Academic Journal of Engineering and Technology Science
ISSN 2616-5767 Vol.8, Issue 2: 103-110, DOI: 10.25236/AJETS.2025.080214

Research on Ontology Based Intelligent Method for HAZOP of Ocean Platform

Yuan Liu[1,a,*], Aijun Ling[1,b]

[1]Offshore Engineering Technology Center, China Classification Society, Tianjin, China
[a]liu_yuan@ccs.org.cn, [b]aijling@ccs.org.cn
**Corresponding author*

Abstract: *HAZOP (Hazard and Operability Study) should be conducted prior to the construction and operation of offshore platforms to prevent critical safety risks. However, the conventional methodology faces challenges in knowledge management due to inefficient analysis processes and excessive workload requirements. This study proposes an ontology-based approach integrated with HAZOP to enable systematic knowledge reuse, sharing, inheritance, and expansion. Specifically, we developed a formal HAZOP ontology system that facilitates structured preservation and utilization of historical case data. Furthermore, a set of natural language processing-driven reasoning rules was established to codify and extend domain experts' tacit knowledge. The proposed framework was validated through a comprehensive case study involving offshore oil and gas processing systems, demonstrating its technical feasibility and operational effectiveness.*

Keywords: *Ontology, Ocean Platform, HAZOP, intelligent reasoning, knowledge system*

1. Introduction

With the deepening of international strategic cooperation on carbon neutrality, the types and functions of offshore platforms are constantly enriched, and various new economic platforms such as offshore CCUS (Carbon Capture, Utilization and Storage), hydrogen production, and ammonia production are constantly emerging. Compared with traditional oil and gas platforms, these new platforms have more complex process flows, lower/higher processing temperatures, higher storage and process pressures, and lower explosion lower limits, which means they face higher risks.

HAZOP (Hazard and Operability Study) analysis is typically used to identity process risks. However, the biggest difficulty in risk identification lies in the lack of dedicated identification methods (Abou et al., 2008)[1]. The existing HAZOP method for process risk is essentially a traversal analysis and judgment based on expert experience. The completeness of traversal analysis ensures comprehensiveness, while the correctness of traversal judgment ensures the accuracy of process risk identification. This leads to the problem that the results of HAZOP analysis are difficult to reuse, share, and expand.

Firstly, the HAZOP analysis conducted during the process of scheme demonstration and comparison will result in the waste of analysis knowledge due to the elimination of schemes. Secondly, when the design stage transitions from basic design to detailed design, due to minor adjustments in production conditions, design/operating parameters, process equipment, etc., it is still necessary to conduct traversal comparison based on existing HAZOP analysis results. In essence, it also requires "traversal" and "judgment" based on experience, making it impossible to achieve efficient reuse. Finally, the analysis and judgment made in HAZOP analysis based on the experience of the team members may lead to difficulty in sharing and recognizing the analysis results due to differences in the professional backgrounds of the team members and adjustments to the team members.

Whether it is the waste of knowledge in the design and evaluation process or the difficulty in reusing and sharing knowledge in the analysis process, both limit the efficiency and quality of HAZOP evaluation for complex processes, which urgently needs to be studied and resolved.

2. Ontology-based HAZOP Analysis Method for Offshore Platforms

The concept of ontology originated from German metaphysics in the 1960s, used to describe the essence of things. R. Studer (1984) [2] proposed that "ontology is an explicit formal specification of a

ISSN 2616-5767 Vol.8, Issue 2: 103-110, DOI: 10.25236/AJETS.2025.080214

shared conceptualization."

Ontology is adopted in risk analysis. Ferreira et al (2007) [3] described an ontology construction process in a risk analysis project, and Abou et al (2008) developed a Case-Based Reasoning system to help experts realize risk analysis studies. Cameron et al. (2008) [4] established a domain ontology for system risk identification and analysis targeting the traditional FMEA (Failure Modes and Effects Analysis) method. Aziz et al. (2019) [5] proposed a dynamic hazard identification method based on standardized ontology descriptions.

