Human reliability at electrical equipment service in agroindustry companies

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Abstract
Reliability of the electromechanical system couldn't be better than human reliability, so we must use information about human reliability in analysis of this kind of systems. Performance shaping factors (PSF) are differs from sector to sector so our aim is to choose PSF's for electrical equipment service workers using expert judgment, calculate PSF weights and develop model for working places examination and dynamic simulation of system degradation process using fuzzy sets theory. We have made expert survey in 2010 year for PSF choosing and weights calculating. The target group was middle-level management of the agroindustry companies and electrical equipment service companies. Using our SAM method modification we receive weights of PSF's and define core of them. The main factors, with respect of results of our survey, are: small experience of work, carelessness, badly formed specialist, unconscientiousness, bad emotional condition. So, we can use survey results for quantitive evaluation of reliability of “man-machine” systems.

Keywords: reliability, PSF, expert survey, fuzzy sets, hierarchy analysis method

Introduction
Usually the first place at electromechanical system reliability analysis take calculation of technical system reliability and this value using for decision making. But one of the most unreliable part of systems now is a man, and the losses, connected with “human factor” can be really huge. By the words of S.E. Magid, chief of «Technical educational systems in energy technologies» UNESCO department: “Number compelled faults of domestic power units because of equipment refusals on heat power stations is 30 %. The share of operational personnel fault in these infringements makes considerable size (to 15 %). As a whole in the RAO "United Power Systems" the infringements percentage because of the personnel from infringements total makes 2 %. At the same time, on power stations this quantity makes 18 %. In power supply systems of Siberia the relative quantity of infringements because of the personnel reaches 50 %.” [Маги́д 2006].

So, we must have model for human reliability evaluation for personnel, taking part at electromechanical system assembly and service. Here under for “human reliability” we use definition: human reliability is a probability of (1) it carries out correctly some, demanded by system, action for demanded time and (2) doesn't carry out the superfluous actions, capable to lead to decrease in reliability of served system.
Materials and methods

We are spent expert survey in 2009-2010 where energy department's managers has been asked for feedback form completion. We received 47 fully filled questionnaires, and all of them used for work. For an estimation of human error possibility in the set conditions we are offered the approach consisting in paired comparison by experts of importance of negatively influencing factors for revealing of their relative scales [Гущинский, Рузанова, Гаљченко, 2010]. In total it was offered to use 30 performance shaping factors (PSFs) effect on the personnel serving the power equipment, that concern six groups: psychological, social, external industrial, physiological, an equipment condition, qualification.

We represent questions as a scales, where center is an equal influence degree of two PSF's on worker, and the ends – maximal degree of influence by near written to mark of expert PSF under second. For example, on fig.1 expert is offered to compare two factors from “External industrial” group: noise and lighting.

![Figure 1. Example of scale for noise and lightning comparison](image)

Expert mark three point – maximum, expect and minimal influence, so, we have triangle fuzzy number, that we can use for our purposes. Because of some PSF’s are noncomparable, and for question count reduction we compares factors contained in one groups, and ask to compare groups of factors. So, we have only 29 question for form, that reduce time of expert.

Results are coded in table, using scale $[1/9,9]$, where 1 represent equal level of influence.

For survey results processing we used the SAM method [Hsi-Mei Hsu, Chen-Tung Chen 1996], where the distance between the triangular fuzzy numbers, calculated under formulas (1) — (3).

\[
S(\hat{R}_i, \hat{R}_j) = \frac{R_i}{R_j}
\]

\[
Val(S) = \frac{(5 + 4 + 5 + 5)}{6}
\]

\[
D = \begin{cases} 
\frac{1}{Val(S)}, & Val(S) \leq 1; \\
\frac{1}{Val(S)}, & Val(S) > 1 
\end{cases}
\]

Where $\hat{R}_i$ - the fuzzy number corresponding to an expert estimation of the superiority of one factor over another, $S$ — a measure of same factor estimation by the different experts, $D$ — defuzzifying distance, degree of distinction of expert estimations.

For models triangulation method we used hierarchy analysis method (HAM) [Ногин, 2007]. First, we defuzzify numbers using (2) for groups and PSF's relative weights. On second stage we calculate pair compared matrix. For this purpose weights of PSF's were recalculates by (4).
where \( rw \) – PSF relative weight, \( rwd \) – “dirty” PSF relative weight from questionnaire, \( rwg \) – group of PSF relative weight from questionnaire, \( j=1..6 \) – group number.

For aggregation of experts choices we used information about groups of factors weights from questionnaire and expected group relative weight, calculating by (5).

\[
EW_j = \sqrt[6]{\prod_{i=2}^{k} rwd_{ij}}
\]

(5)

where \( k \) – PSF's count in group, \( j=1..6 \) – group number.

Quality of every expert work we evaluate with measure, calculating by formula (6):

\[
Q = \begin{cases} 
1 & \text{if } EW_j / rwg_j \leq 1; \\
\frac{EW_j / rwg_j}{Value > 1} & \text{if } EW_j / rwg_j > 1.
\end{cases}
\]

(6)

Quality of expert work is a number in \([0,1]\) and 1 match up great expert work: expected weights of all groups are equal to weights from questionnaire. In our case about half of experts (46%) have quality \( Q > 0.8 \), and about 70% have \( Q > 0.6 \). So, we can say that most part of questionnaires can be used for aggregation and quality of survey is good.

