EVALUATION OF HUMAN FITNESS FOR DUTY IN A REAL WORKING SITUATION

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ABSTRACT

According to the results of root causes analyses in the complex highly automatised systems almost 80% of reported events and scrams are due to the human error or malfunction. 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 demanded task. Most of the workers in the system have adequate psychophysiological abilities and basic knowledge. So their performance in a real working situation depends on their fitness for duty or actual availability.

Actual availability and consequently human performance depends on: • *human abilities (basic human traits)*

• *human knowledge (knowledge received in educational process and in special training)*
• *human motivation (willingness to take part in the activity)*

Actual availability is the interference of abilities, knowledge and motivation in the real situation and it shapes human performance.

Workers are able to self estimate their fitness for duty. On these estimations modelling of human performance in a real situation is possible.

By the level of human performance system's performance should be predicted.

We have developed questionnaire VTP for self estimations of well- being, mood, fatigue, arousal level, stress and motivation. At the same time data indicating human performance have been collected. Indicators of human performance have been the results on dual task and effectiveness in primary task.

Connections between human fitness for duty and human performance have been modelled. Developed model explain the impacts of particular factors of fitness for duty on systems performance.

1 INTRODUCTION

In the beginning of industrialisation machines have been very rigid and less efficient and perfect than man had been. Because of that engineers have paid all their attention to the technological part of the system - to machines. Since then machines have been more and more improved to today's level - to the level of complex automated systems - very reliable and stable. Man hasn't changed very much since the beginning of industrialisation - his abilities are almost the same as they were a hundred years ago. But something has changed: man's knowledge and motivation has been changed.

According to the results of root causes analyses [1] in complex high automated systems almost 80% of reported events and scrams are due to human errors or malfunctions. Nowadays technological parts of the systems are more stable and scrams as the consequence of technological malfunction are less frequent.

Nowadays reported events are mostly consequences of human mistakes. Human mistakes are, according to the results of root cause analyses, consequences of [2]:

• human unfitness - 22%,
• neglecting of procedures - 25%,
• inadequate training - 20%,

• organisational factors - 33%.

Workers in a good working condition who are fit for duty are able to compensate inadequate training, bad procedures or inadequate organisation. If their fitness for duty is low, they will not be able to react and behave in accordance with expectations.

Inadequate level of fitness for duty didn't influence only 22% of reported events. Indirectly it influenced more than 60% of reported events.

Due to these facts researchers have tried to measure or evaluate human fitness for duty in a real working situation.

Soon after the beginning of industrialisation they were 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 general performance. On this data selection of workers and their training have been organised. In automated system system's performance is more sensitive on particular influences of technological and human part of the system and because of that data describing human basic traits are not sufficient any more. In productional situations in modern systems the performance depends even more on human actual availability or fitness for duty than it did 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. Today it is obvious that system's performance depends on human posibility to realise potential abilities in real situation. In the real situation each operator has to realise his:

• basic traits like intelligence, personality,
• knowledge received in educational process and in special trainings,
• motivation - willingness to take part in some activity.

Potential availability is the interference of abilities, knowledge and motivation in real situation and it shapes human and system's performance. Perceived potential availability is fitness for duty.

Workers are able to self estimate their potential availability - they are able to self estimate their fitness for duty. Self estimations are subjective evaluations of fatigue, well-being, mood and arousal span estimated by workers themselves in a real situation.

Workers aren't able to self estimate their levels of cognitive and sensorimotor availability - but they are able to self estimate their fatigue and well-being.

Fatigue, stress and exhaustion effect human cognitive and sensorimotor efficiency in a real situation. Decrease in the human performance is the consequence of fatigue's influence on human availability [3].

Control of a complex automatised system is a very complex work, demanding effective cognitive evaluation of different, often unknown productional situations. It depends on the cognitive evaluation of an operational situation whether an unexpected event ends in a scram, incident, accident or only a transient.

During the training process the operators are trained for cognitive evaluation of different situations on the basis of skill rules and knowledge.

Maintaining the system within safety limits demands operators' behaviour based on skills. Situations that might endanger the environment call for an immediate response and effective conduct based on skills.

Behavioural patterns based on skills must be very familiar to the operators.

