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REVIEW ARTICLE

Investigating the probability of human error in Iran's industrial control rooms – A systematic review

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ABSTRACT

Following the occurrence of human errors in industry control rooms, catastrophic events with a high socio-economic burden may occur. The present study was aimed to investigate the probability of human error in Iranian industrial control rooms. In this review study, related articles were thoroughly reviewed in the Google Scholar, Scopus, Embase, PubMed, Web of Science, Magiran, SID, and IranDoc databases from 2010 to 2021. The used search terms were "human error", "Human failure", "control room", "industry", "human error assessment", "safety management", "Error analysis" and "human error probability". In order to extract the required data, all parts of the articles have been reviewed. To evaluate the quality of the reviewed articles, the JBI checklist was used. Out of 412 studies identified through systematic search, 22 articles were qualitative for analysis of which 14 articles (63.6%) are related to process industries and 8 articles (36.4%) are related to other industries. Among the 10 techniques used in the articles, CREAM and SHERPA techniques were the most used. In the process industries, using the CREAM method, execution failure (31.72%-55%), and interpretation failure (18.57%-29.20%), and using the SHERPA method, action errors (48.62%-67.64%) and checking errors (11.61%-31.97%) were the main types of errors in the control rooms. As well as, in other industries, using the SHERPA method, action errors (38.08%-58.80%) and checking errors (29.40%-39.04%), and using the Human HAZOP method, delete errors and performance errors were the main types of errors in the control rooms. The results of studies show that human error has a significant share in the occurrence of accidents in control rooms, but in Iran in some industries such as rail and nuclear has been less attention.

KEYWORDS: *Human error, Human failure, control room, systematic review, industry*

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INTRODUCTION

Many large industries, such as nuclear, oil and gas, petrochemical, and cement, have complex processes that process hazardous chemicals [1]. In all these industries, control rooms have been installed in order to control and monitor the processes. These control rooms use advanced and sensitive systems to perform operational processes [2]. These advanced and sensitive systems are constantly in touch with operators, and operators play an essential role in setting up and controlling these systems [2].

Control room operators are responsible for coordinating and overseeing operational processes. Catastrophic events may occur if control room operators fail to perform their assigned tasks [3]. Increasing process complexity, sophisticated management strategies, reducing people without improving their cognitive skills in the face of emergencies, and performing multiple simultaneous tasks pave the way for human error in many parts of industrial processes, including control rooms [4].

In many parts of industrial processes, including control rooms, there is much irreparable damage in the event of an accident. Sometimes the economic and psychological burden of the accident in industrial processes goes beyond one country and affects the surrounding countries [1]. This can increase public concern (social stability) and damage the environment. The occurrence of important events such as Flixborough (England, 1976), Three Mile Island (America, 1979), and Chernobyl (Russia, 1986) shows that human error can lead to huge (unfortunate) events with high intensity and consequences [5].

Many catastrophic events have occurred following human factor in Iran. For example, one of them was the collision of two trains on the Semnan-Damghan axis (November 25, 2016), which killed 47 and injured 103 people [6]. The study of the human role and subsequent human error as a direct factor in accidents can be critical, given such incidents. For this purpose, research has been conducted in Iran's industrial control rooms. In a cross-sectional study conducted in an Iranian gas refinery using the Systematic Human Error Reduction and Prediction Approach (SHERPA) method, the results showed that 66.5% of the errors were action errors, 28% of the errors were checking errors, 1.8% of the errors were retrieval errors, 2.8% of the errors were communication errors, and 0.9 % of errors were selection errors [7]. In another cross-sectional study using the Cognitive Reliability and Error Analysis Method (CREAM) in the petrochemical industry, the results showed that 48.57% of the errors were execution failure, 18.57% were Interpretation failure, 15.71% were planning, and 17.15% were observation failure [8].

On the other hand, due to the dispersion of studies conducted in the control rooms of different industries in Iran, in order to compile and cover the studies conducted in this field, a systematic review study should be conducted. In addition, according to the searches conducted by the authors of this study, no review studies have been conducted in this area so far. This systematic review study was conducted to investigate the probability of human error in Iran's industrial control rooms. Finally, this study assisted to transfer knowledge about human error in industry control rooms.

