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Human error assessment in electric power company of Serbia

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Abstract. This paper presents a case study which confirmed that the use of APJ for proper assessment of human error in the Electric Power Company of Serbia (hereinafter EPS). The proposal methodological framework was used for human error identification and quantification in the case of a repair intervention on a steel lattice tower 10/0.4 kV (jurisdiction of an EPS subsidiary ED "Jugoistok", Nis, Serbia) which resulted in an accident with a fatal outcome. 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.

Keywords: Human Error, Human Error Assessment, Absolute Probability Judgement, Risk Assessment, Industrial accident.

1. Introduction

Intensive development of methods for human error assessment has started after numerous accidents caused by human errors, or after inadequate actions of the people who were either controlling or managing complex technological processes. Analyses of the accidents in Chernobyl, Bhopal, Three Mile Island, etc., have proven the significance and necessity of human error study. Human error was the cause behind 80% of all major accidents.

In a number of foreign and domestic research papers, methods used to assess human error, based on expert assessment, are analyzed. These are the following methods: Absolute Probability Judgement - APJ; Paired Comparisons - PC; Human Error Assessment and Reduction Technique - HEART; Technique for Human Error Rate Prediction - THERP; Success Likelihood Index Method - SLIM; Influence Diagrams Approach - IDA; Human Cognitive Reliability - HCR; Technica Empirica Stima Errori Operatori – TESEO, etc.

Evaluation of these methods was based on the evaluation of the following quantifiers: accuracy, validity, usefulness, effective use of resource, acceptability and maturity. The best rated methods are HEART, APJ, THERP, SLIM, slightly lower rated methods are PC and IDA, and the lowest rated are methods TESEO and HCR [4, 5].

In Serbia in the past, there was not an adequate approach to this issue and little attention was devoted this research. The existing solutions are based on very simplified requirements, and some of the methods were applied in the analysis of human reliability in coal mines with underground mining and centers for control and management of automated systems, so that there are few written data on the assessment of human error by domestic authors. However, M. Grozdanovic and E. Stojiljkovic, applying a systematic and synergistically methodological approach in the last five years, a significant number of papers have been published in this domain.

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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.

In modern companies for transmission and distribution of electricity, in addition to demands for the stable and continuous standard quality electric energy supply, the implementation of appropriate working standards and living environment are also required.

As such situations had not been analyzed before and as we had not had an opportunity to use experiential, empirical data on these situations and compare them to our research in order to predict new situations and connect them to the accidents that had occurred in these companies, we first had to make a database i.e. a database examining three specific groups of job posts, whose operators are closely related in executing tasks, and where, according to the 10-year study reports the largest number of human errors and injuries occur, and accidents and failures are of the highest frequency [6, 9].

2. Methodology

In Electric Power Company of Serbia for human error assessment was used Absolute Probability Judgement (APJ). APJ is as a concept the simplest approach to quantification of human errors, since it is based on the assumption that people can directly assess their likelihood in this case, a human error [3, 5]. When it comes to risk assessments for existing plants or systems, it is arguable that the more experienced personnel will have a reasonable memory of their own errors, as well as of other operators' errors and their rates of occurrence.

The APJ procedure consists of 7 steps which are described in detail in the research papers [1, 2, 5, 7].

Only the basic features of the procedural steps in the APJ method will be presented here:

Step 1: *The choice of tasks and experts.* The experts making the judgements must be familiar with the tasks to be assessed. Experts are chosen according to their competence in the problematic area that is assessed. The number of engaged experts cannot be strictly defined although it is useful to engage a greater number of experts (6-10).

Step 2: *The definition of tasks*. It is necessary to clearly define the task and identify the specific human errors that experts need to quantify. Preferably it is useful to introduce the relevant elements for evaluation (facilities, equipment, photos, etc.).

Step 3: *Forming the assessment tools* serves as the support to the experts in the assessment. For this purpose probability scales may be used (for example 10^0-10^{-6}), databases of human errors for certain types of jobs, etc.

Step 4: *Formation of evaluation* is done by application of individual or group methods, which leads to the assessment (Aggregated individual method, Delphi method, nominal group technique, group consensus method). Individual HEP estimates should be used if there is a reasonable level of agreement between the experts. To make the subsequent calculation easier, the set of HEP obtained from the expert is then transformed into their logarithmic equivalents, and are shown in tables.

