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A Cognitive Human Error Analysis with CREAM in Control Room of Petrochemical Industry

Sana Shokria,[1] Sakineh Varmazyar,[2,*] and Payam Heydari[1]

[1]Qazvin University of Medical Sciences, Qazvin, IR Iran
[2]Department of Occupational Health Engineering, Faculty of Health, Qazvin University of Medical Sciences, Qazvin, Iran

[*]*Corresponding author*: Sakineh Varmazyar, Department of Occupational Health Engineering, Faculty of Health, Qazvin University of Medical Sciences, Qazvin, Iran. E-mail: Svarmazyar@qums.ac.ir

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Abstract

Background: The cognitive human error analysis technique is one of the second-generation techniques used to evaluate human reliability; it has a strong, detailed theoretical background that focuses on the important cognitive features of human behavior.
Objectives: The aim of this study was to assign task and jobs crisis using analysis of cognitive human error with CREAM. Finally, based on the results, the major causes of error were detected.
Methods: This cross-sectional study was conducted on 53 people working in an olefin unit. It is one of the most important control rooms located in a special economic zone in Assaluyeh petrochemical industry. In this study, first a job analysis was conducted and the sub-tasks and conditions affecting the performance of the staff were determined. Then, the control mode coefficient and control mode type, as well as the possibility of total error were determined. Finally, the cognitive functions and type of cognitive error related to each sub-task were identified.
Results: Among the six evaluated occupational tasks, the tasks performed by board-man and site-man had the highest values of total human error in terms of transitory overall error coefficient (0.056 and 0.031, respectively). In addition, the following results were obtained on the basis of the extended CREAM: execution failure (31.72%), interpretation failure (29.20%), planning failure (14.63%), and observation failure (24.39%).
Conclusions: Common Performance Conditions (CPCs), empowerment, and the time available for work were among the most important factors that reduced occupational performance. To optimize a communication system, it is necessary to arrange the priority of tasks, hold joint meetings, inform the staff about the termination of work permits, hold training sessions, and measure the pollutants.

Keywords: Human Error, Control Room, Petrochemical Industry, CREAM

1. Background

The increasing development of the industry has led to the increased competition to produce more. To this end, manufacturers set goals to increase the production and remove barriers and limitations. One of the causes of industrial accidents is human error, which accounts for about 60% to 90% of all accidents (1). Therefore, human errors are considered as a major cause of fatal accidents, injuries, and damages. Garrison conducted a study in 1989 to review 100 major losses due to accidents in the hydro-carbide industry during a period of 30 years; the results indicated that human error played a major role in accidents reported in the chemical industry from 1984 to 1989. The results of some studies also show that human errors account for about 563 million dollars of damages to the industry. A new analysis, reported by the same reference, shows that during 1985 to 1990 there was about 2 billion loss due to human error (2, 3). Obviously, human error, as small as it can be, in many industrial environments can lead to a catastrophic event (4). Texaco Refinery explosion and fire in 1994, that killed 26 people and caused losses of about 48 million pounds, is an example of such accidents caused by human error. In that accident, the control room operator should have recognized 275 warnings and alarms, became aware of them, and took the necessary measures just within 11 minutes before the explosion (5). One of the common features of large process systems, such as oil and petrochemical companies, is that huge quantities of potentially dangerous substances are hoarded in a centralized unit and are controlled by various users (6). Human and financial burden of accidents in such units are not only imposed on the industry itself, but it can affect the economic situation of the country and even adjacent countries (7). Taking into account the above-mentioned facts, the critical task of process control is continuously carried out by the operators and control room staff; as a result, there is a dire need to pay special attention to human errors in such settings. In the process of assessment of human error, it is necessary to consider and detect operator error or potential human error, causal factors, and alternative strategies to solve such problems (8). Human error is known as a noble factor and key element in the control room of petrochemical industries. In the context of human error, measures such as investigating different methods of assessment, developing of new methods of analysis, trying to check more errors, and creating more detailed understanding of predisposing factors will be appropriate and effective in the reduction of human errors (9). Cognitive reliability and error analysis method (CREAM) was first introduced by Erik Hollnagelin 1998 (10). This technique is one of the second-generation techniques for Human Reliability Analysis (HRA); it has a strong, detailed theoretical background and focuses on the areas of cognitive features of human behavior. Among the most important advantages of this technique than other techniques of human error analysis, we can enumerate the followings: this method has a systematic structure for quantification of both prospective errors (anticipating human error) and retrospective errors (analyzing past events); it has a classification scheme; it is a model of cognition contextual control; it can define human errors on the basis of factors related to human, technology, and organization; hence, it is a man-technology-organization (MTO) model (11, 12). It is assumed that the most important clue to estimate human performance or human failure probability is the degree of control that human operators have over the situation (13). As a result, given the important role of human error in work system, it seems necessary to identify and evaluate human errors and adopt the necessary control measures in all operational systems – especially in critical systems like control rooms, so that to reduce the rate of accidents and reduce their related burden, which in turn can increase the efficiency and productivity of the industry and promote job satisfaction of staff (14).

