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Evaluating Human Errors using HEART and TRACEr Methods: Case Study at a Petrochemical Plant

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ABSTRACT

Human error is one of the most important factors contributing to accidents. Unfortunately, in many reported accidents, a human error such as Bhopal, Three Mile Island, and Chernobyl played a significant role. The purpose of this research was to identify and evaluate the human errors that happened by the butene-1 unit's control room operators in a petrochemical industry using Human Error Assessment and Reduction Technique (HEART) and Technique for the Retrospective and Predictive Analysis of Cognitive Errors (TRACEr) methods. In this study, 9 control room operators in a petrochemical industry unit based on the three-shift work schedule was investigated in 2016. The census sampling method was used to select sample size through all operators. The data were collected using observation methods, interview with control room's operator, and shift controller as well as by previous incidents assessment. The research included three major parts. In the first part, all functions of control room operators were analyzed and a Hierarchical Task Analysis (HTA) was conducted. In the second part of this research, the types and reasons of human errors in each task were identified by the TRACEr method. Finally, in the third part, HEART method was applied regarding each job to review tasks, human error pre-condition impact factors, and determine the risk of error. In the current study, 2273 External Error Modes (EEM's), 1768 Internal Error Modes (IEM's), 1401 Performance Shaping Factors (PFS's), 1185 Psychological Error Mechanism (PEM's) were identified in the petrochemical plant's control rooms. According to the results obtained from the TRACEr technique, the most influential factors affecting the occurrence of human errors happened by the control room operators were alertness, concentration, fatigue, improper use of communication devices, and the quality of communication. Based on the findings, the most effective performance shaping factors for control room operators were alertness, concentration, and fatigue, respectively. Since, control room operators had to repeat tasks in a seated posture and in front of a monitor which may cause to decrease their alertness, concentration, and increase fatigue. So it is recommended to use smart ergonomic chairs for control room operators to prevent loss of consciousness.

KEYWORDS: *Human Error, Petrochemical Industry, Control Room, Human Error Assessment, Reduction Technique*

BACKGROUND

In recent years, human error is one of the most important factors contributing to incidents and accidents [1], additionally, this factor was a meaningful reason for most of the serious accidents in the oil and gas (O&G) industries. Stephen C et al. reviewed 163 major and/or fatal in the O&G industry accidents that happened from 2000 to 2014. The results obtained showed that the predominant context for errors was internal communication, mostly influenced by factors of perception. [2]. Therefore, it is necessary to recognize and find out human errors' main reasons, also control human errors in the petrochemical plant. The large volumes of potentially hazardous materials concentration in one unit and processes control by several operators are those general characteristics of large industries such as oil and petrochemical industries. Incidents occurring in these units are not only a threat to the equipment and personnel but also are crucial due to the consequences for neighboring areas and even neighboring countries [3].

Accidents in the gas and petrochemical industries may also lead to hydrocarbons emission into the environment. Due to their solubility, volatility, and biodegradability, they are known among the most common organic pollutants in the environment and are considered poisonous for many organisms [4]. Considering the significant importance of this problem, it is necessary that human errors are identified and evaluated in all operational systems, especially in sensitive systems such as control rooms, where human error can result in severe consequences. Additionally, appropriate controlling measures should be taken so that as a result of these measures, incidents, and the resultant costs are decreased, production and productivity are increased, and job satisfaction is enhanced [5].

Any errors in the operator function in the control room as the heart of a system may cause inevitable consequences [6]. Since the control room operator (Board Man) due to greater involvement in the process control as well as the complexity of their task, stress, fatigue is one of the most critical jobs, so that unsafe behavior can lead to disastrous results.

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On the contrary, very little human error analysis in the petroleum, petrochemical, and chemical industries was performed compared to the nuclear and aerospace industries. A complex of Buten-1 unit, LC catalyst, and TEA catalyst was selected to investigate considering to this complex potentiality for catastrophic accident such as explosions, loss of life, property, and productivity.

OBJECTIVES

The purpose of this research was to identify and evaluate the human errors that happened by the butene-1 unit's control room operators in a petrochemical industry using Human Error Assessment and Reduction Technique (HEART) and Technique for the Retrospective and Predictive Analysis of Cognitive Errors (TRACEr) methods to provide solutions to reduce or eliminate such errors. The results of this study can be generalized to all operators of the oil and petrochemical industries because similar unwanted incidents can potentially be repeated.

