UDC 614.8

DOI: 10.29202/nvngu/2018-1/7

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SYSTEM APPROACH FOR READINESS ASSESSMENT UNITS OF CIVIL DEFENSE TO ACTIONS AT EMERGENCY SITUATIONS

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СИСТЕМНИЙ ПІДХІД ДО ОЦІНКИ ГОТОВНОСТІ ПІДРОЗДІЛІВ ЦИВІЛЬНОГО ЗАХИСТУ ДО ДІЙ ПРИ НАДЗВИЧАЙНИХ СИТУАЦІЯХ

Purpose. Mutual consideration of social complex and technical indexes while assessing the civil defense (CD) divisions readiness for actions in emergency situations (ES) of various character.

Methodology. As readiness level index of CD divisions, probability assessment of professional-technical readiness state for response to various emergencies at the scheduled time has been used. The level of readiness of the unit is estimated on the general scale – "ready to perform tasks", "limited ready to perform tasks", "do not meet the requirements".

Findings. Analytical dependences of CD units' readiness level on their fitting with both one-type and different-type equipment have been received. A model for evaluating the level of readiness of CD units to act in emergencies is proposed. It is of a systemic nature and integrates modules which are logically and informationally connected according to intended purpose, solvable tasks, input and output data and other parameters each of which solves specific tasks.

Originality. Systems approach and the readiness principle assessment of CD divisions for actions at emergency have been offered. It was based on the consideration of complex indexes of divisions' technical equipment and professional readiness of their staff.

Practical value. The offered readiness level index of CD divisions for actions in emergency allows carrying out the comparative analysis of condition of a readiness of CD divisions for the purpose of development actions to increase effectiveness of their use.

Keywords: *emergency situation, civil protection, hardware of division, professional readiness of staff*

Introduction. Ensuring national security is the integral function of the state. This guarantees necessary conditions for life and activity of the citizens, the prevention and elimination of the emergency situations (ES) of technogenic and natural character.

Safety is such a condition of human activity at which realization of potential danger is avoided with particular probability. Safety at emergency demands reliable functioning of the response system for emergency of natural and technogenic character adequate to the level and the nature of threats [1]. The natural levels, technological and social hazards which significantly influence structure of forces and tools for timely and efficient response to emergency of natural, technogenic and social character [2] are inherent in each administrative and territorial unit of the state.

The number of the civil defense (CD) structures has been defined on the basis of potential threats of technogenic and natural character considering economic opportunities of the state [3]. Timely and efficient responses to emergency of various character and realization actions for elimination of their consequences are assigned to CD forces which unite the relevant rescue services and divisions of the central and local executive authorities, the enterprises and the organizations irrespective of ownership forms and managing. The basis of CD forces has been made by the quick rescue service of civil defense consisting of operating controls, rescue units of the central subordination, rescue units of a special purpose, express aviation and other formations, the state rescue and fire fighting divisions (parts), training centers and support units. At the same time the readiness level index of CD divisions for effective implementation of

tasks which are bound to mitigation of various emergency consequences, namely with protection of the population and territories against negative impact on people's activities, is defined by suitable technical equipment, its readiness level for application and professional ability divisions for implementing objectives. Thus, efficiency of performing intended tasks by CD divisions, first of all, depends on the level of their readiness for actions for emergency response.

However, the question of the approach to estimation of readiness level index of CD divisions for actions at emergency remains open for the moment.

Analysis of the recent research. Readiness of CD forces and means is the condition of CD forces and means defining their ability to carry out the tasks assigned to them [4].

The readiness condition assessment of CD forces to actions on mission is carried out at their transfer from the functioning mode in peace time to the functioning mode in the conditions of the singular period at mobilization of express formations for CD task performance while monitoring readiness for actions for prevention of emergency and response to them.