MATERIALS AND METHODS

Search strategy

The authors used eight databases: Google Scholar, Scopus, PubMed, Embase, Web of Science, Magiran, SID, and IranDoc to check for related articles. Research articles published in English and Persian in these databases were extracted from 2010 to 2021. Keywords used for the search included "human error", "Human failure", "control room", "industry", "human error assessment", "safety management", "Error analysis" and "human error probability".

Study selection

The authors separately reviewed search results and screened eligible articles for full-text review. All studies that specifically examined the likelihood of human error in Iran's control rooms between 2010 and 2021 were included in the study. In contrast, non-research articles such as authors' notes, editorials, common texts, letters to the editor, and articles not written in Persian and English were removed. Figure 1 shows the general process of selecting articles.

Data extraction

The authors used a form that contained information such as the study design, the method of task analysis, the technique of identifying and evaluating human error, the type of industry, and the results.

Evaluation criteria for the quality of articles

The Joanna Briggs Institute (JBI) checklist was used to measure the quality of the articles [9]. With this 9-question checklist, the quality of the articles was evaluated as "yes", "no", "unspecified" and "not applicable" by answering these questions. The Meta-analyzes Of Observational Studies in Epidemiology (MOOSE) checklist was also used to write the article itself. This 35-question checklist contains features for specifying systematic review articles and observational meta-analyses [10].

