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HUMAN RELIABILITY MODEL

MODEL NIEZAWODNOŚCI OPERATORA URZĄDZEŃ

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Abstract: The paper is focusing on reliability model of transport devices' human operator. The presented operator model is base on operation potential approach, with taken into account his features and states helping assure of safety decision-making process. The human reliability model is important for future improvement the human - machine interfaces (HMI).

Keywords: Human, reliability, transportation.

Streszczenie. Przedmiotem artykułu jest model niezawodnościowy operatora urządzeń, w szczególności środków transportu. Model operatora uwzględnia potencjałowe podejście do wyrażania wymagań jakościowych i ilościowych w zakresie jego przydatności do realizacji określonych wymaganych działań z użyciem środka transportu.

Słowa kluczowe: Człowiek/ operator, niezawodność, transport

1. Introduction

Human reliability analysis (HRA) deals with deviation of numerical operator error probabilities for the use in fault tree analysis [CCPS, 1994]. Currently there are several HRA methods in use worldwide [Kariuki & Loewe, 2007]. The most widely used are THERP [Swain & Guttman, 1983] and success likelihood index method, SLIM [Embrey et al, 1984]. There are other recent developments known as second-generation HRA methods like cognitive reliability and error analysis method (CREAM) [Hollnagel, 1998] and a technique for human event analysis (ATHEANA) [NRC, 2000], which mostly focus on cognitive error causes and mechanisms [Jung, 2001]. All these methods aim at transforming human error events into human error probabilities (HEPs). The limitations of the current HRA related to this study could be summarize as follow: HRA methodologies are not able to effectively identify various causes of human errors, inadequacy of data for human error analysis, effects of organizational and management strategies as well as safety cultures are not adequately considered.

The modeling problems [Kleijnen, 2008] and safety and reliability problem focused on technical devices is well known today in publications [Ważyńska-Fiok & Jadźwiński, 1990; Jaźwiński & Grabski, 2003]. The human - operator description based on potential approach, with taken into account his features and states helping assure of safety decision-making process (oriented on transport devices controlling), have been not mentioned in biography. The safety and reliability states modeling of operators of transport devices is an important in practice, for example crane operators operating into container terminals [Kim et al, 2004].

2. Human – operator reliability model

For operator operated in specified environment conditions the nominal operation potential PO1N is possible to define, and $PO1N \subset PO1$ (critical condition) [Szpytko & Wozniak, 2007] – Fig.1. The operation potential of the operator PO1 of transport devices' is a function of selected of *j-th* type attributes (ZW_j, j = 1,...n): $PO1 = f_1(ZW_j)$. The operation potential of an operator PO1 is time variable and could be shaping oriented object of *j-th* attributes ZW_j: perception, knowledge, skills, decision-making ability, and reaction on external stimulus.

Direct impacts on operation potential of the operator and possibile changes have:

– energetic (power) supply (possibly with excess or underflow),
– information supply, which can be incorrect and transferred data without processing and interpretation algorithms can be useless (similarly information interpretation under stress situations and incomplete information),

– surroundings and device influences on man- operator (which can influence on effectiveness and correctness decision making process; decision making process errors elimination is possible results active and passive methodologies based devices),
– extreme situations (incorrect decisions minimization in extreme situations is possible as a results of proper selection of an operator and then his training process).

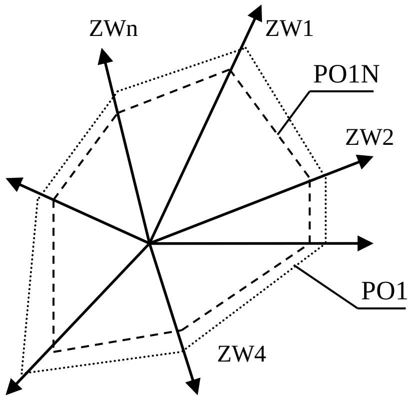

Fig. 1 Nominal PO1N and real PO1 operation potential of operator as attributes ZW function

The attribute ZW is a object of reinforcement or attenuation: $PO1 = f_2(ZW_j \cdot W_j)$, where: W_j – weight of *j-th* operator attribute. Reinforcement of the operator attribute is possible because of training, education and operator decision supporting with use engineering techniques. Attenuation is a result of unit or cumulated load substitute, unsatisfactory (too small, too high) or lack of energetic and/or informatics supplies, as well as disturbances.