Effective skill based behaviour demands adequate level of sensorimotor capacity - it demands effective perception and motoric reactions.

Because of high level of complexity of operation of an automated system it is impossible to train the operators to govern all operational situations on the basis of skills.

Great number of situations are managed on the rule and knowledge based behaviour. Rule based behaviour demands identification of situations and the choice of behavioural pattern adequate to the situation in accordance with procedures. Efficiency of rule and knowledge based behaviour is shaped by the level of cognitive availability.

Adequate level of sensorimotor availability assure efficient skill based behaviour. Adequate level of cognitive and sensorimotor availability assure safe and efficient operation of the nuclear power plant or any other automatised system in each operational situation.

Estimations of each parameter reflecting levels of cognitive and sensorimotor availability should be a useful tool for prediction human behaviour and consequently of system's performance. Prediction of human availability should be necessary to avoid human errors and consequently scrams and undesirable events.

2 METHODS

Levels of workers' cognitive and sensorimotor availability were measured during normal system's operation. Measurements of human availability are based on the theory of dual task.

Dual task method is based on Brown's theory of limited human capacity: one part of capacity is occupied with human main task; the remaining capacity could be occupied with dual task. More capacities are occupied with main task less capacities are available for dual task. Efficiency on dual task should be an indirect indicator of human capacity in a real situation.

Sensorimotor availability was measured with measurements of reaction times on additional visual signal.

Cognitive capacity was measured by results on Decoding test. The measure of cognitive availability is the number of decoded letters in limited time.

Sensorimotor availability was measured for prediction of skill based behaviour.

Cognitive availability was measured for prediction of rule and knowledge based behavioural patterns.

Indicators of system's performance were time distributions of scrams and transients.

Indicators of fitness for duty were self estimations on VTP. Fitness for duty was measured with self estimations of:

- physical fatigue,
- psychical fatigue,
- general well-being,
- vigilance - attention span,
- mood,
- stress,
- motivation.

For self estimations of fitness for duty "Questionnaire of momentary feeling - VTP with 47 amounts with five point scale for each item (1 means very good condition, 5 means very bad condition) was used.

Subjective estimations of fitness for duty data were collected in the morning and in the night shift four times per day (n=4). We have N = 153 measured "men-days"

Indicators of human availability are: 1. sensorimotor availability - reaction times - defines as "b" 2. cognitive availability - number of decoded letters - defined as "b2" 3. System's performance indicators are:

- trips - defines as C1
- transients - defines as C2

For deeper qualitative analyses root cause analyses for 23 reported events were performed. These data were used for qualitative analyses of connections between fitness for duty, human availability and system's performance.

The main purposes of the research were:

- modelling of system's performance with human availability data $B \longrightarrow C$
- modelling of human availability with fitness for duty data $A \longrightarrow B$
- modelling of system's performance with fitness for duty data $A \longrightarrow C$

2.1 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

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

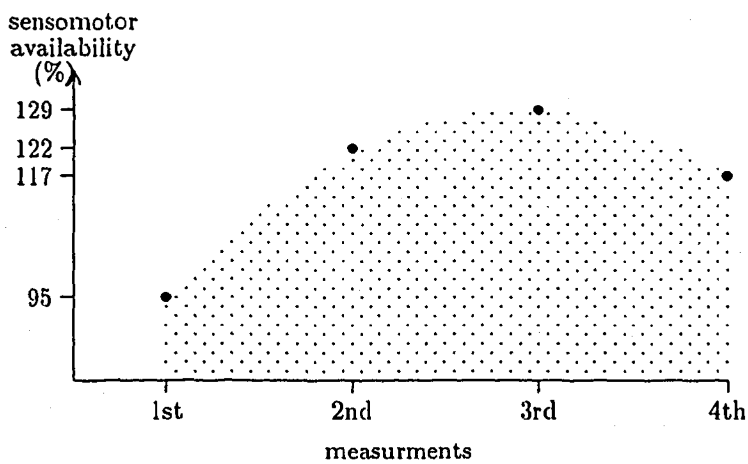
then there is probability P, that we can approximate b_m with a_i and a_j. Quality of this approximation is