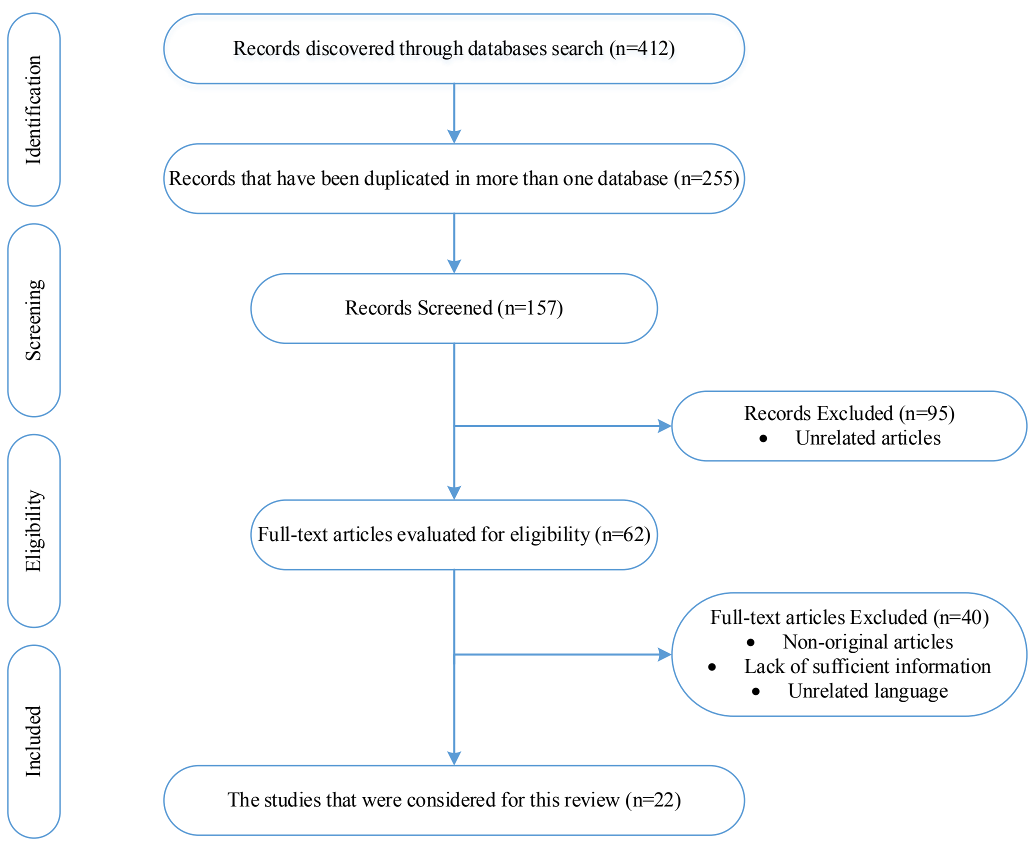


Figure 1. The process of identifying and selecting article

Table 1. Human error investigations in the process industry's control rooms

Study Design	Task Analysis Method	Technique	Results	Reference
		Petrochemical industries		
Cross-sectional Study	HTA	CREAM	**Error types:** • Execution failure (48.57%) • Interpretation failure (18.57%) • Planning failure (15.71%) • Observation failure (17.15%)	[8]
Cross-sectional Study	HTA	CREAM	**Error types:** • Execution failure (31.72%) • Interpretation failure (29.20%) • Planning failure (14.63%) • Observation failure (24.39%)	[11]
Cross-sectional and Analytical-Descriptive study	HTA	CREAM	**Error types:** • Execution failure (51.70%) • Interpretation failure (19.55%) • Planning failure (14.94%) • Observation failure (13.81%)	[12]
Descriptive-Analytic Study	HTA	CREAM	**Error types:** • Execution failure (55%) • Interpretation failure (20%) • Planning failure (14.9%) • Observation failure (10.1%)	[13]
Case Study	HTA	SHERPA	**Error types:** • Action errors (48.62%) • Checking errors (31.97%) • Retrieval errors (6.75%) • Communication error (11.70%) • Selection errors (0.90%)	[1]
Case Study	HTA	TRACEr	Detected errors (n= 1171) **Error types:** • Internal error modes (50.67%) • External error modes (49.33%)	[14]
Case Study	HTA	HEART	**Tasks with a high probability of error (Job):** • problems review (Work shift) (0.98) • Launch the boiler (Supervisor) (0.844) • production control (Supervisor) (0.497) • Repairs (Work shift) (0.436)	[15]
		Oil and Gas industries		
Case Study (Oil Refinery)	HTA	SHERPA	Detected errors (n= 198) **Error types:** • Action errors (67.64%) • Checking errors (11.61%) • Retrieval errors (12.12%) • Communication error (5.6%) • Selection errors (3.03%)	[2]
Cross-sectional Study (Gas Refinery)	HTA	SHERPA	Detected errors (n= 218) **Error types:** • Action errors (66.5%) • Checking errors (28%) • Retrieval errors (1.08%) • Communication error (2.8%) • Selection errors (0.9%)	[7]

Study Design	Task Analysis Method	Technique	Results	Reference
Case Study (Oil Refinery)	HTA	HEIST	Detected errors (n= 300) **Significant causes of human error** (71%): • interactions with controllers and indicators • instructions • training and experience	[16]
Retrospective Study (Gas Refinery)	RCA	HFACS	**Levels of human error distribution**: • Unsafe acts (31%) • Prerequisites for unsafe actions (27.93%) • Insecure monitoring (26.27%) • Organizational impacts (14.80%)	[17]
		Cement industries		
Case Study	HTA	CREAM	**Error types:** • Execution failure (43%) • Interpretation failure (26%) • Planning failure (20%) Observation failure (11%)	[3]
Cross-sectional Study	HTA	CREAM	**Error types:** • Execution failure (42.74%) • Interpretation failure (23%) • Planning failure (20.61%) • Observation failure (13.74%)	[18]
Case Study	HTA	HEART	Detected errors (n= 80) **Tasks with a high probability of error:** • monitoring and controlling warning symptoms by the operator • coordination to resolve this problem by supervisor	[19]

Abbreviations

HTA: Hierarchical Task Analysis; **CREAM**: the Cognitive Reliability and Error Analysis Method; **SHERPA**: Systematic Human Error Reduction and Prediction Approach; **TRACEr**: Technique for the Retrospective and predictive Analysis of Cognitive Errors; **HEART**: Human Error Assessment and Reduction Technique; **HEIST**: Human Error Identification in Systems Tool; **RCA**: Root Causes Analysis; **HFACS**: Human Factors Analysis and Classification System.