The ideas of readiness come down to a concept of a condition of operating controls and CD forces which is characterized by their ability of realization of tasks taking into account interrelation "readiness level – risk level", "readiness level – the level of the acceptable damage", "readiness level – danger level" that allows considering readiness as the category displaying need for population safety at emergency. For the readiness mobilization assessment of units in article [5, 6] the following generalized criteria groups have been offered: organizational and legal, material (financial) and criterion of actually readiness mobilization. These groups make system of the main indicators whose quantitative and high-quality estimation gives an assessment according to the common index. The readiness condition assessment has been defined by common assessment basis and persistency measure assessment, power and reliability. In article [7] the readiness model of rescue systems using hardware for recovery operations is presented. Rescue divisions are considered by the authors as a system whose elements include corresponding experts (rescuers) who use the necessary technical equipment (production module). Proceeding from the assessment and analysis of readiness for actions on mobilization process mission of divisions for definition of quality of their work has been simulated. In general, mathematical models of production module functioning in various operational states and rescuers in various functional modes are considered for a complex assessment of mobilization readiness.

In article [8] a mathematical functioning model of both one rescuer and a rescue group as important components of the rescue system in various readiness modes for actions on mission is presented.

Estimation of degree of readiness of a division [9] was carried out on the basis of the analysis of values of characteristics inherent in concrete division such as:

- manning level of division staff;
- completeness of division technical means;
- completeness of division's respiratory protective equipment and protective clothes;
- professional standard of staff division;
- existence of a necessary package of documents on scheduling of actions and technologies of performance work;
- existence of a stock of material tools;
- a possibility of an exit and deployment around works at the scheduled time and others.

For readiness assessment of rescue divisions on the basis of the described characteristics a spectral approach has been used. It allows estimating quantitatively the readiness level of each division in compliance to particular characteristics. As an index of readiness level, a mean value of particular characteristics estimates has been chosen. These characteristics have been taken with the corresponding weight loadings.

However, to assess the readiness level of CD divisions for realization of mission tasks it is necessary to consider the division as a uniform system which includes a human factor and hardware. In this case the readiness level indicator of the division has to display not only the division readiness in general to realization of objectives on emergency response in the unrestricted instant, but also the degree of non-failure operation of its functioning as systems, throughout a run time of works, which is defined by an objective of this research.

Presentation of the main research. Readiness level of a division has been defined by probability that there will be two dependent events:

- the division is ready technically for realization of tasks on emergency response (event A). It means that at the time of emergence in the division there will be a necessary quantity of efficient technical means out of the available ones. From this time on, facilities will smoothly function throughout a run time of emergency response works (t_w);
- the division is professionally capable to carry out objectives provided that it is technically ready for realization of tasks of emergency response (event B).

Then the probability that CD divisions are at the sufficient readiness level for realization of objectives on mission can be written down as follows [10]

$$P = P(A) \cdot P_A(B), \qquad (1)$$

where $P(A)$ is the probability of event A, being that the CD division is technically ready to perform tasks of emergency response; $P_A(B)$ is the probability of event B which is that the CD division is professionally capable of carrying out objectives provided that it is technically ready for realization of tasks of emergency response.

The probability $P(A)$ is defined by two components: completeness of division the necessary quantity of technique, its readiness for application at the time of initiation emergency and trouble-free operation throughout a run time t_w of works on its elimination

$$P(A) = P_T \cdot R^{div.}(t_w), \qquad (2)$$

where P_T is probability of division completeness technique; $R^{div.}(t_w)$ is probability of readiness of the unit's sufficient facilities required for elimination of emergen-

cy at the time of its initiation, and its trouble-free operation throughout a run time of works on emergency response; t_w is the run time of works on emergency elimination response.

Let the staff list assume existence of n units of the one-type equipment. If there are m pieces of equipment available, then the probability of completeness of equipment of the division is calculated according to the classical determination of probability [11] and looks as follows

$$P_T = \frac{m}{n}, \tag{3}$$

where n is the nominal number of units of the one-type equipment; m is the actual number of the one-type technique units.