2. Objectives

The current study aimed to identify and analyze human errors using a cognitive ergonomics approach by means of CREAM in one of the control rooms in petrochemical industry, so that to propose control measures to prevent and reduce human errors.

3. Methods

This cross-sectional study was conducted in one of the control rooms located in a special economic zone in Asaluyeh petrochemical industry in 2015. After initial investigations, based on interviews with health and safety experts and our observations, we selected Olefin unit control room among four possible sites, as the process in this unit has a great deal of sensitivity and complexity (Olefin, as the largest petrochemical product in Iran and also one of the largest in the world, benefiting state of the art and environmentally friendly technologies with flexible furnaces to use both liquid and gas feed). Our selection was also based on the workload assigned to control room operators and staff and the tasks/sub-tasks performed by employees. A total of 53 people were working in the olefin unit. After the primary visits and interviews, to analyze human errors using CREAM, we selected the tasks performed by control room deputy, supervisor of hot unit, supervisor of cold unit, supervisor of shift work, operator of control room, board-man, and site-man as these tasks were more challenging and complex. To use and implement this method in this study, we carried out the following steps:

The first step: analysis of job tasks via hierarchical task analysis (HTA): First, all executive tasks performed by the staff were analyzed using HTA method. Accordingly, each of the tasks was first identified via interviews and classified into sub-tasks.

The second step: evaluation of common performance conditions (CPCs) affecting user performance: In this step, after the analysis of job tasks, the general characteristics and common performance conditions affecting the operator were identified, which are presented in Table 1 (15).

In Table 1, all of the factors that improved, decreased, or had no role (Not being significant) in the performance were specified and detailed scores for each task were calculated. Every above-mentioned factor affected the probability of human error.

The third step: determining the cognitive failure probability total (CFPt): At this step, all of the activities that reduced the performance were subtracted from all activities that improved performance; the obtained value was considered as the coefficient of control mode (β), which was obtained from Equation 1.

$$\beta = \sum R - \sum I \qquad (1)$$

R: Total activities that decrease performance; I: Total activities that improve performance.

Using the values obtained from Equation No. No. 1 (Improved and reduced values) and in accordance with Figure 1, we identified the control modes of operators as described below.

Scrambled control: The choice of the forthcoming action is unpredictable or haphazard. This indicates that the operator has the least control over the system.

Opportunistic control: The next action is selected without considering the identified characteristics and condition; it might be due to operator's lack of available time, experience, etc.

Table 1. Relationship Between the Common Performance Conditions (CPCs) and the Level of Performance Reliability

