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ELABORATION AND APPLICATION OF GRAPHICAL MODELS TO OPTIMIZE THE RESPONSE TIME TO EMERGENCY SITUATIONS

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Abstract. This article presents methods for timing the key milestones and timing of the emergency response. A graphic model is proposed that allows you to determine the stage and time of the response process, regardless of the nature of the ongoing processes manifestation. The model allows a detailed analysis the process effectiveness of responding to various emergencies. And it also allows to determine the boundaries of responsibility areas to optimize management decisions of the response process, increasing its quantitative and qualitative values. The presented mathematical models exclude errors in assessing the effectiveness of the response. The developed mathematical apparatus can be used for effective management of emergency response units.

Keywords: *decision making, safety, timing, emergency situations, areas of responsibility, emergency response.*

Rezumat Articolul prezintă metode de cronometrare a reperelor cheie și de sincronizare a răspunsului în caz de urgență. Este propus un model grafic care permite determinarea stadiului și timpului procesului de răspuns, indiferent de natura manifestării proceselor în derulare. Modelul permite o analiză detaliată a eficacității procesului de răspuns la diverse situații de urgență. Și, de asemenea, să determine limitele domeniilor de responsabilitate pentru a optimiza deciziile de management ale procesului de răspuns, sporind valorile cantitative și calitative ale acestuia. Modelele matematice prezentate exclud erorile în evaluarea eficacității răspunsului. Aparatul matematic dezvoltat poate fi utilizat pentru gestionarea eficientă a unităților de răspuns la urgențe.

Cuvinte cheie: *luarea deciziilor, siguranță, sincronizare, situații de urgență, domenii de responsabilitate, răspuns în caz de urgență.*

Introduction

The statistics of recent years indicate an increase in natural and man-made phenomena and disasters (Figure 1). As a result, there is a steady dynamics of an increase in the number of human victims and material losses. All this leads to the economic weakening

of the affected territories, thereby significantly reducing the values of the economic indicators of the development of certain states.

At the initial stage of occurrence, each emergency situation proceeds purely individually, in view of many internal characteristics and external factors, in conditions of complete uncertainty [1, 2]. To conduct successful missions, it is necessary to define a set of qualitative and quantitative indicators, to develop a set of monitored and measurable indicators, with the help of which it is possible to standardize and optimize the processes of responding to emergency incidents.

This article proposes to consider the key points of response to determine effective time intervals that allow to assess qualitatively the actions of each participant in the process. The formation of the content of the material presented is based on the works [3 – 7]. Various stages of the response process of specialized emergency teams, focused on individual emergency situations, are described in detail.

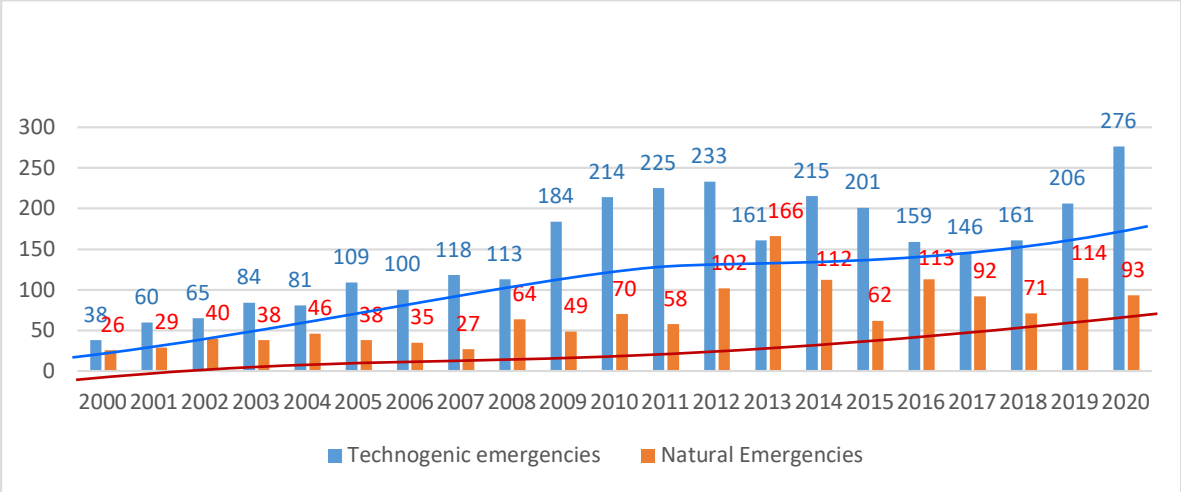

Figure 1. Graphical model of statistics of data on the growth of man-made and natural emergencies in quantitative terms that occurred in the Republic of Moldova.

