

Research Article

Legal Reconstruction of Human Error in Automatic Industrial Systems (Case Study: Iranian Petrochemical Industries)

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Abstract

This study reflects the new concern with water as an essential force in all of life. Too little water means death, and too much water can have the same effect. Humans need good drinking water, and all cultural history has already confirmed the essential function of water. Living in the Anthropocene today, taking care of water and respecting nature's resources, both from a historical-literary and a natural-scientific perspective constitutes a conditio sine qua non for our future. Studying medieval and early modern writers' and artists' stance toward water provides us with a critically important discursive platform to understand the relationship between people and their natural environment in deep terms, uncovering the history of water awareness as it still affects us today.

Keywords: Human Error, Digital Forensic Medicine, Legal Reconstruction, Iranian Petrochemical Industries, Automated Systems

1. Introduction

The rapid automation of industrial systems has transformed safety and accountability paradigms globally (Sheridan). However, human error in automated environments remains a critical yet underexamined legal challenge, particularly in high-risk sectors like petrochemicals. In Iran, where petrochemical industries contribute significantly to economic output (Iranian Ministry of Petroleum, 2020), incidents involving human-machine interaction errors often face “non-expression”—a lack of thorough investigation or legal documentation (Ghasemi et al.,). This gap undermines both safety protocols and liability frameworks.

The petrochemical industry, a cornerstone of Iran's economy (accounting for 15% of GDP in 2022; Ministry of Petroleum, 2023), increasingly relies on automated systems to optimize production and safety [1]. However, the interplay between human operators and complex automated technologies has introduced new risks, particularly in contexts where systemic pressures, training gaps, and design flaws contribute to operator errors. These errors, often underreported or “non-expressed” due to legal, cultural, or organizational barriers, create challenges for accountability and safety improvement [2,3].

While international studies emphasize the role of cognitive biases and poor system design in human error, Iranian regulatory frameworks lack standardized protocols for attributing liability in automated systems (Tavakoli & Rezaei) [3]. Furthermore, cultural and organizational factors unique to Iran's industrial context, such as hierarchical decision-making structures, exacerbate error underreporting (Sharif University of Technology, 2018).

In Iran, economic sanctions and technological restrictions have exacerbated reliance on legacy-automated systems, heightening vulnerabilities to human error [4]. Simultaneously, the legal framework governing industrial liability remains fragmented, with Iranian labor laws (e.g., Article 34 of the Labor Code) inadequately addressing human-machine error attribution [5]. Globally, scholars advocate for interdisciplinary approaches to error analysis, combining forensic techniques with human factors research [6]. Yet, this integration remains understudied in Iranian industrial contexts.

This study bridges these gaps by applying digital forensic medicine—a data-driven approach using sensor logs, AI analytics, and incident timelines—to reconstruct operator errors. Combined with human factors research, this interdisciplinary lens uncovers latent system flaws and

clarifies legal accountability. By analyzing incidents in Iranian petrochemical plants (2018–2023), the research proposes reforms to mitigate “non-expression” and align national policies with global safety standards (e.g., ISO 31000).

1.1. Literature Review

The legal and technical challenges posed by human error in automated industrial systems have garnered attention across disciplines, yet limited research addresses their intersection in high-risk sectors like petrochemicals. This review synthesizes global and Iranian scholarship on human factors, digital forensic methodologies, and legal frameworks to contextualize gaps in current knowledge.

1.2. Human Factors in Automated Systems

Human error in industrial automation is often rooted in cognitive limitations, poor system design, and organizational pressures. Reason’s Human Error (1990) categorizes errors as skill-based slips, rule-based mistakes, or knowledge-based oversights, a framework applied to industrial incidents globally [3,6]. In Iran, studies highlight how sanctions-driven technological constraints force operators to override automated systems, increasing error risks [4]. Ahmadi et al., note that 40% of Iranian petrochemical incidents stem from inadequate training on legacy systems, exacerbated by economic pressures limiting workforce development [2].

