ORIGINAL ARTICLE

Human Reliability Assessment in Critical Operations of Blast Furnace Steering in an Iron Melting Industry

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Abstract

Background: Human errors play a crucial role in the incidence of industrial accidents. Hence, human reliability assessment (HRA) is essential as the most significant element of the system. The present study was conducted aiming at assessing human reliability in steering a blast furnace in an iron melting industry.

Methods: The study comprised all HRA stages, namely data collection (through questionnaire), determination of the scope of the study (using interviews and questionnaires), task analysis (through hierarchical task analysis (HTA), determination and identification of errors (SHERPA), screening, error quantification (HEART), and analysis and effect assessment of human error reduction.

Results: A number of 169 errors were identified among 140 Bottom-Level Tasks obtained from HTA diagrams. Among the 38 error producing factors, 22 were identified as effective factors, among which low workforce spirit (19%), excess team members (15.7%), operator inexperience (12.4%), and the poor quality of data transmission through instructions and through person-to-person interaction (11.75%) accounted for the highest effect on the whole operation.

Discussion: Human errors in operations for steering blast furnace occur due to a variety of factors, often rooted in various management levels, instructions for steering operations and repair, operators-panels interaction levels, and some factors affecting performance. As a single approach, the techniques used in this study yielded fruitful results. These techniques enjoy high validity though there were signs of technical immaturity, which led to failure in providing consistent control methods.

Conclusion: Despite the technical weaknesses in the HRA techniques, currently the HRA is a useful method to enhance the reliability of crucial operations, such as the steering operation of blast furnace.

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Introduction

The Human Reliability Assessment (HRA) is a general framework for investigating the complex system areas which indicates how human error can leave adverse effects on the risk level by penetrating the layers of protection of the system. In a more applied definition, HRA can be considered as a set of techniques used for the qualitative and quantitative assessment of human error risks in working systems.[1, 2]

There is no longer any doubt that human error plays a major role in the incidents and events after years of research to identify the causes of incidents and presentation of different statistics and models. Industrial accident analysis indicates that human error has played a decisive role in these events by 50-80%.[3] Having presented the “Swiss Cheese Model” in 1990, James Reason indicated the role and status of the human factor in events and accidents.[4-6] He also indicated that although front-line operators are often blamed by unsafe acts, the incident is the result of several hidden errors at various system levels that complete the course of accident along with the active error.

Using the current technique and its effect on many industries has been considerably less than expected along with the significant advances in this field. In comparison, a large body of literature and studies done in this field has been in the form of the development of techniques.[7] In Iran, the number of industries that utilize the human reliability analysis is still quite low compared to the existing capacities and needs. Still, many major and key industries in the country have been working for many years with a high potential beyond their planned life. Enormous amounts of energy and high volume of steering operations in this facility are controlled by multiple operators, while many of the system’s layers of protection and barriers have undergone erosion and change in nature.

A human reliability study, i.e. reducing the risk of a human agent, is necessary in order to achieve the ultimate and significant goal to identify and quantify the probable errors, and investigate them in terms of the risk nature. In this project, which is a case study, attempts were made to find the most appropriate HRA techniques considering the limiting factors of the study and the available technical capabilities and evaluate a corner of the system steering operation in the existing blast furnace.[1]

Materials and Methods

Determining the extent and scope of the study is the most basic issue in conducting HRA studies.[8] Since the HRA requires expensive resources,[9] the study will play a significant role in its results. Since the beginning, the blast furnace unit was considered as the heart of the system and the bottleneck of the production process desired by industry managers, especially safety managers, and was proposed as the site for the study since the beginning of the study. We first sought the determining factors in order to determine the most vulnerable steering operation of the blast furnace. In fact, it was necessary to determine the most risky operation among various steering operations. Considering the fact that the risk is a combination of the probability of occurrence and the severity of the outcome, for this selection we sought an operation that is more consistent with the following defined indices:

- In the first place, the operation has more repetition than other steering operations (repeating the operations).
- There are further time bottlenecks in operation (Unforgiving situations).
- The highest probable outcome is the result of failure in steering blast furnace, while the probability of an unintended outcome is not unlikely (Severity Index).
- Compared to other operations, it should have events with more repetition than other operations to have adverse and significant outcome (probability index).

Using direct observation methods, open interviews, and review of technical and operational documentation, we first obtained the technical information and the required equipment to get familiar with the system. A list of all operations was developed in steering the blast furnace. Then, all instructions pertaining to job descriptions and safety instructions pertaining to different operations were scrutinized. Although several years have passed since the last review of the instructions used in the study, it is still usable to a great extent and provided useful information to the analysts as to the the operation. Evidence and documentations revealing the history of human error were inaccessible and only the statements of the safety personnel and the control room indicated the high talent for maintaining and repairing compared to the occurrence of human error. The above indices were studied and compared considering the mentioned documents. Also, open questions were posed tailored to the operators of the blast furnace control room and were verbally asked. Eventually, the results of investigating the documents confirmed the responses of operators and safety personnel, and the “short-term stopping without burning gas in the furnace opening” and “setting up the blast furnace from the short-term stop” were selected as the most critical operations in the blast furnace steering.