As the moment of initiation emergency has casual character, readiness of one technique unit for intended application can be characterized by coefficient of operational readiness $R^{unit}(t_w)$, that is, probability that at the time of emergence initiation it will be efficient and, from this time on, it will smoothly function throughout a run time of works on elimination of an emergency situation [12]

$$R^{unit}\left(t_w\right) = K_R^{unit} \cdot P^{unit}(t_w) = \frac{T_F}{T_F + T_{Ren}} \cdot P^{unit}(t_w),$$

where $K_R^{unit} = \frac{T_F}{T_F + T_{Ren}}$ is the availability coefficient of the technique unit [13], that is the relation of average time between failures of the technique unit to the sum of time average between failures T_F and average time of restoration T_{Ren} which characterizes probability that the technique unit will be efficient at the time of emergence initiation; $P^{unit}(t_w)$ is the probability trouble-free functioning of the technique unit throughout a run time of works on emergency response t_w; $T_F = \int_0^\infty P^{unit}(t)dt$ – mean time to failure (MTTF) of the technique unit; $T_{Ren} = \int_0^\infty t[P_{Ren}^{unit}(t)]' dt$ is the average recovery time of the technique unit; $P^{unit}(t)$ is the distribution law of a random value time of no-failure operation of the technique unit; $P_{Ren}^{unit}(t)$ is the distribution law of a random value time of trouble-free operation of the technique unit; $[P_{Ren}^{unit}(t)]'$ is the density function of a random value recovery time of the technique unit.

Now the facilities of CD divisions of Ukraine includes both the equipment which has not reached the end of its service life (the period of normal operation), and the equipment whose serviceable life exceeds 20 years (the aging period). Given this, distribution of trouble-free time operation submits to the law of E. H. Weibull for which [12]

$$P^{unit}(t) = e^{-\left(t/a\right)^b}; \qquad \left(T_F = a \cdot G\left(1 + \frac{1}{b}\right)\right),$$

where a, b are the distribution law parameters; $G\left(1 + \frac{1}{b}\right)$ is the table gamma-function.

Parameters of the distribution law can be determined for a particular technique unit on the basis of statistical processing of these results of operation.

For technique units with obviously expressed effect of aging and wear, it is expedient to use the J. Rayleigh ratio [12] for which

$$P^{unit}(t) = e^{-\left(t/a\right)^2}; \qquad \left(T_F = \frac{\sqrt{\pi}}{2}\right).$$

For technique units which are on the period of normal operation, it is expedient to use the exponential distribution law [12] for which

$$P^{unit}(t) = \exp(-\lambda t); \qquad \left(T_F = \frac{1}{\lambda}\right),$$

where λ is the failure rate of the technique unit.

Let us consider that the recovery time of the technique unit submits to the exponential law to distribution, for which [12]

$$P_{Ren}^{unit}(t) = 1 - e^{-\mu t}; \qquad \left(T_{Ren} = \frac{1}{\mu}\right),$$

where μ is the intensity restorative function of the technique unit.

Let the CD division be equipped with the one-type of the technique unit. There are m available pieces of equipment.

Then the probability $R^{div.}(t_w)$ is defined from a condition that at the time of emergency initiation there have to be efficient no less than ν units from m available. From this time on, these units will smoothly function throughout a run time of works [12]

$$R^{div.}(t_w) = 1 - \sum_{k=0}^{\nu-1} R_m(k), \tag{4}$$

where $R_m(k) = C_m^k \cdot \left[R^{unit}\left(t_w\right)\right]^k \cdot \left[1 - R^{unit}\left(t_w\right)\right]^{m-k}$ is the probability that exactly k technique units from m available will be efficient; $C_m^k = \frac{m!}{k! \cdot (m-k)!}$ is the number of combinations m from k elements.