METHODS

In this study, 9 control room operators in a petrochemical industry unit based on the three-shift work schedule was investigated in 2016. The census sampling method was used to select sample size through all operators. The data were collected using observation methods, interview with control room's operator, and shift controller as well as by previous incidents assessment. The research included three major parts. In the first part, all functions of control room operators were analyzed and a HTA was conducted. In the second part of this research, the types and reasons of human errors in each task were identified by the TRACEr method. Finally, in the third part, HEART method was applied regarding each job to review tasks, human error pre-condition impact factors, and determine the risk of error [9-10-11].

TRACEr technique:

The TRACEr was expanded as a means of categorizing human errors and their causes in United Kingdom air traffic incident reports (NATS). This

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technique provides feedback on organizational performance before and after unwanted events. The TRACEr decision flow diagram was classified as follow: task error, information, performance shaping factors (PSF's), external error modes (EEM's), internal error modes (IEM's), psychological error mechanism (PEM's), error detection and error correction [12-13].

The TRACEr method was summarized and has been presented in Table 1.

HEART technique:

Human Error Assessment and Reduction Technique (HEART) is one of the main tools for assessment and evaluating the probability of human erroneous actions. The HEART technique was summarized and has been showed in Table 2 [14-15].

Table 1. TRACEr methodology

Step	Task
1	Analyses incident into ”error events“
2	Task Error Classification
3	EEM Classification Information
4	IEM Classification Information
5	PEM Classification
6	PSF Classification
7	Error detection and Error correction

Table 2. HEART methodology

Step	Task	Output
1	Generic Task Unreliability: Classify the task in terms of its generic human unreliability into one of the 9 generic HEART task types (Table 3)	***Nominal human unreliability probability***
2	Error Producing Condition & multiplier: Identify relevant error producing conditions (EPCs) to the scenario/task under analysis which may negatively influence performance and obtain the corresponding multiplier (Table 4)	Maximum predicted nominal amount by which unreliability may increase(***Multiplier)***
3	Assessed Proportion of Effect: Estimate the impact of each EPC on the task based on judgment	***Proportion of effect*** value between 0 and 1
4	Assessed Effect: Calculate the " assessed impact" for each EPC according to the formula: *Muliplier-1)Assessed Proportion of Effect* 1	***Assessed impact value***
5	Human Error Probability: Calculate overall probability of failure of task based on the formula: *Nominal human unreliability× Assessed impact1× Assessed impact 2, etc.*	***Overall probability of failure***

Table 3. Generic task unreliability

	Generic Task	Proposed nominal human unreliability (5^{th}-95 th percentile bounds)
A	Totally unfamiliar, performed at speed with no real idea of likely consequences	0.55(0.35-0.97)*
B	Shift or restore system to a new or original state on a single attempt without supervision or procedures	0.26(0.14-0.42)
C	Complex task requiring high level of comprehension and skill	0.16(0.12-0.28)
D	Fairly simple task performed rapidly or given scant attention	0.09(0.06-0.13)
E	Routine, highly practiced, rapid task involving relatively low level of skill	0.02(0.007-0.045)
F	Restore or shift a system to original or new state following procedures, with some checking	0.003(0.0008-0.007)
G	Completely familiar, well designed, highly practiced, routine task occurring several times per hour, performed at the highest possible standards by highly motivated, highly trained and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids	0.0004(0.00008-0.009)
H	Respond correctly to system command even when there is an augmented or automated supervisory system providing accurate	0.00002(0.000006-0.0009)
M	Miscellaneous task for which no description can be found.(Nominal 5^{th} to 95^{th} percentile data spreads were chosen on the basis of experience suggesting log– normality)	0.03(0,008-0.11)

(*5^{th}-95^{th} percentile bounds)

Table 4. Error- producing conditions (EPCs)