(CPC)	CPC Level/Description		Effects
Adequacy of organization	Very efficient	-0.6	Improved
	Efficient	0	Not significant
	Inefficient	0.6	Reduced
	Deficient	1	
Working conditions	Advantageous	-0.6	Improved
	Compatible	0	Not significant
	Incompatible	1	Reduced
Adequacy of MMI and operational Support	Supportive	-1.2	Improved
	Adequate	-0.4	Not significant
	Tolerable	0	Not significant
	Inappropriate	1.4	Reduced
Availability of procedures/plans	Appropriate	-1.2	Improved
	Acceptable Inappropriate	0	Not significant
	Appropriate Improved	1.4	Reduced
Number of simultaneous Goals	Fewer than capacity	0	Not significant
	Matching current capacity	0	Not significant
	More than capacity	1.2	Reduced
Available time	Adequate	-1.4	Improved
	Temporarily inadequate	1	Not significant
	Continuously inadequate	2.4	Reduced
Time of day	Day time (adjusted)	0	Not significant
	Night time (unadjusted)	0.6	Reduced
Adequacy of training and Experience	Adequate, high experience	-1.4	Improved
	Adequate, limited experience	0	Not significant
	Inadequate	1.8	Reduced
Crew collaboration quality	Very efficient	-1.4	Improved
	Efficient	0	Not significant
	Inefficient	0.4	Not significant
	Deficient	1.4	Reduced

Tactical control: Operator's performance more or less follows planned procedures while some later deviations are still possible.

Strategic control: Because of the availability of sufficient time, the operator is able to control action at higher levels so that the operator can more efficiently select and take other control measures.

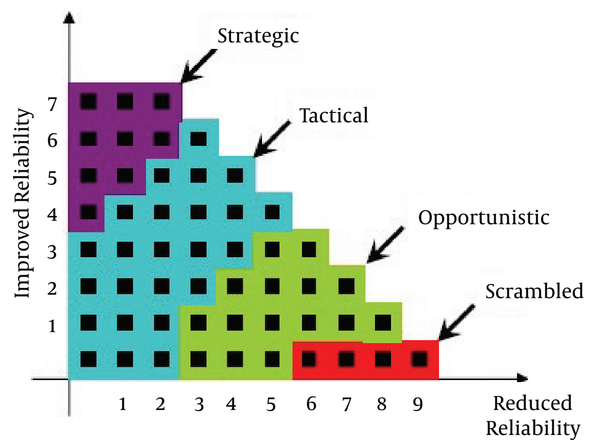

Figure 1. Determining the Control Modes on the Basis of Control Mode Coefficient (β)

Using the obtained β value, and based on Equation 2, the cognitive failure probability total (CFPt) was calculated.

$$CFPt = 0.0056 \times 10^{0.25\beta} \quad (2)$$

The fourth step: Error analysis Using extended CREAM and quantification of Cognitive failure probability (CFPi): In this step, after breaking down the tasks into sub-tasks, cognitive functions and type of cognitive errors were determined as shown in Table 2. In this cognitive cognitive functions are categorized into four classes of observation, interpretation, planning, and execution errors. Based on the type of identified error, each of the identified sub-tasks was placed in one of the sub-classes (types of cognitive errors).

Taking into account the scores obtained from the second step (total CPCs scores) and the fourth step (CFPo scores) and using the following equation, cognitive failure probability for each of the sub-tasks was calculated as follows (10):

$$CFPi = CFP \times 10^{0.25\rho II} \quad (3)$$

$$PII = \sum_{i=1}^{9} Pi \quad (4)$$

PII: The parameter defined in Equation 3 represents the total CPCs or Pi scores obtained in Table 1.

Table 2. Cognitive Failure Probability Associated With Cognitive Functions

Cognitive Function	Generic Failure Type	Basic Value
Observation	O1. Wrong object observed	0.001
	O2. Wrong identification	0.007
	O3. Observation not made	0.007
Interpretation	I1. Faulty diagnosis	0.02
	I2. Decision error	0.01
	I3. Delayed interpretation	0.01
Planning	P1.Priority error	0.01
	P2.Inadequate plan	0.01
Execution	E1. Action of wrong type	0.003
	E2. Action at wrong time	0.003
	E3. Action on wrong object	0.0005
	E4. Action out of sequence	0.003
	E5. Missed action	0.003