1.3. Digital Forensic Medicine in Industrial Incidents

Digital forensic medicine—the use of sensor data, AI analytics, and system logs to reconstruct events—is emerging as a tool for industrial safety [7]. Unlike traditional accident investigations, this approach enables precise timelines of operator-system interactions, crucial for untangling liability [5]. However, its application in legal contexts remains underexplored. For example, while Perrow emphasizes systemic “normal accidents” in complex technologies, forensic methods could redefine accountability by isolating human vs. machine failures [8].

1.4. Legal Frameworks and Liability Gaps

Iranian industrial law struggles to address liability in human-machine error cases. Article 34 of Iran’s Labor Code (2015) assigns primary responsibility to operators, yet fails to account for design flaws or automation complexities [5]. Globally, Aven argues for risk-based liability models that balance operator, designer, and regulatory accountability. Such frameworks are absent in Iran, where non-expression of errors (e.g., unreported system overrides) is incentivized by punitive legal cultures [2,9].

1.5. Case Studies in Petrochemical Safety

Iranian petrochemical disasters, such as the 2018 Mahshahr refinery fire, reveal systemic underreporting of operator errors [4]. Comparative studies, like the 2019 Texas petrochemical explosion, show how forensic reconstruction informed U.S. regulatory reforms. Yet, Iranian investigations often lack transparency, with state-owned firms resisting external audits [5].

1.6. Theoretical and Methodological Gaps

Existing research siloes human factors analysis (e.g., cognitive workload assessments) from forensic data (e.g., sensor logs). A hybrid approach—merging digital timelines with ergonomic evaluations—could address this gap (Salmon et al., 2021). Furthermore, Iranian studies rarely engage with global safety models, limiting policy transferability [2].

2. Method

This study employs a mixed-methods, interdisciplinary approach to reconstruct human error in automated industrial systems, combining digital forensic analysis, human factors research, and legal inquiry. The methodology is structured around a case study of Iranian petrochemical plants (2018–2023), ensuring rigor through triangulation of data sources and validation via Iranian and global frameworks.

2.1. Research Design

- **Case Study Approach:** Focuses on 12 incidents across three Iranian petrochemical plants (anonymized as Plants A, B, and C) involving automated system errors.
- **Interdisciplinary Framework:** Merges digital forensic medicine (technical reconstruction) with human factors analysis (ergonomic and cognitive assessments) and legal liability frameworks.

2.2. Data Collection

- **Primary Sources:** Incident Reports: Official logs from Iran’s Occupational Health and Safety Organization (OSH) and plant-specific records.
- **Digital Forensic Data:** Sensor logs, control system timestamps, and alarm records from distributed control systems (DCS). AI-driven anomaly detection tools (e.g., MATLAB/Simulink) to identify operator-system interaction patterns.
- **Operator Interviews:** Semi-structured interviews with 25 operators and supervisors (coded as OP1–OP25) to assess decision-making pressures, training gaps, and system overrides.
- **Simulation Experiments:** Replication of incident scenarios using HYSYS software to test human-machine interface (HMI) design flaws.
- **Secondary Sources:** Iranian legal documents (Labor Code, Industrial Safety Regulations). International standards (ISO 11064 for control room design, IEC 61511 for safety systems).

2.3. Data Analysis

2.3.1. Digital Forensic Reconstruction

- **Timeline Analysis:** Chronological mapping of incidents using sensor data and operator logs to identify error triggers (e.g., delayed responses, unauthorized overrides).
- **Anomaly Detection:** Machine-learning algorithms (Random Forest) to flag deviations from standard operating procedures.

2.3.2. Human Factors Analysis

- **Cognitive Workload Assessment:** NASA-TLX (Task Load Index) surveys to evaluate operator stress during critical tasks.

- **Ergonomic Audits:** Evaluation of HMI design against ISO 11064 standards (e.g., screen complexity, alarm prioritization).

2.3.3. Legal Liability Analysis

- **Comparative Review:** Contrast Iranian labor laws (Article 34) with EU Directive 89/391/EEC on employer liability.
- **Scenario Modeling:** Simulate liability outcomes under proposed tiered frameworks (operator-designer-regulator accountability).

2.4. Validity and Reliability

- **Triangulation:** Cross-check digital evidence (sensor logs) with operator accounts and simulation results.
- **Peer Debriefing:** Validation workshops with Iranian industrial safety experts (n=8) and legal scholars (n=5).
- **Audit Trail:** Document all data sources and analysis steps for replicability.

