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HUMAN RELIABILITY ASSESSMENT – A SERBIAN EXPERIENCE

Evica Stojiljkovic[1, a], Miroljub Grozdanovic[2,b]
[1,2]University of Nis, Faculty of Occupational Safety in Nis, Carnojevica 10a, Nis, Serbia
[a]evica.stojiljkovic@znrfak.ni.ac.rs; [b]mirko@ni.ac.rs

Abstract: In complex industrial systems, human error has been cited as a cause or a contributing factor in accidents and disasters. Human error assessment (HEA) is certainly a challenge for all the experts involved in risk assessment today. In Serbia, this issue has not received proper attention yet. Therefore, this paper presents the case study which confirmed that the usage of Absolute Probability Judgement (APJ) and Human Error Assessment and Reduction Technique (HEART) in Electric Power Company of Serbia (EPCS) for proper human reliability assessment (HRA). The usefulness of techniques for HRA is approved in a case study of an accident which occurred during a repair on a 10/0.4 kV steel lattice tower "Maričiće", Kuršumlija and steel lattice tower "Nova Kolonija", Veliki Trnovac in EPCS (jurisdiction of EPCS, ED "Jugoistok", Nis, Serbia). For the purpose of this studies, a database on work-related injuries, accidents, and critical interventions that occurred over a 10-year period was created. The research comprised analysis of 1074 workplaces, with a total of 3997 employees. The case studies performed at the EPCS confirmed that the the conventional APJ and HEART approach is not only highly applicable for quantification of human errors, but also comprehensive and simple to use in risk assessment of complex systems.

Keywords: Human Reliability Assessment; Human Error; Absolute Probability Judgement; Human Error Assessment and Reduction Technique; Accident; Case Study.

1. INTRODUCTION

The analysis of complex systems of various industrial activities (electric power industry, mining, aviation, petrochemical industry, etc.) has proved that human error is the most common cause of accidents. A review of literature shows that "human factor" was the cause in 80% of major accidents in the past (e.g. Chernobyl, Bhopal, Three Mile Island, etc.) and a crucial factor in around 90% of occupational injuries.

The common term "Human Error" has been defined by Swain [1] as "a member of a set of human actions that exceeds some limit of acceptability, i.e. an out of tolerance action (or failure to act) where the limits of performance are defined by the system". Human error may be triggered by different factors: insufficient qualifications of an operator, lack of precision, cognitive failure or concentration deficiency, failure to understand and follow rules, etc. [2]. Therefore, human errors are the result of person's performances, i.e. character. Performance depends on many different factors that are called Performance Shaping Factors (PSFs). Performance Shaping Factors can increase or decrease the HEP, depending on the individual characteristic of person, environment, work organization, task complexity and similar [3; 4; 5; 6].

Industrial studies of accidents are the ideal source of data on human error. Other sources are simulation data and data derived from literature on human performance. However, there are many difficulties in obtaining such information: reliability of data, different causes and mechanisms of

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error, out-of-date data, etc. [7]. For this reason methods based on the expert judgment are used for Human Error Assessment [more in: 7]. All methods for the quantification of human reliability (first, second and third generation) are based on calculation of HEP, as a measure of human reliability.

Among the first generation techniques are: Absolute Probability Judgement (APJ), Human Error Assessment and Reduction Technique (HEART), Success Likelihood Index Method (SLIM), Technique for Human Error Rate Prediction (THERP), Human Reliability Management System (HRMS), Simplified Plant Analysis Risk Human Reliability Assessment (SPAR-H), etc. Second and third generations of human reliability assessment methods are developed to overcome the deficiencies of the previous generations. Some of the second-generation methods are as follows: Cognitive Reliability and Error Analysis Method (CREAM), A Technique for Human Error Analysis (ATHEANA), Cognitive Environmental Simulation (CES), Connectionism Assessment of Human Reliability (CAHR) and Méthode d'Evaluation de la Réalisation des Missions Opérateur pour la Sûreté (Assessment Method for the Performance of Safety Operation) (MERMOS). The only methods now defined as third generation is Nuclear Action Reliability Assessment (NARA) and Railway Action Reliability Assessment (RARA) and is, in fact, an advanced version of HEART for the nuclear field.

For quantification of Human Error Probabilities in the Electric Power Company in Serbia (hereinafter EPCS), the expert team had a few meetings in order to choose the suitable methods for the mentioned type of assessment. Following four methods, APJ, HEART, THERP and SLIM were chosen as appropriate for the HRA in EPCS.

The main purpose of this paper is to show the practical application of APJ and HEART for human errors analysis in Electric Power Company of Serbia (EPCS).

