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Human Factors Reliability Study of Oil and Gas Field Accidents

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Abstract **Case Studies**

This study investigates human factors reliability in oil and gas field accidents, combining theoretical analysis with empirical data. It identifies that human factors contribute to 70–80% of accidents, underscoring the inadequacy of technical solutions alone and the need for systemic improvements. The research defines key concepts such as Human Error (HER) and Performance Shaping Factors (PSFs), categorizing errors into skill-based, rule-based, knowledge-based, omissions, and commissions. Using the HFACS-OGI framework, it reveals that 86% of accidents involve contractor personnel, with 90% attributed to suboptimal contractor working environments. High-risk operational phases include drilling and workover, while organizational influences like weak safety culture and insufficient training are critical. Strategies to enhance reliability integrate Human Factors Engineering (HFE), safety culture cultivation, and robust management—including proactive design, targeted training, and PSF management. The study emphasizes a systemic approach to address interlinked factors from individual behaviors to organizational-level latent conditions.

Keywords: Oil and Gas Accidents, Human Factors Reliability, Human Error (HER), Performance Shaping Factors (PSFs), HFACS-OGI, Safety Culture.

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1. INTRODUCTION

The oil and gas (O&G) industry is inherently high-risk and has a history of catastrophic accidents.Numerous studies and accident investigations have shown that human factors are one of the main causes of these accidents, often contributing more than 70-80%.For example, an analysis of accidents at member companies of the International Association of Oil and Gas Producers (IOGP) shows that more than 80% of accidents are caused by human factors.The high rate of human factors-related accidents despite advances in technology suggests that technological solutions alone are not sufficient to ensure safety in the oil and gas industry, and that there are deeper systemic issues with human-system interactions.

Human Reliability (HR) is defined as the probability that a person will correctly perform an operation required by a system within a specified time period and will not perform any extraneous behavior that could lead to degradation of system performance.This definition reveals the dual challenge of ensuring the correctness of operations while preventing the introduction of new risks due to extraneous behaviors.Thus, human factors reliability is not only about the quality of task performance, but also about the avoidance of potential negative impacts.Human Reliability Analysis (HRA) is a systematic approach aimed at identifying the role of human factors performance in risk through qualitative and quantitative assessment.

The purpose of this paper is to provide a brief overview of the current state of research on human factors reliability in oil and gas field accidents, covering the basic concepts, analytical methods, key issues revealed by accident data, and strategies to enhance human factors reliability, so as to provide a reference for safety management in the oil and gas industry.

2. CONCEPT AND PERFORMANCE INFLUENCING FACTORS OF HUMAN ERROR

Human Error (HER) is an event in which human behavior or decision-making deviates from established standards or expected outcomes, which may lead to a reduction in the safety or efficiency of a system.It is important to emphasize that Human Error is an inherent characteristic of human behavior and is not necessarily equivalent to negligence or malfeasance.Understanding the types of human-caused errors is critical to developing effective prevention strategies.Common types of errors include:

(1)Skill-based errors: refers primarily to unconscious errors during the performance of skilled tasks.

1) Slips: Errors at the level of behavioral execution, such as pressing button B when you meant to press button A, or opening or closing a valve by mistake during valve operation.

2)Lapses: Errors at the memory level, such as forgetting to perform an action step or missing a critical check.

(2)Knowledge-based and Rule-based Mistakes (Mistakes): refer to conscious behaviors that are based on faulty planning or knowledge.

1)Rule-based mistakes : refers to the incorrect application of a rule or the failure to correctly apply a known rule.For example, in an emergency situation, misjudging and activating an inapplicable emergency plan.

2)Knowledge-based mistakes: Decisions based on incorrect understanding in the absence of relevant knowledge or experience.For example, when faced with a failure of a new and complex piece of equipment, an incorrect diagnosis is made due to a lack of familiarity with how it works.

(3)Errors of Omission and Errors of Commission : the former refers to failure to perform a necessary operation, the latter to performing an incorrect operation or performing an unnecessary operation.

