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IMPACTS OF HUMAN FITNESS FOR DUTY ON SYSTEM'S PERFORMANCE - HUMAN RELIABILITY AND SYSTEM'S PERFORMANCE

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Abstract

According to the results of root cause analyses almost 80% of all the events in nuclear power plants are consequences of human mistakes.

Human errors are consequences of cognitive and sensorimotor availability. Low level of cognitive availability causes knowledge based errors - consequences are usually incapabilities to evaluate the situation in the system. Low level of sensorimotor availability causes skill based errors which are obvious in inadequate reactions in production situation. Self estimations of fitness for duty are indicators of human actual availability and include also perceived abilities, knowledge and motivation. According to our model we are able to estimate human cognitive and sensorimotor availability in a real situation from the fitness for duty data. Final purpose of this model is to predict a system's performance data from human fitness for duty data.The developed model is a tool for this prediction in a real working situation.

1 INTRODUCTION

In the beginning of industrialization man had been much more perfect and efficient than machine had been. Because of that engineers have paid all their attention to the technological part of the system - to machines. Since than machines have been improved to today's level - to the level of complex automated systems - very reliable and stable. Man has stayed on the same level as he had been in the beginning of industrialization.

According to the results of root cause analyses [3] in complex highly automated systems almost 80% of reported events and scrams are due to human error or malfunction. Modern systems are more stable and scrams are less frequent than in the beginning of industrialization. Nowadays scrams are mostly consequences of human mistakes. Human mistakes are according to the results of root cause analyses consequences of unfitness or inability to perform the required task. Most of the workers in the system have adequate psychophysiological abilities and basic knowledge.

Soon after the beginning of industrialization it was able to measure human potential availability. Researchers have been able to measure or to estimate human anthropological, physiological and psychological traits and abilities. Since the new age of automation these data have been sufficient for the prediction of human performance. In automated systems, the performance is even more dependent on human actual availability or fitness for duty than it was in less complex systems.

Fitness for duty hasn't been measured since now, because it hasn't been fatally important for the performance of a machine or system.

In a real situation in each system human performance depends on:

- human abilities (basic human traits like intelligence, personality)
- human knowledge (knowledge received in educational process and in special training)
- human motivation (willingness to take part in some activity)

Potential availability is the interference of abilities, knowledge and motivation in a real situation and it shapes human performance. Workers are able to self estimate their potential availability - they are able to estimate their fitness for duty. Self estimations are subjective evaluations of fatique, well being and atteniton span estimated by workers themselves.

A system performance estimation should be based on self estimations of workers potential availability. The data of human fitness for duty can be used for estimations of system performance. Self estimations have been very often used for the last ten years in basic researches in ergonomics and occupational psychology. Self estimations are convenient for collection also in field studies.

Self estimations are valid enough to predict human behavior (correlations between physiological indicators of fatigue recorded with EMG, EEG and subjective self estimations of fatigue are between 0,40 to 0,60). According to the analyses of self estimations among the spinners, weavers, drivers, masons and carpenters these data are quite good picture of self estimated fitness for duty. Workers are able to self estimate different levels of fatique or well being in correspondence with task duration and work load.

In a real work situation, in the control room of an automated system self estimations are the only convenient technique - other measurements are very difficult to be applied.

All these facts are issues of our approach to human performance estimations.

2 PROBLEM

On the basis of knowledge about workers' self estimations valid and convenient technique for workers' performance estimation began to develop.

Assumptions of our work have been:

- according to the results of root cause analyses system's performance depends on human performance
- measurements of human abilities don't give enough data about predicted system's performance
- human performance depends on abilities, knowledge and motivation (abilities and knowledge should be tested or measured, motivation shouldn't be measured)
- people are able to self-estimate quite precisely their availability. Human behavior in real situations and readiness for work depends on an individual self estimation of his well-being and fatigue.
- subjectively estimated potential availability is described in term "fitness for duty".

Fitness for duty is readiness of an individual for work and it includes his subjective estimation of ability to perform the demanded task in accordance with procedure, knowledge and technical specification in a real working situation.

Our research has been focused on modelling of connections between human self estimated fitness for duty and system's performance.

3 MODEL

3.1 Collection of human availability data

For the last fifteen years subjective questionnaire named "Questionnaire of momentary feeling - VTP" has been developed. Questionnaire has 47 amounts with five points scale for each item (1 means very good condition, status or feeling, 5 means very bad condition).