2. METHODOLOGY

The APJ procedure consists of 7 steps (Figure 1) which are described in detail in the research papers [6; 7; 8; 9; 10; 11; 12; 13; 14]. There are two basic APJ approaches. In a "single expert APJ", only one expert needs to assess the probability of a human error. Kirwan (1994) emphasized the importance of group evaluation, in order to reduce the subjectivity of the assessment.

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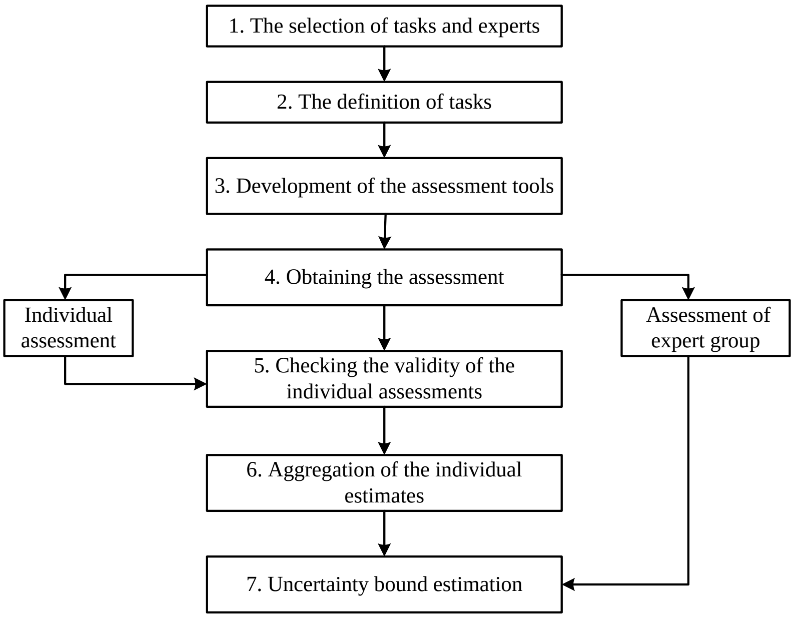

Figure 1. Procedural steps of the APJ method.

Human Error Assessment and Reduction Technique are based on the knowledge of human activities (and generic task type), the EPCs and expert experience. The method can be divided in 6 procedural steps. Following are the procedural steps of the HEART method and their basic characteristics.

Identification of Human Error: Identification relates to guidelines for identification of type and source of human error for specific situation. These guidelines are enabling a qualitative insight of error type and can be used by an expert in case of error quantification.

Task Quantification: This step is important for deriving HEP since EPCs, basically, increase the nominal HEP when a general category is set, which serves as a limit beyond which human reliability cannot increase. Determining nominal human unreliability is done based on the classification of task type (complex task, routine tasks, etc.) [more in: 7; 10; 15; 16]

Identification of Error Producing Condition: EPCs are very important for defining HEP as they have a negative impact on human characteristics [7; 10; 15; 16]. Using a small number of EPCs is obviously present in the scenarios which produce precise results.

Expert Impact Assessment: Proportion of Affect (POA) is the most difficult step for experts having in mind that selection of general categories and EPCs is a very complex process. Experts are reluctant to use the scenarios with large number of EPCs as these scenarios give confusing and poor results. For each EPCs expert, the assessment of probability on scale from 0 to 1 is determined, and that assessed overall HEART impact is assessed using the following expression:

$$E = ((ME - 1) \cdot EA) + 1 \tag{1}$$

Where: *ME* – maximum HEART effect, *EA* – expert assessment of EPCs on analyzed system (assessed POA), *E* – assessed overall HEART effect.

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Based on the classification of tasks and assessed effect for each EPCs total probability of human error is determined.

$$HEP = NHU \cdot E_1 \cdot E_2 \cdot etc. \tag{2}$$

Where: *NHU* – Nominal Human Unreliability for generic task; *E1, E2...* – Assessed overall HEART effect for EPCs.

Error Reduction: Reduction is done based on the nominal probabilities assessment and ranging, with necessary formation of specific Error Reduction Mechanisms (ERMs).

Documentation: Documentation is very important if large number of HEART calculations is done. It is important that expert's assumptions are adequately recorded, especially those that refer to the expert impact assessment.