These distinctions between types of errors are not purely academic; they directly guide the choice of interventions.For example, slippage and forgetfulness can be reduced by optimizing the design of the human-machine interface, using checklists, etc., whereas knowledge-based and rule-based errors require deeper interventions, such as improving the content of the training, refining the operating procedures, or developing a decision support system.

Human behavioral performance is influenced by a variety of factors known as Performance Shaping Factors (PSFs) or Performance Influencing Factors (PIFs.) PSFs are those that enhance or diminish a person's work performance and reliabilityconditions.PSFs are usually categorized into three groups:

(1)Individual factors : e.g., skill level, experience, level of training, state of fatigue, stress, mood, health .

(2)Work/task factors : e.g., clarity and usability of operating procedures, human-machine interface design, workload, time pressure, maneuverability of tools and equipment, work environment (lighting, noise, temperature, etc.) .

(3)Organizational and management factors : e.g. safety culture, leadership, communication mechanism, training system, teamwork, resource allocation, change management, monitoring mechanism, etc.

PSFs are often interrelated and have cascading effects.For example, a weak organizational safety culture (organizational PSF) may lead to insufficient training inputs and poor protocols (work/task PSF), which in turn increases employee stress and fatigue (individual PSF), ultimately significantly increasing the probability of human-caused errors.Therefore, HRA must be customized to the specific operating environment, task characteristics, and prevalent PSFs of oil and gas operations, as generic probability of error data has limited reference value in the absence of specific contexts.

Table 1: Common types of human-caused failures and key performance influences in oil and gas operations

Types of errors	DESCRIPTION	Examples of oil and gas operations	Key Associated PSFs
Slip	Unconscious behavioral execution errors	Accidentally opening the wrong valve during line connection; pressing the wrong button during equipment operation	Poor HMI design, distractions, environmental disturbances (noise, insufficient lighting), time pressure
Lapse	Unconscious memory errors, forgetting to perform steps	Forgetting to isolate a stressor before maintenance; omitting a step in a complex sequence of operations	Fatigue, excessive workload, interruptions, unclear or lengthy procedures
Rule-Based Mistake	Misapplication of known rules or procedures	Misapplication of standard contingency plans under non-routine conditions; misinterpretation of alarm signals and execution of inappropriate procedural steps	Inadequate or inapplicable protocols, insufficient training, experience-based, incorrect scenario assessment
Knowledge-Based Mistake	Decision-making errors caused by insufficient knowledge or misunderstanding.	Misdiagnosis due to lack of understanding of the principles when faced with complex failures of new equipment; risky operations in the face of unknown risks	Lack of knowledge and experience, insufficient training, insufficient or contradictory information, high uncertainty, cognitive bias.
Omission	Failure to perform required operations or procedures	Failure to perform required equipment inspections; failure to activate critical safety systems during emergency response	Forgetfulness, inattention, workload, lack of procedural guidance, miscommunication

Commission	Wrong operation was performed or unnecessary operation was performed	Incorrect shutdown of critical equipment in operation; manual intervention when it should not have been done	Diagnostic errors, poor decision making, protocol understanding bias, overconfidence, violation of operating procedures

3. HUMAN FACTORS RELIABILITY ANALYSIS (HRA) METHODOLOGY FOR OIL AND GAS FIELD ACCIDENTS

The purpose of HRA is to identify potential human-caused failures, assess the likelihood of their occurrence, and identify ways to minimize them in order to improve overall system safety .Understanding how accidents occur is a prerequisite for effective HRA, and Reason's Accident Causation Model (often referred to as the "Swiss Cheese Model") provides an important theoretical foundation for understanding systemic failure.The model suggests that accidents do not occur for a single reason, but rather that defects in multiple layers of defenses ("cheese holes") accidentally align in tandem under certain conditions, allowing hazards to penetrate all layers of defenses, ultimately leading to an accident.These "holes" fall into two categories:

(1)Active Failures (Active Failures): These are mistakes made directly by front-line operators, such as operational errors and violations of protocols.The impact is usually immediate and direct .

