage pipeline: (1) converting unstructured PDF datasheets (technical data package) into high-resolution images to provide visual context for multimodal LLM analysis; (2) utilizing an expert-persona prompt engine to extract structured technical data into JSON format; and (3) executing a Python-based automation library to directly populate HWP templates. This agentic approach minimizes human error and ensures consistent design quality by replacing manual documentation with an integrated and intelligent workflow.

3.2 Agentic AI for quality reclassification

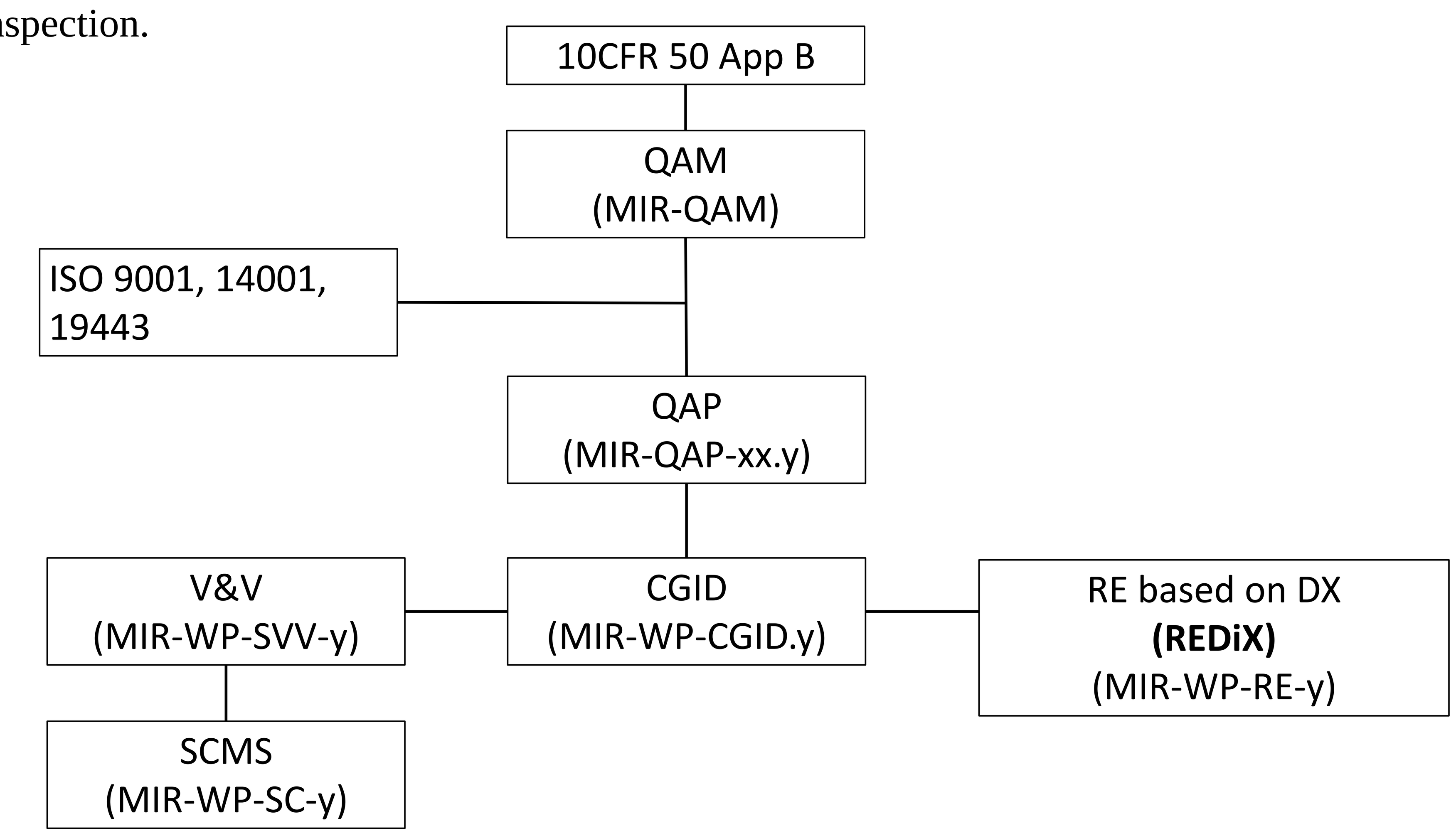
The engine proposed in this study performs the function of determining the quality class of replacement parts to be manufactured through reverse engineering (RE) due to obsolescence, assuming the main equipment is rated as Q and/or A class. While RE parts are fundamentally designed to inherit the quality class of the mother equipment, this study proposes a methodology to adjust them to an appropriate class based on reliability analysis results, considering the balance between safety and economic feasibility.

