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Modeling human actions and psychophysical reactions in emergency situations

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A B S T R A C T

The authors propose a model describing the process of human psychophysical reactions to a signal, stimulus, and the information processing process in decision-making by managers and staff members, as well as formulate the basic principles of modeling actions in emergencies.

1. Introduction

The practice of life shows that a person possessing knowledge and experience of behavior and activity cannot always implement them in a specific situation. The situation is always personally mediated, and a person's behavior has situational features. The deciding role belongs to a set of properties, qualities, habits, knowledge, abilities, skills, preparedness for life, activity and meeting extreme situations, which are inherent in a specific person and have been consistently shaped in him/her. The totality of these psychological and pedagogical phenomena determines the preparedness of a person to meet various objective and subjective difficulties and to overcome them. Therefore, an extreme situation is an indicator of a special state of the system "a person in a situation" (and not just an environment), changing in a certain range depending on the degree of preparedness and the choice of behavior by the person him- or herself. Extreme situations are an extreme manifestation of difficult situations, require maximum exertion of mental and physical efforts to get out of them [1].

When working in conditions of heightened danger in emergency situations (ES), managers and members of emergency response personnel often operate at the limit of their psychophysiological capacity. As a result, their behavior becomes difficult to predict, especially if there is an inevitable choice: whom, what, how and in what order to save. Such a choice should ideally be ruled out. Therefore, the knowledge of how to prepare a leader for error-free actions makes it possible to save the health and life of each victim, as well as property.

At present there are only general formulations of possible directions in solving the problems

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that arise in an emergency [2]. Theoretical frameworks suitable for the analysis and quantitative assessments of personal characteristics of the personnel are still in the development stage. It was established from investigations of accidents, analysis of their circumstances and causes, that human actions are determined, first and foremost, by the spiritual component of personality, and then by the level of professionalism and physical capabilities [3].

Therefore, a quantitative assessment of managers' personal characteristics and establishing their connection with the ability to avoid emergency situations allows increasing the preparedness of personnel for accident-free work and is an urgent problem of great importance in ensuring labor and life safety [4].

The purpose of this study is to build a model describing the process of psychophysical reactions of a person to a signal, stimulus, and the information processing process in decision-making by managers and staff members, as well as to formulate the principles of modeling actions in emergencies.

2. Methods for modeling psychophysical processes

To solve the topical problem of accident prevention it is necessary to develop a mathematical apparatus that allows simulating the decision-making process in the event of an emergency situation.

The basic psychophysical Weber-Fechner law [5] reflects the relationship between the intensity of sensations I and the strength of the stimulus R:

$$I = k(\ln R - C) \tag{1}$$

where k and C are constants. This dependence is true only for stimuli of average intensity.

The authors of [6] cite Raymond Cattell's assertion that an adequate theory of functioning and development of personality must be based on rigorous research methods and precise measurements. As an advocate of mathematical analysis of personality, he was of the opinion that behavior prediction can be accomplished by means of the specification equation. The main formula used by Cattell to predict behavior with a certain degree of accuracy is as follows:

$$K = f\ (S, P) \tag{2}$$

It is noted here that the nature of a person's specific response K, which signifies what he does, or thinks, or expresses in words, is some indeterminate function f of the stimulating situation S at a particular time and of the personality structure P. The specification equation shows that a characteristic response to a situation is a function of the combination of all traits significant to that situation. And each trait interacts with situational factors that may influence it. Cattell acknowledges that it is difficult to predict a person's behavior in a given situation. To increase the accuracy of prediction, the personologist must consider not only the traits that a person possesses, but also non-trait variables such as the person's mood at the moment and the specific social roles required by the situation. Moreover, each trait must be weighed in terms of its relevance to the situation at hand. For example, if a person were placed in an emotionally arousing situation, then the trait of anxiety should be given the most weight in predicting their response. Therefore, equation (2) represents the simplified gist of Cattell's theory of personality traits. From a cognitive point of view, however, it should not be forgotten that this main formula, $K = f\ (S, P)$, confirms Cattell's conviction that human behavior can be determined and predicted.