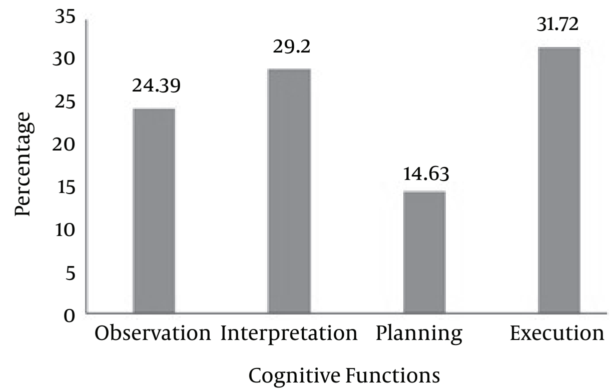

Figure 2. Percentage of Cognitive Functions in the Sub-Tasks of the Studied Jobs

4. Results

Based on the results of the present study, the highest levels of Cognitive Failure Probability total (CFPt) were observed in the tasks of control room operator – board-man, site-man, supervisor of the cold unit, supervisor of the hot unit, deputy head of the control room, and supervisor of the shift, which were 0.056, 0.031, 0.0099, 0.0099, 0.0056, and 0.0031, respectively. The score of control mode coefficient (β), scores of common performance conditions (pi), total scores of pi (PII), scores of each of cognitive errors in each sub-task (CFPo), and Cognitive Failure Probability (CFPi) were calculated via CREAM and the results are presented in Table 3.

According to Table 3, the highest levels of cognitive failure probability total (CFPt) were observed in the tasks performed by board-man and site-man, which were equal to 0.056 and 0.031, respectively; they had opportunistic control mode. The control modes of the tasks performed by the supervisor of the cold unit, the supervisor of the hot unit, and the supervisor of shift were of tactical control mode.

Based on the results of Figure 2, among all the identified tasks of six analyzed jobs, the cognitive function of Execution had a Cognitive Failure Probability total of 31.72%, which compared to other cognitive functions, it gave the highest value.

5. Discussion

Based on the results, the highest levels of cognitive failure probability total (CFPt) were observed in the tasks performed by board-man and site-man. The highest level of cognitive failure probability total (CFPt) in board-man's tasks was observed in the control mode coefficient, β, which was due to four activities that reduced the performance without any improvement in the common performance conditions. Among the effective conditions and factors that reduced the performance, we can note the followings: empowerment, the relevance of human-machine systems, the time available for work, and the quality of available trainings. Mohammadfam et al. conducted a study in 2015 and compared the two approaches of CREAM and standardized plant analysis risk human reliability analysis (SPAR-H) to examine human errors; it was found that CREAM is a reliable method to identify and analyze human error caused by the nurses (16). The control mode coefficient for the site-man's task was 3, which indicated that one activity improving the performance is subtracted from the four activities reducing performance. Among the effective conditions and factors reducing the performance of site-man, we can suggest the followings: empowerment, working conditions, performing two or more tasks simultaneously, and the time available for work. Concerning the factors improving the conditions, we can point out to the availability of procedures and plans. A comparison of the tasks of the board-men and those of the site-men showed that the two factors of empowerment and the time available for work were the common causes of reduced performance in both the tasks. In a study by Greger et al. in 1999, the authors used CREAM to analyze the causes of train crashes among the cities of Sweden; the results obtained for four tasks showed that three factors of "performing two or more tasks simultaneously", "time available for work", and "quality of available trainings and work experience" were associated with reduced performance reliability (17). According to the results obtained from Figure 2, the highest level of cognitive failure related to cognitive function (31.72%); this type of cognitive failure had the highest percentage of error among the site-man tasks. In addition, Mazlomi et al. conducted a study in 2011 using cognitive ergonomics approach to evaluate human error in a control room in petrochemical industry; according to the results, the performance error had the highest level (51.70%) (18). Among the sub-tasks of site-men, the cognitive failure of "defects in the Execution" had the highest level of cognitive failure probability (0.05). Concerning the other subtasks of site-men, including receiving permit, exchanging information, checking a site, and registering the reports, the cognitive failure probability was 0.03. The highest level of cognitive failure probability in the sub-tasks of boardmen related to observation errors, which was equal to 0.22. The observed level of cognitive failure related to the subtasks of information exchange with previous shifts, which among cognitive failures, they were sub-classes of nonobservation and incorrect detection, in sequence. In addition, concerning the sub-tasks of board-men, the highest value of cognitive failure probability (0.316) was obtained for the cognitive functions of planning and interpretations. Mirto et al. conducted a study in 2006 in order to quantify the errors in the maintenance tasks of control room operators in the chemical industry using fuzzy classification systems based on CREAM; the results showed that most cognitive activities related to connection, implementation, monitoring, diagnosis, planning, coordination, evaluation, verification and authentication, scanning, and recording, in sequence (19). Given the results of various studies, errors are associated with human factors and ergonomics science and technology (human-machine interaction) (20). Therefore, the review and evaluation of errors have an important role in the identification and reduction of common performance conditions and errors in staff operations; consequently, it can reduce human injuries and also damages to equipment, properties, and the environment. Limitations of the study included a cross-sectional nature and ignoring other methods of data collection but questionnaire and interview. Among different methods of human reliability analysis (HRA), CREAM takes a new cognitive ergonomics approach and takes human reliability into account; hence, it plays an important role in the prevention of accidents and the related outcomes.