Fundamental factors, which are influence operator activities expressed via attributes ZW, are stressors, which have situation and time characters. For operators of transport devices the essential is time stressor, which have strengthening or attenuation character of their attributes [Szpytko et al., 2006]. Stressors have crucial influence on psychophysical status of the device operators'.

One of the essential operator attribute is his predisposition. The operators' predisposition ZW1 is a set of his individual feature S: physical (ZW1S1), mental (ZW1S2), psychical (ZW1S3), psychophysical (ZW1S4). At the operator features S the crucial influence have the following individual parameters Ij: age (I1), tiredness (I2), biological rhythms (I3), diseases (I4), other reasons (I5), where: $ZW1 = f_3$ (ZW1Si, Ij).

At the operator predisposition, the biological rhythms (with the various activity duration periods) have a stimulate influence (both positively and negatively). The biological rhythms of the operator are under both internal and external influences. The operator predisposition ZW1 is also the subject of other impacts which include satisfaction results out of performed job, expressed by the personal realization of own needs and aspirations (e.g.: safety, physiology, acknowledgement, self-realization).

The knowledge and skills ZW2 of the transport device operator are acquiring during the education and training periods. The important skill of the operator is his practical custom, so-called reflex type based on action and reaction behaviour. At the proper utilization of the operator resources named: predisposition, knowledge and skills, the direct impact have also the energetic (energy) supply ZE1 (e.g.: food, sleep, light).

Tiredness is a characteristic feature of human - operator controlling the transport device that accompanies realization by him the particular activities with the same intensity during the fixed time. Tiredness is a particular state of human, in which operator predisposition ZW1 is dropping below acceptable level, and in extreme conditions – below limiting or critical level. The accretion speed of the operator tiredness depends from personal features and operator physical reserve ability.

The changes of operation potential of the operator can be also shown as follows – Fig.2:

SI	- state of operation status (activities realization with transport device use)	readiness (A)
SII	- awaiting state (at operation realization with transport device use)	
SIII	- regeneration state (rest, operator energetic and information supply period)	
	………………………..	
SIV	- diagnostic state (assessment of the current operation potential of the operator, operation potential/ health degradation)	lack of readiness (B)
SV	- awaiting state for operator operation potential reforming/ reproduction methodology (methodology helping reforming the operation potential of the operator)	
SVI	- reproduction state of the operation potential of the operator (therapy)	

where:

$P_1(t)$ - probability of being the operator in the state of usefulness, operation potential of the operator make possible all activities with use the transport device at the moment t,

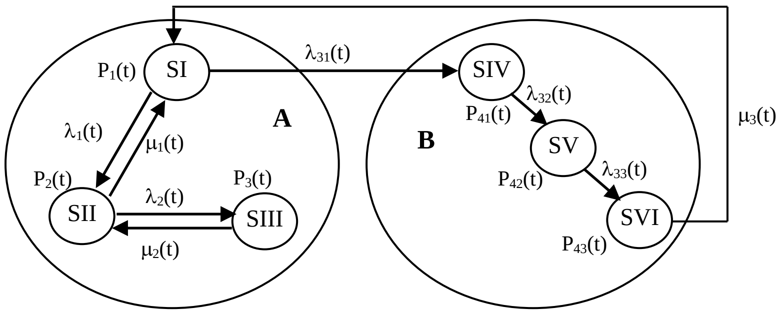

Fig. 2 Operators' states changes

$P_2(t)$ - probability of being the operator in the state of usefulness at the moment t (operation potential of the operator is acceptable) and operator is awaiting for being used decision (activity with use the transport device),

$P_3(t)$ - probability of being the operator in the state of usefulness at the moment t and refilling his operation potential (regeneration, e.g. energy and information supply, training),

$P_4(t)$ - probability of being the operator out of the state of usefulness (non-availability) at the moment t, because: lossing his required operation potential and awaiting for operators' operation potential assessment P_{41} (problem identification with use the cause-results methods), identification the possible replacement method of loosed operation potential P_{42} of the operator, replacement operation potential of the operator to the required level P_{43} ,

$\lambda_1(t)$ - intensity of change from the state of operation (activity) of the operator to the state of inactivity (awaiting for operation with use the transport device),

$\lambda_2(t)$ - intensity of change from the state of inactivity to the state of regeneration of the operation potential of the operator,

$\lambda_3(t)$ - intensity of change from the state of activity to the state of reproduction of the operation potential of the operator,

$\mu_1(t)$ - intensity of change from the state of inactivity to the state of activity (operator operation status),

$\mu_2(t)$ - intensity of change from the state of regeneration of the operation potential of the operator to the state of awaiting (stoppage),

$\mu_3(t)$ - intensity of change from the state of reproduction of the lossed operation potential of the operator within *i-th* possible states to the state of activity (operation).