This article employs an ontology-based approach to achieve the purposes of knowledge reuse, sharing, inheritance, and expansion in the process of risk identification and HAZOP analysis for offshore platform processes. Firstly, a process description ontology and a HAZOP analysis ontology are constructed to facilitate the reuse and inheritance of historical knowledge. Then, multiple reasoning rules are created based on natural language to facilitate the sharing and expansion of experts' experience. Finally, the accuracy and feasibility of the system are verified through offshore oil and gas engineering cases.

The framework comprises marine platform knowledge, process risk knowledge, an ontology repository, and a reasoning rule base. The ontology repository consists of two parts: a process ontology translated from process knowledge and a HAZOP ontology translated from HAZOP analysis knowledge. The ontology repository is completed by ontology designers using Web Ontology Language (OWL), making it possible for real-time updates based on actual cases. The rule base is expressed in Semantic Web Rule Language (SWRL) and designed based on HAZOP analysis experience and process analysis experience. The ontology repository and rule base are integrated through ontology editing tools and reasoning engines, forming a marine platform HAZOP analysis system for designers, operators, and HAZOP risk analysis researchers.

3. Process Analysis of Offshore Platforms Based on Ontology

3.1. Design of the Ontology for Offshore Platform Process Analysis

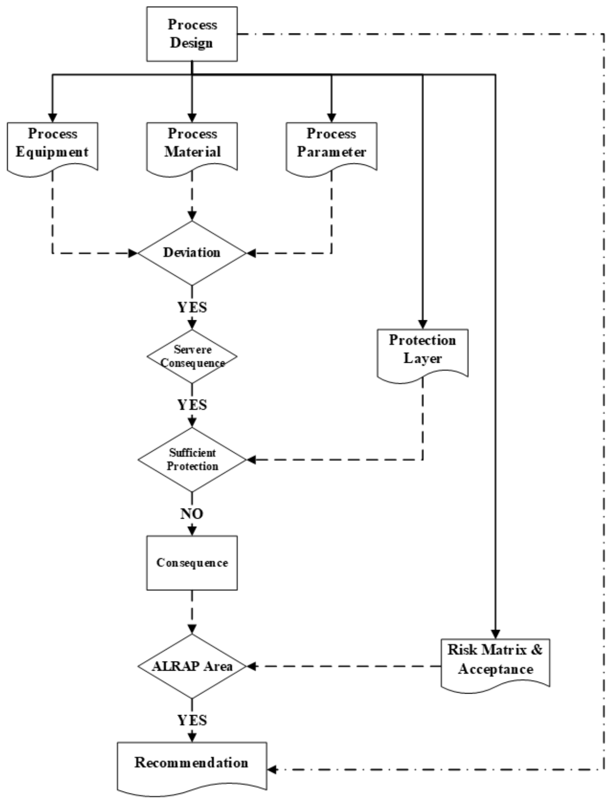

Figure 1 HAZOP Process Analysis Process Based on Ontology

During the process safety analysis of offshore platforms conducted by the HAZOP team, a thorough understanding of the platform's relevant conditions is required first, including the general layout, operating environment, and main process objectives. Subsequently, a detailed understanding of the

ISSN 2616-5767 Vol.8, Issue 2: 103-110, DOI: 10.25236/AJETS.2025.080214

platform's process design is necessary, encompassing process equipment and materials, key process parameters, and the design of process control and safety instrumentation systems. Finally, the HAZOP analysis team, consisting primarily of process design representatives, operation representatives, and safety analysis representatives, will carry out a HAZOP analysis of the entire process flow. Based on local regulatory requirements, risk matrices, the ALARP (As Low As Reasonably Practicable) principle, and the owner's management regulations, the team will propose recommended measures as appropriate, thus completing the process HAZOP analysis, as shown in Figure 1.