Stevens' empirical power relationship between sensation and irritation is also used [7], [8]:

$$Y = k(I - \varphi)^n \tag{3}$$

where Y is the force of subjective sensation, I is information entering a person's memory, n is an index varying from 0.2 to 3.5 depending on the type of stimulus; k is a constant; φ is the threshold intensity of the stimulus.

The literature proposes an equation for information processing by human memory [3, 9-11]:

$$\frac{dI}{d\tau} = R + \frac{I - \varphi}{T}$$

where I is information entering a person's memory; τ is time; R is the pace of information delivery; φ is information stored in memory for a sufficiently long period of time; T is the constant of information processing time.

There is a known Gabor model [12], which models the process of storing a signal $A(\tau)$ beginning at $\tau = 0$ in long-term human memory over time t_1 as an integral of image convolution:

$$\varphi(t_1) = \int_0^T A(\tau)A(t_1 - \tau)d\tau, 0 < t_1 < T \quad (4)$$

where T is the total signal duration.

The memory function$R(t)$ has the form of a correlation between A' and φ:

$$R(t) = \int_t^T A'(t_1 - \tau)\varphi(t_1)dt_1 \quad (5)$$

The proposed models describe mainly the process of human reaction to the signal, stimulus, and the information processing process. Mathematical apparatus describing psychophysical processes requires improvement and extending it to solve a wider range of problems for analysis of decision-making process in an emergency by managers and members of emergency response personnel in case of emergencies.

3. Principles of modeling actions in emergency situations

A system of legal, socio-economic, organizational and technical, sanitary and hygienic, therapeutic and preventive measures and means operates and is constantly being improved in all countries. They are aimed at preserving human life, health and working capacity in the process of labor activity. Specific measures are taken to improve cooperation between all services and departments to ensure that workers enjoy healthy and safe working conditions. According to the Constitution of the Republic of Azerbaijan, "Everyone has the right to work in safe and healthy conditions", " Officials who conceal facts and circumstances threatening life and health of people are accountable under the law " [13]. The Labor Code formulates the basic principles of ensuring labor protection by state authorities, owners, employers and employees [14]. These principles include: collectivity of actions of state authorities, owners, employers and employees, aimed at improving working conditions and labor protection, elimination of industrial accidents, injuries, harm and industrial diseases; precedence of life and health of an employee over the results of production activity of an enterprise; coordination of activities in the field of labor protection with other directions of economic and social policy, as well as with activities in the field of environmental protection; unified requirements in the field of labor protection for all enterprises regardless of form of ownership and organizational and legal form, etc.

Unfortunately, cases of occupational injuries at work and in emergencies still occur. The system of instructions, explanations, guidelines in work orders and workplaces, personal examples of actions during training of workers and other forms of training and instruction are used to prevent emergency situations. At the same time, the main thing in ensuring occupational safety is the link of work site managers. Establishing regularities in the growth of managers' and teams' preparedness to prevent emergency situations by scientific and methodological support of the improvement of management's leadership qualities, including in carrying out professional trainings with them is a topical scientific problem, which is of great importance for the improvement of labor and life safety.

We know that a person is capable of independently producing knowledge that they consider to be new. Novelty, as a rule, is determined through comparison of produced knowledge with that which is known to a person from various sources. Imagine that a person is capable of producing new knowledge in an amount proportional to the sum of the sets of knowledge available to them. Moreover, these sets of knowledge contain erroneous knowledge. In the process of saturation and production of new knowledge erroneous knowledge is replaced with true knowledge. The change in the total amount of knowledge during learning is determined by the gain of new knowledge and the loss of erroneous knowledge. If the growth of new knowledge is taken in percentage, for example, using coefficient α, and the loss of erroneous knowledge using coefficient β, then the growth of knowledge, starting from some initial level (i_0), can be represented as the well-known Malthus equation [4].

$$i(t) = e^{(\alpha-\beta)(t-t_0)}, \tag{6}$$

where $(t - t_0)$ is the duration of the acquisition of new knowledge and the loss of erroneous knowledge.