Considering the ratio of (3, 4) probability $P(A)$ (2) is defined as follows

$$P(A) = \frac{m}{n}\left\{1 - \sum_{k=0}^{\nu-1} C_m^k \left[R^{unit}(t_w)\right]^k \left[1 - R^{unit}(t_w)\right]^{m-k}\right\}, \tag{5}$$

where $R^{unit}\left(t_w\right) = \frac{T_F}{T_F + T_{Ren}} \cdot P^{unit}(t_w)$.

Let us consider a case when the staff of division includes technique l types with the total number n units from which $n_1, n_2, \ldots, n_1$ make the number of corresponding type units $\left(n = \sum_{i=1}^{l} n_i\right)$.

Let there be m pieces of equipment available among which there are $m_1, m_2, \ldots, m_1$ of the corresponding type

$\left(m=\sum_{i=1}^{l} m_i\right)$, then the probability of division completeness is calculated by an equation

$$P_T=\sum_{i=1}^{l}\frac{m_i}{n}. \quad (6)$$

In this case the probability $R^{div.}(t_w)$ is defined from the condition that at the moment of emergency initiation there have to be efficient as many as ν units from t_w available. From this time, these units will smoothly function throughout a run time of works t_w on emergency response. At the same time for each type there are to be as many as v_i units of this type from m_i available exemplars of this type. Then it is possible to write down

$$R^{div.}(t_w)=\prod_{i=1}^{l}\left\{1-\sum_{j=0}^{v_i-1}R_{i_{m_i}}(j)\right\}, \quad (7)$$

where $R_{i_{m_i}}(j)=C_{m_i}^{j}\cdot\left[R_i^{unit}(t_w)\right]^{j}\cdot\left[1-R_i^{unit}(t_w)\right]^{m_i-j}$ is the probability that exactly j units from available of m_i of i type will be efficient; $R_i^{unit}(t_w)$ is the readiness operational coefficient of the technique unit of i type.

Considering the ratio of (6, 7) the probability $P(A)$ (2) is defined as follows

$$P(A)=\sum_{i=1}^{l}\frac{m_i}{n}\prod_{i=1}^{l}\left\{1-\sum_{j=0}^{v_i-1}\left(C_{m_i}^{j}\cdot\left[R_i^{unit}(t_w\right]^{j}\times\left[1-R_i^{unit}(t_w)\right]^{m_i-j}\right)\right\}, \quad (8)$$

where $R_i^{unit}\left(t_w\right)=\frac{T_{F_i}}{T_{F_i}+T_{Ren_i}}\cdot P_i^{unit}(t_w)$; $T_{F_i}=\int_0^{\infty}P_i^{unit}(t)dt$ is the mean time between failures of the technique unit of type i; $T_{Ren_i}=\int_0^{\infty}t[P_{Ren_i}^{unit}(t)]'dt$ is the mean time of maintenance of the technique unit of type i; $P_i^{unit}(t)$ is the value random distribution law of time between failures of the technique unit of type i; $P_{Ren_i}^{unit}(t)$ is the value random distribution law of the technique unit availability recovery time type of i; $[P_{Ren_i}^{unit}(t)]'$ is the density function of the random value of recovery time of the technique unit of i type.

The probability $P_A(B)$ of the fact that the CD division is professionally capable of carrying out objectives provided that it is technically ready for realization of emergency response tasks characterizes professional ability to carry out staff mission tasks of CD division. It depends on the manning level of division staff and vocational training for actions in emergency. The probability $P_A(B)$ is defined by two components: manning level of division staff and vocational training for actions in emergency

$$P_A(B)=P_{Staff}\cdot P_{PR}, \quad (9)$$

where P_{Staff} is the probability of manning level of division staff; P_{PR} is the probability of professional readiness to actions in emergency.

If the staff list of personnel division provides r staffing positions of experts available, and there are w available, then the probability of experts' staff completeness is equal to [11, 13]

$$P_{Staff}=\frac{w}{r}, \quad (10)$$

where r is the regular number of experts; w is the valid number of experts.

The complex of knowledge and abilities, as well as skills and existence of division staff professional experience make professional readiness to actions in emergency [14, 15].