It is also necessary to bear in mind that structural units, endowed with various functions, interact in the time interval. To improve the quality of management decisions, it is necessary to determine the exact boundary of the areas of responsibility of these services [8, 9]. The model proposed in this article will improve the efficiency and quality of the decision made and, as a result, reduce the response time to sudden processes.

1. The essence and content of the emergency response process.

As a rule, the response process begins with the receipt of information in a specialized subdivision, which includes dispatching subdivisions of enterprises and specialized services. At the state level, such a unit is the Unified National Emergency Call Service 112. The process ends when the last rescue team departs.

The size of the duration of the time period of the process is set based on the difference between the start time and the end time of the response.

$$T_r = t_f - t_s \tag{1}$$

where:

T_r – response time

T_s – response start time

T_f – response end time

The usage of only the given two time parameters does not allow to fully assess the level of effectiveness of actions taking place within the response stage.

The effected analysis of the ongoing events made it possible to divide the responders into the following four groups, as well as to highlight the main functions they are responsible for.

1) A group of participants that generates information provision. These include victims, witnesses of emergencies or specialized devices that record physical deviations of the ongoing processes.

2) Personnel responsible for receiving, validating and registering incoming information with subsequent transfer to a specialized dispatch service. This group includes operators of the Unified National Emergency Call Service 112.

3) Personnel for dispatching the response forces and means, organizing the arrival to the scene of the incident, with the subsequent technical and informational support of these forces. The group consists of dispatchers of various emergency response services.

4) Forces of emergency response, which include - any resources with their own individual response means and specialized capabilities subordinate to their dispatching services.

This division was carried out on the basis of the need for a clear delineation of areas of functional responsibility. Figure 2 visually reflects the sequence of linear interactions of the above four groups involved in the emergency response process. The vertical lines delineate the limits of the areas of responsibility. The participants of the third and fourth groups are in constant interaction until the completion of the response mission (Figure 2).

It should be noted that in the Republic of Moldova three main groups are constantly involved in the response process: 1) 112 service operators; 2) dispatchers of three emergency services (rescuers and firefighters, police officers, ambulance); 3) response forces related to emergency response services.

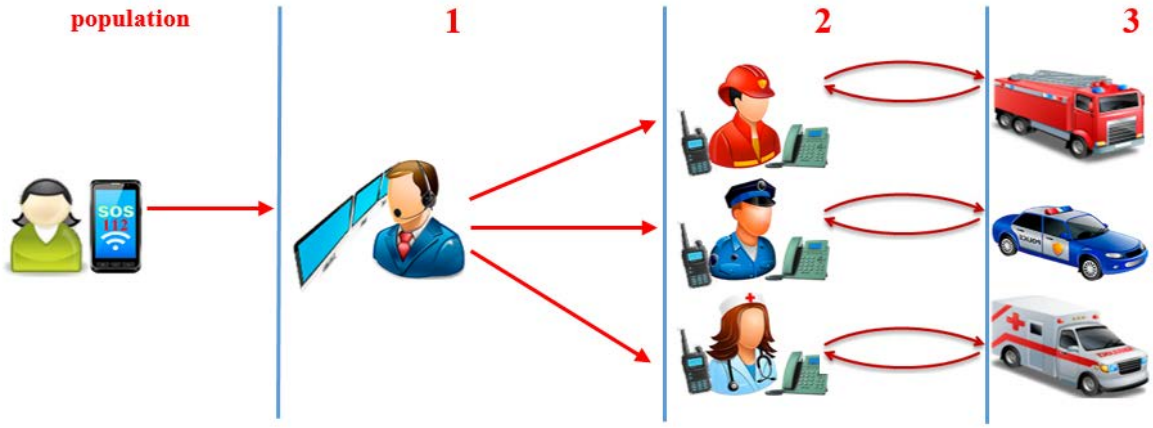

Figure 2. A graphical model of the sequence of interaction of participants in a unified emergency response process.