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

3 RESULTS

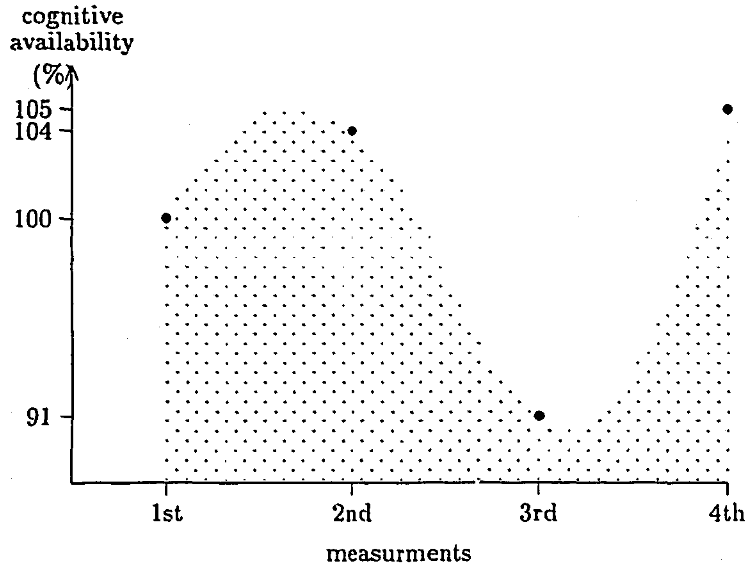
3.1 Sensorimotor availability

Level of sensorimotor availability was on average higher in the night shift. The lowest level of sensorimotor availability was about 11 o'clock in the morning - at the time when according to the effects of biological rhythms it should be the highest.



3.2 Cognitive availability

Average level of cognitive availability was also higher in the night shift. Cognitive availability was at the time of the lowest level of vigilance higher than in the morning shift at the time of the highest arousal level, according to the effects of biological rhythms. Differences in the average levels of cognitive availability between morning and night shift were smaller than in the level of sensorimotor availability.



3.3 System's performance

The highest number of scrams was in the morning shift between 9 and 11 o'clock , at the time of highest level of hypothetic psychophysiological availability. The lowest number of scrams was in the second part of the night shift when psychophysiological availability should be the lowest.

	Day shift		Night shift		
measure	f	%	f	%	χ^2
1st	6	17.7	5	14.7	0.8
2nd	8	23.5	4	11.8	1
3rd	5	14.7	1	2.9	.6
4th	4	11.8	1	2.9	1
	$\Sigma = 23$		$\Sigma = 11$		

Table 1: Level of system's performance : distribution of scrams

In the morning shift there were more transients than in the night shift. The highest number of transients were at the second part of the morning shift.

3.4 Root cause analyses

For qualitative additional analyses collected data were compared with the results of root cause analyses.

According to the results of root cause analyses:

- 73.9% of all scrams occured during normal operation on power
- 47.8% of scrams occured as the consequence of mistakes done during maintenance work
- 43.5% of scrams were consequence of mistakes in planned, routine task
- 52.2% of scrams were due to inadequate knowledge and training
- 43.5% of scrams were the results of neglecting to a certain task.

3.5 Analyses of behavioural patterns

For detailed analysis of human role in the system behavioural patterns in event's operational situation were focused.

3.5.1 Morning shift

The most frequent in the day shift were knowledge based behavioural patterns. The most frequent were mistakes in decision making - not taking into the account all the condition and side effects. A bit higher number of these mistakes was at the time of the "best biological availability" at the middle of the morning shift. It was at the time of quite low level of cognitive ability.

The other more frequent behavioural pattern in the morning shift was motorical variability - inadequate motoric reaction based on skills. These were pure skill based errors at the time of lower level of sensorimotor availability.

3.5.2 Night shift

In the night shift the same behavioural patterns were the most frequent as they were in the morning shift. The most frequent were mistakes "not taking into the account all the condition and side effects". Less frequent were mistakes on skill based level - as the consequence of inadequate level of sensorimotor availability.

Lower efficiency in the night shift was at the beginning of the shift at the time of the lowest level of cognitive and sensorimotor availability.

Comparing the results of root cause analyses with results of measurement of cognitive and sensorimotor availability it is obvious that there are some connections.