Every person has a conditional limit of knowledge saturation, and when this limit is reached, the digestibility of knowledge rapidly decreases. This is explained by the fact that a person must arrange knowledge in a new way, which takes a certain amount of time.

Suppose that when the conditional limit is reached, knowledge is "cramped" in the permissible volume of operative long-term memory (OLTM), and the level of "cramming" is proportional to the *n*-th degree of its density or, for instance, to its quantity at some instant squared (Verhulst was the first to suggest such dependence when refining the Malthus equation) [15]. Then, if $\frac{\Delta i}{\Delta t} = (\alpha - \beta)i$, then, taking into account the compaction of knowledge in the volume of the OLTM, we get

$$\frac{\Delta i}{\Delta t} = (\alpha - \beta)i - \gamma i^2, \tag{7}$$

where γ is coefficient of specific knowledge saturation in the learning period, which describes the course of knowledge compaction up to some limit. This limit, based on the growth of new knowledge, loss of erroneous knowledge and learning time, can be determined using numerical values of α, β and γ in the following form:

$$h = \frac{\alpha-\beta}{\gamma}. \tag{8}$$

Then the function

$$f(i) = (\alpha - \beta)\frac{h - i_0}{h} \tag{9}$$

can be represented as a relationship between the total amount of knowledge and its specific characteristics: growth α, decline β and saturation limit h.

By integrating equation (7), we obtain its solution as

$$i(t) = i_0 \frac{h}{(h - i_0)e^{-(\alpha-\beta)(t-t_0)} + i_0}. \tag{10}$$

The curve of knowledge saturation during learning is shown in Fig. 1, where q is the number of correct answers to questions (20% error).

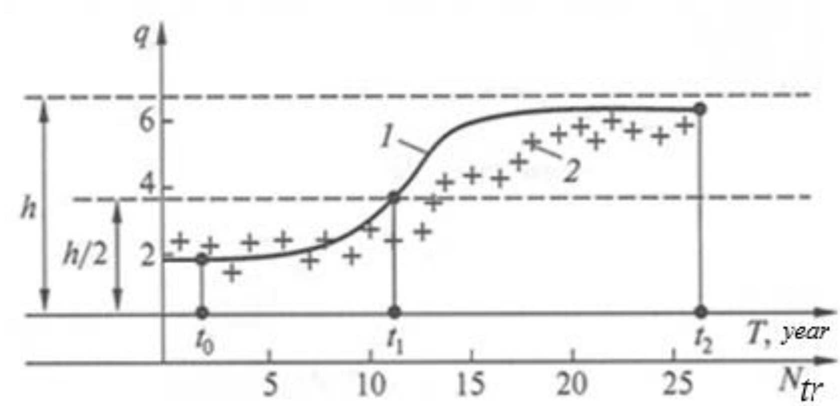

Fig. 1. Knowledge saturation in learning: *1* – theoretical knowledge; *2* – empirical data; N_{tr} – number of trainings; q – number of correct answers

In various interpretations, the relationship $i(t)$ is used in solving learning problems under conditions where all or some of the coefficients from the set $\{\alpha, \beta, \gamma\}$, as well as i_0 or h, or others of these initial quantities are determined, to find values of $i(t)$ in the learning range $(t - t_0)$.

We summarized the results of available studies and developed scientific and methodological guidelines for conducting occupational safety trainings to improve the professional level of managers responsible for the organization of activities in emergencies. The basic scientific and methodological principles of their preparation and implementation are given below.

The structure and execution of a training is based on the fact that if it is impossible for the trainee to avoid answering the question asked, he/she is forced to answer it. A mistake in the answer is immediately corrected.

