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Methodological Approach to the Formation of a Model for Assessing the Effectiveness of Search and Rescue Units in Conducting Emergency Rescue Operations during the Destruction of Buildings

Alibayev Xurshid Narkazakovich, Tursunov Abdumansur Abduazizovich
Deputy Minister of Emergency Situations of the Republic of Uzbekistan

Annotation: The article presents the formulation of the problem related to the development of a model for assessing the effectiveness of search and rescue units in conducting emergency rescue operations. An algorithm for its solution is proposed, which forms the basis of a model that allows assessing the efficiency of emergency rescue operations during the destruction of buildings. Proposals are formulated for further research directions in the field of increasing the efficiency of emergency rescue operations during the destruction of buildings.

Key words: search and rescue units, emergency rescue operations, building demolition, performance evaluation, labor costs, emergency situations.

The catastrophic earthquakes in Armenia (1988), Tajikistan (1985, 1989) and Turkey (2023) were accompanied by massive destruction of buildings, as a result of which tens of thousands of people were trapped under the rubble, for whose rescue emergency rescue operations (ASR) were carried out with the involvement of significant resources. The process of conducting ASR itself is a targeted activity, its effectiveness is largely determined by the quality of decisions made by management bodies.

The assessment of the effectiveness and readiness of rescue teams in the liquidation of emergency situations is carried out in the following areas:

Organizational and staffing structure. Each link of the formation is analyzed according to the tasks and functions performed, the required and available personnel, the availability of the necessary specialists;

Level of personnel training. For this purpose, standards are developed that should be common for all formations and special, taking into account their purpose;

The order of response to the threat and occurrence of an emergency. They evaluate the promptness of the formation's arrival to the site or zone of an emergency, assess the situation and select the technology of emergency rescue operations, manage and direct the work; level of equipment. They take into account the availability of modern technology and special equipment, transport and communications, means of primary life support for forces and the affected population.

Some indicators of the effectiveness of emergency rescue and other urgent operations (AS and DNR):

Percentage of people saved in the emergency zone;

Probability of localization of emergency within 24 hours.

The readiness of rescue teams is tested during training, control checks and exercises.

To assess the readiness of rescue teams to eliminate emergencies, you can pay attention to the following parameters:

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Staffing. It is important that the staff is staffed with employees with the necessary education, experience, specialties and qualifications;

Provision with equipment, devices and gear. The overall level of equipment should be analyzed by groups, for example, by the provision of automotive equipment, watercraft, and communications equipment;

Level of professional training. They evaluate the professional and physical training of personnel, as well as the level of training of management personnel;

Availability of the necessary package of documents. These are documents on planning the actions of forces and technology for performing work;

Availability of a mobile reserve of material and technical resources and food resources;

The ability to enter and deploy to the work area within the established timeframes.

The readiness of rescue teams to promptly respond to emergencies and carry out work to eliminate them is assessed according to the following criteria:

"Ready". The formation is certified and staffed by at least 80% of workers with the necessary specialties and qualifications, provided with equipment, devices and gear by at least 90% of the established equipment standards, the preparation activities are completed in full and within the established timeframes.

"Limited readiness". The formation is certified and staffed by at least 70% of workers with the necessary specialties and qualifications, provided with equipment, devices and gear by at least 80% of the established equipment standards, the preparation activities were completed within the established timeframes, but at the same time, individual shortcomings were allowed.

"Not ready". The requirements for the "Limited ready" rating have not been met, or an accident occurred when the formation was deployed, and safety rules were not followed during the emergency response work, which resulted in injuries (deaths) of people.

The efficiency theory takes into account three approaches to obtaining the process efficiency indicator, characterizing:

Resource intensity (costs);

Efficiency (time of work);

Effectiveness (number of people saved) [1].

The first approach proposes an assessment of the effectiveness of the ASR based on economic benefits, taking into account the total costs of using all types of resources to carry out rescue operations, as well as the cost of losses from the loss of life. The disadvantage of this approach is that under certain conditions the costs of conducting ASR may exceed the prevented damage, including loss of life. In such a case, the efficiency of the work will be negative. The second approach is the "time-efficiency" method. The essence of this method corresponds to the previous one, with the only difference being that the cost indicators are replaced by the indicators of the time of work execution. The efficiency indicator for this approach is the result achieved per unit of time. However, this approach allows us to evaluate the efficiency of the work only after its completion and does not take into account the dynamics of the change in the situation during the work. Based on the fact that the main goal of the ASR is to save lives and preserve the health of victims, it is logical to evaluate the effectiveness based on the effectiveness, the number of rescued. At the same time, the number of rescued is an absolute value, which depends on both factors related to the capabilities of the forces and

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the conditions at the site of the work, which complicates an objective assessment under different conditions [2].