Step 5: *Checking the validity of individual assessment*, consists of 13 sub steps as follows: Calculate the column totals (n), Calculate the row totals (m), Calculate the grand total (T), Calculate the correction term (C), Calculate the sum of the squares (x^2) of the raw scores, Calculate the total sum of the squares (TSS), Calculate the "between column sum of squares" (t^2), Calculate the "between row sum of squares" (r^2), Calculate the "residual sum of squares" (SS), Enter the appropriate degrees of freedom into the summary table (df), Calculate the variance estimates by dividing each of the sums of squares by the appropriate degrees of freedom, Calculate the F ratios and the intra-class correlation coefficient (K).

Step 6: *Aggregate the individual estimates* are done after collecting and checking the validity of individual assessments so as to determine their arithmetic mean.

Step 7: *Rating limits of uncertainty* is performed using the following expression adapted to Seaver & Stillwell, 1983:

$$\log HEP \pm 2s.e \tag{1}$$

where s.e – standard error

$$s.e = \left(\sqrt{\frac{V(\log HEP_i)}{m}} \right) \tag{2}$$

$$V(\log HEP_i) = \frac{\left[m\sum_{j=1}^{m} (\log HEP_{ij})^2 \right] - \left[\sum_{j=1}^{n} (\log HEP_{ij})^2 \right]}{m(n-1)} \tag{3}$$

m – number of experts
n – number of events.

3. Results and discussion

The proposal methodological framework was used for human error identification and quantification in the case of a repair intervention on a steel lattice tower 10/0.4 kV at location “Maricice”, region of Kursumlija (jurisdiction of an EPS subsidiary ED “Jugoistok”, Nis, Serbia) which resulted in an accident with a fatal outcome.

In the first step of the human error probability assessment by the application of the APJ procedure, the individual assessment of 10 experts was used. The experts are competent for the problem area which is being investigated, have complete knowledge of all sectors, activities and procedures, most with professional experience of over 20 years, and some are the direct executives.

In the second step the identification of 10 typical human errors was performed:

1. Improper and imprecise issue of a job order,
2. Absence of job authorization,
3. Failure to implement the fundamental principles of job organization,
4. Inadequate cooperation between operators,
5. Incomplete implementation of safety measures on the job site,
6. Breach of field operation protocol,
7. Erroneous routine operations which require meticulous attention,
8. Communication error,
9. Failure to use the prescribed tools, and
10. Failure to use the prescribed equipment for personal safety.

In the third step, the experts had an insight into the scale for estimating the probability [8], database on human errors [9] and Risk Assessment Act in the workplace and working environment in ED “Jugoistok”, Nis, Serbia.

In the fourth step, in Table 1 shows the individual expert assessment of the identified human error probability for the researched case, and Table 2 logarithmic value of the estimated probabilities.

Table 1

Individual expert assessment for the researched case

m	n									
	1	2	3	4	5	6	7	8	9	10
1	0.01	0.06	0.0009	0.015	0.008	0.034	0.004	0.001	0.11	0.0011
2	0.006	0.11	0.0008	0.004	0.005	0.025	0.015	0.0011	0.06	0.0006
3	0.005	0.08	0.001	0.016	0.007	0.028	0.01	0.0008	0.12	0.0009
4	0.008	0.12	0.0011	0.01	0.009	0.027	0.016	0.0009	0.08	0.0004
5	0.001	0.05	0.0012	0.005	0.01	0.029	0.013	0.0006	0.13	0.0008
6	0.007	0.13	0.0006	0.013	0.017	0.026	0.005	0.0004	0.05	0.0007
7	0.009	0.07	0.0005	0.012	0.001	0.031	0.006	0.0013	0.09	0.0016
8	0.018	0.09	0.0013	0.011	0.019	0.032	0.008	0.0014	0.07	0.0012
9	0.017	0.14	0.0007	0.008	0.006	0.033	0.012	0.0018	0.15	0.0013
10	0.019	0.15	0.0019	0.006	0.018	0.035	0.011	0.0007	0.14	0.0014
Σ	0.1	1	0.01	0.1	0.1	0.3	0.1	0.01	1	0.01
$\bar{f}$	0.01	0.1	0.001	0.01	0.01	0.03	0.01	0.001	0.1	0.001