	Error-producing condition	Maximum predicted nominal amount by which unreliability might change going from "good" conditions to "bad"
1	Unfamiliarity with a situation that is potentially important but that only occurs infrequently or	17
2	A shortage of time available for error detection and correction (P)	11
3	A low signal-to-noise ratio (C)	10
4	A means of suppressing or overriding information or features that is too easily accessible	9
5	No means of conveying spatial and functional information to operators in a form that they can readily assimilate	8
6	A mismatch between an operator's model of the world and that imagined by the designer (C, M)	8
7	No obvious means of reversing an unintended action	8
8	A channel capacity overload, particularly one caused by simultaneous presentation of non-redundant information	6
9	A necessity to unlearn a technique and apply one that requires the application of an opposing philosophy	6
10	A necessity to transfer specific knowledge from task to task without loss (C)	5.5
11	Ambiguity in the required performance standards	5
12	A mismatch between perceived and real risk	4
13	Poor, ambiguous, or ill-matched system feedback (C, I)	4
14	No clear direct and timely confirmation of an intended action from the portion of the system over which control is to be exerted	3
15	Operator inexperienced (e.g., a newly qualified tradesman, but not an "expert")	3
16	An impoverished quality of information conveyed by procedures and person-person interaction	3
17	Little or no independent checking or testing of output (P, I, M)	3
18	A conflict between immediate and long-term objectives	2.5
19	No diversity of information input for veracity checks	2.5
20	A mismatch between the educational achievements level of an individual and the requirements of the task	2
21	An incentive to use other more dangerous procedures (P, C)	2
22	Little opportunity to exercise mind and body outside the immediate confines of the job	1.8
23	Unreliable instrumentation (I, M)	1.6
24	A need for absolute judgments that are beyond the capabilities or experience of an operator (C)	1.6
25	Unclear allocation of function and responsibility	1.6
26	No obvious way to keep track of progress during an activity	1.4
27	A danger that finite physical capabilities will be exceeded (P)	1.4
28	Little or no intrinsic meaning in a task	1.4
29	High-level emotional stress	1.3
30	Evidence of illness among operatives, especially fever (P)	1.2
31	Low workforce morale (C, M)	1.2

32	Inconsistency of meaning of displays and procedures	1.2
33	A poor or hostile environment (below 75% of health or life threatening severity) (P)	1.15
34	Prolonged inactivity or highly repetitious cycling of low mental workload tasks	×1.1 for first half hour ×1.05 for each hour thereafter
35	Disruption of normal work-sleep cycles (C, M)	1.1
36	Task pacing caused by the intervention of others	1.06
37	Additional team members over and above those necessary to perform task normally and satisfactorily	× 1.03 per additional man
38	Age of personnel performing perceptual tasks	1.02

RESULTS

The main findings of the study have been presented in three parts based on the research methodology:

First, the results of hierarchical task analysis (HTA): The results of HTA showed that 16 major tasks and 305 minor tasks totally were identified in in the petrochemical plant's control rooms whereas all identified major and minor tasks have been summarized in Table 5.

The results of TRACEr:

Second, the results of TRACEr showed that 2273 external error modes (EEM's), 1768 internal error modes (IEM's), 1401 performance shaping factors (PFS's), and 1185 psychological error mechanism (PEM's) were identified in the petrochemical plant's control rooms. The number of EEM, IEM, PFS and PEM for control room's operator and shift controller were showed in Tables 6, 7, 8, and 9, respectively.

Table 5. The number of Major and Minor tasks

Position	Major task	Minor task
Control room's operator	9	279
Shift controller	7	26
Total	16	305

Table 6. The results of EEM summary

Error Types	EEM	Control room's operator		Shift controller	
		Frequent	**Percent**	**Frequent**	**Percent**
Selection and Quality					
	Omission	79	3.87	16	6.84
	Action too much	26	1.28	0	0
	Action too little	27	1.33	0	0
	Action in wrong direction	72	3.53	18	7.69
	Wrong action on right object	114	5.59	0	0
	Right action on wrong object	112	5.49	0	0
	Wrong action on wrong object	205	10.05	3	1.28
	Extraneous act	88	4.33	1	0.43
Timing and sequence					
	Action too long	44	2.16	0	0
	Action too short	85	4.17	5	2.13
	Action too early	160	7.85	1	0.43
	Action too late	275	13.49	10	4.27
	Action repeated	25	1.22	0	0
	Miss-ordering	73	3.58	1	0.43
Communication					
	Unclear information transmitted	82	4.02	19	8.12
	Unclear information recorded	23	1.13	16	6.84
	Information not sought/obtained	56	2.74	40	17.09
	Information not transmitted	140	6.87	19	8.12
	Information not recorded	23	1.13	16	6.84
	Incomplete information transmitted	142	6.96	19	8.12
	Incomplete information recorded	23	1.13	16	6.84
	Incorrect information transmitted	142	6.96	19	8.12
	Incorrect information recorded	23	1.13	15	6.41