Table 2. Human error investigations in other industries' control rooms

Factory	Study Design	Task Analysis	Technique	Result	Reference
Pipe Manufacturing Company	Cross-sectional analytical study	HTA	THERP	**Tasks with a high probability of error:** Problem occurrence and keeping device on Mounting coil on the saddle Shutting device down quickly Removing excrescences from roller	[20]
Syringe Factory	Analytical Study	HTA	PHEA	Detected errors (n= 175) **Error types:** • Action errors (58.85%) • Checking errors (14.28%) • Retrieval errors (5.71%) • Information errors (2.28%) • Selection errors (8.57%) • Sequence errors (10.28%)	[5]
Polymer Company	Descriptive and Cross-sectional Study	HTA	CREAM	**Error types:** • Execution failure (45%) • Interpretation failure (22%) • Planning failure (11%) • Observation failure (22%)	[21]
Combined cycle power plant	Cross-sectional Study	HTA	SHERPA	Detected errors (n= 115) **Error types:** • Action errors (38.08%) • Checking errors (39.04%) • Retrieval errors (8.61%) • Communication error (13.89%) • Selection errors (3.03%)	[22]
An Airport Control Tower	Case study	HTA	TRACEr	Detected errors (n= 315) **Error types:** • Internal error modes (40.63%) • External error modes (59.37%)	[23]
A Flour Company	Descriptive-Cross-sectional Study	HTA	Human HAZOP	Detected errors (n= 144) **Error Type:** • Delete (75%) • Performance (9.02%) • Sequence (6.94%) • Irrelevant actions (4.86%) • Schedule (4.16%)	[24]
Desalting Unit and Compression Station at Maroon	Cross-sectional Study	HTA	Human HAZOP	**Causes of human error:** • Not performing job tasks (88.33%) • Doing the duty less than necessary (1.88%) • Doing the duty more than necessary (8.13%) • Doing duty late (1.88%)	[25]
Pipe Mill	Descriptive study	HTA	SHERPA & HET	**Error types:** • Action errors (58.80%) • Checking errors (29.40%) • Retrieval errors (0%) • Communication error (0%) • Selection errors (11.76%)	[26]

Abbreviations
HTA: Hierarchical Task Analysis; **THERP**: Technique for Human Error Rate Prediction; **PHEA**: Predicted Human Error Analysis; **CREAM**: the Cognitive Reliability and Error Analysis Method; **SHERPA**: Systematic Human Error Reduction and Prediction Approach; **TRACEr**: Technique for the Retrospective and predictive Analysis of Cognitive Errors; **HAZOP**: Hazard and Operability Analysis; **HET**: Human Error Template.

RESULTS

Table 1 lists the final studies selected to estimate the probability of human error in process industry control rooms. Table 2 also shows the final list of selected studies on estimating human error probability in control rooms of other industries (manufacturing and services) in Iran. Tables 1 and 2 also show the methods used to investigate the probability of human error in Iran's industrial control rooms.

As shown in Tables 1 and 2, out of 22 articles, 14 articles (63.6%) are related to process industries and 8 articles (36.4%) are related to other industries (manufacturing and services). In addition, 8 articles (36.4%) were case-based, 6 articles (27.3%) were cross-sectional, and other articles were published in other study design. In most studies (96%), the Hierarchical Task Analysis (HTA) technique has been employed to analyze the task. 7 articles (32%) used the CREAM technique and 5 articles (23%) used the SHERPA technique to identify and evaluate the possibility of human error (Figure 2).