According to the process illustrated in the figure above, it is necessary to construct knowledge ontologies of equipment, materials, parameters, process controls, protections, etc. in the process ontology library, and construct knowledge ontologies of parameters, guide words, deviations, causes, consequences, recommended measures, responsible units, etc. in the HAZOP analysis ontology library. At this point, the reasoning engine will conduct reasoning based on the established rule base and the selected content of the ontology library, thus obtaining the final risk consequences corresponding to the platform.

3.2. Ontology Modeling

The ontology library consists of process knowledge ontologies and HAZOP analysis knowledge ontologies.

The process knowledge ontology, ProcessOnto, includes EquipmentOnto, MaterialOnto, ParameterOnto, BPCSOnto, and SIFOnto. EquipmentOnto is composed of various types of tank groups, towers, pump groups, and pipelines between equipment; MaterialOnto is composed of various typical process materials such as crude oil, diesel, seawater, hydrogen, natural gas, and instrument air; ParameterOnto is composed of liquid level, pressure, temperature, and flow rate; BPCSOnto and SIFOnto are composed of corresponding sensors, processors, and actuators.

The HAZOP knowledge ontology includes GuidewordOnto, ParameterOnto, DeviationsOnto, CausesOnto, ConsequencesOnto, ProtectionOnto, RecommendationOnto, and ResponsibilityOnto. GuidewordOnto includes all the guide words used in HAZOP, such as More, Less, No, As Well As, etc.; ParameterOnto is shared with the one in the process description ontology; CausesOnto encompasses various causes such as high/low pressure/temperature/flow rate of upstream feedstock, incorrect opening/closing (malfunction/mis-operation) of upstream/downstream valves, blockage of upstream/downstream process flow, pump shutdown (malfunction/mis-operation), internal leakage of equipment/pipelines, damage to equipment/pipelines, and material composition exceeding design specifications; ConsequencesOnto covers consequences like fire and explosion, pollution, overpressure, backflow, and impact on production output; ProtectionOnto includes various alarms, interlocks, PSVs, redundancy in equipment or design capacity, cofferdams, video surveillance, etc.; RecommendationOnto is similar to protection measures; and ResponsibilityOnto covers designers, operators, owners, etc.

Further relationships between ontology classes are constructed through object properties, and relationships between ontology classes and key parameters are constructed through data properties.

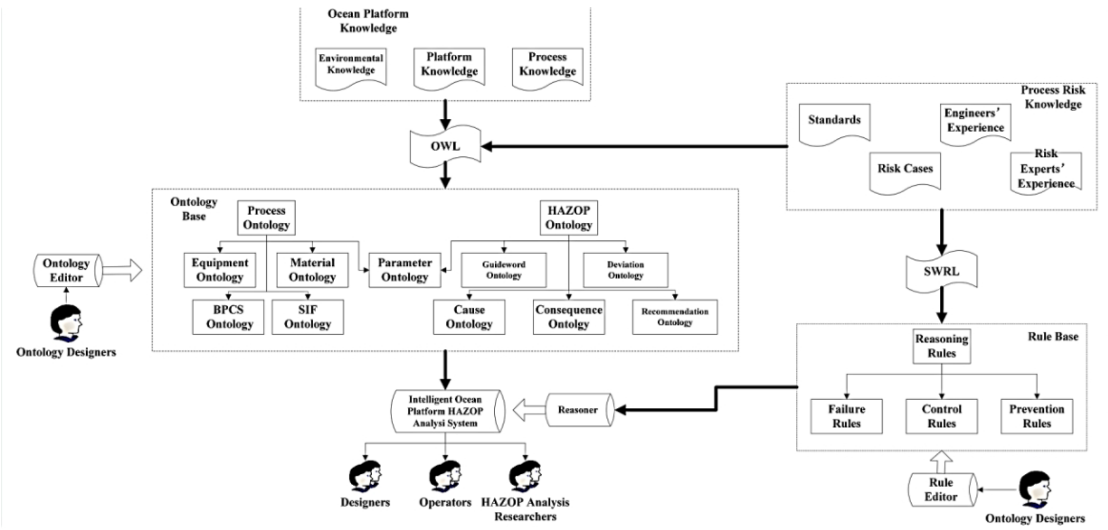

Figure 2 Framework for process risk identification of offshore platforms

ISSN 2616-5767 Vol.8, Issue 2: 103-110, DOI: 10.25236/AJETS.2025.080214

The process description ontology and the HAZOP analysis ontology have been constructed separately through local ontologies and object property relationships, but they are not interconnected. As can be seen from Figure 2, a branch of reasoning rules needs to be constructed to associate the process description ontology with the HAZOP analysis ontology, in order to achieve HAZOP intelligent analysis based on ontologies and rules.