In the presented model, the beginning of each significant event is considered to be a time value determined by a spatial point in time with which a specific trigger is associated. The beginning of the next action is the moment of completion of the previous one. The interval between two spatial time points allows you to determine the period of time spent performing a particular action.

Any response to emergencies or their consequences begins with dialing the emergency call number, after which the operator 112 receives the call, then there is a dialogue between the operator and the caller. At this stage, the operator performs the function of validating the incoming information, on the basis of which the area of responsibility between the named participants is delineated. If the validation is successful, the operator interviewing the caller creates and fills out an incident card, then the latter provides it to the appropriate emergency response service.

As soon as the dispatcher of the emergency response service received the card about the incident from the operator 112, at this time moment the zone of responsibility for the ongoing processes is delineated between the latter. Based on the information received, the dispatcher decides what forces and means to send for the successful completion of the mission.

The stage of transferring the mission begins, which includes actions, dialing (dialing a phone number in order to establish communication) to the selected forces and transferring the response mission. At this stage, the area of responsibility is transferred to the emergency response forces at the moment the dispatcher receives confirmation of receipt of the transmitted information from the latter.

It is important to emphasize that at this stage the value of the time period directly depends on the following factors: a) the stability (reliability) of communication systems, b) the promptness (speed) of the response of the emergency response forces to the incoming call, c) the brevity and accuracy of the presentation of the content of the transmitted information by the dispatcher, as well as its perception and understanding by the emergency response team.

At the initial stage of the transfer of the mission, it is enough to transfer only two basic triggers:

1) where to go, that is, the address of the object or geographic territorial coordinates;

2) what kind of emergency or incident needs to be responded to.

This bundle of triggers allows you to instantly activate the next stage - collecting on alarm, and additional information can be received at the stage of moving to the scene.

It should be borne in mind that outside the emergency mode, members of the emergency response team are not in the same room at the same time, but perform various tasks (training, chores, personal hygiene, etc.).

Therefore, this time period is necessary to analyze the actions of the persons involved in the response, in order to determine how quickly they will go to the scene of the incident. The moment the rescue team gets into the vehicle and starts moving towards the scene of the incident, it is necessary to record this event of the control time point.

In the future, the same emergency response team is obliged to report to its control center the time points indicating the evolution of events such as arrival at the scene of an emergency, localization (this factor applies only to fires and situations of chemical leakage), completion of rescue operations, leaving the place of work, readiness to fulfill new missions.

These indicators of temporary control points allow the dispatcher or decision-maker to ensure an appropriate level of response safety, timely provide technical support to the emergency response leader, and also understand at what time stage the response process is.

The accumulated experience of the Republic of Moldova, as well as the results of the analysis of foreign activities, indicate that for a more detailed mastery of the current situation, it is necessary to divide the stage of the response process into 11 intermediate time stages, which are part of the twelve temporary control points of the response.

The stages, in turn, are combined into the following three time phases.

1) The phase of the reaction time of specialized services to emergency calls from citizens. This includes the reaction period between the time the first call is received by the emergency operator and the time the first emergency response crew arrives at the scene of the emergency. In this interval, all time characteristics are subject to mandatory fixation and standardization.

2) The phase of the time of the rescue operations. For this period of time, the values are fixed, but not standardized, in view of the pronounced specificity of the ongoing processes.

3) The phase of the time of returning to the base or determining the moment of readiness to continue serving. The data from this phase allows the dispatcher to determine which emergency response forces are available for the following missions.

For optimal tracking of the ongoing emergency response processes, a universal timeline of control points has been developed and used, shown in Figure 3.

2. Development and application of a scale of control points at the stages of a unified emergency response process.

The named scale provides the following composition, content and sequence of the control points of the stages of response to emergency situations.

Point 1 - dialing the emergency call number. It represents the so-called zerotime point when the subscriber starts calling the emergency service. The unique emergency call number in the Republic of Moldova is 112. From this point, the operator's response time begins, which ends at the moment of fixing the second checkpoint. At this stage, the response time of the operator of the 112 service is recorded, which determines the speed of the call addressed to emergency services, while simultaneously controlling the quality of the reliability of the communication equipment and the promptness of the operator's response to the call. Indicated as the $t_{\text{operator's answer}}$

Point 2 - Receiving a call from the operator of the service 112. Between points 2 and 3, the parameter $t_{\text{interview}}$ is entered - fixing the working time of the operator of the service 112 to collect information about the incident, filling out an emergency response card and transferring the latter to a specialized dispatch service.