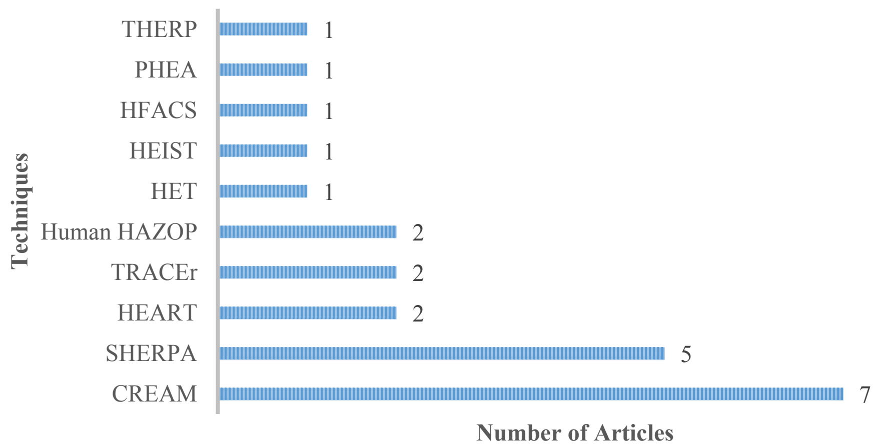


Figure 2. Distribution of studies based on techniques used to identify and evaluate human error.

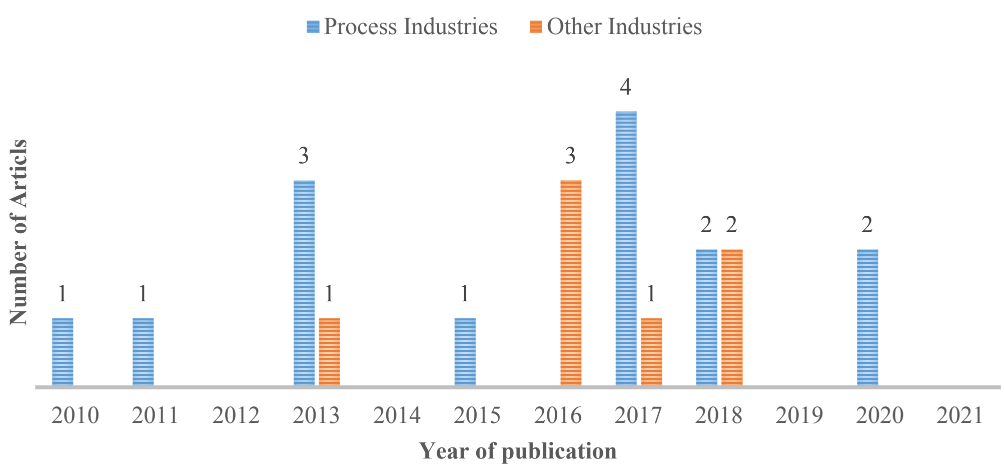


Figure 3. Distribution of articles by year of publication

The distribution of published articles to investigate the human error in Iran's control rooms based on the year of publication is shown in Figure 3. The number of related articles in prior years has not been significant. So that between 2010 and 2015, seven articles have been published in this regard. However, since 2015, this trend has been on the rise (15 articles).

Among the applied techniques, CREAM and SHERPA techniques are mostly used in process industries. In these industries, by using the CREAM technique, the major errors identified were execution failure (31.72%-55%) and interpretation failure (18.57%-29.20%) [3, 8, 11-13, 18, 19]. Also, using SHERPA technique, the major errors identified were action errors (48.62%-67.64%) and checking errors (11.61%-31.97%) [1, 2, 7].

It is worth noting that, SHERPA and Human Hazard and Operability Analysis (HAZOP) techniques are mostly used in other industries. According to the SHERPA method in these industries, action errors (38.08%-58.80%) and checking errors (29.40%-39.04%) have been the main errors identified [22, 26]. According to the Human HAZOP method, the significant errors were delete errors or performance errors [24, 25].

DISCUSSION

This systematic review study was conducted to investigate the probability of human error in the control rooms of Iranian industries. Significant studies in Iran have been conducted to estimate the probability of human error of control room operators in process industries. Control rooms are of particular importance in process industries, and in case of any defect or breakdown in them, the working processes of these industries will be disrupted [27].