3 RESULTS AND DISCUSSION

The APJ and HEART was used for HRA in the Electric Power Company of Serbia (EPCS). The research comprised the analysis of 1074 workplaces with a total of 3997 employees. The expert team, experienced in the field of HRA, had appropriate knowledge of all sectors, activities, and procedures within EPCS. Most of them were with over 20 years of professional experience and some were the direct executives of the Risk Assessment Project that was implemented in EPCS. Previous consideration of accidents in the EPCS indicated that the largest number of accidents occurred at 10/0.4-kV steel lattice towers. Therefore, the expert team has focused their attention on this objects in order to identify human errors. For the purpose of this study, a database on work-related injuries, accidents and critical interventions that occurred over a ten-year period has been developed.

One of the aims of this study is to show the necessity of human error assessment not only in manufacturing industries but, as it will be shown in this paper, in companies that distribute electric energy, as well. An assessment of ten typical human errors was made by ten experts. These are the following:

- Improper and imprecise issue of a work order;
- Lack of job authorization;
- Failure to implement the fundamental principles of job organization;
- Inadequate cooperation between operators;
- Incomplete implementation of safety measures on the job site;
- Breach of field operation protocol;
- Erroneous routine operations, which require meticulous attention;
- Communication error;
- Failure to use prescribed tools, and
- Failure to use the prescribed personal safety equipment.

Individual HEP estimates were used because a reasonable level of agreement between the experts has been achieved (correlation coefficient K>0.5 confirms the consent of the expert opinion). To make

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the subsequent calculation easier, the set of HEP obtained from the expert is then transformed into their logarithmic equivalents [see more: 6; 7; 12]. The experts had an insight into the scale for estimating the probability [14], database on human errors [7] and Risk Assessment Act in the workplace and working environment in ED “Jugoistok”, Nis, Serbia.

Figure 2 shows the values of using the APJ method for human error assessment in the case of a repair intervention on a steel lattice tower 10/0.4 kV “Nova Kolonija” in EPCS (jurisdiction of EPCS, Veliki Trnovac, ED “Jugoistok”, Nis, Serbia), which resulted in an accident.

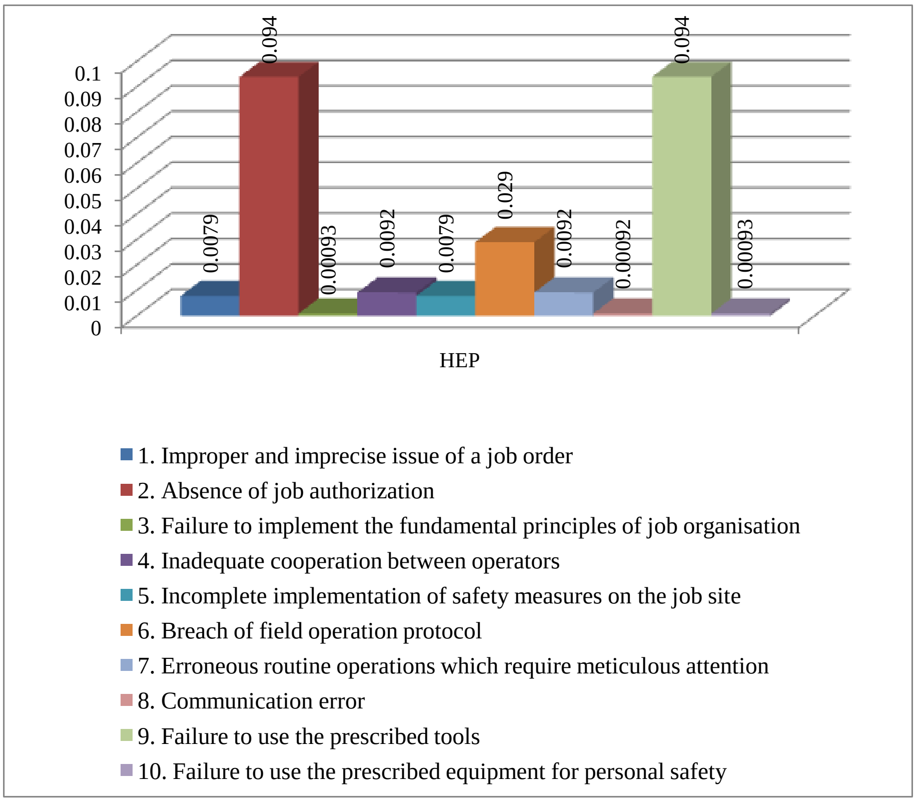

Figure 2. Values HEP using the methods APJ for HRA in the case study in EPCS.