3.3. Representation of Reasoning Rules

To conduct intelligent process risk analysis, it is necessary to reproduce the expert's traversal judgment based on experience. Therefore, the process ontology and HAZOP ontology need to be connected through object attributes, and the reasoning rules generated based on these attributes represent the expert's experience, while the reasoning engine is used to simulate the logical judgment in the expert's mind. The meaning of the reasoning rules is listed in Table 1.

Table 1 Typical reasoning rules of HAZOP

Category	Rules	Explanation
Parameter Reasoning	Equipment(?x)^LiquifiedMaterial(?y)^hasMaterial(?x,?y)^HazopParameterL(?z)->hasHazopParameterL(?x,?z)	When equipment x contains liquid material y, equipment x should consider the liquid level parameter z.
	Equipment(?x)^GaseousMaterial(?y)^hasMaterial(?x,?y)^HazopParameterP(?z)->hasHazopParameterP(?x,?z)	When equipment x contains gaseous material y, equipment x should consider the pressure parameter z.
Deviation Reasoning	HazopParameterF(?x)^GuidewordMore(?y)^hasGuideword(?x,?y)->MoreFlow(?z)	When the parameter "Flow" exists, the deviation "More" should be considered, namely the deviation "MoreFlow".
	HazopParameterT(?x)^GuidewordMore(?y)^hasGuideword(?x,?y)->MoreTemperature(?z)	When the parameter "Temperature" exists, the deviation "More" should be considered, namely the deviation "MoreTemperature".
	HazopParameterF(?x)^GuidewordLess(?y)^hasGuideword(?x,?y)->LessFlow(?z)	When the parameter "Flow" exists, the deviation "Less" should be considered, namely the deviation "LessFlow".
	HazopParameterT(?x)^GuidewordLess(?y)^hasGuideword(?x,?y)->LessTemperature(?z)	When the parameter "Temperature" exists, the deviation "Less" should be considered, namely the deviation "LessTemperature".
Equipment Process Deviation Reasoning	Equipment(?x)^LiquifiedMaterial(?y)^hasMaterial(?x,?y)^HazopParameterL(?z)->hasHazopParameterL(?x,?z) HazopParameterF(?z)^GuidewordMore(?a)^hasGuideword(?z,?a)-> MoreFlow(?b)	When a device contains material y in x, and material y has parameter z with the guide word a, then the device has deviation b.
Analysis Reasoning	Equipment(?x)^Deviation(?y)^hasDeviation(?x,?y)^Equipment(?z)^hasDownstream(?x,?z)^ InfluenceOnDownstream(?a)^hasConsequence(?x,?a)^BPCS(?a)^BPCSControls(?a,?z)^ -> hasCause（?z,?a)	When device X contains deviation Y, which leads to consequence a in downstream device Z, and there is BPCSb in the downstream, the possible cause of consequence Z could be a fault in BPCSa.

According to the identification process shown in Figure 1, and by combining the already constructed process description ontology and HAZOP analysis ontology, the two ontologies are connected through the shared entities "Parameter" and "HAZOP Parameter". Meanwhile, based on the parameter ontology and the guideword ontology, all potential deviations of the equipment are derived. For instance, in the process description ontology, the equipment under analysis (Reject oil tank) is associated with upstream and downstream equipment, materials (Reject oil), BPCS, and SIF. The materials are further associated with process parameters (Level) through their state (liquid). In the HAZOP analysis ontology, HAZOP parameters and guidewords jointly relate to deviations, and HAZOP parameters are one-to-one mapped to process parameters. Additionally, deviations will retrieve protective measures such as alarms and interlocks on the same equipment. If no corresponding protection is found, it is determined that the deviation affects the equipment itself as well as upstream/downstream equipment, thereby achieving the interconnection between the process description ontology and the HAZOP analysis ontology.