Table 2

Log HEP

m	n 1	2	3	4	5	6	7	8	9	10	Σ
1	-2	-1.22	-3.05	-1.82	-2.09	-1.47	-2.39	-3	-0.96	-2.96	-20.96
2	-2.22	-0.96	-3.09	-2.39	-2.3	-1.60	-1.82	-2.96	-1.22	-3.22	-21.78
3	-2.3	-1.09	-3	-1.79	-2.15	-1.55	-2	-3.09	-0.92	-3.05	-20.94
4	-2.09	-0.92	-2.96	-2	-2.05	-1.57	-1.79	-3.05	-1.09	-3.39	-20.91
5	-3	-1.30	-2.92	-2.30	-2	-1.54	-1.89	-3.22	-0.89	-3.09	-22.15
6	-2.15	-0.89	-3.22	-1.89	-1.77	-1.59	-2.30	-3.39	-1.30	-3.15	-21.65
7	-2.05	-1.15	-3.30	-1.92	-3	-1.51	-2.22	-2.89	-1.05	-2.79	-21.88
8	-1.74	-1.05	-2.89	-1.96	-1.72	-1.49	-2.09	-2.85	-1.15	-2.92	-19.86
9	-1.77	-0.85	-3.15	-2.09	-2.22	-1.48	-1.92	-2.74	-0.82	-2.89	-19.93
10	-1.72	-0.82	-2.72	-2.22	-1.74	-1.46	-1.96	-3.15	-0.85	-2.85	-19.49
Σ	-21.04	-10.25	-30.3	-20.38	-21.04	-15.26	-20.38	-30.34	-10.25	-30.31	-209.55
$\bar{f} = \log HEP$	-2.104	-1.025	-3.03	-2.038	-2.104	-1.526	-2.038	-3.034	-1.025	-3.031	

In the fifth step, the checkout of validity of the individual assessments is presented.

Calculate the column totals (n): -21.04, -10.25, -30.3 etc., above

Calculate the row totals (m): -20.96, -21.78, -20.94 etc., above

Calculate the grand total (T): -209.55

Calculate the correction term (C):

$C = 439.112$

Calculate the sum of the squares (x^2) of the raw scores:

$$\sum_{i=1}^{n} x_i^{\ 2} = 496.26$$

Calculate the total sum of the squares (TSS):

$$TSS = \sum_{i=1}^{n} x_i^{\ 2} - C = 57.148$$

Calculate the “between column sum of squares” (t^2):

$$\sum_{i=1}^{n} t^2 = 4916.33$$

$$t^2 = \frac{\sum_{i=1}^{n} t^2}{n} - C = 52.521$$

Calculate the “between row sum of squares” (r^2):

$$\sum_{i=1}^{m} r^2 = 4398.95$$

$$r^2 = \frac{\sum_{i=1}^{m} r^2}{m} - C = 0.783$$

Calculate the “residual sum of squares” (SS):

$$SS = TSS - t^2 - r^2$$

$$SS = 3.844$$

Enter the appropriate degrees of freedom into the summary table (df):

$$df_{columns} = n - 1 = 9$$
$$df_{rowes} = m - 1 = 9$$
$$df_{total} = n \cdot m - 1 = 99$$
$$df_{residual} = df_{columns} - df_{rowes} - df_{total} = 81$$

Calculate the variance estimates by dividing each of the sums of squares by the appropriate degrees of freedom:

$$Column\,variance = 5.84$$
$$Row\,variance = 0.087$$
$$Residual\,variance = 0.047$$

Calculate the F ratios

$$F_{columns} = 124.25$$
$$F_{rows} = 1.85$$

The last step is to determine the intra-class correlation coefficient (K), according to the following formulae:

$$K = \frac{F - 1}{F + (n-1)}$$
$$K = 0.92$$

Correlation coefficient value $K = 0.92$ confirms the consent of the expert opinion.

In the sixth step, in Table 3, a statistical analysis of the individual assessments is shown for each *HEP*.

In the seventh step, assessment of uncertainty limits and determination of standard errors is shown (Table 3).