If the answer is correct, the knowledge is consolidated. Proceeding from this, the **first principle** (*gamified assessment*) postulates: for a significant acceleration of the gain of true knowledge and the loss of erroneous knowledge, game conditions are created, under which an answer to the question must necessarily be given. This principle can be implemented only in a game situation, when a wrong answer does not threaten the leader's reputation, and the right one strengthens it. Mathematically, the first principle can be represented in the form of the expression

$$i(t)^* = k_{ab}\left(\sum_{i=1}^{n} i_{ni} + \sum_{j=1}^{m} i_{0j}\right) + \begin{cases} +i_{in}k_1, i = i_n, \\ -i_{i0}k_2, i = i_0, \end{cases} \quad (11)$$

where $i(t)^*$ is values of the function of knowledge saturation in the process of implementation of a game situation with answers to questions; $\sum_{i=1}^{n} i_{ni}$ is the amount of true knowledge in memory before the training began; $\sum_{j=1}^{m} i_{0j}$ is the amount of erroneous knowledge; $i_{in}k_1$, $i_{i0}k_2$ is the amount of true knowledge obtained during training and the amount of erroneous knowledge removed, respectively; k_{ab} is the ability to absorb knowledge in a game situation.

The level of the fixed true knowledge in the OLTM is measured by the reflexivity of their implementation in the answers. Usually a trainee spends a certain time t_c to make a decision to answer a question. If the knowledge is firmly embedded in the OLTM, the duration of the answer is determined mainly by the ability to present it correctly, so that the answer would not be qualified as unclear or erroneous (Fig. 2).

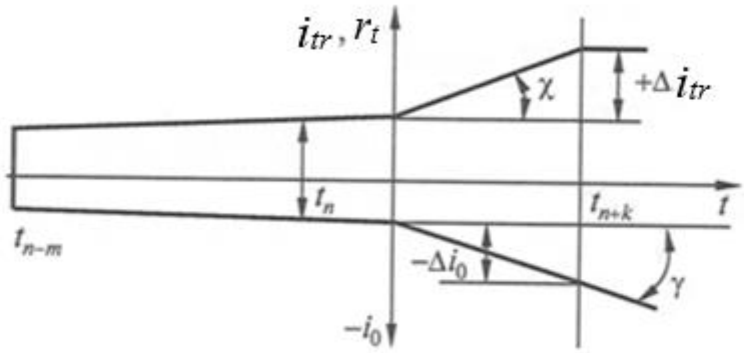

Fig. 2. Toward interpreting the processes of knowledge saturation during a professional training over a period of time $(t - t_{n+k})$ with the growth of new true knowledge Δi_{tr} and the loss of erroneous knowledge Δi_0 ; i_{tr} – true knowledge, r_t – training rate

Polar personality traits are known to manifest themselves in extreme situations. These include an industrial accident, where the number of exits or entrances to the workspace is limited, and often they are blocked. In this situation, the self-preservation instinct prevails most often. The manager must act expertly and decisively here. From the "can", "want", and "must" priorities of each subordinate and him/herself, the leader must synthesize a collective aspiration - we: we want to get out, we can do it, and we need to help the weak and inexperienced.

The equation of the synthesis of the collective aspiration "to survive all together" can be presented in the following way:

$$\sum_{i=1}^{n}(\mathrm{c} + \mathrm{w} + \mathrm{d}) + \mathrm{LW} = (\mathrm{cw})N + \mathrm{CAH} + \mathrm{TC}, \qquad (12)$$

where N is the number of employees in the team, each of whom: c – can save themselves, w – wants to do it and knows that it is their duty (d); LW is the leader's will, a special combination of his c, w and d; (cw)N is a qualitatively new collective desire to save themselves, especially on the realization that everyone can and wants to do it; CAH is collective assistance and help; TC is the care of each for all and all for everyone (total care).

It follows from equation (12) that a strong-willed leader is able to unite the team, i.e., to synthesize from disparate "can", "want", and "need" the collective desire to "survive all together" while helping those in need. Equation (12) describes the **second principle**, *the consolidation of collective aspiration* (or the *principle of team cohesion*).

The **third principle** determines the necessity of bringing a leader's actions in an emergency situation to the level of reflexive actions by means of professional training. The level of reflexivity of actions is determined by the formula

$$R = R_0 e^{n}, \qquad (13)$$

where R_0 is the initial level of reflexivity of actions; n is the number of professional trainings.