The task analysis was conducted relying on the methods mentioned above for data collection, after determining the extent and limits of the HRA. In the task analysis step, the hierarchical task analysis (HTA: 5, 6, 7, 9, 10) was selected as a task analysis approach. The basis of task analysis was formed through direct observation during fulfilling the tasks, along with interviews with operators. The operational instructions were used as well.

The HTA was conducted for the intended operations, and while analyzing the tasks into its sub-tasks the plans related to the tasks of the control room and enclosure operators (shift supervisor: SS, shift technolog: TS, senior technician of gas facility: TATG, senior Gazban of gas facility: GATG, senior

Atashkar of the area: AAM, first class Atashkar as a senior Atashkar assistant: A_{NO1}, ordinary Atashkars as subordinate personnel: A), were determined as the sequence of task fulfilment. After depicting the HTA diagrams, its details were reviewed and modified by experienced operators. Some tasks were removed from control and steering operations, and some also underwent some significant changes compared to the instructions. A part of the analysis was reviewed by each operator considering his expertise, and the HTA was finally approved after minor modifications.

Probable errors were identified and evaluated along with the causes and outcomes, as well as the potential for recovery and error reduction in order to achieve the HRA purposes. Since the technique used for this purpose should enjoy reasonable capability, considering the weaknesses and strengths of the techniques and the existing conditions, one of the most reliable methods of human error identification (HEI) is SHERPA technique[1, 10] (Systematic Human Error Reduction and Prediction Approach). This technique has proven its special capabilities in different validation studies that were conducted to date. It utilizes hierarchical task analysis (HTA) along with the specific error classification (errors of actions, retrieval, revision, selection, information and communication) to determine the errors pertaining to human activity. The SHERPA technique acts by determining which of the error scenarios are probable for each of the bottom-level task steps in an HTA.[11]

The potential error was detected for each Bottom-Level Task; then, the outcomes, the error recovery, probability, and severity were determined, and eventually, probable solutions were proposed for each detected error. The probability of human error in the three categories was defined such that the repetition of the human error can be well-differentiated. According to some records of the error occurrence, this index fell into three categories of high (H), moderate (M) and low (L). In this technique, the criterion for ranking included the severity of the extent of the damage due to the probable outcomes defined as follows:[12]

- The outcome of the errors that result in direct and extensive damage to the vital elements of the furnace, and stop production for more than a month, requiring prompt action (H).
- Errors leading to weak/moderate damage, or to financial losses equivalent to the loss of one week of working, and there is also a relative shortage of time (M).
- Errors that do not directly affect the system's performance, can cause minor disruption in production, can be retrieved directly, are likely to be corrected in a relatively long time without causing incident, and do not affect the critical factors of the furnace (L).

Using the Human Error Assessment and Reduction Technique (HEART), in the quantification step, the final uncertainty number of the task was obtained only for those errors with the most severity and probability in the error identification method. Actually, severity and probability were used as indices to estimate the relative risk of the tasks, and during screening, the tasks with a higher relative risk entered the quantification stage. In the HEART method, the task was first classified into one of the general categories. Each general category had a General Error Probabilityy (GEP), especial to its own. After determining the error probability, the Error Producing Conditions were determined among 38 cases expressed by the technique regarding the conditions of doing the task. Each EPC has its own HEART effect of its own, and proportionate to the *assessed* proportion of the affect (APOA), a coefficient between 0 and 1 is considered for it. The final HEP calculation is relatively straightforward and utilizes the following empirical equation:[13]

