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AI-Assisted HAZOP Automation via Integrated Large Language Models and Knowledge Graph

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ABSTRACT

HAZOP analysis is one of the most widely used process hazard analysis (PHA) techniques in the chemical process industry. It is a systematic and structured method used by engineers to identify possible deviations in a plant, determine their potential causes and consequences, assess the adequacy of existing safeguards, and recommend additional measures to prevent hazards and mitigate their effects. However, performing HAZOP study is laborious, knowledge-intensive, time-consuming, and expensive [1]. Typically, conducting a HAZOP study requires between one- and eight-weeks duration, five team members participation, and cost between $13,000 and $25,000 per week [2, 3].

Given the significant resources required to conduct a HAZOP study, there is a strong incentive to automate the analysis. Over the past decades, several intelligent tools based on knowledge-based frameworks have been developed to automate HAZOP analysis [1, 4, 5]. While these tools offer certain benefits, they also have inherent limitations that have prevented their widespread adoption in industrial settings. For example, most of these systems are built on specialized and proprietary software platforms. This dependency limits their scalability, portability, shareability, and potential for large-scale deployment in industry. Another limitation is the lack of generalized models within their knowledge repositories, which often requires the development of highly customized models and continuous updating of the knowledge base whenever a new process is evaluated.

To address the challenges associated with automating HAZOP analysis, we developed an intelligent system based on the integration of a large language model (LLM) with a knowledge graph (KG). As a branch of generative AI, LLMs have been proven effective in automating tasks involving the generation, understanding, and processing of human language, such as text. Meanwhile, the use of a KG helps ground the LLM's responses, reduce the risk of hallucinations, and improve the transparency and explainability of the HAZOP results. Since both the LLM and KG are implemented on widely used commercial software platforms, the system can be easily accessed and deployed.

To evaluate the performance of the system, we tested it using an industry-motivated hydrocarbon processing case study reported in the literature. The results generated by the

system were then benchmarked against those obtained from a manual HAZOP study conducted by human experts.

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KEY WORDS

Chemical process safety; HAZOP analysis; Knowledge base system; Artificial intelligence; Large language model; Knowledge graph.

BIOGRAPHY

Iskandar Halim is a Research Scientist at ISCE2, A*STAR. His research focuses on process systems engineering applications to support the design and operation of safe and sustainable chemical processes. His expertise involves the development of qualitative methods, mathematical modelling, process simulation, and optimization strategies to address complex engineering challenges. His research on systematic methodologies and intelligent systems for chemical process sustainability has been featured in leading journals. Notably, his project on decision-support systems for sustainable pharmaceutical supply chains received the IChemE Singapore Sustainability Award in 2017.

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