After calculation of weight vector for each expert by HAM method [Ногин, 2007] we aggregate this values, using weighted arithmetic average for each PSF and groups of PSF's. Results of weights calculation can be found at table 1.

<table>
<thead>
<tr>
<th>Table 1: Weights of PSF's groups, two methods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group</strong></td>
</tr>
<tr>
<td>External industrial</td>
</tr>
<tr>
<td>Psychological</td>
</tr>
<tr>
<td>Physiology</td>
</tr>
<tr>
<td>Social</td>
</tr>
<tr>
<td>Equipment condition</td>
</tr>
<tr>
<td>Qualification</td>
</tr>
</tbody>
</table>

Results are quite equal, so we can conclude that methods are correct and choosing survey method guarantee quality results on groups of PSF's level. We can conclude, that qualification, equipment condition and psychological factors are gives about 67% for human
failure and must be corrected firstly.

For PSF's we have more complex problem: our experts has slightly different types of work, so marks for concrete PSF's can reflect nature of concrete type of workplaces. So, we have deviations between results of two methods (Table 2).

### Table 2: PSF’s with highest weights and ranks

<table>
<thead>
<tr>
<th>Group</th>
<th>PSF</th>
<th>Weight, HAM</th>
<th>Rank, weight HAM</th>
<th>Rank, weight SAM</th>
<th>Rank difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>External industrial</td>
<td>Bad lightning</td>
<td>5.01%</td>
<td>1</td>
<td>8</td>
<td>-7</td>
</tr>
<tr>
<td>External industrial</td>
<td>Low/high temperature at working place</td>
<td>4.42%</td>
<td>7</td>
<td>9</td>
<td>-2</td>
</tr>
<tr>
<td>Psychological</td>
<td>Inadvertency</td>
<td>4.73%</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Psychological</td>
<td>Shortcoming</td>
<td>4.70%</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Psychological</td>
<td>Bad emotional condition</td>
<td>4.18%</td>
<td>8</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Psychological</td>
<td>Bad educability</td>
<td>4.05%</td>
<td>9</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Qualification</td>
<td>Badly formed</td>
<td>4.94%</td>
<td>2</td>
<td>3</td>
<td>-1</td>
</tr>
<tr>
<td>Qualification</td>
<td>The small experience of work</td>
<td>4.94%</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Qualification</td>
<td>Absence of the admission</td>
<td>4.68%</td>
<td>6</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>41.65%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results shown that specialist with small experience of work and badly formed specialist are unreliable and theirs work places must be formed taking into account this fact. But, inadvertency and shortcoming gives dangerous situation for human reliability. So, using tables for PSF's and PSF's, HR specialist can recruit personnel on more scientific basis, using tests and probation period results.

For human reliability value calculation statistical data or simulation data needs. Main problem for this part of work became falsification of this kind of data on enterprises or assignment it to commercial classified information. At [Pekka, 2000] can be find model, based on logistic distribution for human failure probability and some remarks for model validity. Using this model as base we try to simulate results for it and model, constructed on our PSF's and PSF's groups with the similar description [Гущинский, Липатов, 2012] (7), where all variables in [0,4] interval.

\[ w_1 \] — Expressiveness of a sluggishness,
\[ w_2 \] — A skill level of the personnel,
\[ w_4 \] — An estimation of complexity of the equipment,
\[ w_5 \] — An estimation of a condition of the equipment,
\[ w_6 \] — Degree of expressiveness of negative psychological factors.
Models show similar results. Using this fact we can suppose, that sigmoid function with HAM weights can be used for calculation of human reliability, using full set of parameters with undefined constant $C$ (8).

$$p = \frac{e^{\sum w_i x_i - 9 x_1 x_p}}{1 + e^{\sum w_i x_i - 9 x_1 x_p}}$$

where $w_i$ – PSF weight, calculated with HAM, $x_i$ – estimation of PSF intensity, $x_1 \in [0,9]$ $x_p$ – estimation of PSF intensity liminal value (minimal value of intensity, influenced on worker), $x_{p1} \in [0,9]$. When $x_i=0$ for all $i$ human error probability must be near zero, and when $x_i=9$ for all $i$ human error probability must be near zero. This conditions gives us possibility to find diapason of $C$, and this diapason $[2.2, 4.6]$. On this interval probability on ends of PSF values intervals looks as shown on fig. 2. So, we can conclude that on the ends of intervals with $C$ variation $p$ grows smoothly and chosen interval can be recommend for $p$ evaluation.

Figure 2. Human error probabilities on the end of PSF intensity intervals, $C$ variation

Questionnaire for experts have parts, where experts marked estimation of PSF intensity liminal value and shows level of equipment failures at 5-balls scale. Only 39 questionnaires had this part filled. That’s why we binned 5-balls scale on two parts: from 1 to 3 – failures rating more average, and from 4 to 5 – low failure rating.

For $C=3.5$ analysis with KNIME [7] shown, that predictability in this binary scale is good: accuracy of model is 67%, so we can use this model with coefficient $C=3.5$ (9) in described above cases.
Results

Our experts choose only some PSF as main. As we see, the qualification, psychological factors are the main at the PSF's structure. So, skills and characteristics, mentioned above (table 1, 2) must be corrected firstly at departments. Using this set of characteristics we can calculate human reliability.

Conclusion

Now we work under more complex dynamical model and multiagent simulation, where time-factor can be allowed. More, we try to use more complex models for error possibility, that can use information of one factor intensity strengthening depending from others.

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