3.6 Modeling of connections

Further on we tried to define these connections between human availability, human efficiency and system's performance. For this purpose model describing connections between three kinds of data was developed.

Mathematical model describe connections between fitness for duty, human availability and system's performance has been developed. It explains connections and it should be a useful tool for prediction performance availability from human data.

3.6.1 Morning shift

performance - P
sensorimotor availability - S
cognitive availability - C

$$P + 14.09 = --0.0147 \times S - 0.0235 \times C$$

3.6.2 Night shift

performance - P
sensorimotor availability - S
cognitive availability - C

$$P + 1.293 = -0.00097 \times S + 0.03944 \times C$$

3.7 Self estimations of fitness for duty

In real operating situation collection of data with dual task is difficult. From this issue method for self estimation of fitness for duty has been developed. The basis issues for this development were:

on the basis of fitness for duty predict human availability and performance
and
are people able to self estimate their fitness for duty objectively
and
are there any connections between human fitness for duty and human performance.

Fitness for duty had been self estimated in different productional situations among different kind of workers. On the basis of these results scales for self estimation of operators' fitness for duty were developed.

Scale for physical fatigue contains data about pains in different parts of the body and exhaustedness.

Scale for psychical fatigue contains feelings of depression, confusion and concentration problems.

Scale of general fatigue contains feelings of tiredness, fatigue and unconfortness.

Scale of motivation contains feelings of getting sick, being bored, being lazy and wishes to finish the task.

Scale of vigilance contains feeling of sleepiness.

Scale of mood contains feelings of sadness, sickness, anxiety and tiredness.

Scale of stress contains feelings of irritation, fear, anger and stomac pains.

All seven scales cover the whole space of well-being. A bit closer together are scales of psychical fatigue and general fatigue.

Fitness for duty data were collected among guards and operators. Guards were the control group for the operators (the same shift schedule but less complex task).

3.7.1 Morning shift

In the morning shift general well-being of guards was better than operators' one. Differences were small but they were obvious.

3.7.2 Night shift

In the night shift the general well-being of operators was much better than the guards' one. Differences were quite great. General well-being of operator was in the interval of adequate well-being; general well-being of guards was in the interval of bad feeling and tiredness.

In the general well-being of operators there were small differences between morning and night shift. Adequate well-being in the night shift is a consequence of lower work complexity and a bit of stress for all the time - also during normal operation. This moderate stress keep vigilance and well-being on the adequate level also at the time of lower biological availability.

Operators' fitness for duty in the night shift was higher zhan it should be according to the results of classic shift work's studies [4].

In the general well-being of guards there were great differences among the shifts. Differences in the estimated well-being were in accordance with results of other shift work's researches.

3.8 Model of connection

According to our results in the morning shift system's performance depends on the vigilance and general fatigue level.

In the night shift system's performance depends on the psychical fatigue and stress level.

Human performance and variability also depends on human fitness for duty.

In the morning shift human performance depends on the level of motivation and vigilance. In the night shift human and system's performance depends on the mood and motivation.

From our results motivation, vigilance, stress, mood and fatigue shape human and cause guently also system's performance.

Perceived stress, mood and fatigue are subjectively estimated human fitness for duty indicators.

We are able to perceive stress and fatigue, everybody around us perceive our mood. From everyday life it is obvious that our mood and fatigue shape our performance level. In our researches we tried to qualitate this connections and to develop a method for self estimations of fitness for duty in a real operational situation.

4 CONCLUSIONS

The main purpose of our work had been: to develop a tool for prediction of system's performance from human fitness for duty data. For this purpose scales for self estimations of fitness for duty and model of connections were developed. Right now we are in the phase of method's validation in a real work situation - also outside nuclear power plant. We collected some data for carpenters and other construction workers who have to perform their work highly about the earth.

Colecting data for nurses in the intensive health care unit

Validation of model is so now in progress. On the basis of our results we intend to implement fitness for duty self estimations in every day operational and work practise in nuclear object and in the work places with highly stress work.

Subjective data are less valid than objectively measured data from

technological part of the system. But they are the only available data about human part of the system - about the part caused 80% of all the events.

From this issue use of self estimation for measure level of human fitness for duty and modeling of influence on human and system's performance is reasonable and a wise path to achieve better prediction of system's performance.

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