ISSN 2616-5767 Vol.8, Issue 2: 103-110, DOI: 10.25236/AJETS.2025.080214

3.4. Application Case

In this article, we introduce the use of OWL for ontology modeling to represent knowledge. We employ SWRL to express reasoning rules and Jena as the reasoning engine. Taking a typical oil and gas platform production process as Figure 3, the target platform needs to be included as an analysis object, and the constructed ontology is shown in Figure 4, we verify the HAZOP analysis method based on ontology.

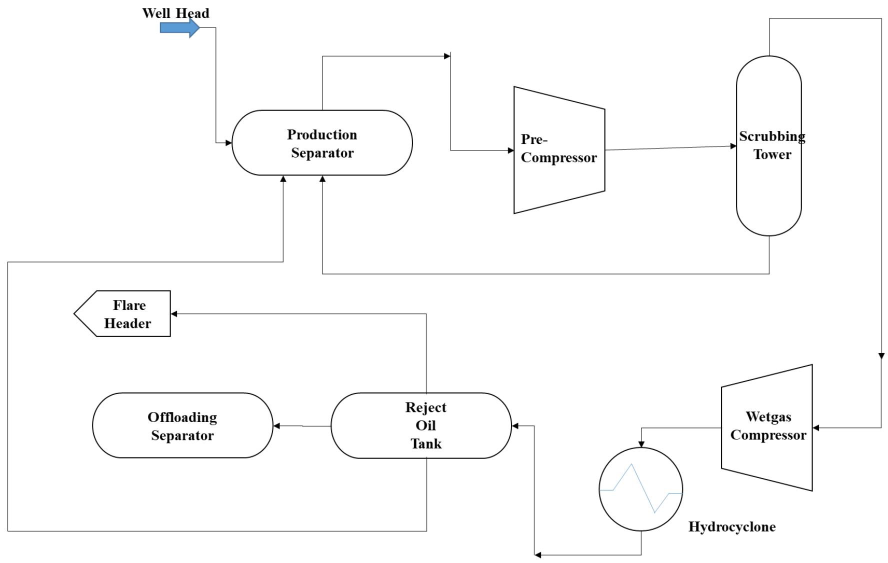

Figure 3 Typical offshore oil and gas production process for application

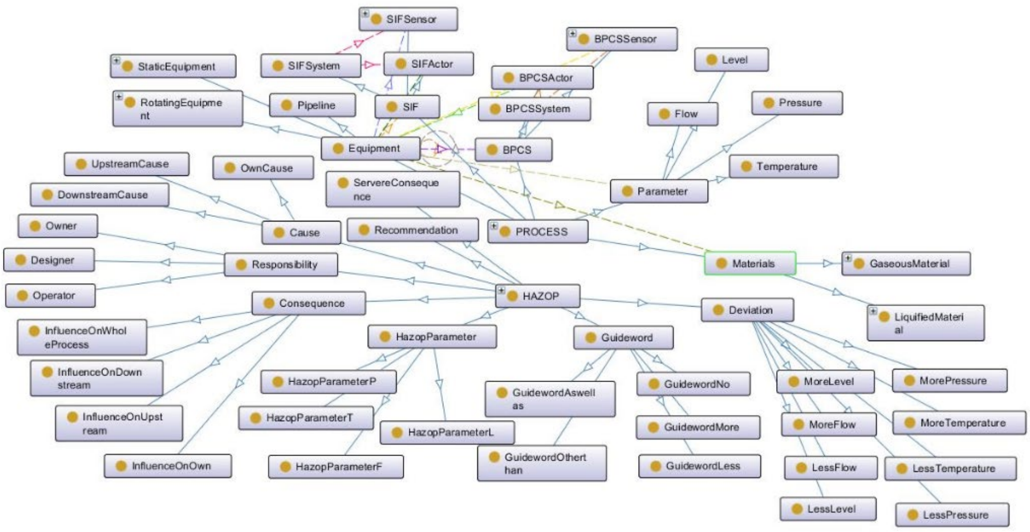

Figure 4 Typical process ontologies and their relationships

Based on the already established ontology classes and object properties, typical process procedures can be constructed within the ontology. For example, in a certain oil and gas process, the upstream of the reject oil tank is the water-containing reject oil separated by the hydrocyclone. The gas phase outlet of the tank is connected to the flare header, and the liquid phase outlet passes through a filter and returns into the production separator. In terms of process control system, the oil-water phase inside the tank is equipped with a temperature sensor, which controls the electric heater through BPCS (Basic Process Control System).

It also has a liquid level sensor that controls the incoming water-containing oil through BPCS and the liquid level control valve LCV1001 (Level Control Valve 1001). The oil phase inside the tank is equipped with a liquid level sensor, which controls the outflow of reject oil through BPCS and the liquid level control valve LCV1002. In terms of the safety instrumented system, the gas phase of the tank is equipped with PSV (Pressure Safety Valve), which trips and discharges gas to the flare header when the gas pressure is too high. The oil-water phase is equipped with a liquid level sensor, which is independently controlled within the SIS (Safety Instrumented System). When the liquid level triggers a high-high condition, it shuts off the upstream incoming material SDV (Shut Down Valve). The final analysis result (partial) is shown as Table 2.

Table 2 HAZOP analysis based on Ontology