(2)Latent Conditions: These are deficiencies in the system that already exist and are caused by "upstream" factors such as organizational management, decision-making, design, etc., e.g., inadequate protocols, insufficient training, poor safety culture, equipment design deficiencies.These conditions can lie dormant for years until they are combined with active errors and specific triggers to cause accidents.

The Human Factors Analysis and Classification System (HFACS), a structured accident analysis tool developed based on the Reason model, has been widely used in several industries and has been developed for the oil and gas industry in the HFACS-OGI (Oiland Gas Industry) version. HFACS-OGI typically contains the following dimensions (see Figure 1):

(1)Unsafe Acts: direct errors and violations by frontline personnel, corresponding to active errors in the Reason model.

(2)Preconditions for Unsafe Acts: environmental factors (e.g., working conditions, physical and mental state of personnel) and personnel factors (e.g., bad habits, lack of personal preparedness) that affect individual behavior.

(3)Unsafe Supervision: deficiencies at the supervisory level, such as poor planning, failure to correct known problems, and supervisory oversight.

(4)Organizational Influences: Systemic problems at the organizational level, such as poor resource management, poor organizational climate (safety culture), and flawed organizational processes. Some HFACS extension models (e.g., HFACS-OGAPI) may also include higher-level

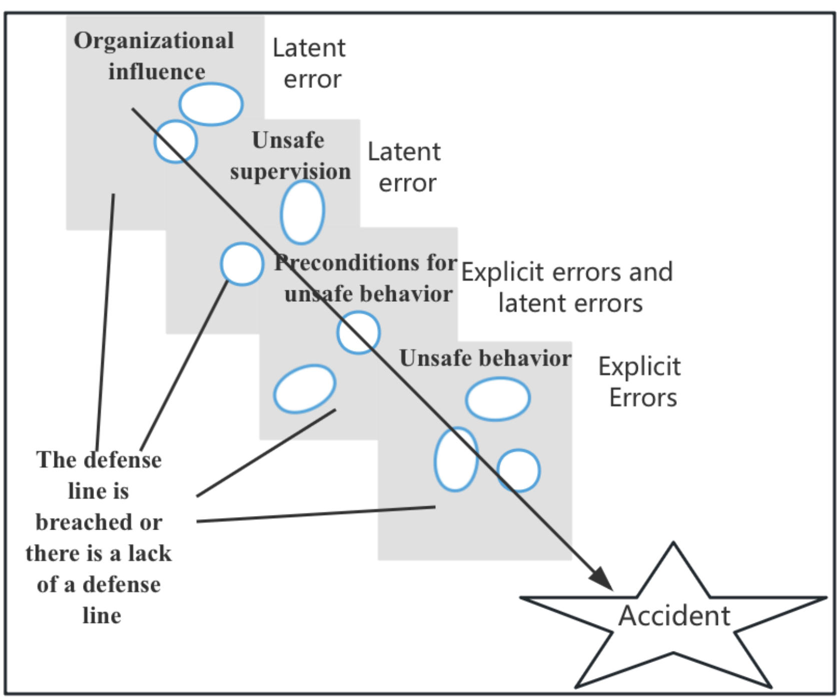

Fig. 1 The "Swiss Cheese" model of accident causation

The development of HRA methods has gone through an evolution from the first generation to the second generation and even systematic methods.The first generation of HRA methods, such as THERP (Technique for Human Error Rate Prediction) and HEART (Human Error Assessment and Reduction Technique), focused primarily on thequantitative assessment of individual error probabilities (Human Error Probabilities, HEPs).The second and subsequent generations of systematic approaches, such as CREAM (Cognitive Reliability and Error Analysis Method) and HFACS, emphasize more on the analysis of cognitive processes, situational factors, and systemic causes.The oil and gas industry has benefited greatly from this evolution, particularly from tools such as HFACS-OGI, which can help to analyze industry-specific systemic and regulatory failures.The strength of HFACS-OGI lies in its ability to systematically identify "latent conditions" at the organizational and regulatory levels, which are often the result of "active failures" by front-line personnel.These are often the source of "active failure" on the part of frontline personnel, thus shifting the focus of intervention from blaming the individual to improving the system.Although quantitative HRA methods provide probabilistic values, in the oil and gas industry, due to data constraints and situational complexity, their greater value is likely to lie in identifying system vulnerabilities and guiding risk-reduction measures, rather than in accurately predicting the failure rate itself.