Process industry control rooms

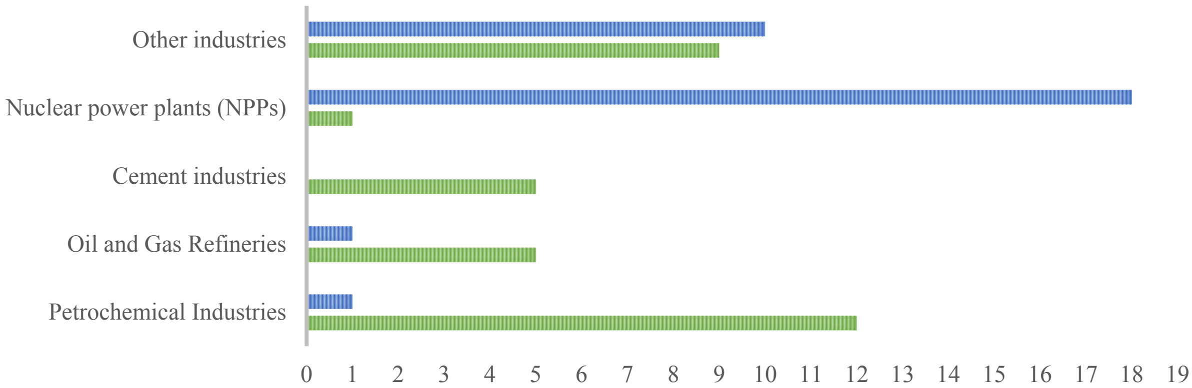
In the process industry, control room operators oversee a wide range of processes in large work environments [27]. Operators in these industries monitor and control processes using sophisticated and modern hardware such as Closed-Circuit TVs (CCTVs) or visual displays [28]. Operators must evaluate a large amount of data when reviewing and controlling these complex and dangerous processes to make effective and robust decisions to achieve the system goal [29]. Correct and principled evaluation of data by operators becomes critical when the work processes of these industries are unstable or the equipment and work processes are defective and perform poorly [27]. In this situation, operators are responsible for this particular equipment and the health and safety of workers, and their decisions can be critical [30]. This level of responsibility increases stress and increases the probability of human error in the operation of control room operators [30]. Given the environmental conditions in control rooms and the stressful job nature of control room operators in these industries, it is necessary to investigate the probability of human error by control room operators. The petrochemical industry is one of the process industries that Iranian researchers have considered, and the probability of human error in the operators of control rooms of these industries has been investigated.

The petrochemical industry is one of the most dangerous process industries, including many process units with multiple control loops [31]. In these industries, the presence of these control loops keeps hazardous materials in a safe area and prevents accidents as much as possible; however, due to two inherent characteristics and the use of large volumes of these hazardous substances in the petrochemical industry, several operators are used for control and monitoring [32].

Following the occurrence of problems in the processes of these industries, such as the breakdown of devices or equipment, the operator's role becomes very serious and significant [31]. Catastrophic events can occur in the petrochemical industry if operators have problems in performing their assigned tasks. In a medium-sized petrochemical plant, unusual events resulting from process problems and operational accidents result in an annual loss of $ 100 million [4]. Petrochemical fire in Imam Mahshahr port, a devastating fire in Bu Ali petrochemical tank, and 12 accidents in 156 days in 2016 are devastating events in Iran's petrochemical industry [33]. Investigating the causes of the accidents, the researchers concluded that human error is the leading cause of accidents in the chemical and petrochemical industries. A case study conducted using the SHERPA method in a petrochemical plant in Iran showed that 71.25% of the errors were unacceptable, 26.75% inappropriate, and 2% with acceptable corrections [8]. As a result, it is necessary to investigate the probability of human error, identify and control the causes of such errors in the petrochemical industry. In addition, the occurrence of human error in these industries is mainly due to the additional psychological burden on the individual as a result of job stress [34]; therefore, working conditions must be created in such a way as to reduce this amount of stress.