The shortcomings of existing approaches can lead to unfounded calculations, which in turn can cause erroneous decisions and, as a consequence, an increase in the amount of damage and the number of victims. In this regard, a problematic situation has arisen in assessing the effectiveness of the ASR in the destruction of buildings in the dynamics of changing conditions. This paper proposes an approach to assessing the efficiency of ASR in the destruction of buildings, taking into account the dynamics at the site of the work. The object of the work within the framework of the study is the building (structure) that has been damaged. The efficiency indicator is calculated based on the ratio of the required labor costs and the labor resources involved at each point in time. The destruction of buildings is accompanied by a large number of victims in the rubble, who must be freed as soon as possible. In this case, some of the victims will die at the moment of the destruction of the buildings, and the rest - within a few days [4, 5].

Considering that the forces of search and rescue teams intended for conducting ASR are limited, and the work must be carried out at several sites, the issue of assessing the effectiveness of ASR not only at the end of the work, but also in the dynamics of changing situations in order to redistribute forces during these works becomes relevant. A reliable assessment of the effectiveness of ASR requires taking into account the factors and conditions under which these works are carried out [2].

To evaluate the effectiveness, it is necessary to solve the following tasks:

Determine the values of the necessary labor costs for carrying out the ASR at each facility, taking into account the factors and conditions. In this paper, the term "necessary labor costs" means the amount of effort and time required to carry out the ASR in certain time intervals;

Carry out calculations of the labor resources involved in carrying out the ASR. In this paper, the term "labor resources" refers to the forces and time involved in carrying out the ASR in certain periods of time during the work;

To evaluate the effectiveness of conducting emergency response operations during the destruction of buildings in the context of changing conditions.

The presented algorithm forms the basis of the model for assessing the effectiveness of the ASR during the destruction of buildings. The conceptual model for assessing the effectiveness of the ASR itself can be depicted using an IDEF0-type diagram, the use of which allows one to present the structure and functional processes necessary to obtain an assessment of the effectiveness of the ASR.

Solution to the problem:

1. determining the values of the necessary labor costs for conducting ASR, taking into account the factors and conditions at each facility. To calculate the necessary labor costs, the following operations must be performed:

determine the number of victims at each work site;

calculate the required amount of work, the completion of which will allow the victims to be extracted;

calculate the amount of labor required to complete the work, taking into account the conditions at the work sites.

The operation of determining the number of victims can be decomposed into separate subtasks.

The number of people in a building at a given time, taking into account the functional purpose of the building and information, is calculated using the formula specified in the methodology [6]:

$M_i(t_z) = L_i P_{Si}(t_z)$ (1)

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where,

$M_i(t_z)$ - number of people in a building depending on astronomical time, persons;

t_z - astronomical time of damage to the building, hour;

L_i - number of registered people in buildings according to information, persons;

P_s - the probability of people being in buildings [6].

At the next stage, the number of survivors (Nvi) in the destroyed building is determined taking into account the degree of its damage using the formula:

$$N_{vi} = M_i(t_z)P_{ni}(c) \quad (2)$$

where,

N_{vi} - number of survivors after a building was damaged, people;

$P_{ni}(c)$ - conditional probability of human survival depending on the degree of damage to the building [4];

c - degree of damage to the building.

By approximating statistical data on the probability of survival of victims depending on the time spent in the rubble, we obtain a function that allows us to calculate the number of survivors at a certain point in time:

$$N_i = (N_{vi} – N_{спас})(-0{,}161n(t_{xi}) + 0{,}9107), \quad (3)$$

where,

N_i - number of survivors injured in building collapse, depending on time spent in collapse, people.;

t_{xi} – time elapsed since the building was damaged, hours;

$N_{спас}$- number of people saved by the moment in time.

Using information about the damage to the building in accordance with the methodology, we determine the height of the rubble using the formula:

$$hi = \frac{yHi}{100+kHi}, \quad (4)$$

where,

h_i - building collapse height, m;

H_i - building height, m;

y - rubble volume per 100 m^3 of building volume, m;

k - an indicator taken equal to:

during an earthquake $k = 0{,}5$;

to blow up a building $k = 2$;

for an explosion inside a building $k = 2{,}5$.