5.1. Conclusions

The results of the present study suggest that the tasks of the board-man had the highest level of cognitive failure probability, while the tasks of the supervisor of the shift had the lowest level of cognitive error. Among the tasks of the board-men, the cognitive function of observation and among the tasks of the supervisor of the hot unit, the cognitive function of interpretation had the highest levels of cognitive failure probability. The results indicate that, concerning the tasks of staff at higher levels of organizational structure, for instance at managerial levels, there are less cognitive administrative functions and higher levels of cognitive failure probability in interpretation and planning. As a result, according to the findings of this study, control mode in managerial tasks is of opportunistic type, while in tasks requiring cognitive administrative function, the control mode is tactical. The most important recommendations to improve the existing situation and thus to reduce the rate of human errors are as follows: optimizing communication system, arranging the sequence of tasks, making coordination with other colleagues during different shifts, holding joint meetings, using practical software to empower the personnel, and using devices to measure contaminants and pollutants.

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Footnotes

Authors' Contribution: Sana Shokri, Sakineh Varmazyar and Payam heydari carried out the study design, data collection, and statistical analysis and also drafted the manuscript.

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Table 3. Results of Analysis of Human Error Using CREAM Based on a Cognitive Ergonomics Approach

(CPC)	Description	Pi	Sub-Task	Cognitive Function	Generic Failure Type	CFPi	CFP.
Task: Deputy Head of the Control Room (β = 0 Tactical) (PII = -0.6)							
Adequacy of organization	Reduced	0.06	Check out the entire unit	Observation	Observation not made	0.0049	0.007
Working conditions	Not significant	0	Study report	Observation	Wrong object observed	0.0007	0.001
Adequacy of MMI and operational Support	Reduced	1.4	Test results	Interpretation	Decision error	0.007	0.01
Availability of procedures/plans	Improved	-1.2	Repair works	Interpretation	Faulty diagnosis	0.014	0.02
Number of simultaneous Goals	Not significant	0	Problems staff	Execution	Missed action	0.0021	0.003
Available time	Improved	-1.4	Submit a report	Interpretation	Faulty diagnosis	0.014	0.02
Time of day	Not significant	0					
Adequacy of training and Experience	Not significant	0					
Crew collaboration quality	Not significant	0					
Task: Supervisor of the Hot Unit(β = 1 Tactical) (PII = -0.8)							
Adequacy of organization	Reduced	0.6	Study Report	Planning	Inadequate plan	0.00189	0.003
Working conditions	Reduced	1	Coordination with management	Interpretation	Delayed interpretation	0.0063	0.01
Adequacy of MMI and operational Support	Not significant	-0.4	Export Permit	Execution	Action of wrong type	0.00189	0.003
Availability of procedures/plans	Improved	-1.2	Monitoring of doing things	Observation	Wrong identification	0.00441	0.007
Number of simultaneous Goals	Reduced	1.2	Safety at Work	Interpretation	Decision error	0.0063	0.01
Available time	Improved	-1.4	Relationship with site-man	Execution	Action of wrong type	0.00189	0.003
Time of day	Not significant	0	Check out Board-man	Observation	Wrong identification	0.00441	0.007
Adequacy of training and Experience	Not significant	0	Report writing	Execution	Missed action	0.00189	0.003
Crew collaboration quality	Not significant	0.4	Record permit	Execution	Missed action	0.00189	0.003
Task: Supervisor of the Cold Unit (β = -1 Tactical) (PII = 1.6)							
Adequacy of organization	Not significant	0	Exchange of information	Execution	Action of wrong type	0.0075	0.003
Working conditions	Reduced	1	Study Report	Interpretation	Decision error	0.025	0.01
Adequacy of MMI and operational Support	Not significant	-0.4	Follow-up work	Planning	Priority error	0.025	0.01
Availability of procedures/plans	Reduced	-1.2	Access to routine work	Observation	Observation not made	0.0175	0.007
Number of simultaneous Goals	Reduced	1.2	Investigate and eliminate equipment failure	Interpretation	Decision error	0.025	0.01
Available time	Not significant	1	Data entry work order	Observation	Faulty diagnosis	0.005	0.02
Time of day	Not significant	0	Record permit	Planning	Priority error	0.025	0.01
Adequacy of training and Experience	Not significant	0	Association with shift work site	Planning	Inadequate plan	0.025	0.01