2.5. Ethical Considerations

- **Informed Consent:** Obtained from all interviewees, with anonymity guaranteed.
- **Data Anonymization:** Plants and participants labeled

generically to protect identities.

- **Institutional Approval:** Reviewed by the Ethics Committee of [Name of Iranian University/Institution].

2.6. Limitations

- **Data Gaps:** Underreporting of errors due to organizational secrecy in state-owned plants.
- **Sanctions Impact:** Limited access to advanced forensic tools due to trade restrictions.

3. Result

The integration of digital forensic medicine and human factors research into the legal reconstruction of human error in Iranian petrochemical industries reveals critical insights into systemic vulnerabilities, liability ambiguities, and pathways for reform. Below, key findings are contextualized through thematic analysis and supporting tables.

3.1. Systemic Vulnerabilities in Automated Systems

Iranian petrochemical plants face unique challenges due to aging infrastructure, sanctions-driven technological constraints, and high cognitive demands on operators.

Factor	Incidents (n=12)	Percentage
Legacy system failures	9	75%
HMI design flaws	7	58%
Operator overrides	5	42%
Training deficiencies	4	33%
Alarm flooding	3	25%

Table 1: Main Human Error Factors Identified in this Study (Ahmadi et al., 2021; Ghorbani & Maleki, 2020) [2,4]

3.2. Legal Ambiguities and Liability Gaps

Iranian labor laws inadequately address liability in human-machine error cases.

Criterion	Iranian Law (Article 34)	EU Directive 89/391/EEC
Operator accountability	Strict liability	Context-dependent
Designer liability	Not addressed	Explicitly mandated
Error reporting	Punitive culture	Protected disclosures
System design standards	Voluntary guidelines	Legally binding (ISO)
Alarm flooding	3	25%

Table 2: Legal Liability Frameworks: Iran vs. International Standards (Habibi, 2019, EU Directive 89/391/EEC) [5]

3.3. Digital Forensic Medicine: Bridging Technical and Legal Domains

Forensic reconstruction using sensor logs and AI tools

(Table 3) provided granular insights into operator-system interactions, challenging narratives of “operator negligence” in 40% of cases.

Incident Type	Digital Evidence Findings	Legal Implication
Unauthorized override	System logs show 2.5s delay in response	Operator liability reduced due to alarm flooding
Calibration error	Sensor drift undetected for 18 days	Manufacturer liable for poor diagnostics
Emergency shutdown	HMI mislabeled valves	Designer liability under ISO 11064

Table 3: Forensic Reconstruction Outcomes (MATLAB/Simulink Analysis and Plant Records)

3.4. Policy Recommendations

To address non-expression of errors and legal gaps, Table 4 outlines proposed reforms aligned with global best practices.

Policy Area	Recommendation
Error reporting	Anonymous digital reporting platforms
Liability frameworks	Tiered accountability (operator-designer-regulator)
System design	Mandatory ISO 11064 compliance for HMIs
Training	Forensic literacy modules for operators

Table 4: Comparative Analysis of EU and Iranian Policies (Salmon et al., 2021; Ministry of Petroleum, 2023) [1,6]

3.5. Cross-Disciplinary Insights

The study demonstrates that human error is rarely isolated but a symptom of systemic flaws. For instance, Table 1 shows that 75% of incidents involved legacy systems, yet Iranian law (Table 2) does not hold designers accountable for outdated technology. This disconnect perpetuates unsafe conditions and legal disputes.

4. Discussion

4.1. Systemic Vulnerabilities and Error Dynamics

The findings underscore that human error in Iranian petrochemical plants is not merely an operational failure but a symptom of deeper systemic flaws. Legacy systems—exacerbated by economic sanctions and technological restrictions—contributed to 75% of incidents (Table 1), while poor human-machine interface (HMI) design and alarm management intensified cognitive burdens on operators. Unauthorized overrides, driven by organizational pressures and inadequate training, accounted for 42% of errors, highlighting a culture of “non-expression” where errors are concealed to avoid punitive measures. These findings align with global studies on high-risk industries but are uniquely compounded in Iran by geopolitical and economic constraints [3,6].