Dynamics of professional readiness is defined by processes of knowledge acquisition, skills in the course of preparation in educational institutions and in the systems of retraining and professional development and professional experience. It can be described with a ratio which considers results of professional selection and efficiency forms and methods of the specialist training system [14]

$$P_{PR}(S)=P_q(S)=P_1(S)+\left[P(S)-P_1(S)\right]\times\times B(S)\cdot\left[1-A(S)\right]^{-1}\left[1-A^{q-1}(S)\right], \quad (11)$$

where $q\left(q=\overline{1,\infty}\right)$ is the number of occupations and trainings which coincide with possible tasks at emergency response; $P(S)$ is the probability of faultless performance of the mastered type task S; $P_1(S)$ is the initial level of readiness; A and B are model parameters which consider efficiency of forms and methods of training.

Let it be necessary to perform several tasks, generally z for successful performance of a task by division. Then the professional readiness level of staff is defined as follows

$$P_{PR}=\sum_{i=1}^{z}Q(S_i)\cdot P_{PR}(S_i), \quad (12)$$

where $Q(S_i)$ is the probability of need for realization of a task of type S_i at emergency response; $P_R(S_i)$ is professional readiness level of staff for performing a task of type S_i.

Taking into account (11) expression (12) will take a form

$$P_{PR}=\sum_{i=1}^{z}Q(S_i)\left\{\begin{matrix}P_1(S_i)+\left[P(S_i)-P_1(S_i)\right]\cdot B(S_i)\times\\ \times\left[1-A(S_i)\right]^{-1}\left[1-A^{q-1}(S_i)\right]\end{matrix}\right\}. \quad (13)$$

By substitution of expressions (10) and (13) in (9) expression for probability $P_A(B)$ has been obtained

$$P_A(B)=\frac{w}{r}\sum_{i=1}^{z}Q(S_i)\left\{\begin{matrix}P_1(S_i)+\left[P(S_i)-P_1(S_i)\right]\times\\ \times B(S_i)\left[1-A(S_i)\right]^{-1}\times\\ \times\left[1-A^{q-1}(S_i)\right]\end{matrix}\right\}. \quad (14)$$

Taking into account ratios (5, 8) and (14) of the division's readiness level for realization of tasks of mission (1) will be as:

- for the divisions equipped with the one-type technique units

$$P = \frac{m}{n}\left\{1 - \sum_{k=0}^{v-1} C_m^k \cdot \left[R^{unit}\left(t_w\right)\right]^k \cdot \left[1 - R^{unit}(t_w)\right]^{m-k}\right\} \times$$

$$\times \left\{\frac{w}{r}\sum_{i=1}^{z} Q(S_i) \cdot \begin{Bmatrix} P_1(S_i) + \left[P(S_i) - P_1(S_i)\right] \times \\ \times B(S_i) \cdot \left[1 - A(S_i)\right]^{-1} \times \\ \times \left[1 - A^{q-1}(S_i)\right] \end{Bmatrix}\right\};$$

- for the divisions equipped with technique units of several types

$$P = \sum_{i=1}^{l} \frac{m_i}{n} \prod_{i=1}^{l} \left\{1 - \sum_{j=0}^{v_i-1} \begin{pmatrix} C_{m_i}^J \cdot \left[R_i^{unit}(t_w)\right]^j \times \\ \times \left[1 - R_i^{unit}(t_w)\right]^{m_i - j} \end{pmatrix}\right\} \times$$

$$\times \left\{\frac{w}{r} \cdot \sum_{i=1}^{z} Q(S_i) \cdot \begin{Bmatrix} P_1(S_i) + \left[P(S_i) - P_1(S_i)\right] \times \\ \times B(S_i) \cdot \left[1 - A(S_i)\right]^{-1} \times \\ \times \left[1 - A^{q-1}(S_i)\right] \end{Bmatrix}\right\}.$$

Divisions readiness level can be estimated based on the common scale – "are ready for performing tasks", "restrictedly are ready to realization of tasks", "do not meet the requirements". It is expedient to establish by the following criteria of estimation:

- "are ready for realization of tasks" if the probability is $P \geq 0.9$;

- "are restrictedly ready for performing tasks" if the probability is $0.7 \leq P < 0.9$;

- "do not conform to requirements" if the probability is $P < 0.7$.