Table 7. The results of IEM results

Cognitive domains	IEM	Control room's operator		Shift controller	
		Frequent	**Percent**	**Frequent**	**Percent**
Perception					
	No detection (visual)	38	2.3	3	2.8
	No detection (auditory)	16	0.96	3	2.8
	Late identification (visual)	73	4.39	3	2.8
	Late auditory recognition	13	0.78	3	2.8
Memory					
	Forget previous actions	79	4.76	16	14.96
	Forget temporary information	45	2.71	1	0.94
	Forget stored information	76	4.57	5	2.8
Judgment, planning, and decision making					
	No plan	57	3.43	5	4.67
	Poor decision	255	15.35	1	0.94
	Late decision	265	15.96	5	4.67
	No decision	188	11.32	0	0
Action execution					
	Selection error	119	7.16	1	0.94
	Timing error	178	10.72	21	19.63
	Transmission error	187	11.26	24	22.43
	Record error	72	4.33	18	16.82

Table 8. The results of PSF summary

PSF	Control room's operator		Shift controller	
	Frequent	**Percent**	**Frequent**	**Percent**
Fatigue	139	10.72	9	8.65
Stress	69	5.32	1	0.96
Information complexity	73	5.63	22	21.15
Tasks complexity	13	1	4	3.85
Poor design	74	5.7	3	2.89
Displays and controls	112	8.64	0	0
Improper use of communication tools	131	10.1	10	9.61
Quality Communications	129	9.95	3	2.89
Experience	55	4.24	16	15.38
Training	41	3.16	3	2.89
Concentration	144	11.1	16	15.38
Mental skills	51	3.93	14	13.46
Alertness	266	20.51	3	2.89

Table 9. The results of PEM summary

PEM	Control room's operator		Shift controller	
	Frequent	**Percent**	**Frequent**	**Percent**
Preoccupation	177	15.82	10	15.15
Inadvertent words use instead of word	124	11.08	-	-
Lack of detailed interpretation	52	4.65	6	9.1
Insufficient information	16	1.43	-	-
Decision based action to ignore side effects	4	0.36	2	3.03
Confusion	91	8.13	1	1.51
Interference	213	19.03	22	33.33
Overload	184	16.44	17	25.76
Variability	0	0	4	6.06
Decries alertness of fatigue	250	22.34	3	4.55
Attention for one cause	8	0.72	1	1.51

The results of HEART:

After job analysis and duties error detection, all duties were imported to HEART worksheets based on the risk of error for different tasks. Afterward, those were ordered separately and the probability of those errors was calculated. The results of these calculations have been denoted in Table 10.

Table 10. The results of HEART Summary

Control room's operator		Shift controller	
Tasks	**The possibility of human error**	**Tasks**	**The possibility of human error**
Controls the reactor outlet 2001	0.945	Decision-making and action in emergency situations.	0.368
Dilution T.E.A	0.816	Operations Control	0.198
Control Catalyst Poison	0.743	Preparation instructions	0.153
Control of catalysts	0.741	restart	0.142
Getting Started	0.675	Out process of service at the time of overhaul	0.142
Control reactor pressure	0.551	Handing over shifts	0.04
Control reactor temperature	0.531	Taking over shifts	0.034
Control track	0.485		
T.E.A injection into the reactor 2001	0.232		

DISCUSSION

The aim of the study was to investigate the human errors of control room operators via HEART and TRACEr methods in a petrochemical plant.

The results of the current study showed that the transmission error and late decision were the utmost internal errors among shift controller and control room operator, respectively. On the contrary, Shah Gholi investigated the control room of an oil refinery unit human errors using the TRACEr method among the operators and identified ultimately 670 internal errors and 738 external errors in the Northern sector while 661 internal errors and 744 external errors in the Southern sector. In addition, the most number of internal errors among the shift controller and control room operator was the non-performed action error and perception error, respectively. Therefore, these findings showed inconsistency with the previous studies [12].

According to the results, performance shaping most prevalence factors among control room operators' was alertness, concentration, and fatigue, respectively. This result was in line to the findings from the study conducted by Ghalehnoi et al. which showed performance shaping most prevalence factors were fatigue, experience, and alertness [6].