In the case study, ranking the probabilities for the occurrence of human errors that is given in descending order indicates which errors in particular should be considered, for the purpose of their elimination or reduction. The order of the probabilities (given in brackets) of occurrence of human errors in this EPCS case study is as follows:

- Lack of job authorization and Failure to use prescribed tools (9.4 10^{-2}),
- Breach of field operation protocol (2.9 10^{-2}),
- Erroneous routine operations, which require meticulous attention and Inadequate cooperation between operators (9.2 10^{-3}),
- Improper and imprecise issue of a work order and Incomplete implementation of safety measures on the job site (7.9 10^{-3}),

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- Failure to implement the fundamental principles of job organization and Failure to use the prescribed personal safety equipment (9.3 10^{-4}),
- Communication error (9.2 10^{-4}).

The APJ approach is conceptually the most straightforward HRA approach. The APJ uses a group of experts for assessment of human error probability and for indication of the contradictions of the analyzed process. The APJ is the simple to use, however, it is important to carefully select experts, since lack of motivation and/or excessive self-confidence can influence early conclusion, which can undermine the APJ method validity. The APJ is prone to certain biases, as well as to personality group problems and conflicts, which, if not effectively countered (e.g., by a facilitator), can significantly weaken the validity of the technique. Although the APJ method does not consider the performance shaping factors related to the operator and the environment, and the fact whether those factors have positive or negative impact on the operations, the task of the experienced experts is to provide the interpretation of measures for improvement.

In the following text, the results that refer to the HRA case study related to a repair intervention on a 10/0.4-kV steel lattice tower “Maričiće“, Kuršumlija (jurisdiction of EPCS, ED “Jugoistok”, Nis, Serbia) are presented. Detailed expert analysis based on the use of the HEART has resulted in identification of 10 typical human errors (the same as with APJ). For researched case, the following tasks are quantified:

- G – Simple task, performed quickly or with limited attention, with proposed limit for nominal human unreliability (5-95%) of 0.09.
- D – General, routine, very practical, quick task, requiring relatively low skill level, with proposed limit for nominal human unreliability (5-95%) of 0.02.
- E – Totally familiar, properly designed and accurate, routine task, performed by a highly motivated, properly trained and experienced operators that are aware of possible implications or failures, with sufficient time to correct the potential error, with proposed limit for nominal human unreliability (5-95%) of 0.0004.

Error producing conditions are based on the analysis of human performance literature. For the researched case, following EPCs (Table 1) which have a negative impact on the human characteristics have been selected.

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Table 1. EPCs for case study.

Nm	EPC_S	Maximum *HEART* Effect (ME)
1.	Ignoring easily accessible information.	X 9
2.	Inadequate transfer of spatial and functional information to the operator.	X 8
3.	A mismatch between perceived and real risk.	X 4
4.	Inadequate action after performed control.	X 4
5.	An impoverished quality of information conveyed by procedures and person-to-person interaction.	X 3
6.	Insufficient checking of output information.	X 3
7.	Training. Poor quality of information in procedures and inadequate training are causing poor interaction between operators.	X 3
8.	Inexperience: Personal approach to assessing of hazards can be adequate only for experienced operators, while others must use standardized procedures.	X 3
9.	Inadequate education of operators in relation to the given tasks.	X 2
10.	Incentive for using alternative procedures.	X 2
11.	Unclear allocation of functions and responsibilities.	X 1.6
12.	Low workforce morale: Management must constantly support the activities of operators by improving safety condition, through various additional explanations and instructions.	X 1.2

On account the quantified task and assessed overall effect of EPCs we determined the human errors probabilities for each task (Table 2).

Based on everything mentioned above we can conclude that the use of HEART method provides a group assessment of human error probabilities for break downed tasks and activities, whereas EPCs are considered during the assessment (i.e. conditions that have a significant impact on occurrence of human error). Also, based on the quantified human error with application of HEART method, and taking into account the calculated values of EPCs, following conclusions can be made:

– HEP value of 5.2 10^{-3} indicates that following human errors are most probable: improper and imprecise issue of a work orders and lack of job authorization. Ignoring easily accessible information is the main condition (63.46%) contributing to improper execution of initial activities in the analyzed case, followed by incentive for using alternative procedures (14.42%), unclear allocation of functions and responsibilities (11.92%) and low workforce morale (10.20%).
– HEP value of 7.8 10^{-1} indicates that following human errors are most probable: failure to implement the fundamental principles of job organization, inadequate cooperation between the operators, and incomplete implementation of safety measures on the job site and breach of field operation protocol. In this case, inadequate action after performed control (35.21%) is the main factor contributing to the increased probability of human error which requires a lot of attention in order to reduce errors. Other factors are an impoverished quality of information conveyed by

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procedures and person-to-person interaction (25.35%), insufficient checking or testing of output information (22.54%), and training (16.9%).