GW	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS
NODE 1 WELL HEAD				
No	1. No Flow	1.1. Electrical Submersible Pump (ESP) Failed and Stopped	1.1.1. Single-well production has been interrupted, resulting in flow fluctuations that affect the normal operation of production.	1.1.1.1. Central Control System Fault Alert for Electrical Submersible Pump 1.1.1.2. Manual Intervention for Multi-Well Adjustment 1.1.1.3. PI 'H' Pressure Indication 1.1.1.4. PI 'B' Pressure Indication, Low Alarm
		1.2. Safety valves on and below the well have malfunctioned and closed.	1.2.1. Wellbore pressure buildup, damage to the electrical submersible pump, affecting the normal operation of production.	1.2.1.1. Local and remote indirect indication of safety valve status via hydraulic signals 1.2.1.2. Full pressure design for wellhead design pressure 1.2.1.3. Low-low interlock shuts down the electrical submersible pump when the pressure fluid control line switch module of a single well is activated (both above-ground and downhole safety valves close simultaneously)
		1.3. CV 'A' is falsely closed or malfunctioned closed	1.3.1. Wellhead pressure rises, causing the above-ground safety valve to activate and close, affecting the normal operation of production.	1.3.1.1. PI 'H' Pressure Indication 1.3.1.2. PI 'B' Pressure Indication, Low Alarm 1.3.1.3. Low-low pressure interlock shuts down the above-ground safety valve and the electrical submersible pump (both above-ground and downhole valves close simultaneously) via PI 'D' pressure indication.
More	2. More Flow	2.1. Excessive opening of the choke (or damage to the CV 'A' valve core)	2.1.1. Pipeline pressure rises, leading to pipeline overpressure damage in severe cases.	2.1.1.1. PI 'B' Pressure Indication, High Alarm 2.1.1.2. High-high pressure interlock shuts down the above-ground safety valve and the electrical submersible pump via PI 'D' pressure indication. 2.1.1.3. Quality control for CV 'A'
		2.2. Abnormal formation pressure	2.2.1. Pipeline overpressure damage	2.2.1.1. PI 'B' Pressure Indication, High Alarm 2.2.1.2. High-high pressure interlock shuts down the above-ground safety valve and the electrical submersible pump via PI 'D' pressure indication. 2.2.1.3. Adjust the opening of the choke valve.

