Large Language Models for Reliability-Centered Maintenance of energy systems

Context of the research

Reliability-Centered Maintenance (RCM) is a maintenance decision-making strategy to systematically determine the maintenance policy which best suits the components of a system. It is widely applied to energy systems, e.g., in the nuclear and oil & gas fields. The RCM framework requires to identify the system functions and perform the Failure Mode, Effects and Criticality Analysis (FMECA) by listing the possible failure modes, their consequences, likelihood and severity. Then, the reliability critical items are identified, and the maintenance actions are scheduled considering also the system maintenance procedures and the equipment manuals. The aim is to preserve system functionality while optimizing cost, safety, and reliability. RCM implementation is often labor-intensive and expert-driven, relying heavily on detailed system knowledge that may not always be available in practice.

In many cases, relevant information exists in unstructured formats such as maintenance reports, failure logs, and operational manuals. Extracting meaningful insights from this textual data remains a major bottleneck in adopting RCM practices. Recent advances in natural language processing, particularly the capabilities of Large Language Models (LLMs) for language understanding and reasoning, offer new opportunities to automate parts of the RCM process.

This research investigates the use of LLMs to support the key steps of RCM by extracting relevant information directly from unstructured sources, such as identifying failure modes and consequences, selecting reliability-critical items, and scheduling maintenance actions. The goal is to facilitate data-driven and scalable RCM strategies across diverse industrial contexts.

The potential of the methodology will be explored through its application to energy systems—including power generation, renewable installations, and smart grids—oil and gas assets and nuclear facilities.

Objective of the research

This research aims to develop a methodology based on Large Language Models to support RCM of energy systems. The activity will include:

- Literature review on LLMs and their application in safety engineering, specifically for risk assessment and maintenance;
- Definition of the research problem;
- Development of the methodology;
- Application to a case study;
- Validation;
- Writing of scientific papers, as chapters of the thesis.

Required competencies and skills

- Interest in developing innovative applications of Natural Language Processing, Machine Learning and Artificial Intelligence algorithms for maintenance engineering of energy systems;
- Good knowledge of Python programming or willingness to learn.

Composition of the research group

- 2 full professors;
- 1 postdoctoral researchers;
- 1 PhD student.

Total thesis duration

- 8 to 12 months.

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