Table 3

Statistical analysis of individual assessments, determination of standard errors and uncertainty limits

n	Σ	$\bar{f} = \log HEP$	HEP	$s.e = \left(\sqrt{\frac{V(\log HEP_i)}{m}}\right)$	*Rating limits of uncertainty*
1	-21.04	-2.104	$7.9 \cdot 10^{-3}$	0.12	$6 \cdot 10^{-3} \langle 7.9 \cdot 10^{-3} \langle 1 \cdot 10^{-2}$
2	-10.25	-1.025	$9.4 \cdot 10^{-2}$	0.051	$8.4 \cdot 10^{-2} \langle 9.4 \cdot 10^{-2} \langle 1.1 \cdot 10^{-1}$
3	-30.3	-3.03	$9.3 \cdot 10^{-4}$	0.053	$8.3 \cdot 10^{-4} \langle 9.3 \cdot 10^{-4} \langle 1.1 \cdot 10^{-3}$
4	-20.38	-2.038	$9.2 \cdot 10^{-3}$	0.065	$7.9 \cdot 10^{-3} \langle 9.2 \cdot 10^{-3} \langle 1.1 \cdot 10^{-2}$
5	-21.04	-2.104	$7.9 \cdot 10^{-3}$	0.12	$6 \cdot 10^{-3} \langle 7.9 \cdot 10^{-3} \langle 1 \cdot 10^{-2}$
6	-15.26	-1.526	$2.9 \cdot 10^{-2}$	0.012	$2.8 \cdot 10^{-2} \langle 2.9 \cdot 10^{-2} \langle 3.1 \cdot 10^{-2}$
7	-20.38	-2.038	$9.2 \cdot 10^{-3}$	0.065	$7.9 \cdot 10^{-3} \langle 9.2 \cdot 10^{-3} \langle 1.1 \cdot 10^{-2}$
8	-30.34	-3.034	$9.2 \cdot 10^{-4}$	0.06	$8.1 \cdot 10^{-4} \langle 9.2 \cdot 10^{-4} \langle 1.1 \cdot 10^{-3}$
9	-10.25	-1.025	$9.4 \cdot 10^{-2}$	0.05	$8.4 \cdot 10^{-2} \langle 9.4 \cdot 10^{-2} \langle 1.1 \cdot 10^{-1}$
10	-30.31	-3.031	$9.3 \cdot 10^{-4}$	0.06	$8.1 \cdot 10^{-4} \langle 9.3 \cdot 10^{-4} \langle 1.1 \cdot 10^{-3}$

As it can be seen in Table 3, human errors with the highest probability are „failure to use the prescribed tools“ and „absence of job authorization“ ($9.4 \cdot 10^{-2}$), then the following: „breach of field operation protocol“ ($2.9 \cdot 10^{-2}$), „inadequate cooperation between operators“ and „erroneous routine operations which require meticulous attention“ ($9.2 \cdot 10^{-3}$), „improper and imprecise issue of a job order“ and „incomplete implementation of safety measures on the job site“ ($7.9 \cdot 10^{-3}$), „failure to implement the fundamental principles of job organization“ and „failure to use the prescribed equipment for personal safety“ ($9.3 \cdot 10^{-4}$), while the lowest probability of a „communication error“ ($9.2 \cdot 10^{-4}$).

4. Conclusion

The research presented in this paper required a system approach based on multidisciplinary principles. The methodological framework for human error assessment, based on an analytic-synthetic approach and successfully applied in EPS, could be implemented in other industrial sectors too. This would certainly contribute unification of the methodology for human error assessment in Serbia and make it an integral part of risk assessment procedure.

The method of absolute assessment probability uses a group of experts for assessment of human error probability and for indication of the contradictions of the analyzed process. It is the simplest to use and it is important to carefully select experts, for excessive self-confidence, making an early conclusion and motivation can undermine the APJ method validity.

Implementation of APJ method and the achieved research results contribute to:

- Operator reliability (through identification and quantification of human errors, detection of mechanisms that lead to erroneous performance, and by discovering performance shaping factors), which confirms validity of safety/risk probability assessment;
- 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.

Although the APJ method does not consider the PSF related to the operator and the environment and that fact that it influences his operations positively or negatively, experienced experts can give their interpretation of measures for improvement.

Compliance with internal and external regulations, training and education are the best measures to reduce human error in the Electric Power Company of Serbia.

In EPS, computer program exercises have been created by use of which the operators, by means of answers to questions and simulation of these answers learn how and in which order to perform their tasks. Also, the training of operators can be performed by use of many cognitive models of training people to act appropriately in emergency situations [10].

On the basis of all the above mentioned, it can be concluded that the APJ has application in the electric power companies, i.e. in companies for the distribution of electric energy.

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