Point 3 - Sending an emergency card to the dispatcher's room. This time point is given a special attention, since it contains the moment of transition of zones of responsibility and the zone of responsibility of service 112 ends, and the process goes to the emergency response **dispatcher's** room. Between points 3 and 4, the parameter $t_{\text{dispatcher response}}$ is entered. It comes down to recording the time spent on opening an emergency card, monitoring the quality and reliability of the software, network equipment and the actions of the dispatcher.

Point 4 - Opening of the emergency card by the dispatcher. Between points 4 and 5, a $t_{decision\text{-}making}$ parameter is introduced, which boils down to identifying the time of the dispatcher's true understanding of which emergency it is necessary to respond to and which unit will be sent to perform the assigned task.

Point 5 - Selection of reaction forces (S). Between points 5 and 6, the parameter $t_{transfer\text{-}mission}$ is entered, on the basis of which the time spent by the dispatcher to make a call to the emergency response unit, activate the alarm, transmit a message about the type of emergency and the address is calculated.

Point 6 - Confirmation (C). It is activated from the moment the dispatcher receives confirmation of the upcoming mission from the response team. This temporary point also has an important role, as it provides for the transfer of the area of responsibility from the dispatch service and the emergency response forces.

Between points 6 and 7, the $t_{collection}$ parameter is entered, which consists of calculating the collection time for an emergency response unit, the time for putting on specialized uniforms, and the time for the rescue team to get into the car.

Point 7 - Departure (D). The time of departure is fixed, i.e. the beginning of the movement of the vehicle with the crew to carry out an emergency response mission.

Between points 7 and 8, the parameter $t_{en\ road}$ is introduced, which is reduced to calculating the time stage of finding the combat response units on the way to the scene of the incident.

Point 8 - Arrival at the scene (A). At this time point, the standardization of time indicators ends. The stage of immediate response to an emergency begins.

Between points 8 and 9, the $t_{localization}$ parameter is introduced, which consists of calculating the time stage spent on localization. As a rule, this parameter is used mainly in response to a fire, in other cases of response is not used.

Point 9 - Localization of fire (LZ). The point fixes the moment of termination of the further spread of combustion and the creation of conditions for its elimination with the available forces and means.

Between points 8 and 10, the $t_{liquidation}$ parameter is introduced, which consists of calculating the time stage spent on carrying out all the necessary work to eliminate the emergency at the response stage.

Point 10 - Liquidation (L). It records the end time of all rescue operations.

Between points 10 and 11, the parameter $t_{of\ equipment\ collection}$ is introduced, which consists of calculating the time step spent on collecting all the equipment used, the time for the rescue team to get into the car.

Point 11 - Return (R). The starting point for the return of the emergency response forces to the place of deployment.

Between steps 11 and 12, the parameter is entered to $t_{return\ to\ base}$ for calculating the time spent on the way back to the place of deployment, refueling, if necessary, with fuel, water, and completing the missing equipment. As practice shows, the maximum time of this stage is equal to twice the travel time to the scene.