To support this, a Bayesian Network model was constructed in three stages to quantitatively infer circuit components reliability. First, basic reliability is calculated by applying an exponential distribution model to component failure rates (λ). Second, a hierarchical network is designed to reflect the causal relationships of the circuit components , and Conditional Probability Tables (CPD) are assigned to each node. Third, the Probability of Failure on Demand (PFD) is calculated using a variable elimination algorithm. If the PFD value appears higher than the established criteria, the system suggests adjusting the quality class or modifying the design. This approach provides a quantitative basis for proving that reverse-engineered parts meet the stringent reliability requirements of nuclear safety systems.

3.3 Agentic AI for CFSI discriminator

The proposed agentic AI for CFSI discrimination provides an evidence-based screening prototype for commercial replacement items during procurement and incoming inspection, and fuses were selected as a demonstration case. The system is implemented as an offline local Python and Streamlit application and follows a three-stage pipeline. (1) It automatically localizes the fuse region without manual labeling and stabilizes the cropped region by reselecting or recalculating the region when detection is inaccurate. (2) It applies a fuse probability gate to identify non fuse cases or unreliable cropped regions. For samples that pass this gate, it computes a Quality_score (0–100) by comparing ResNet feature embeddings against known OK samples, mapping the score to SUSPECT, CHECK, or OK. (3) It generates supporting evidence through OCR label reading with confidence filtering and by measuring fuse length and width, converting pixel dimensions to estimated millimeters using a fixed px/mm scale, and exporting overlay images and a structured CSV log. This agentic workflow reduces repetitive inspection effort while improving decision consistency and traceability.

CFSI of course requires the inspection of design traceability and its certificate through a various technical package, this is only applying CFSI discrimination through visual inspection.



4. Conclusion

This paper proposes a multi-agent pilot operation method supporting the REDiX platform model and REDiX subprocesses. This approach will be extended to the rest of subprocess(es) in Figure 1, including PQI and CGID for the preparation of plan and procedure in the future.

ACKNOWLEGEMENTS

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Climate, Energy & Environment (MCEE) of the Republic of Korea (No. RS-2022-KP002857).

REFERENCES

[1] ANSI N45.2.11, Quality Assurance Requirements for the Design of Nuclear Power Plants
[2] EPRI 3002011678(EPRI TR-107372, Rev.1), Guidance for the Use of reverse engineering Techniques
[3] NRC Information Notice 2016-09, Recent Issues Identified When Using Reverse Engineering Technologies in The Procurement of Safety-Related Components
[4] ISO/IEC/IEEE 24641:2023Systems and Software engineering — Methods and tools for model-based systems and software engineering
[5] IAEA Safety Standards SSG-48, Ageing management and development of a programs for Long Term Operation of Nuclear Power Plants
[6] IAEA Safety Reports No. 82(Rev 2) , Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL)

---

[1] patent pending
[2] ISO/IEC/IEEE 24641:2023, Systems and Software engineering — Methods and tools for model-based systems and software engineering
3counterfeit, fraudulent and suspicious item