4. OIL AND GAS ACCIDENT DATA ANALYSIS AND KEY FINDINGS

A large number of accident statistics confirm that human factors are the main contributors to oil and gas accidents, often accounting for as much as 70-80% [3].In-depth analysis of accident data can help to reveal the patterns and key contributing factors of human-caused errors.

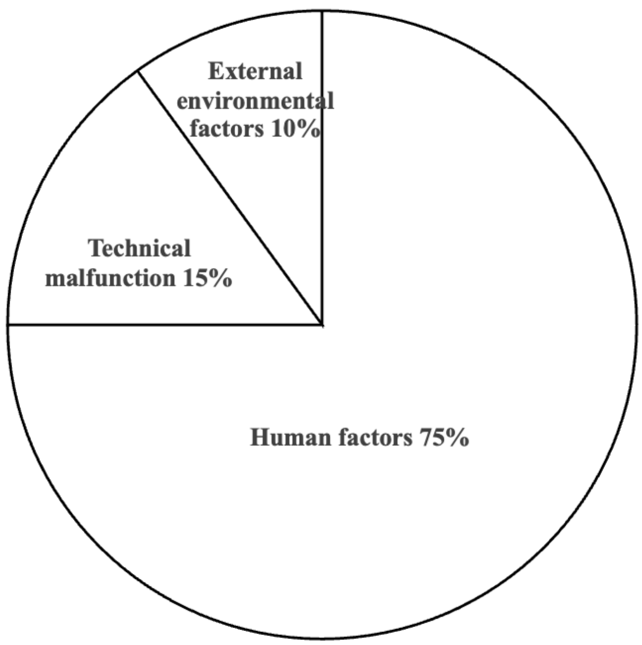

Fig. 2 Schematic diagram of the main causes of oil and gas accidents

Analyzing oil and gas accidents based on frameworks like HFACS-OGI reveals several general patterns. An HFACS-OGI study of 184 oil and gas industry accidents between 2013 and 2017 showed that contractor personnel were involved in up to 86% of the accidents. In terms of high-risk operational phases and locations, about 28% of accidents occurred during operational phases such as drilling, workover, and completion services, while 69% took place at onshore work sites.

Regarding key human factors categories: At the prerequisite level, the "contractor's working environment" was identified as the main human factor in 90% of accident cases, highlighting potential systemic weaknesses in contractor management and control of the operating environment. Other important prerequisites include fatigue, poor communication, etc. In the dimension of unsafe behaviors, common issues include skill-based failures (e.g., failure to correctly implement operating procedures) and decision-making failures (e.g., poor judgment in dynamic an d complex situations). The dimension of unsafe supervision involves inadequate supervision, failure to correct known problems, insufficient risk assessment, inadequate contingency plans, etc. The organizational impact level is characterized by a weak safety culture, insufficient resource investment, deficiencies in management systems, inadequate training systems, and other issues.

Table 2: Schematic decomposition of human factor contributions in oil and gas accidents (Hypothesis-based HFACS-OGI analysis)

HFACS-OGI dimensions/factor categories	Illustrative Incident Contribution Percentage (%)	Brief example/explanation
Unsafe Behavior		
Skill-based errors	25	Failure to follow operating procedures, improper operation of equipment
Decision-making errors	20	Errors of judgment and inadequate risk identification in complex working conditions
Prerequisites for unsafe behavior		
Undesirable working conditions (especially for contractors)	30	High noise levels, inadequate lighting, time pressure, poorly maintained equipment
Poor communication and coordination	15	Incorrect or untimely transfer of information within the team, across departments, or with contractors
Fatigue and stress	15	Long hours, intense work, understaffing
Unsafe supervision		
Inadequate supervision/poor planning	20	Lack of effective supervision of high-risk operations, inadequate emergency plans or insufficient drills
Organizational impact		
Weak safety culture	25	Emphasis on production over safety, high tolerance for violations, low employee safety awareness
Inadequate resources/training	18	Insufficient safety investment, training content out of touch with reality, personnel skills not meeting job requirements