$\text{Max } t_{return\ to\ base} = 2 * t_{\ on\ the\ way}$

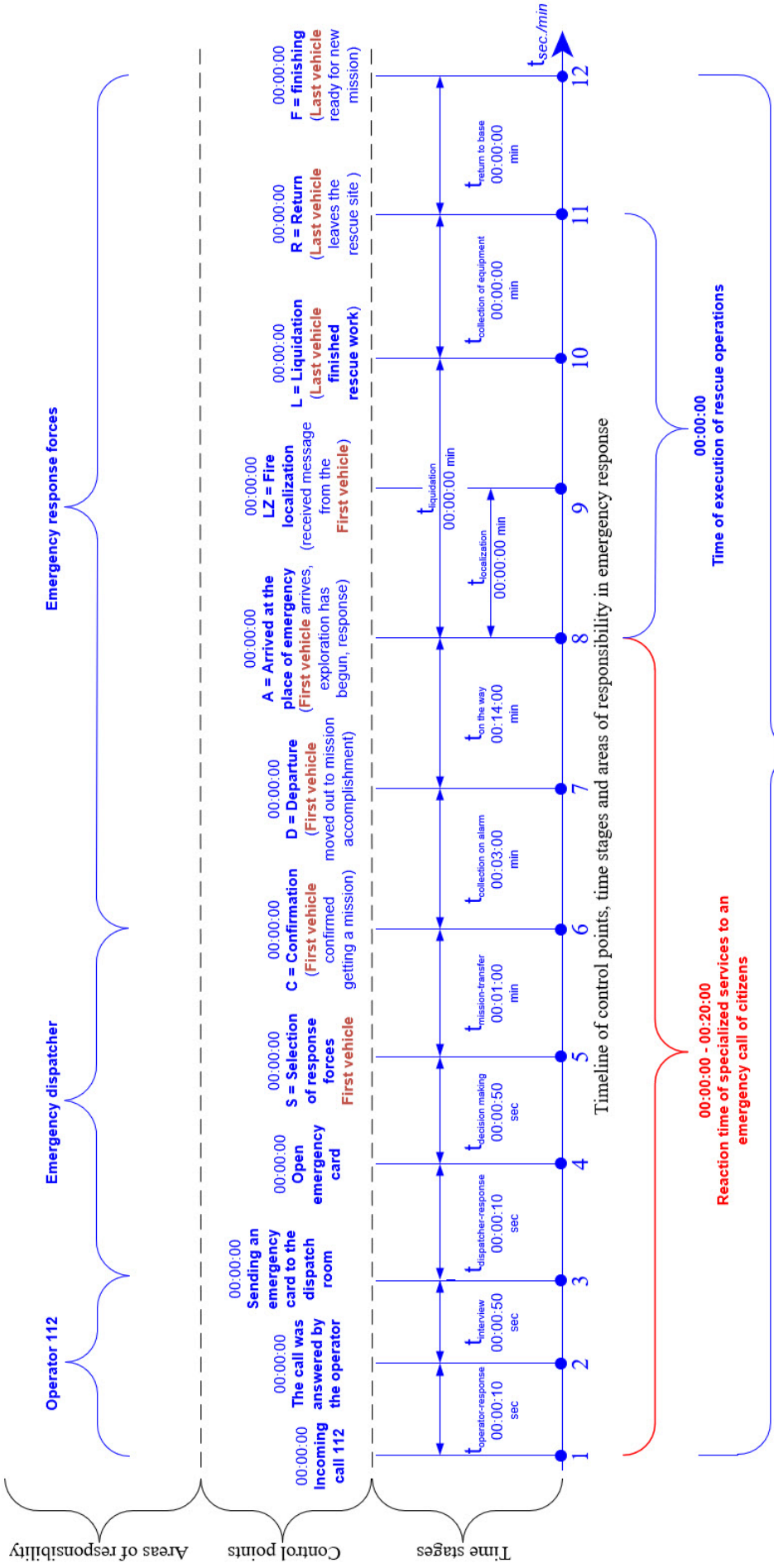

Figure 3. Graphical model of the response time to emergency calls.

Point 12 - Finishing (F). It is activated when the dispatcher receives a corresponding message from the response team. This message completes the process of splitting the response phases in time, assuming that the vehicle is complete, fueled and the rescue team is ready for new response missions.

Based on the developed composition of response time points and the sequence of their implementation, the volume of the total response time is determined by the following formula:

$$T_r = (t_2 - t_1) + (t_3 - t_2) + (t_4 - t_3) + (t_5 - t_4) + (t_6 - t_5) + (t_7 - t_6) + (t_8 - t_7) + (t_9 - t_8) + (t_{10} - t_9) + (t_{11} - t_{10}) + (t_{12} - t_{11}) \quad (2)$$

or

$$T_r = \sum_{n=1}^{12}(t_n - t_{n-1}) \quad (3)$$

where **n** - is the number of response checkpoints.