The assessment model of CD divisions' readiness level for actions is presented in Figure.

Module *1* represents the database on CD divisions' completeness of equipment and facilities, their technical condition, production characteristics, completeness of division staff and the level of its vocational training. On the basis of these data the corresponding estimates are given in modules *2, 3, 4* and *5*.

Module *2* is intended for assessment of the division's completeness probability for equipment and facilities with both one-type and different-type equipment. Data of Module *2* are used further for carrying out calculations in Module *6*.

Module *3* intends to assess the probability of manning level of division staff. Data of Module *3* are used further for carrying out calculations in Module *7*.

Module *4* intends to assess the probability of readiness of sufficient facilities and equipment of the division for emergency response with one-type and different-type equipment available. Data of the module *4* have been used further for carrying out calculations in the module *6*.

Module *5* intends to assess the staff's professional readiness level for actions in emergency. Data of Module *5* are used further for carrying out calculations in Module *7*.

Module *6* intends to assess the probability that the CD division is technically ready to perform tasks of emergen-

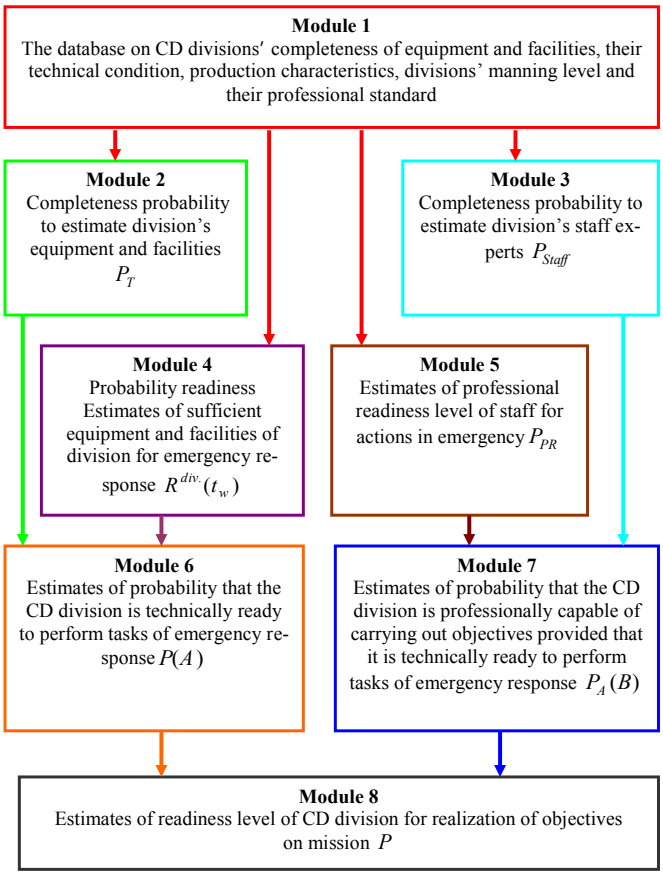

Fig. CD Division's readiness level assessment model for actions in emergency

cy response on the basis of data from Modules *2* and *4*. Data of Module 6 are used further for carrying out calculations in Module *8*.

Module *7* intends to assess the probability that the CD division is professionally capable of carrying out objectives provided that it is technically ready to perform tasks of emergency response on the basis of data which come from Modules *3* and *5*. Data of Module *7* are used further for carrying out calculations in Module *8*.

Module *8* intends to assess readiness level of CD division for realization of mission objectives on the basis of data which come from Modules *6* and *7*.