The high level of contractor involvement in accidents and the critical impact of their work environment suggests that there may be systemic vulnerabilities in the management, integration, and oversight of contractor work.This may involve issues such as reciprocity of safety standards, communication and coordination between owners and contractors, or pressures specific to contract work.In addition, the high incidence of accidents during specific phases of operations (e.g., drilling, workover) suggests that these phases are "hotspots" of human-caused risk, which may require targeted human-caused reliability analyses and interventions, perhaps due to their high complexity, fast-changing dynamics, or more frequent human-computer interactions.The multidimensional nature of accident causes revealed by OGI implies that effective accident prevention requires a multi-pronged strategy that focuses not only on individual behaviors, but also on improving the regulatory and organizational systems that shape those behaviors.

5. STRATEGIES TO IMPROVE HUMAN FACTORS RELIABILITY IN OIL AND GAS OPERATIONS

Improving human factors reliability in oil and gas operations requires a synergistic approach integrating Human Factors Engineering (HFE), safety culture building, and robust management systems. HFE principles should be embedded throughout project lifecycles—from conceptual design to decommissioning—via user-centered equipment, HMI, and workspace design (e.g., optimized control room layouts or alarm systems), as guided by OGP's Report 454. This proactive model prevents human error at the design stage, proving more efficient than post-accident corrections.

A strong safety culture is equally vital, fostering organizational values where safety is a core priority through leadership commitment, open communication, and a Just Culture that encourages error reporting. Complementary strategies include:

Targeted training (e.g., simulator-based drills for critical tasks and emergencies) with a focus on non-technical skills like decision-making and teamwork.

Streamlined operating procedures that are regularly updated to support frontline efficiency.

Proactive supervision, clear role definitions, and leadership enforcement of safe practices.

Managing Performance-Shaping Factors (PSFs) is also critical: implementing fatigue risk systems, optimizing workloads to avoid under/over-staffing, and improving work environments—particularly for contractors. Accident investigations using frameworks like HFACS-OGI must identify root causes to drive corrective actions, while contractor safety management demands rigorous systems for selection, training, and performance alignment with organizational standards.

These strategies form an interconnected ecosystem: a robust safety culture enhances incident reporting, which fuels learning that refines procedures and training—both rooted in HFE. Success requires a holistic, systemic mindset to ensure seamless integration.

6 CONCLUSION

Human factors are key aspects of safety in oil and gas fields and have a significant impact on the occurrence of accidents.Human factors reliability analysis (HRA), especially structured methods such as HFACS-OGI that are applicable to the oil and gas industry, provides a powerful tool for a deeper understanding of the types and patterns of human factors failures and the performance influencing factors (PSFs) behind them.The analysis shows that everything from individual unsafe behaviors to systemic organizational deficiencies can be a link in the accident chain.

Improving human factors reliability in oil and gas operations is a long-term and complex systematic project that requires sustained commitment and dedication at the organizational level.This includes not only integrating Human Factors Engineering (HFE) principles into the design and management of equipment, systems and work, but also actively fostering and reinforcing a safety culture so that safety becomes a shared value and code of conduct for all employees.Targeted interventions based on incident data and HRA analysis results, such as improved training, optimized protocols, enhanced supervision, managing fatigue and workload, and enhanced contractor safety, are effective ways to reduce the risk of human factors failure.

The ultimate goal is to build resilient socio-technical systems in which human adaptability and flexibility can be a positive force in responding to emergencies and ensuring safety, rather than just being viewed as a potential source of risk.Human factors reliability management is not permanent, and HRA results must be reviewed and updated periodically as technology, processes, people, and operating environments change to ensure the continued effectiveness of the safety strategy.In the future, there is still a need for continued research and practice in the area of human factors to continually improve overall safety in the high-risk industry of oil and gas.

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