According to the results of our previous researches the amounts in the questionnaire are grouped in the following items:

1. physical fatigue - (defines as 'a_1')
2. psychical fatigue - (defines as 'a_2')
3. general wellbeing - (defines as 'a_3')
4. vigilance - attention span - (defines as 'a_4') defines as **A**
5. mood - (defines as 'a_5')
6. stress - (defines as 'a_6')
7. motivation - (defines as 'a_7')

Subjective estimations of fitness for duty data were collected in the day and in the night shift (8 hours) four times per day ($n = 4$). We have $N = 153$ measured "*men-days*". Let $A_\tau = [\vec{a}_{1,\tau}, \vec{a}_{2,\tau}, ..., \vec{a}_{7,\tau}]$ be fitness for duty data for one individual operator in one shift (τ^{th} "*men-day*"). Here $\vec{a}_{i,\tau} = [a^1_{i,\tau}, a^2_{i,\tau}, ..., a^n_{i,\tau}]$ is i^{th} measured item of availability of τ^{th} "*man-day*".

3.2 Collection of system's performance data

System's performance indicators are :

1. trips - (defines as 'b_1')
2. transients - (defines as 'b_2')

defines as B

Transients for observed year and trips for three years period were taken. Human data and system's data were collected for the same crews.

3.3 Purpose

Our purpose is modelling of system's performance with human availability :

$$\mathbf{A} \xrightarrow{\text{Model}} \mathbf{B}$$

3.4 Premises

- Human availability and system's performance are continousely dependent on time.
- Time units are equal for all the time.
- Collected human data are almost the best description of human fitness for duty and system's performance should be modeled by them.

3.5 Mathematical part of the model

- From n measurements time distributions of each particular fitness for duty indicator are estimated by polynomial interpolation. We define $p_{i\tau}(t)$ as polynomial approximation of $\vec{a}_{i\tau}$.
- We define $h_1(t)$ as 'estimated' probability of trips in time t and $h_2(t)$ as 'estimated' probability of transients in time t.
- According to the nature of analyzed data (peacks aren't important) we choosed $\|\cdot\|_1$ norm.
- Suppose fixed τ. Let it be $X = C[0,8]$, $S_{ij\tau} = L(p_{i\tau}, p_{j\tau}, 1) \subseteq X$. For $h_m \in X$ we find best polynomial approximation $h_{mij\tau} \in S_{ij\tau}$ in $(X, \|\cdot\|_1)$, where is

$$h_{mij\tau}(t) := \alpha_{mi\tau} \cdot p_{i\tau}(t) + \alpha_{mj\tau} \cdot p_{j\tau}(t) + \beta_{mij\tau} \cdot 1\,; \quad m = 1,2$$

$$||h_m||_1 = ||h_{mij\tau}||_1 + r_{mij\tau}$$

- From a set $A_{mi} = \{\alpha_{m,i,1}, \alpha_{m,i,2}, ..., \alpha_{m,i,N}\}$ we get probability $\varphi_{A_{mi}}(x)$, that exist τ, so that is $x = \alpha_{mi\tau} \in A_{mi}$. Define index set

$$I^P_{mi} := \{\tau \; ; \; \varphi_{A_{mi}}(\alpha_{mi\tau}) \geq P\}$$

- If

$$I^P_{mij} := I^P_{mi} \cap I^P_{mj} \neq \{\}$$

then there is probability P, that we can approximate $\mathbf{b_m}$ with $\mathbf{a_i}$ and $\mathbf{a_j}$. Quality of this approximation is

$$r_{mij} := \max_{\tau \in I^P_{mij}} \{r_{mij\tau}\}$$

3.6 Application

Now we choose probability $P = 0.8$. If $I^P_{mij} \neq \{\}$, then we define

$$\mathcal{A}^P_{mij} := \{ (\alpha_{mi\tau}, \alpha_{mj\tau}) \; ; \; \tau \in I^P_{mij} \}$$

Now we get

$$(\alpha_{mi}, \alpha_{mj}) := \overline{\mathcal{A}^P_{mij}}$$

coeficients in approximation $\mathbf{b_m}$ with $\mathbf{a_i}$ and $\mathbf{a_j}$. Quality of this approximation is r_{mij}.

Example :

Morning shift:

$$\vec{b}_1 \approx -38 \cdot \vec{a}_4 + 20 \cdot \vec{a}_3 - 25,96 \tag{1}$$

$$\vec{b}_2 \approx +17,4 \cdot \vec{a}_4 - 8,08 \cdot \vec{a}_7 + 8,63 \tag{2}$$

Night shift:

$$\vec{b}_1 \approx -10,66 \cdot \vec{a}_6 + 0,78 \cdot \vec{a}_2 - 21,4 \tag{3}$$

$$\vec{b}_2 \approx +7,11 \cdot \vec{a}_5 - 1,08 \cdot \vec{a}_7 + 9,36 \tag{4}$$

4 RESULTS

Workers' cognitive and sensorimotor abilities to perform their work were measured at the same time as their self-estimations of fitness for duty were collected.

Cognitive and sensorimotor residual abilities were indicators of human actual performance. Actual performance of workers in the system is the most important system's performance shaping factor. From our results of root cause analyses 80% of reported events are caused by human performance.

According to our hypothesis, system's performance could be predicted from human actual performance.The curve of the system's performance distribution is very much alike to the curve of actual performance.