Oil and gas refineries are also part of the processing industry. In recent years, the equipment and processes in the oil and gas industry have made great strides [35]. However, severe accidents in these industries cause a lot of human and financial losses [35]. In these industries, potentially hazardous materials are concentrated in one area and monitored by many operators [2]. Accident assessment in these industries clearly shows that many causes of severe accidents reflect human errors that can be avoided if addressed. The 1994 Texaco Refinery explosion and fire, which killed 26 people and caused approximately 48 million pounds in damage, is an example of an industrial accident caused primarily by human error [11]. In these industries, due to the high economic and psychological burden caused by accidents following human errors, it is necessary to investigate the probability of human errors by control room operators and the causes that cause them. The results of a cross-sectional study using the Human Factors Analysis and Classification System (HFACS) method in one of the gas industries showed that 31% of errors occurred due to unsafe practices, 27.93% errors occurred due to prerequisites of unsafe acts, 26.27% errors occurred due to insecure monitoring, and 14.80% errors occurred due to organizational impacts [17]. As a result, working conditions and organizational programs in the industry should be adjusted in such a way as to reduce the scope of unsafe actions by operators as much as possible.

The cement industry is also one of the critical process industries with a significant share in the national economy of developing countries [19]. Control room operators in these industries also play a vital role in implementing workflow processes [3]. In these industries, too, the human errors of the control room operator, due to their sensitive and vital nature in the processes, can have serious harmful effects [3]. For this purpose, several studies have been conducted to estimate the probability of human error in the control room operators of the cement industry. In a case study that examined the probability of human error in the control room operators of a cement plant using the CREAM method in Iran, the results showed that among the identified errors, 42.74% of the errors are related to execution failure,



	Petrochemical Industries	Oil and Gas Refineries	Cement industries	Nuclear power plants (NPPs)	Other industries
Other countries	1	1	0	18	10
Iran	12	5	5	1	9

Figure 4. The number of articles reviewed in human error in industrial control rooms in Iran and other countries from 2010 to 2021.

23% are errors related to interpretation failure, 20.61% are errors related to planning failure and 13.74% are errors related to observation failure [18]. In other industries, operators also play an essential role.

Control rooms of other industries

Control rooms can be found in many factories and other industries. Many service industries that cater to other occupations, such as rail and air transportation, have control rooms to manage and monitor their work processes. The situation is the same in the manufacturing industry. In these industries, the occurrence of human errors, however simple, in control rooms can lead to catastrophic accidents. For this purpose, studies have been conducted in this field. In a descriptive cross-sectional study conducted using the SHERPA method and the cooperation of control room operators of a combined cycle power plant in Iran, the results showed that 38.08% of the errors were related to action errors, 39.04% were related to checking errors, 13.89% were related to communication errors, 8.61% were related to retrieval errors, and 3.03% were related to selection errors [22]. Another cross-sectional study conducted using SHERPA and Human Error Template (HET) methods in a pipe mill in Iran showed that more than half of the errors were action errors, and about one-third were checking errors [26]. There are many other industries in Iran whose working conditions and nature are such that human errors should be investigated. Some of these critical industries, including the nuclear industry, have attracted the attention of other countries, while in Iran, little attention has been paid to the nuclear industry (Figure 4) [1-5, 7, 8, 11, 12, 14-20, 22-25, 27-34, 36-67].

Very little research has been done in Iran on human error in the control rooms of some industries, including the control rooms of the nuclear industry and the central control rooms of the train. In Iran, much attention has been paid to the petrochemical industry control rooms, while in other countries, the focus has been on the nuclear industry. In Iran, the control rooms of the oil, gas, and cement industries have received equal attention, while in other countries, there has not been much focus on these industries.