To determine the volume of rubble from which victims must be extracted, we use the formula specified in the methodology:

$$V_i = 1{,}25 \times N_i \times h_i, \quad (5)$$

where,

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N_i - number of people trapped in the building rubble, persons;

V_i - volume of building rubble that must be cleared to extract victims, m^3;

1,25 - a coefficient that takes into account the increase in the volume of the debris to be cleared due to the impossibility of equipping a shaft measuring 1 x 1 m (collapse of the debris, tilt of the shaft, etc.).

To calculate the volume of labor costs, it is necessary to take into account the factors and conditions that affect the time of work:

$$W_{ni} = \int_0^{txi} \left(0{,}1 \text{x } ko \text{ x } kc \text{ x } \Pi \text{ x } Vi\ (t)\right) dt, \ (6)$$

where,

W_{ni} - the value of the required labor costs at the moment of time (t_{xi}) in the building collapse, man-hours;

Π - labor intensity of rubble removal, man-hours/m3;

k_c - coefficient taking into account the structure of the rubble;

k_o - a coefficient that takes into account the illumination at the site where the work is being carried out;

k_n - weather factor.

2. Calculation of the values of the labor resources involved in carrying out the ASR during the destruction of buildings. The calculation of the labor resources involved is determined by the formula:

$$W_{ci} = \int_0^{tci} Sidt, \ (7)$$

where,

W_{ci} - the value of the labor resources involved in carrying out the ASR in the building rubble, man-hours;

S_i - number of personnel involved in conducting emergency rescue operations in the building rubble, people;

t_{ci} - time of conducting emergency response operations in a building rubble, hours.

The calculation of the number of rescued victims ($N_{спас}$) at time tci is carried out using the formula:

$$N\text{спас} = \sum_0^{tci} \text{Wci} + \text{Wci}, \ (8)$$

where, W_{xi} - the value of the required labor costs to extract one victim from a building collapse, man-hours.

3. Evaluation of the effectiveness of emergency response operations during the destruction of buildings.

The model for assessing the effectiveness of the ASR can be demonstrated (fig. 1), the curves of which characterize the value of the labor resources involved in the ASR and the necessary labor costs for rescuing victims in the rubble. In this case, the number of victims (Ni) is a dynamic value and depends on both the time the victims are in the rubble and the number of those rescued.

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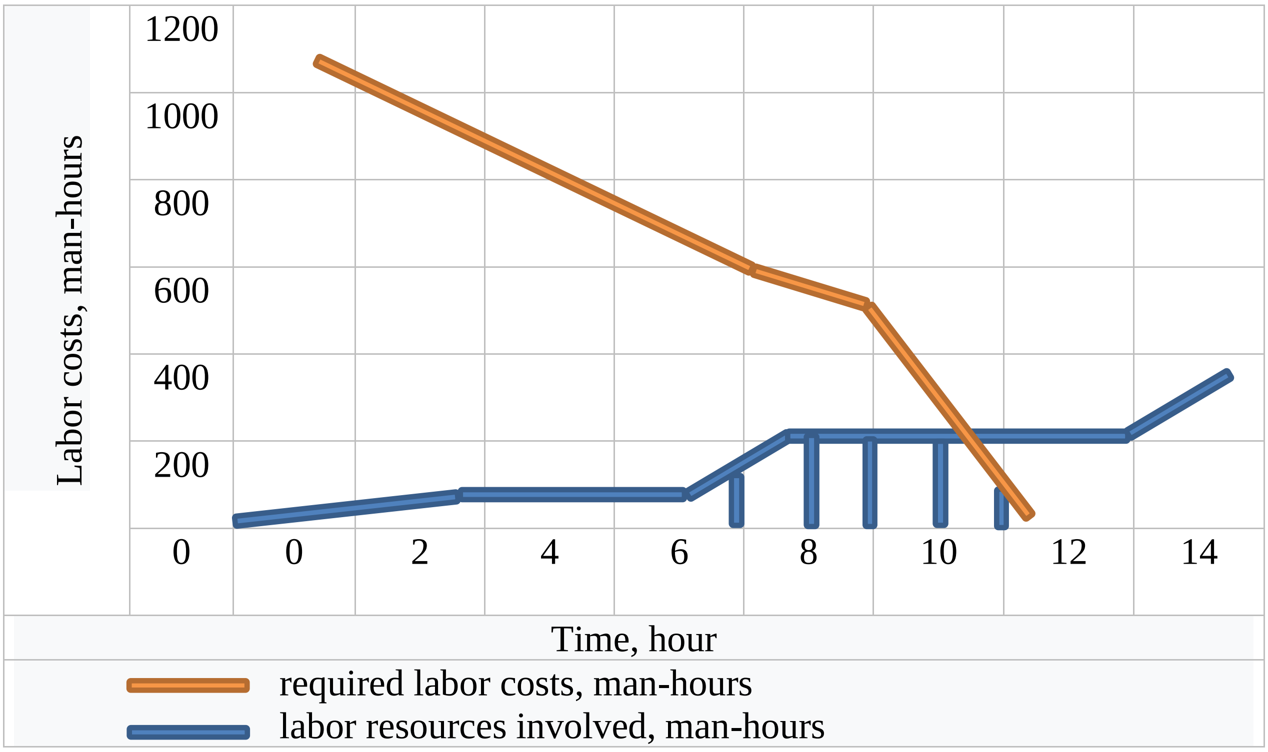