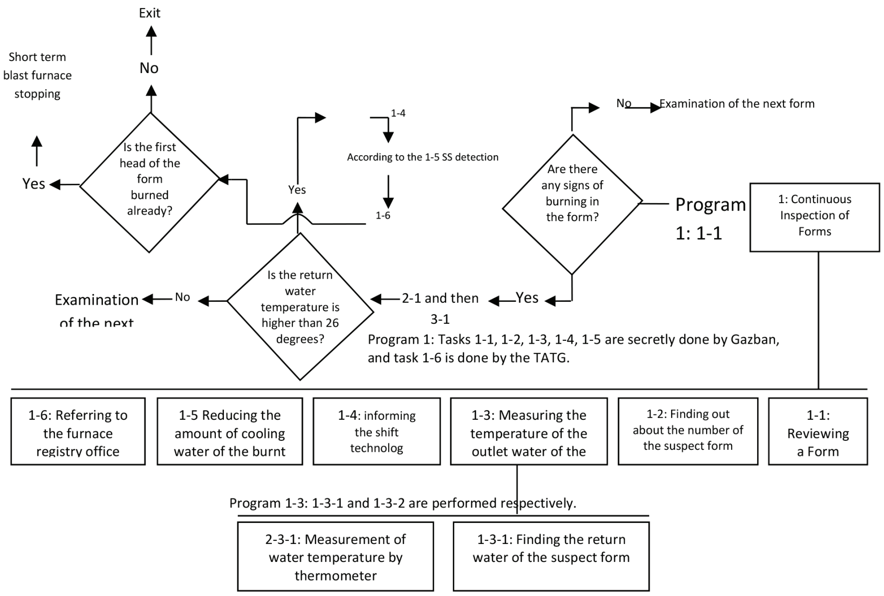
$$\text{Final HEP} = [\text{GEP} \times \prod_{i=1}^{n} APOA_i \times (\text{EPC}_{i\_} 1) + 1]$$

The effect assessment step consisted of assessing the effect of probable errors in achieving the general system purpose. At this stage, the analyst sought to know which identified errors had a significant effect failing to achieve the general purpose of the operation, and that how critical this effect was.

Results

The findings of the first step of the HRA were the information obtained following the data collection methods. Collecting data on the system hardware, operator functions, mechanism of marker and control systems, and their related ergonomic characteristics, while specifying the sensitive tasks, provides the required ground for hierarchical task analysis. The HTA results were obtained in the form of task charts and the hierarchy for operations "short-term stopping without burning gas in the furnace opening" as well as "setting up the blast furnace from a short-term stop" was indicated. Figure 1 presents a sample of the hierarchical task analysis concerning "continuous inspection of forms".

"Repairing suction valve" was analyzed along with routine operational tasks as one of the most repeated repair tasks. The final HTA tasks were subjected to human error analysis, using the SHERPA method. Table 1 presents a sample of SHERPA Tables. Among the 140 final tasks obtained, 169 errors were identified. Table 2 presents the distribution of the errors identified in a variety of errors in the SHERPA technique. As seen, the highest share of predicted errors (52.80%) pertains to error in operation. Errors in this category include committed errors and omission errors.



⁎ Forms are unlabeled and have a counting sequence.

♣ The form burning symptoms include:

• Water leakage at the form joint
• Hammering sound at the form joint
• Finding slag particles in water
• Change of the return water temperature by more than 1.8° C (a confirming sign of the burned form)

Figure 1: Hierarchical analysis of the task of investigating the forms

Table 1: A sample of the results for identifying the human error pertaining to operation during furnace stopping

Human error analysis work sheet (SHERPA)

Tasks : Operation during stop / control of gas pressure in clean gas pipe / ...
Monitoring the vapor pressure inside the gas collector / ...

Task step	Error type	Error retrieval step ¥	C	P	Psychological mechanism	Causes, outcomes and explanations	Suggestions: Instructions	Suggestions: Education	Suggestions: Equipment
1-3	A8	....	H	L	Memory defect	The gas pressure control of the clean gas pipe is ignored; decline of the pressure drop can lead to air penetration and explosion.	Update instructions for operation during furnace stop	Simulator training	Sufficient redundancy of people along with scheduled checklists
	A2	....	M	M *	Location error	Delaying the control of the pressure of a clean gas pipe can increase the risk of explosion.	Dividing workload on more people	Simulator training	Defined redundancy of people
1-4	C1	....	H	L	Defect in attention	Failing to monitor the pressure and its potential drop can increase the probability of flame or heat flush inside the duct and cause an explosion.	Separating tasks in the control room		Using the task checklists/ Create sufficient redundancy
1-5-1	C1	....	M	M	Forgetting doing the separate act / feeling of the need to information does not occur in individuals	Failing to monitor the pressure temperature of the Kauper's dome and its possible drop can lead to furnace disruption.	Separation of tasks in the instructions	Operator training in relation to Kauper's factors	task checklists
1-5-2	A6	....	M	M	Error among various cases	Opening the wrong valve among the valves and the probability of unintended events associated with the Kaupers.	....	Simulator training	Simple naming of equipment in software / creation of error messages

*The probability of an error is moderate due to the fact that all these gas tasks are handled by the senior gas facility technician (TATG), time is also limited, and the individual may lose the order of the tasks; as a result, the action is done at the wrong time.

