Model of Rescue Units Control in Event of Potential Emergency

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Abstract. A problem of organization and efficiency improvement of the system controlling the rescue units of the Ministry of Civil Defense and Emergency Response of the Russian Federation considered using the example of potential hydrological emergency, a model of a system for controlling rescue units in the event of potential hydrological emergency. The problem solution is based on mathematical models of operational control of rescue units and assessment of a hydrological situation of area flooding.

1. Introduction

Under the current conditions of growing economic, social and political risks, the role of rescue units and response groups of the Ministry of Civil Defense and Emergency Response of the Russian Federation is becoming increasingly important. Rescue units are one of the key links of population and national economy safeguarding [1].

The relevance of researching rescue units activity and the present-day rescue operations is based on the need to simulate the activities of territorial bodies of the Ministry of Civil Defense and Emergency Response of the Russian Federation and the selection of the optimum variant for controlling rescue units in the event of potential natural and man-caused emergencies.

Therefore, an inconsistency between the capabilities of rescue units and the requirements of operations carried out may occur, which is caused by the growth of decision speed and action rate, and acceleration of changing a situation under the emergency response and recovery conditions [2-4].

This fact requires the development of new methods, different mathematical models and mechanisms for controlling rescue units based on adaptation to particular conditions in the event of potential emergency.

When developing a model of the rescue units control system, the principle of combination of a systematic approach, strategic and tactical initiative, current adjustment and implementation of emergency measures shall be used. When applied to control strategy analysis, this principle is focused on elaboration of concepts of emergency propagation scenarios and emergency response measures.

To solve the problem specified, the authors have analyzed the field work of rescue units. The model of the rescue unit control system is considered to be one the most important indicators of readiness for actions, an organizational and technical excellence level of an entity, and ability of a unit to prevent and eliminate emergencies of different nature.

For this purpose, a problem of organization and efficiency improvement of the system controlling the rescue units of the Ministry of Civil Defense and Emergency Response of the Russian Federation.
shall be considered using the example of potential hydrological emergency. In this context, one needs to develop a model of a system for controlling rescue units in the event of potential hydrological emergency.

The problem solution is usually based on mathematical models of operational control of rescue units and assessment of a hydrological situation of area flooding, the use of a program package for decision-making support, which allows for estimation of action efficiency and selection of the best methods of control under the emergency conditions [5-7].

The research objective – development of an algorithm for controlling rescue units in the event of potential hydrological emergency based on the risk assessment, and also development of the corresponding program package.

The subject of research – rescue units control system.

2. The solution of the problem of rescue units control optimization

The authors have used the solution of the problem of rescue units control optimization as the basis for development of a numerical method with the mass service theory used. The rescue units, participating in hydrological emergency response and recovery activities at minor water intake facilities with length $L$, are represented as the mass rescue units service system, which can have the following four states: $S_0$ – no emergency at a water body, $S_1$ – emergency (accident) occurred at a water body, $S_2$ – spill over a dam crest, $S_3$ – formation of cracks (passages) in a dam body. Figure 1 shows the transition graph for the rescue units’ service system.

Figure 1. Transition graph for mass rescue units service system in event of hydrological emergency with length $L$ at minor water intake facilities

Notations: $\lambda_1, \lambda_2, \lambda_3$ – emergency frequency – accidents, spillovers and cracks per unit of dam length, $\mu_1, \mu_2, \mu_3$ – rate of emergency elimination.

Frequencies $\lambda_i$, $\lambda_2$ and $\lambda_3$ can be defined using the statistics of the particular minor water intake facility. Rates $\mu_1, \mu_2$ and $\mu_3$ can be estimated from expressions; consequently:

$$\mu_i = (t_{oi} + L/V + t_1 + t_{B1})^{-1}, i \in \{1, 3\}$$

where $t_{oi}$ – time of detection of hydrological emergency $i$; $V$ – average speed of rescue units moving from a home station to a hydrological emergency scene; $t_1$ – time of elimination of hydrological emergency $i$; $t_{oi}$ – time of recovery of readiness for action required for rescue units after hydrological emergency $i$.

Times $t_{oi}, t_1, t_{oi}$ and speed $V$ are defined as statistical values for each particular situation and are random variables. Within the framework of common assumptions, the following system of numerical linear algebraic equations corresponds to the graph of steady-state processes given in Figure 1:

$$0 = - 0.5 L (\lambda_1 + \lambda_2 + \lambda_3) p_0 + \mu_1 p_1 + \mu_2 p_2 + \mu_3 p_3 ;$$

(1)
\[ 0 = 0.5L \lambda \mu p_0 \] (2)
\[ 0 = 0.5L \lambda \mu p_0 \] (3)
\[ 0 = 0.5L \lambda \mu p_0 \] (4)

where \( \{p_i\} \) – probability of state \( \{S_i\} \), with \( p_1 + p_2 + p_3 = 1 \).

The solution of equation system (1 - 4) makes it possible to find probabilities of states of the mass rescue units service system:

\[ p_i = 0.5 \lambda (t_{i1} + L/V + t_{i+1}) p_0, i \in 1..3 \] (5)

\[ p_0^{-1} = 1 + 0.5L[\lambda_1(t_{i1} + L/V + t_1 + t_{10}) + \lambda_2(t_{i2} + L/V + t_2 + t_{12}) + \lambda_3(t_{i3} + L/V + t_3 + t_{13})] \] (6).