1-discussion. Values of labor costs during the implementation of ASR

The graph shows that the initial stage is characterized by a significant need for labor resources - this is due to the fact that up to 60% of victims who can be saved are under the rubble. Over time, the volume of necessary labor costs decreases with the number of victims in the rubble, associated with the death and extraction of victims. The obtained indicator of the efficiency of the ASR can be used as a target function for optimizing the process of conducting the ASR through the rational distribution of labor resources among the objects of work.

Table 1 Characteristics of the building

№ Building	Building height, H, м	Building structure	Number of registered residents, L, people
1.	20	Brick	100
2.	29	Brick	150
3.	20	Panel	100
4.	29	Panel	150

1.1. The formula (1) determines the number of people in the building (M) depending on the astronomical time. The calculation results are presented in table 2.

1.2. The number of survivors (Ni) after each building has received damage is determined using formula (2). The calculation results are presented in table 3.

1.3. The number of surviving victims (N) is calculated using formula (3), it depends on the time the victims were in the rubble. The calculation results are presented in the fragment of table 4.

1.4. The height of the rubble (h) of each building is determined by formula (4). The calculation results are presented in table 5.

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1.5. The volume of rubble (V) that must be cleared is calculated using formula (5) and depends on the height of the rubble and the number of surviving victims. The calculation results are presented in table 6.

1.6. The volume of necessary labor costs (Wn) for clearing debris is determined by formula (6) and taking into account factors and conditions. The calculation results are presented in the fragment of table 7.

1.7. The number of labor resources involved (Wc) is calculated using formula (7), with the number of personnel taking into account work in two shifts. The calculation results are presented in table 8.

1.8. Let us determine the number of rescued depending on the time of the work. The calculation results are presented in the fragment of table 9.

Table 2 Dependence of the number of people in the building on the time of day

№ Building	Astronomical time of damage to the building, t_z	Probability of people being in buildings, P_s	Number of registered people in buildings, L_i, people	Number of people in a building depending on astronomical time, M, people
1.	10.00	0,7	100	70
2.	10.00	0,7	150	105
3.	10.00	0,7	100	70
4.	10.00	0,7	150	105

Table 3 Dependence of the number of people in the building on the time of day

№ Building	Astronomical time of damage to the building, t_z	Probability of people being in buildings, P_s	Number of registered people in buildings, L_i, people	Number of people in a building depending on astronomical time, M, people
1.	10.00	0,7	100	70
2.	10.00	0,7	150	105
3.	10.00	0,7	100	70
4.	10.00	0,7	150	105

Table 4 Dependence of the number of survivors on the degree of damage to the building

№ Building	Extent of damage to the building, c	Probability of survival of victims, P_s	Number of people in buildings depending on astronomical time, M, people	Number of survivors after a building has been damaged, N_t, people
1.	Full	0,4	70	28
2.	Full	0,4	105	42
3.	Full	0,4	70	28
4.	Full	0,4	105	42

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Table 5 Dependence of the number of survivors on the time spent in the rubble