Conclusions and recommendations for further research.

1. The systems approach and principle of assessing CD divisions' readiness for actions in emergency based on the relative accounting of complex social and technical efficiency functioning factors of division have been offered.

2. Probability assessment of professional readiness degree of task performance on eliminating emergency of various characters at the scheduled time is used as an index of division readiness level.

3. Analytical dependences of CD divisions' readiness level on the level of their equipment both one-type and different-type have been obtained.

4. The model of assessing a CD division's readiness for actions in emergency has been offered. The model has been constructed based on the modular principle. It includes logical and informational modules connected among themselves, each of which carries out specific objectives.

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Мета. Взаємне врахування комплексних соціально-технічних показників при оцінці готовності підрозділів цивільного захисту (ЦЗ) до дій при надзвичайних ситуаціях (НС) різного характеру.

Методика. В якості показника рівня готовності підрозділу ЦЗ використана ймовірність оцінки ступеню професійно-технічної готовності виконати завдання з ліквідації НС у встановлені терміни. Рівень готовності підрозділу оцінюється за загальною шкалою – „готові до виконання завдань", „обмежено готові до виконання завдань", „не відповідають вимогам".

Результати. Отримані аналітичні залежності рівня готовності підрозділів ЦЗ від рівня їх оснащення як однотипною, так і різнотипною технікою. Запропонована модель оцінки рівня готовності підрозділу ЦЗ до дій при НС. Вона носить системний характер і об'єднує в єдине ціле логічно та інформаційно пов'язані між собою за призначенням задачі, що вирішуються, вхідними й вихідними даними та іншими параметрами, модулі, кожний з яких вирішує конкретні завдання.

Наукова новизна. Запропоновано системний підхід і принцип оцінки готовності підрозділів ЦЗ до дій при НС, оснований на врахуванні комплексних

показників технічного оснащення підрозділів і професійної підготовленості їх особового складу.

Практична значимість. Запропонований показник рівня готовності підрозділів ЦЗ до дій при НС дозволяє проводити порівняльний аналіз стану рівня готовності підрозділів з метою розробки заходів для підвищення ефективності їх застосування.

Ключові слова: *надзвичайна ситуація, цивільний захист, технічне оснащення підрозділу, професійна підготовленість особового складу*

Цель. Взаимный учет комплексных социально-технических показателей при оценке готовности подразделений гражданской защиты (ГЗ) к действиям при чрезвычайных ситуациях (ЧС) различного характера.

Методика. В качестве показателя уровня готовности подразделения ГЗ использована вероятностная оценка степени профессионально-технической готовности выполнения задания по ликвидации ЧС различного характера в установленные сроки. Уровень готовности подразделения оценивается по общей шкале – „готовы к выполнению задач“, „ограничено готовы к выполнению задач“, „не отвечают требованиям“.

Результаты. Получены аналитические зависимости уровня готовности подразделений ГЗ от уровня их оснащения как однотипной, так и разнотипной техникой. Предложена модель оценки уровня готовности подразделения ГЗ к действиям при ЧС. Она носит системный характер и объединяет в единое целое логично и информационно связанные между собой по предназначению, решаемым задачам, входными и выходными данными и другими параметрами, модули, каждый из которых решает конкретные задачи.

Научная новизна. Предложен системный подход и принцип оценки готовности подразделений ГЗ к действиям при ЧС, основанный на учете комплексных показателей технической оснащенности подразделений и профессиональной подготовленности их личного состава.

Практическая значимость. Предложенный показатель уровня готовности подразделений ГЗ к действиям при ЧС позволяет проводить сравнительный анализ состояния уровня готовности подразделений с целью разработки мероприятий для повышения эффективности их использования.

Ключевые слова: *чрезвычайная ситуация, гражданская защита, техническое оснащение подразделения, профессиональная подготовленность личного состава*

Рекомендовано до публікації докт. техн. наук А.М. Соболем. Дата надходження рукопису 08.12.16.