Table 2: Distribution of the types of errors detected in the entire operation

Error type	Number of observe	Frequency
Action error	89	52.8%
Checking Error	24	14.0%
Retrieve Error	11	6.4%
Communication error	21	12.5%
Selection Error	24	14.3%
The total number of detected errors	169	100%

Table 3: Result of error quantification

Table No. :	Human error quantification worksheet (HEART)		Date : January/ 2017
Task Code : 2-1-7-2-5	Task: Repairs to replace the new cog/Making sure of the repair completion		
Task type (TT): E	Human Uncertainty Number : 0.02		
Error producing conditions (EPC$_S$)	**Most Effect**	**The evaluated Share effect**	**Computation**
A motivation to use other more dangerous instructions	×2	0.3	((2 - 1) × 0.3) + 1 = *1.30*
Low quality of information transfer through person-to-person interactions	×3	0.6	((3 - 1) × 0.6) + 1 = *2.20*
The task has a low or vague intrinsic meaning	×1.4	0.3	((1.4 - 1) × 0.6) + 1 =*2.86*

HEP = 0.02 ×*1.3* × *2.2* × 2.86 = 0.16

The quantification of the identified errors was conducted for medium and high risk errors. Using the HEART method, a sample of the results of human error quantification is presented in Table 3. Among the 38 factors producing the error, 22 were identified as effective factors, among which the low workforce spirit (19.00%), excess team members (15.70%), operator inexperience (12.40%), and the poor quality of data transmission through instructions and through person-to-person interaction (11.75%) had the most effect on the whole operation.

Here, regarding the fact that the crisis index in the error detection method also has a mixture of effect assessment, and also considering that the criterion for selecting the tasks for quantifying has been based on the error crisis rate and risk index, it can be said that the assessment of the effect has been applied at the identification and quantification stages. Although, in some cases, the error has had a low crisis rate but high probability, the analysis of human error reduction regarding the quantified tasks is not much time consuming compared to the time needed for the study period.

The EPC-based human error reduction analysis and suggestions presented in the SHERPA method were conducted considering the cost-effectiveness of the proposed measures. Eventually, suggestions were proposed in the form of simulation tutorials, adequate human resources and equipment redundancy (backing up), steering and repair instructions, locking and labeling, and safety management.

Discussion

The present study mainly aimed to identify and evaluate the errors that could occur in the "short-term stopping without burning gas in the furnace opening" as well as the "setting up the blast furnace from a short-term stop". Actually, the purpose was to identify the most sensitive tasks and promote the reliability of the operation considering the probable errors and the risk index.

The HTA indicated which sub-tasks have the most vulnerability to human error. This technique also played a useful role in identifying the operational weaknesses and providing a proper description of the tasks. Although this technique had weaknesses in this reliability assessment, it provided an adequate platform for using identification and quantification techniques. As seen in Fault Tree Analysis (FTA), HTA was unable to create a logical structure between subtasks in achieving the general purpose. This issue transferred the focus of the HTA effect assessment, mainly to error detection and reduction techniques.[14]

Using its error classification, the SHERPA technique assisted the analyst to identify the error and provided useful corrective suggestions for the error causes. Regarding the fact that SHERPA was able to use the various levels tasks of HTA, it was well associated with the HEART technique.

Human errors happen in blast furnace steering operation due to a variety of factors, often rooted in various levels of management, steering operation and repair instructions, levels of operators-panels interaction, and some factors affecting performance. Repair and maintenance was the most risky task in the investigated operation. The main reasons for this can be found in error producing situations, namely low workforce spirit, inexperience, excess team members and the low quality of the individuals' interactions. In these cases, it was suggested that such operations should be conducted under the ongoing supervision of safety officers.

The implementation method adopted for the HRA was quite consistent with the full process provided by Kervan.[11] This approach is different in some cases compared to that used by Kervan in the reference.[13] The approach proposed by Kervan is based on PSA and requires the synchronization of error risk criteria with the risk assessment criteria of equipment that is usually more detailed. Therefore, given that the present study primarily aimed at identifying and correcting errors, its separation with the PSA, laid the groundwork to modify the scope of the study in another way, considering the possibilities and limitations.

Although many of the error producing conditions have been identified, using different HRA approaches and task analysis can yield better results in assessing the reliability of such operations. In this way, the technical weaknesses can be significantly covered. It is also necessary to conduct comprehensive assessments to investigate the equipment risk such that the results obtained lay the groundwork for more detailed safety assessments.[15]

Conclusion

The identification and quantification techniques used worked well together to achieve the purposes of HRA. However, there are some techniques that need modification and revision. In addition to the immaturity and the need for HRA techniques for further modifications, HRA is currently able to play a significant role in identifying and improving the ergonomic weaknesses and in enhancing the steering operation safety of the industries, especially the significant iron melting industry.

Conflict of Interest: None declared.

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