GW	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS
Less	3. Less Flow	3.1. Internal leakage or inadvertent opening of the 2" valve to the closed drainage system	3.1.1. High-pressure produced fluid enters the closed drainage system, causing an increase in pressure and affecting the safe operation of the closed drainage system.	3.1.1.1. Closed drainage liquid level indication, low alarm 3.1.1.2. Closed drainage pressure indication 3.1.1.3. Regular valve maintenance 3.1.1.4. Double valve setup 3.1.1.5. Gas from the closed drainage tank goes to the vent system 3.1.1.6. Inspection tour

4. Conclusions and further study

4.1. Conclusions

Existing risk identification methods providing only pondering frames lead to difficulties in sharing and reusing existing results, and help slightly in improving identification efficiency and accuracy. These issues have been major restraining factors in risk identification.

In this paper, ontology method was introduced into risk identification and an intelligent identification framework was presented. The platform ontology and risk ontology were built in OWL, and reasoning rules based on experts' experience were constructed in SWRL. As a result, intelligent risk identification orienting to ship owners and designers was achieved.

4.2. Further Study

It is of paramount importance to underscore that, regardless of the technical methodologies employed, the fundamental cornerstone of HAZOP analysis remains firmly entrenched in the rigorous examination and meticulous judgment founded upon the bedrock of expert experience, as thoroughly expounded in the preceding discourse of this paper. Consequently, the central challenge confronting the field lies in the development of efficacious mechanisms that facilitate the storage and reuse of this invaluable expert knowledge, thereby ensuring that the progression of HAZOP analysis technology remains harmoniously aligned with the relentless advancements within the broader engineering disciplines, irrespective of the ever-evolving landscape of external technologies and tools.

In this regard, the engineering application of ontology-based HAZOP analysis necessitates a concerted effort from the industry, whereby shared process ontologies and HAZOP analysis ontologies are collaboratively constructed. This endeavor involves the joint accumulation and dissemination of pertinent HAZOP analysis rules and conclusions, thereby continuously enriching the HAZOP ontology and refining its reasoning rules. Essentially, this collaborative process embodies the storage, sharing, and reuse of expert experience, which forms the lifeblood of the analysis methodology.

Moreover, as design capabilities and equipment reliability continue to soar to new heights, the risk landscape within industrial processes is undergoing a paradigm shift, transitioning from design and equipment-centric concerns to operational issues. Consequently, there is a pressing need to fortify the integration between human reliability and HAZOP analysis, endeavoring to forge a robust mapping relationship between personnel training and human reliability. This integration will serve to further augment the consideration of human reliability within the HAZOP analysis framework, thereby enhancing its comprehensiveness and accuracy.

Additionally, harnessing the transformative potential of emerging technologies, notably CHAT GPT and artificial intelligence, to propel the reuse of knowledge beyond mere application extension and into the realm of knowledge generation, represents a strategic imperative for broadening the applicability of traditional HAZOP analysis into novel and emerging engineering contexts. This transition will undoubtedly usher in a new era of enhanced predictive capability and decision-making prowess within the realm of hazard and operability analysis.

ISSN 2616-5767 Vol.8, Issue 2: 103-110, DOI: 10.25236/AJETS.2025.080214

References

[1] Abou A. A., Lenne D., Debray B. Ontology development for industrial risk analysis, 2008 3rd International Conference On Information And Communication Technologies: From Theory To Applications, 1~5:1362~1366.
[2] Studer R. Abstract models of dialogue concepts. Software engineering, 1984.
[3] Ferreira C. R., Marques P., Martins A. L., et al. Ontology design risk analysis, OTM Confederated International Conference and Workshop, 2007, 4805:522~533.
[4] Cameron IT, Seligmann B, Hangos KM, et al. Afunctional systems approach to the development of improved hazard identification for advanced diagnostic systems.18th European Symposium on Computer Aided Process Engineering. Lyon, France, 2008.
[5] AZIZ A, AHMED S, KHAN F, et al. An ontology-based methodology for hazard identification and causation analysis. Process Safety and Environmental Protection, 2019, 123: 87-98.