Crew collaboration quality	Not significant	0	Monitor and follow control	Planning	Priority error	0.025	0.01
			Monitoring and follow-up site	Interpretation	Decision error	0.025	0.01
			Close permit	Observation	Observation not made	0.025	0.007
			Report writing	Interpretation	Faulty diagnosis	0.005	0.02
Task: Supervisor of the Shift (β = 0 Tactical) (PII = -1.8)							
Adequacy of organization	Not significant	0	Study report	Observation	Wrong identification	0.007	0.0024
Working conditions	Not significant	0	Exchange of information	Interpretation	Faulty diagnosis	0.02	0.007
Adequacy of MMI and operational Support	Not significant	-0.4	Obtaining work permits, repairs and issue a permit	Execution	Action out of sequence	0.003	0.001
Availability of procedures/plans	Improved	-1.3	Process control and monitoring problems	Interpretation	Faulty diagnosis	0.02	0.007
Number of simultaneous Goals	Reduced	1.2	Submit a Report and conclusions	Execution	Action of wrong type	0.003	0.001
Available time	Improved	-1.4					
Time of day		0					
Adequacy of training and Experience	Not significant	0					
Crew collaboration quality	Not significant	0					
Task: Operator Board-Man (β = 4 Opportunistic) (PII = 6.2)							
Adequacy of organization	Reduced	0.6	Exchange data with previous shifts	Observation	Observation not made	0.007	0.22
Working conditions	Not significant	0	Study Report	Observation	Wrong identification	0.007	0.22
Adequacy of MMI and operational Support	Reduced	1.4	Follow-up work	Planning	Priority error	0.01	0.316
Availability of procedures/plans	Not significant	0	Control conditions	Interpretation	Decision error	0.01	0.316
Number of simultaneous Goals	Not significant	0					
Available time	Reduced	2.4					
Time of day	Not significant	0					
Adequacy of training and Experience	Reduced	1.8					
Crew collaboration quality	Not significant	0					
Task: Operator Site-Man (β = 3 Opportunistic) (PII = 4)							
Adequacy of organization	Reduced	0.6	Exchange of information	Execution	Action of wrong type	0.003	0.03
Working conditions	Reduced	1	Get permit	Execution	Action out of sequence	0.003	0.03
Adequacy of MMI and operational Support	Not significant	0	Routine work (Check the website)	Execution	Missed action	0.003	0.03
Availability of procedures/plans	Improved	1.2	Repair works	Execution	Action on wrong object	0.005	0.05
Number of simultaneous Goals	Reduced	1.2	Submit a report	Execution	Action on wrong object	0.003	0.03
Available time	Reduced	2.4					
Time of day	Not significant	0					

Adequacy of training and Experience	Not significant	0					
Crew collaboration quality	Not significant	0					