- HEP value of 8.7 10^{-1} indicates that following human errors are most probable: erroneous routine operations, which require meticulous attention, communication error, failure to use prescribed tools and failure to use the prescribed personal safety equipment. In this case, inadequate transfer of spatial and functional information to the operator (34.24%) is the main factor contributing to the increased probability of human error, followed by a mismatch between perceived and real risk (30.63%), inexperience (23.42%) and inadequate education of operators in relation to the given tasks (11.71%). Therefore, it is important to start timely development of preventive strategies for assessment, prediction and reduction of human errors, and in this way to reduce the consequences and serious financial losses.

Table 2. Quantification of HEP for task E, G, D.

EPCs	ME	EA	E	Contribution made to unreliability modification [%]
NHU for generic task E – 0.0004				
Ignoring easily accessible information.	X 9	0.7	6.60	63.46
Incentive for using alternative procedures.	X 2	0.5	1.50	14.42
Unclear allocation of functions and responsibilities.	X 1.6	0.4	1.24	11.92
Low workforce morale: Management must constantly support the activities of operators by improving safety condition through various additional explanations and instructions.	X 1.2	0.3	1.06	10.20
HEP	$5.2 \cdot 10^{-3}$			100
NHU for generic task G – 0.09				
Inadequate action after performed control.	X 4	0.5	2.50	35.21
An impoverished quality of information conveyed by procedures and person-to-person interaction.	X 3	0.4	1.80	25.35
Insufficient checking of output information.	X 3	0.3	1.60	22.54
Training. Poor quality of information in procedures and inadequate training are causing poor interaction between operators.	X 3	0.1	1.20	16.90
HEP	$7.8 \cdot 10^{-1}$			100
NHU for generic task D – 0.02				
Inadequate transfer of spatial and functional information to the operator.	X 8	0.4	3.80	34.24
A mismatch between perceived and real risk.	X 4	0.8	3.40	30.63
Inexperience: Personal approach to assessing of hazards can be adequate only for experienced operators, while others must use standardized procedures.	X 3	0.8	2.60	23.42
Inadequate education of operators in relation to the given tasks.	X 2	0.3	1.30	11.71
HEP	$8.7 \cdot 10^{-1}$			100

Proceeding from the research results, beside the specific conclusion for the analyzed case (HEART was used for HRA in the EPCS), we came to the following conclusions:

- Quantification of human errors and determining of EPCs point out that reduction and prevention of error repetition is necessary;

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- During the assessment, EPCs were considered without possible interactions between different EPCs;
- Many EPCs can be assessed for existing facilities, but cannot be used for forecasting the state of a new i.e. proposed or developing facility;
- EPCs are based on analysis of human performance commonly found in literature so different experts can use them in their own way;
- Practical experience showed that HEART could adequately predict HEP while offering a series of practical error-reduction strategies that can be used for reducing the impact of error on the system or for preventing them;
- HEART is very applicable in all industries.

4 CONCLUSION

Results obtained in this case studies, according to the positive feedback from the EPCS, have contributed to the following:

- Operator reliability, reducing human error occurrence and increasing awareness on significance of occupational safety, health and environmental protection measures;
- Improvement of occupational safety standards by preventing occupational injuries and fatalities, increase in productivity, and decrease in lost working hours and expenses;
- Improvement of environmental protection standards through reduction of damage in electric power plants, reduction of environmental pollution and substantial economic loss, preservation of natural and material wealth, and prompt and adequate emergency response.

In reference to the results of the conducted research, it has been noticed that the human error with the highest probability is the failure to use the prescribed tools. The most common cause of this human error is related to a PSFs and EPCs. There are indicators related to the operator and the working environment, which influence operations, positively or negatively. In this regard, for the most of operators over 50 years of age, experience appeared as the significant PSFs. A common but negative effect in the EPCS is that the older operators consider themselves sufficiently experienced and confident when performing their tasks. In this case, they are not highly motivated to use tools and equipment for personal safety (which is also the frequent cause of accidents in other companies that distribute electric energy). Additionally, such workers set a bad example for the younger ones who often accept this kind of risky behavior. In such situation, strict application of the internal and external regulations, training and education, can be recommended as measures for reducing this source of human error. The higher and lower management of the company, as well as workers on the terrain, were appropriately informed about the findings of this research.

On the basis of all the above mentioned, it can be concluded that the APJ and HEART has application in EPCS, i.e. in companies for the distribution of electric energy. Successfully applied APJ and HEART for human reliability assessment in EPCS, based on an analytic-synthetic approach, could be implemented in other industrial sectors too.

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