Indicators of actual performance were measured at the same time as the indicators of potential availability or fitness for duty were collected. From connections between human fitness for duty and actual performance, again according to our hypothesis, fitness for duty should be the indicator of actual performance. As an indicator of actual performance it is also system's performance shaping factor [3].

Behavioral patterns in real work situations are determined by the level of **cognitive** and **sensorimotor** availability.

According to the results of our analysis, in the day shift distribution of inadequate behavioral patterns in an event situation depends on the level of human availability. The most frequent were knowledge based behavioral errors (43%) - frequent were also skill based behavioral errors (32%), less frequent were rule based behavioral errors (25%).

Knowledge based errors were the most frequent at the time of the lowest level of cognitive availability - between nine and eleven o'clock in the morning. It was at the time of extreme overloadness of operators (at the same time in the morning also other activities - like testing, maintenance and supervision activities were going on).

Skill based errors were the most frequent at the time of the lowest level of sensorimotor availability - about 11 o'clock in the morning after morning snack.

In the night shift errors were less frequent and also cognitive and sensorimotor availabilities were higher than in the morning shift.

Our model describes connections between fitness for duty - actual availability and system's performance. Although it was a linear model it quite good explains the connections in accordance with the theory.

4.1 Some explanations of results:

Morning shift: According to the equation (1) in the morning shift system's performance depends on the arousal level. Due to the effects of biological rhythms the average attention span is the highest in the morning shift between nine and eleven o'clock. In the morning shift attention span is the most important system's performance shaping factor. An increase in the attention span causes higher number of transients and lower number of trips. Operators are more vigilant and they are able to perceive each change in the operating parameters. From the equation (2) a possible consequence may be a transient but not a trip. Increase in the attention span causes also increase in the system's performance level.

Other two influential factors are motivation and general fatigue. Motivation has positive effect: the higher the motivation, the higher the vigilance. Because of that the system's performance increases. Influence of motivation is interferential - through the arousal level. The general fatigue has negative effect on system's performance - higher level of general fatigue means also more trips in the morning shift.

By these connections the effects of human fitness for duty on the system's performance are described. High attention span has positive effects within certain limits. Too high attention span may cause exhaustion, fatigue, perceived stress and anxiety. Human unfitness caused by overloadness and work overcomplexity is reflected in the level of general fatigue. The feeling of general fatigue includes symptoms like - I'm, exhausted, I'm not able to do something else, I'm not energetic, I feel very bad. These symptoms are very often consequences of stress and psychical overloadness.

Night shift: In the night shift there are different influential factors:

- perceived stress
- psychical fatigue
- mood
- motivation.

According to the equation (4) number of transients is determined by the operators' mood in thee crew. The more they are motivated the higher is the number of transients. There are indirect influences of mood on transients through the attention span. Higher number of transients may mean lower number of trips. On the other hand too high level of activations may cause unnecessary transients which are the consequence of human hyperactivation and non-attentive observation of the process going on in the system.

From the equation (3) the number of trips is shaped by the stress level.The higher is the stress level in the night shift the better is the system's performance. An average stress level of operators in the night shift is higher than that of other shift workers, but it is lower than their average stress level in the morning shift. Basic stress level in the night shift could increase a bit without harm, operators fitness for duty is even better. Due to the stress effects the attention span increases and the system's performance also increases. There are also effects of biological rhythms, sleep deprivation and shift work. All those factors have effects on the level of psychical fatigue which increases. As a consequence the system's performance decreases.

According to our model fitness for duty shapes the system's performance throught the influence on the level of cognitive and sensorimotor availability. We have modelled the effects by linear model. From these results the effects of human fitness for duty are determined by the basic level of stress, mood, fatigue, wellbeing and arousal. Increases from the basic to the actual level of each parameter cause changes in human availability and consequently the system's performance. The effects of attention span, stress and mood differ between shifts. Modelling of these effects in different shift should be a useful tool for the prediction of the system's actual performance, because measurements of real cognitive and sensorimotor availability are rare and unconviniant.

5 CONCLUSION

The main purpose of our work was to get tools for the prediction of the system's performance from self estimations of operators' fitness for duty.

Subjective estimations of fitness for duty include also effects of environmental factors and biological rhythms. At the same time the effects of workers abilities, knowledge and motivation are also included.

The developed model is a useful tool for the prediction of the system's performance. In a real situation in a system also other technological influences must be included. Human impact on the system's performance is without doubt a crucial influential factor. The developed model explains better the impacts of particular fitness for duty factors. The influences are also theoretically based and explained.

Our future activities are focused towards validation of complete model also in other psychically demanding tasks. We are going to start with the validation of firemen and nurses in intensive care.

Analyses of workers' fitness for duty are used in different purposes. They are used also for organizational activities. With our model these data and analyses will be used also in probability analyses and prediction of the system's performance.

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