The prompt response to hydrological emergency occurrence defined by probability \( p_0 \) is of crucial importance for this system of mass rescue units service. By analogy with (5), the following condition can be accepted:

\[ p_0 > 0.999. \] (7)

Expressions (5) and (6) allow for solution of analysis and synthesis problems of a system of mass rescue units servicing minor water intake facilities. In the first instance, with the known length of the dam, the number of rescue units servicing the facility, frequency \( \lambda_1 \), \( \lambda_2 \), \( \lambda_3 \) and speed \( \mu_1 \), \( \mu_2 \), \( \mu_3 \) for each rescue unit, the length of sector \( L \) of hydrological emergency area are defined, and probability \( p_0 \) is found using (6), then, the fulfillment of condition (7) shall be checked. When synthesis problems are solved with the known values of \( \lambda_1 \), \( \lambda_2 \), \( \lambda_3 \), \( \mu_1 \), \( \mu_2 \), \( \mu_3 \), and specified probability \( p_0 \), the maximum length of the sector of hydrological emergency area serviced by rescue units shall be found [8,9]:

\[ 0 = (\lambda_1 + \lambda_2 + \lambda_3) L^2 + V[\lambda_1(t_{i1} + t_1 + t_{10}) + \lambda_2(t_{i2} + t_2 + t_{12}) + \lambda_3(t_{i3} + t_3 + t_{13})]L - 2V(p_0^{-1} - 1). \]

\[ L = \sqrt{b^2 + 8V(p_0^{-1} - 1)(\lambda_1 + \lambda_2 + \lambda_3) - b/2(\lambda_1 + \lambda_2 + \lambda_3)} \]

where \( b = V[\lambda_1(t_{i1} + t_1 + t_{10}) + \lambda_2(t_{i2} + t_2 + t_{12}) + \lambda_3(t_{i3} + t_3 + t_{13})]. \]

Thus, with the obtained model of the mass service system, it is possible to solve the analysis and synthesis problems of systems of emergency elimination at minor water intake facilities with rescue units used.

In the first case, the model allows for assessment of sufficiency of rescue units to assure the response to hydrological emergency; and in the second case – to define the reasonable length of a sector of hydrological emergency area assigned to one rescue unit, and, thus, to define the total number of rescue units. In future, apart from the probability of prompt response of rescue units, it seems feasible to introduce an economic effectiveness criterion based on damage from hydrological emergency and the cost of rescue units upkeeping [10].

3. Conclusion

The suggested numerical method can be used for planning control of rescue units of the Ministry of Civil Defense and Emergency Response of the Russian Federation in the event of hydrological emergency.

Thus, the developed functional model of the rescue units control system allows for checking of control plan implementation, assessment of capabilities of rescue units in the event of emergency (accident), and determination of control required. The significant improvement of efficiency and reasonableness of decisions made is achieved by using the special-purpose automation aids (problem-oriented program package) and, in particular, management decision-making support systems.

The research and development of the system for controlling rescue units in the event of potential hydrological emergency at minor water intake facilities allow for the improved efficiency of a reduction of hazard to population and territories, and economic damage from emergency.
consequences, and the creation of an archive of data on the actual condition of minor water intake facilities in the region.

References
[1] Trostianskij S N, Zenin Ju N 2014 Primenenie modeli racional'nogo pravonarushitelja k ocenke verojatnosti vozniknovenija pozharov v zhilom sektore Vestnik Voronezhskogo instituta MVD Rossii 3 58 – 65
[2] Brushlinskiy N N, Sokolov S V, Klepko E A, Belov V A, Ivanova O V, Popkov S Yu 2012 Osnovyi Teorii Pozharnyih Riskov I Ee Prilozhenie (Moscow: Akademiya GPS MChS Rossii) p 192
[3] Klimkin V I, Matyushin A V, Poroshin A A, Luponov S A, Bobrinev E V, Kondashov A A, Ivanova G G 2012 Analiz vliyaniya posledstviy pozharov na ustoychivost sotsialno-ekonomicheskogo razvitiya regionov Rossiiyeskoy Federatsii Pozharnaya Bezopasnost 1 74 – 84
[4] Karpov A A, Rodionova E YU 2017 Meropriyatiya po zashchite naseleniya ot chrezvychajnyh situacij Naukoemkie Tekhnologii I Intellektual'nye Sistemy V XXI Veke (Ufa: Omega science) pp 206 – 209
[5] Suvorov A D, Kanunnikova O A 2016 Bezopasnost v uslovijah chrezvychajnyh i ehkstremalnyh situacij razlichnogo haraktera Bezopasnost Gorodskoj Sredy (Omsk: Omsk State Technical University)
[6] Kalach A V, Rossiihina L V, Soloviev A S, Stepanov L V 2017 Kompyuternoe modelirovanie informacionnogo processa kriticheskoy situacii pri chrezvychajnyh obstoyatelstvah v potencialno opasnyh zonah Vestnik Voronezhskogo Instituta FSIN Rossii 2 68 – 76
[7] Magnus Ya R, Katyishev P K, Peresetskiy A A 2004 Ekonometrika. Nachalnyiy Kurs: Ucheb.6 Izdanie Pereab. I Dop (Moscow: Delo) p 576
[8] Yamalov I U 2005 Informacionnaya podrerzhka prinyatiya reshenij pri likvidacii chrezvychajnyh situacij na osnove modelirovaniya scenariev upravleniya Informacionnye Tekhnologii 6 51 – 58
[9] Yamalov I U 2006 Konceptualnoe modelirovanie processov vozniknoveniya i razvitiya chrezvychajnyh situacij Informacionnye tehnologii 7 54 – 57
[10] Artyushin YU I 2003 Ocenka effektivnosti meropriyatiy po zashchite naseleniya v chrezvychajnyh situaciyah Gornyj Informacionno-Analiticheskij Byulleten 6 49 – 51