We can also write

$$R_0 = \frac{t_c}{t_s + t_m}, t_c = t_{c0} e^{-k_{ab} n}, \qquad (14)$$

where t_s, t_m are the sensory and the motor components, respectively, of workers' decision-making time in an emergency (with $n \Rightarrow \infty, t_c \Rightarrow 0$); n is the number of trainings conducted (in the general case, the number of repetitions); k_{ab} is coefficient of absorption of new information i in training; t_{c0} is the initial value of the sensory component of a worker's decision-making time in an emergency.

The gain of knowledge directly depends on the amount of new knowledge coming from the presenter, from experts and generated in the process of making independent and collective decisions, and their authenticity depends on the objectivity of the evaluation system, based on its individual, collective and expert components, embedded in the organizational structure of the training (*principle of hierarchy of knowledge evaluation system*). This principle complements the first principle (gamified assessment).

The **fourth principle** is that the knowledge gain as a result of the training equals

$$I_{\mathrm{T}} = I_{\mathrm{P}} + I_{\mathrm{E}} + I_{\mathrm{G}}, \tag{15}$$

where I_{P} is knowledge coming from presenter; I_{E} is knowledge coming from expert; I_{G} is knowledge generated in the process of making independent and collective decisions.

Authenticity (correctness of decisions)

$$\mathrm{A} = 1 - (1 - \mathrm{A_L})(1 - \mathrm{A_T})(1 - \mathrm{A_E}) = 1 - \prod_{i=1}^{n}(1 - \mathrm{A}_i), \tag{16}$$

where $\mathrm{A_L}$ is authenticity of leader's knowledge; $\mathrm{A_T}$ is authenticity of team's knowledge; $\mathrm{A_E}$ is authenticity of expert's knowledge; n is the rank of the organizational structure of the training ($n = 3$).

The **fifth principle** is the principle of generating non-standard solutions in the process of training. The amount of knowledge a person receives himself from areas of knowledge not related to the subject of training, linearly depends on the completeness, subject orientation, timeliness, authenticity and detail level of information. When a person cannot avoid the necessity to make decisions, conditions are created for the generation of non-standard ideas, which increase preparedness to act in an emergency:

$$I_{\mathrm{T}} = f(\mathrm{C}, \mathrm{SO}, \mathrm{Tm}, \mathrm{A}, \mathrm{Det}) \tag{17}$$

where C is completeness of information; SO is subject orientation of information; Tm is timeliness of information; A is authenticity of information; Det is the detail level of information.

Growth in the rate of synthesis of ideas

$$I(n, m) = I_{\mathrm{B}} + I_{\mathrm{N}}m + (ik_{ab})(m + n), \tag{18}$$

where I_{B} is basic knowledge (from life experience, including educational institutions); I_{N} is new knowledge from practical work in the mine; m is number of descents into the mine (work experience); n is number of repetitions of information i in training (number of trainings); k_{ab} is coefficient of absorption of information.

The condition for the emergence of non-standard solutions:

$$P = \lim I(n, m) \longrightarrow I(n, m) + \Delta i. \tag{19}$$

5. Conclusion

We have proposed a model describing the process of human psychophysical reactions to a signal, stimulus, and the information processing process in decision-making by managers and staff members, as well as formulated the basic principles of modeling actions in emergencies.

A scientific and methodological framework for professional trainings has been developed and the correlation between a leader's preparedness for efficient actions in an emergency and the total amount of new knowledge obtained in the course of training has been determined.

Principles of modeling have been developed with the purpose of creating conditions for generating non-standard solutions.

Based on the developed modeling principles, it is possible to conduct professional trainings on labor and life safety.

Thus, a systematic study of the most likely extreme situations, their peculiarities and possible consequences, a training on how to act in such conditions is intended to prepare a person to choosing the right solution for getting out of difficult situations with minimum losses. Such training, according to scientists, should be ongoing at all stages of human life.

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