The results of the human error happening possibility among control room operators showed that the highest human error possibilities were reactor outlet controls 2001, T.E.A dilution, and control catalyst poison, respectively. A different study by Ghalehnoiet et al. showed the highest human error possibility was restarting, operations control, and maintenance, respectively. Accordingly, it can be concluded that these findings were in contrast to previous studies [6]. Based on the results, the highest possibility of human error for control room operator tasks were reactor outlet controls 2001 (0.945). One of the control measures to prevent and reduce human error was changes in the control room's alert system (alarms), and so some changes and optimization in the alert system's board and software were necessary.

Considering the results of performance shaping factors (refer to Table 8), the most effective human error creator for the control room operator was alertness, concentration, fatigue, and improper use of communication tools. Since, control room operators had to repeat tasks in a seated posture and in front of a monitor which may cause to decrease their alertness, concentration, and increase fatigue. So it is recommended to use smart ergonomic chairs for control room operators to prevent loss of consciousness. The smart ergonomic chairs with the ability to create a fine shock (small shock is enough) using embedded sensors in the seat structure and hip muscle may prevent drowsiness and loss of consciousness.

It is suggested to use new and reliable technologies such as collar wireless communications equipment as well as other wireless communication systems to broaden control room operators' movability.

The human error occurring possibility among control room operators was higher compared to shift controller, so to reduce human error in various control room operation tasks, it is recommended that guidelines be developed and equipment installation checklists be provided. Similarly, Ghangiry et al. found that the possibility of human error (Forget) without a reminder was 0.1 and the possibility of human error using equipment installation checklists was 0.0003 [16].

In a study conducted by Ghalehnoei et al. the control room operators' human errors in a petrochemical industry were investigated. They divided main tasks using the HTA technique into subtasks and, thereafter the TRACEr technique was applied to identify and classify related errors. Finally, they used the HEART technique to quantify the occurrence probability of errors and concluded that the most important factors affecting human error among control room operators were fatigue, experience, alertness, complexity of information, concentration, and conditions causing errors, psychological stress, high workload, clarity of instructions, and discord between training and work tasks. The results of their study proved that the most probable error related to the tasks of reviewing faults, boilers start-up, production control, repairs and maintenance, and checking for warning signs [6]. Mazloumi et al. concluded that the most common cognitive error was the implementation error, and the most important cognitive activities associated with the control process in the control room were communication, implementation, recognition, monitoring, and planning [17].

Gülin et al. founded that the human error probability value of workflow was 65.3% in term of human‐ related errors. It means that daily control process in steam boiler, human‐ related errors occurrence probabilities was 65.3% [18].

Babaei et al. used the HTA technique for task analysis and the HEART technique to implement human error assessment. They concluded that the most important and talented operator’s tasks of "Human Error" were "monitoring and controlling of warning signs" and "coordination" to solve this problem with supervisor [19].

CONCLUSION

The results of the performance factors investigation showed that the most effective human error among the control room operators was alertness, concentration, fatigue, inappropriate use of communication devices, and quality of communication.

The control room operators have to repeat the same tasks in a seated posture whereas this situation contributes to alertness and focus reduction, and increased fatigue. It is suggested, therefore, to provide special smart ergonomic seats equipped with tiny shockers on its seat and hip muscle to prevent the loss of alertness.

In addition, it is vital to establish timely and high-quality communication in the control room, especially with the site-men. According to the observation of the researchers, the most frequent connection devices in the control room were wireless and phone. In order to keep the connection reliable, these wireless devices should be fully charged unless it may lead to communication interruptions. Having considered these issues, it is suggested to use new technologies such as specially designed light-weight and small communications devices for the control room operators and site-men wearable on their collar. Some special technical training and problem-solving techniques courses also suggested being planned for the control room operator.

In the present study, there was limited access to accurate human error records, so in the future studies, a dependable record data bank about the industrial human error accident may help to attain better results.

The results of this study showed that the TRACEr technique was time-consuming but it was an effective way to identify and categorize cognitive errors and to find the factors that affect the occurrence of errors. The HEART technique was also a time-consuming but appropriate method to quantify the human error occurrence probability. Hence, in the present study, the TRACEr method was considered as a practical and tangible way to identify and categorize errors and to find the factors that lead to errors. This method was a more practical and easy technique to assess human error than HEART. Furthermore, both TRACEr and the HEART techniques are applicable based on the hierarchical task analysis (HTA) method.

Ultimately, the results of this study provided a practical and useful method to identify hazardous human errors which may lead to accidents.

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