The transition of the operation potential of the operator from usefulness state A (operation potential is satisfactory, $PO1N \subset PO1$) to the usefulness state B (operation potential is not satisfactory, $PO1N \not\in PO1$), can be followed by transition (operator qualification) from readiness to lack of readiness, which is caused by a malfunction of the monitored operators' attributes. Most often monitored human health parameters (attributes) are blood pressure, heart action, eye vision standard and hand sweating, etc. The block scheme of monitoring system of selected human health parameters used for his operation potential formulation has been shown in the Fig.3.

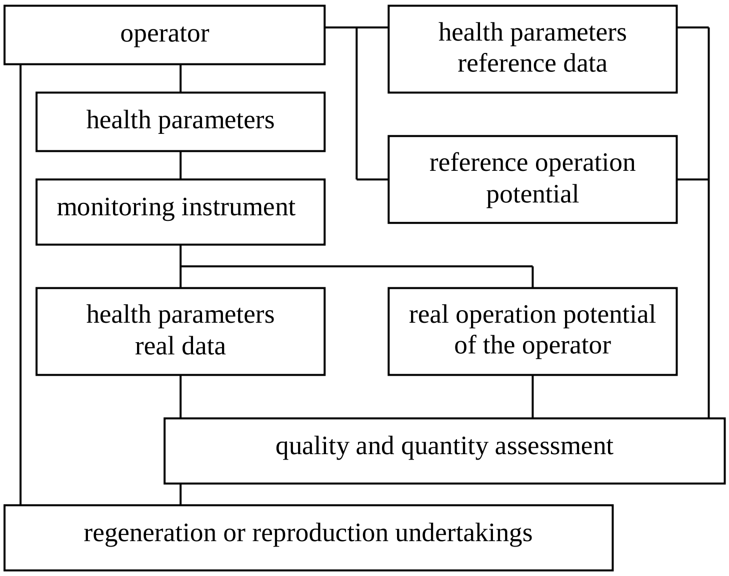

Fig. 3 The block scheme of monitoring system of selected human health parameters used for his operation potential formulation.

In case of lossing by the operator his requirement operation potential the operator will pass through step SIV (operation potential problem identification, diagnostics), to state SV (identification the possible replacement method of loosed the operator his operation potential, awaiting for treatment), then to state SVI (replacement the operation potential of the operator to the required level, treatment) and finally returns to state SI (in which making all required activities with the transport device use are possible). In the state SI (so-called usefulness) operation potential of the operator is satisfactory and conforming with requirements to use the transport device – Fig.4.

3. Potential model of the human - operator

The human – operator is characterize by his usefulness states which have invertibility status (operation potential of the operator which was a subject of degradation make impossible use the transport device) in reproduction process of operation potential (treatment, rehabilitation, education). The potential model of operator with fourth invertibility states presents Fig.5. In the operator potential model, the following states are distinguished:

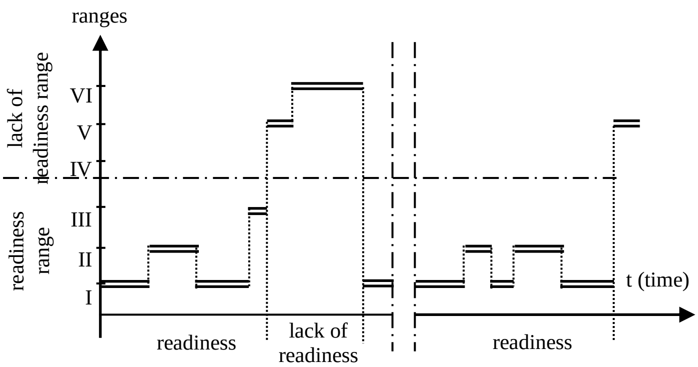

Fig. 4 The operator states characteristics in case of operation undertaken

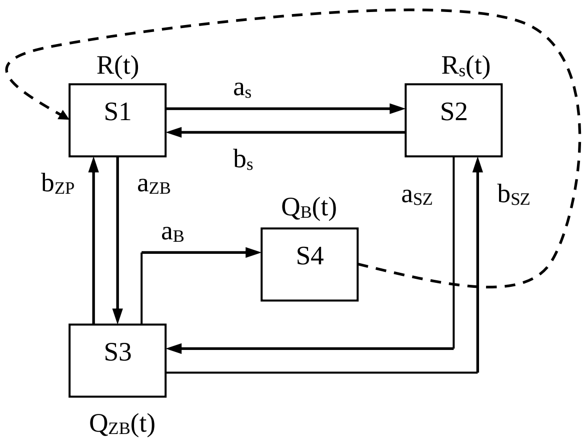

Fig. 5 The fourth invertibility states operator potential model

S1 – the state of full usefulness of the operator; the operator dispose required operation potential and is able satisfactory undertake all actions with transport device support; the state of full usefulness of the operator can be expressed by the operator staying probability R(t) in full usefulness state,

S2 – the no-dependable state of operator efficiency, when the operator can not undertake any activities because his operation potential is a subject of degradation; this state is characterize by the probability of being the operator in the no-dependable status $R_S(t)$,

S3 – the state of safety threaten, when the operation potential of the operator is decreasing up to the hazard level of transport device safety; this state is characterize by the probability of being the operator in the safety threaten status $Q_{ZB}(t)$,

S4 – the no-dependable state of operator safety, when the operation potential of the operator exclude his activities with use transport devices and must be a subject of reproduction; this state is characterize by the probability of being the operator in the no-dependable safety status $Q_B(t)$.

The safety activities with use the transport devices is the operator features, which express his ability to prevent acceptable risk levels (described in regulations and standards) results with undertaken control - based decisions. Moreover transport device operator with undertaken actions is oblige prevent all possible events (outcomes results with transport device use) with critical usefulnesses, which may be hazard for people and results with serious physical/ material losses or other unacceptable consequences.

The safety operation by the operator with use the transport device is possible to express with expected time value $E[T_B]$ up to the no-dependable state of operator safety occur in T_B time. The expected time value $E[T_B]$ has been described by the intensity transition between distinguished states S1, S2, S3, S4:

$$E[T_B] = \overline{T_B}$$

$$\overline{T_B} = \frac{a_S \cdot (b_{ZP} + a_B + a_{SZ} + b_{ZS}) + a_{SZ} \cdot (b_{ZP} + a_{ZB}) + a_B \cdot (b_S + a_{SZ})}{a_B \cdot a_{ZB} \cdot b_S + (a_{ZB} + a_S) \cdot a_B \cdot a_{SZ}} + \frac{a_{ZB} \cdot b_{ZS} + b_S \cdot (b_{ZP} + a_{ZB} + b_{ZS})}{a_B \cdot a_{ZB} \cdot b_S + (a_{ZB} + a_S) \cdot a_B \cdot a_{SZ}} \qquad (1)$$

where:

a_B – transition intensity from the state of safety threaten S3 of the operator results decision making to the no-dependable state of operator safety S4,

a_S – transition intensity from the state of full usefulness of the operator S1 to the no-dependable state of operator efficiency S2 within decision making oriented to the transport device,

a_{SZ} – transition intensity from the no-dependable state of operator efficiency S2 within decision making oriented to the transport device, to the state of safety threaten S3,

a_{ZB} – transition intensity from the state of full usefulness of the operator S1 to the state of safety threaten S3 results of undertaken decisions/ controls oriented to the transport device,

b_S – transition intensity from the no-dependable state of operator efficiency S2 within decision making oriented to the transport device, to the state of full usefulness of the operator S1 results reproduction his operation potential (which was a subject of degradation),

b_{ZP} – transition intensity from the state of safety threaten S3 of the operator results decision making oriented to the transport device, to the state of full usefulness S1 of the operator (results proper operator reaction),

b_{ZS} – transition intensity from the state of safety threaten S3 of the operator results decision making oriented to the transport device, to the no-dependable state of operator efficiency S2 results proper operator reaction.

Results the adequate undertakens in the technique and management areas with use the knowledge within the range of transition intensities between distinguish operators' states (based on monitoring results of selected health parameters of the human – operator), the operator safety operation potential shaping is possible in practice.