Table 3. Some techniques of detecting human error in control rooms

Technique	Advantages	Disadvantages	Ref
CREAM	• This technique can be very comprehensive. • When using this technique, context is taken into account. • CREAM is a straightforward, structured, and systematic approach to identifying and quantifying errors. • This technique can be used both proactively to predict potential errors and retrospectively to analyze error occurrence. • This technique has a broad range of applications. • This technique's classification is thorough and precise.	• This technique is complex and challenging for beginners. • This technique requires more resources than others. • This technique is not highly used. • This technique takes a long time to learn and apply. • Even in the most basic scenarios, application time would be significant.	[12, 70]
SHERPA	• This method provides a planned and practical approach to human error prediction. • The SHERPA categorization alerts the analyst to possible errors. • SHERPA is a proper and exhaustive technique. • This technique's application is speedy. • This technique is simple to learn and teach. • This technique has a broad range of applications.	• For large and complicated tasks, this technique can be laborious. • The preliminary HTA lengthens the analysis. • This technique does not take into account system or organizational flaws. • This method does not account for the cognitive aspects of error mechanisms.	[7, 70]
HEART	• HEART is a simple technique that requires little training. • This technique's application is speedy. • For each error-producing condition, this technique has a corresponding corrective action. • HEART provides a quantitative output to the researcher. • HEART consumes fewer resources than other methods like SHERPA.	• The analyst is given little guidance in some steps of this technique. • Even though HEART has been subjected to several validation studies, the methodology still needs additional validation. • This technique is highly subjective.	[38, 70]
TRACEr	• This technique seems to be a thorough approach to error estimation and analysis. • This technique's effectiveness is scientifically proven. • This technique is comprehensive, well-structured, and practical.	• This technique has its complexities. • For large and complicated tasks, this technique can be laborious. • This technique makes extensive use of resources. • This technique requires a thorough understanding of psychology as well as a significant amount of training time. • This method is more complex and time-consuming than others.	[32, 70]
Human HAZOP	• All errors in the system can be realized and identified by correctly applying and analyzing this technique. • This technique has an extensive range of applications. • This technique is very comprehensive and accurate, and it is built on the expertise of a group of experts. • This technique is simple to learn and teach. • This technique has a broad range of applications.	• This technique requires a significant amount of time to implement over a few weeks. • This technique requires teamwork, which is challenging to provide. • This technique yields a large amount of data that must be analyzed. • This technique's keywords are not exhaustive and are limited to the chemical or nuclear industries.	[24, 70]

Abbreviations

CREAM: the Cognitive Reliability and Error Analysis Method; **SHERPA**: Systematic Human Error Reduction and Prediction Approach; **HTA**: hierarchical Task Analysis; **HEART**: Human Error Assessment and Reduction Technique; **TRACEr**: Technique for the Retrospective and predictive Analysis of Cognitive Errors; **HAZOP**: Hazard and Operability Analysis.

In addition to paying attention to the places studied, much attention should be paid to the methods used to identify human errors. In Iran, most of the research has been done using first and second-generation methods to identify and evaluate human errors in control rooms. The first-generation techniques concentrate on the rules and levels of human activity skills, and the second-generation techniques consider both the underlying factors of human mechanisms and cognitive models [68, 69]. Third-generation techniques were being created in response to the flaws and restrictions of first and second-generation Human Reliability Assessments (HRA) techniques [38]. Therefore, third-generation techniques should be used to identify and evaluate human error in Iran's industrial control rooms. Table 3 shows the main methods used to identify human error in control rooms.

In general, the review of the studies shows that more research should be done using human error detection and evaluation techniques, especially third-generation techniques, in Iran's industrial control rooms, especially the nuclear industry.

CONCLUSION

The issue of human error to accidents appears to be of high relevance to the control rooms. The job nature of control room operators is such that they provide the conditions for error to occur. With this regard, an inherently safe approach should be used in the design of control rooms at the outset to minimize the probability of human error by control room operators. Then, by using management measures and employing competent and skilled people (well-versed and familiar with the system), it provided the ground for reducing human errors.

According to the results section, the contribution of human error studies seems to be small given the importance of the issue. In this regard, it is advised to Iranian researchers to conduct more and more comprehensive research to investigate human errors in Iran's control rooms, especially the nuclear and rail industries. Furthermore, it is recommended to pay more attention to the use of third-generation techniques in order to reduce the risk of human error of control room operators.

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CONFLICTS OF INTEREST

The authors stated that they have no known competing financial interests or personal relationships that could appear to have influenced the work reported in this article.

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