4.2. Legal Ambiguities and Liability Gaps

Iranian legal frameworks, particularly Article 34 of the Labor Code, disproportionately assign liability to operators while neglecting the roles of system designers and regulators (Table 2). This contrasts sharply with international standards like EU Directive 89/391/EEC, which mandates shared accountability across stakeholders. The absence of binding design standards (e.g., ISO 11064) and protected error-reporting mechanisms further entrenches systemic risks, as organizations prioritize secrecy over transparency [11]. Such legal gaps not only hinder justice for affected workers but also perpetuate unsafe practices, as seen in the 2018 Mahshahr refinery fire [4].

4.3. Interdisciplinary Solutions for Reform

The study demonstrates that digital forensic medicine—leveraging sensor logs, AI-driven timelines, and simulation tools—can reconstruct errors with unprecedented precision, challenging simplistic narratives of “operator negligence.” For instance, forensic analysis revealed that 40% of operator overrides were direct responses to system design flaws, shifting liability to manufacturers (Table 3). To address these challenges, the following reforms are proposed:

- **Tiered Liability Frameworks:** Assign accountability to operators, designers, and regulators based on forensic evidence.
- **Mandatory Design Standards:** Enforce ISO 11064 for HMIs and IEC 61511 for safety systems.
- **Protected Reporting Mechanisms:** Incentivize transparency through anonymous digital platforms and legal safeguards.
- **Forensic Literacy Training:** Integrate digital reconstruction tools into operator certification programs.

4.4. Broader Implications and Global Relevance

While this study focuses on Iran, its insights resonate globally. The hybrid methodology—combining technical reconstruction with human factors and legal analysis—offers a template for high-risk industries worldwide, particularly in contexts where legacy systems and regulatory fragmentation persist. For Iran, aligning policies with international standards could mitigate sanctions-driven vulnerabilities while enhancing safety and legal compliance.

4.5. Limitations and Future Directions

Despite its contributions, this study faces limitations, including underreporting of errors in state-owned plants and restricted access to advanced forensic tools due to sanctions. Future research should expand the case study scope, incorporate AI-driven predictive modeling, and explore cross-jurisdictional comparisons to refine liability models. Additionally, longitudinal studies tracking policy reforms could assess the long-term efficacy of proposed solutions.

4.6. Final Remarks

The legal reconstruction of human error is not merely a technical exercise but a societal imperative. By bridging forensic data, human behavior analysis, and legal accountability, this research advocates for systemic reforms that prioritize safety, equity, and transparency. For Iran’s petrochemical sector—a linchpin of its economy—such reforms could catalyze a paradigm shift from reactive blame cultures to proactive, resilience-focused systems, ensuring safer industrial futures in an era of increasing automation.

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References

1. Ministry of Petroleum. (2023). Iranian petrochemical industry annual report. *Tehran: Government Publications*.
2. Ahmadi, M., Rezaei, S., & Sadeghzadeh, A. (2021). Human error analysis in Iranian petrochemical plants. *Journal of Occupational Health and Safety*, 12(4), 45-60.
3. Reason, J. (1990). *Human error*. Cambridge university press.
4. Ghorbani, R., & Maleki, A. (2020). Sanctions and technological adaptation in Iran's energy sector. *Energy Policy*, 147, 111872.
5. Habibi, M. (2019). Legal challenges in Iranian industrial liability. *Tehran Law Review*, 22 (1), 89-104.
6. Salmon, P. M., et al. (2021). Systems thinking in safety investigations. *Safety Science*, 135, 105119.
7. Birk, D., & Wegener, C. (2020). Digital forensics in industrial control systems. *IEEE Transactions on Industrial Informatics*, 16 (5), 3102-3111.
8. Perrow, C. (2011). *Normal accidents: Living with high risk technologies-Updated edition*. Princeton university press.
9. Aven, T. (2016). Risk assessment and risk management: Review of recent advances on their foundation. *European journal of operational research*, 253(1), 1-13.
10. Chemical Safety Board (CSB). (2020). Texas petrochemical fire final report. U.S. CSB.
11. ISO 11064-1:2013. (2013). Ergonomic design of control centers. ISO.