№ p/p	Time spent in the rubble, t_{xi}, c	Number of survivors in the collapsed building N_t, people			
		Building №1	Building №2	Building №3	Building №4
1.	0	28	42	28	42
2.	1	25	38	25	38
3.	2	22	34	22	34
4.	3	21	31	21	31
5.	4	19	29	19	29
6.	5	18	27	18	27
...	…	…	…	…	…
243.	242	1	1	1	1
244.	243	0	0	0	0

Table 6 Results of rubble height calculations

№ p/p	Explosion coefficient, k	Building type	Volume of rubble per 100 m3 of building volume, y	Building height, H, m	Heap height, h, m
1.	2	Frameless brick walls	36	20	5,14
2.	2	Frameless brick walls	36	29	6,68
3.	2	Frame with walls made of large panels	42	20	6
4.	2	Frame with walls made of large panels	42	29	7,79

Table 7 Results of rubble height calculations

Building №1		Building №2		Building №3		Building №4	
Number of survivors N, persons.	Volume of the rubble, V, m^3	Number of survivors N, persons.	Volume of the rubble, V, m^3	Number of survivors N, persons.	Volume of the rubble, V, m^3	Number of survivors N, persons.	Volume of the rubble, V, m^3
28	180	42	351	28	210	42	409
25	161	38	317	25	188	38	370
22	141	34	284	22	165	34	331
21	135	31	259	21	158	31	302

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19	122	29	242	19	143	29	282
18	116	27	225	18	135	27	263
17	109	26	217	17	128	26	253
...	...	...	...	...	...	...	...
1	6	1	8	1	8	1	10

Table 8 Results of rubble height calculations

Building №1		Building №2		Building №3		Building №4	
Volume of the rubble V, m^3	Amount of required labor costs, Wc, man-hours.	Volume of the rubble V, m^3	Amount of required labor costs, Wc, man-hours.	Volume of the rubble V, m^3	Amount of required labor costs, Wc, man-hours.	Volume of the rubble V, m^3	Amount of required labor costs, Wc, man-hours.
180	1080,00	351	2103,96	210	1260,00	409	2454,62
161	868,12	317	1604,83	188	1012,80	370	1977,85
141	706,01	284	1202,68	165	823,68	331	1614,21
135	666,66	259	1039,67	158	777,77	302	1529,58
122	618,31	242	859,12	143	721,36	282	1424,47
116	571,90	225	682,37	135	667,22	263	1323,80
109	528,45	217	78	128	173	253	342
...	...	...	...	...	...	...	...
6	2	8	3	8	11	10	14

Table 9 Results of labor force calculations

№ buildings	First echelon			Second echelon			Third echelon		
	S, чел.	t_c, ч	W_c, чел.ч	S, чел.	t_c, ч	W_c, чел.ч	S, чел.	t_c, ч	W_c, чел.ч
1	25	6	150	75	4	300	125	10	1250
2	25	6	150	75	4	300	125	13	1625
3	25	6	150	75	4	300	125	29	3625
4	25	6	150	75	4	300	125	41	5125

Table 10 Dependence of the number of rescued on the time of the ASR

№ p/p	Time spent in the rubble, t_{xi}, h	Number of people rescued from the collapse of building N, people			
		Building №1	Building №2	Building №3	Building №4
1.	0	0	0	0	0
2.	1	0	0	0	0
3.	2	0	0	0	0
4.	3	1	1	0	0

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5.	4	1	1	0	0
6.	5	1	1	0	0
7.	6	1	1	0	0
8.	7	2	2	1	1
...	...	...	...	...	...
20.	19	11	12	3	3
...	...	...	...	...	...
24.	23	-	16	4	4
...	...	...	...	...	...
39	38	-	-	9	9
...	...	...	...	...	...
51	50	-	-	-	11

Conclusion.

The developed approach to forming a model for evaluating the effectiveness of conducting ASR is applicable regardless of the source of impact (earthquake, domestic gas explosion, and ordinary means of damage). This approach has the following advantages:

1. It allows for an objective assessment of the effective use of labor resources at each point in time, which significantly increases the accuracy and relevance of the assessment.
2. This approach facilitates the analysis of the effectiveness of ASR in all areas of work, which allows for the idealization of general trends and trends. As well as identify potential directions for increasing efficiency in the process of conducting ASR.
3. The efficiency indicator is simple enough to calculate and understand, which should increase the efficiency and the reliability of the adopted management decisions, taking into account the identification of priority directions and the planning of the ASR.
4. The chosen indicator can be used as a target function in optimizing the process of conducting ASR, which will increase their effectiveness.

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