Safety into the controlling processes (done by operators) of transport devices is possible to describe with use safety indicators absolute type. The safety absolute type indicator is expressed by a number of particular events (accidents) occurred during fixed time of device operation. Causes the possible events are: probability $P_t(t)$ of the operators' operation potential PO1 changes (degradations), probability $P_c(t)$ of possible errors occur during operators' decision – making processes, probability $P_z(t)$ of possible external unfavourable influences are occurring (ZO, ZU). The probability of operator favourable ending activities into fixed environment is described as follow:

$$P = P_t \cdot P_c \cdot P_z = \prod_{i=1}^{N} P_i \qquad (2)$$

The required operation potential PO1N of the operator is possible to express with the human – operator availability AOP indicator. The human – operator availability of transport devices means that he has ability to undertaken all operations (activities) during random time and into random working space. The above require necessitate operation potential of the human – operator. The human – operator availability indicator AOP(t) is described by the probability undertaken into the operation space fixed transportation activities during the time $T \leq t$, and finally the operator will be able to undertake new tasks when first is finished:

$$AOP(t) = P(T \leq t) \qquad (3)$$

where :

t - demanded time of the operator availability duration, when operator must have operation potential make possible all required activities.

Into the availability models of the transport device human – operator is possible to accept, that proceed processes have random character, and have been described by the Markovs' models [Cox & Miller, 1965; Feller, 1957; Jadźwiński & Grabski, 2003]. The availability model of human – operator of transport device operates into intermittent transportation cycle and with his renewable availability status, is present in Fig.6. The presented model structure involves:

S_1 - availability state of the operator and awaiting for transportation task or regeneration,

S_2 - availability state of the operator under transportation task,
S_3 - reproduction state of the operation potential of the operator (non- availability state).

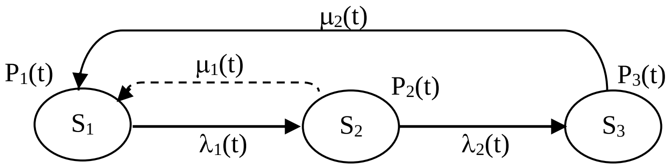

Fig. 6 The availability model of the transport device human – operator operate into intermittent cycle

$P_1(t)$ - probability of being the operator in the state of availability in the moment t (awaiting for transportation task realization or regeneration of his operation potential),
$P_2(t)$ - probability of being the operator in the state of availability in the moment t,
$P_3(t)$ - probability of being the operator in the state of non- availability in the moment t.
$\lambda_1(t)$ - intensity of transition from the awaiting status for transportation task realization or regeneration status of his operation potential to the transportation task realization status by the operator,
$\lambda_2(t)$ - intensity of transition from the transportation task realization state to the reproduction state of the operation potential of the operator,
$\mu_2(t)$ - intensity of transition from the reproduction state of the operation potential of the operator to the awaiting state for transportation task realization,
$\mu_1(t)$ - intensity of transition between states S_2 and S_1.

Assuming that: $\lambda(t)=\lambda$, $\mu(t) = \mu$, for homogeneous stationary Markov process [Jaźwiński & Grabski, 2003] we receive as follow:

$$P_1(t) + P_2(t) + P_3(t) = 1 \tag{4}$$

$$P_1 = \frac{\mu_2 \cdot (\lambda_2 + \mu_1)}{\mu_2 \cdot (\lambda_1 + \lambda_2) + \lambda_1 \cdot \lambda_2 + \mu_1 \cdot (\lambda_2 + \mu_2)} \tag{5}$$

$$P_2 = \frac{\mu_2 \cdot (\lambda_1 + \mu_1)}{\mu_2 \cdot (\lambda_1 + \lambda_2) + \lambda_1 \cdot \lambda_2 + \mu_1 \cdot (\lambda_2 + \mu_2)} \tag{6}$$

$$P_3 = \frac{\lambda_2 \cdot \lambda_1}{\mu_2 \cdot (\lambda_1 + \lambda_2) + \lambda_1 \cdot \lambda_2 + \mu_1 \cdot (\lambda_2 + \mu_2)} \tag{7}$$

4. Final remarks

The presented reliability operator model [Szpytko, 2008] is base on operation potential approach which takes into account his features and states, helping assure the safety decision-making process. The human reliability model is important for future improvement the human - machine interfaces (HMI).

In transportation processes greater significance have HMI systems that are direct communication systems between human (operator) and managed because of him process, supplied tools for visualization industrial process using synoptic images, controlling, monitoring and managing the whole process or choosing devices and means of transportation process, acquisition and data presentation. HMI is the higher levels of control systems that enables raising quality and shorten the transportation tasks realization.

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