Below there are given the calculation formulas for all intermediate stages of the response time.

$$t_{operator's\ answer}\ (t_o) = (t_2\text{-}t_1) \quad (4)$$

$$t_{interview}\ (t_i) = (t_3\text{-}t_2) \quad (5)$$

$$t_{dispatcher\ response}\ (t_d) = (t_4\text{-}t_3) \quad (6)$$

$$t_{decision\text{-}making}\ (t_{dm}) = (t_5\text{-}t_4) \quad (7)$$

$$t_{transfer\text{-}mission}\ (t_{tm}) = (t_6\text{-}t_5) \quad (8)$$

$$t_{collectoin\ on\ alarm}\ (t_a) = (t_7\text{-}t_6) \quad (9)$$

$$t_{on\ the\ way}\ (t_w) = (t_8\text{-}t_7) \quad (10)$$

$$t_{localization}\ (t_{lz}) = (t_9\text{-}t_8) \quad (11)$$

if $t_{lz} \neq 0$, then the liquidation stage is calculated as $t_{liquidation}\ (t_l) = (t_{10}\text{-}t_9)$ (12)

if $t_{lz} = 0$, then the liquidation stage is calculated as $t_{liquidation}\ (t_l) = (t_{10}\text{-}t_8)$ (13)

$$t_{collecton\ of\ eqipment}\ (t_c) = (t_{11}\text{-}t_{10}) \quad (14)$$

$$t_{return\ to\ base}\ (t_{rt}) = (t_{12}\text{-}t_{11}) \quad (15)$$

$$T_r = t_o + t_i + t_d + t_{dm} + t_{mt} + t_a + t_w + t_{lz} + t_l + t_c + t_r \quad (16)$$

where:

T_r - is the total time of a single response process,

t_o - the time stage of the response of the operator of the service 112,

t_i - the time stage of the collection of information by the operator of the 112 service,

t_d - the time step of the response of the emergency response dispatcher,

t_{dm} - the time stage of decision making by the dispatcher,

t_{tm} - the time stage of information transfer to the dispatcher's emergency response units,

t_a - the time stage of the collection on the alarm of the emergency response forces,

t_w - time stage of travel on the way to the scene of the incident,

t_{lz} - the time stage during which the spread of fire was stopped,

t_l – the time stage, fixing the end of rescue operations,

t_c - the time stage of the collection of the applied response means,

t_{rt} - is the stage of time spent returning to the base.

The available experience and the results of the research conducted indicate that the developed formula is applicable for all cases of response to any type of emergency situation in which one unit is involved on one specialized vehicle. If two or more vehicles from two or more units take part in the reaction, the formula takes the following form:

$$T_r = t_o + t_i + t_d + t_{dm} + \sum_{i=1}^{n} t_{tm} + \sum_{j=1}^{m} t_a + \sum_{j=1}^{m} t_w + \sum_{j=1}^{m} t_{lz} + \sum_{j=1}^{m} t_l + \sum_{j=1}^{m} t_c + \sum_{j=1}^{m} t_{rt} \quad (17)$$

where:

T_r - is the total response time,

t_o - the time stage of the response of the operator of 112 service,

t_i - the time stage of the collection of information by the operator of 112 service,

t_d - the time step of the response of the emergency response dispatcher,

t_{dm} - the time stage of decision making by the dispatcher,

t_{tm} - the time stage of information transfer to the dispatcher's emergency response units,

t_a - the time stage of the collection on the alarm of the emergency response forces,

t_w - time stage of travel on the way to the scene of the incident,

t_{lz} - the time stage during which the spread of fire was stopped,

t_l - time stage, fixing the end of rescue operations,

t_c - the time stage of the collection of the applied response means,

t_{rt} - time step spent on returning to base.

n - department,

m - vehicle,

This formula leads to distorted, incorrect results when calculating the response time to emergency calls within the range between dialing the emergency number before the arrival of the first emergency response crew at the scene of missions separately for each unit, since there is a summation of the intermediate time t_{mt} spent by the dispatcher to transmit information about the mission separately for each unit. There is also a summation of the *alarm collection time* t_a and the t_{id} *time on the way* spent by each individual response team.

In this case, the following conditions (factors), indicators and formulas for their calculations are taken into account to calculate the response time to an emergency situation in which more than one unit is involved using more than one vehicle:

Response Force Selection (S) - First Unit Alert Control Point;

Acknowledgment (C) - control point of time of acknowledgment of receipt of information in the first subdivision;

Departure (D) - checkpoint for the departure time of the first emergency response team;

Arrival at the scene (A) - the checkpoint of the arrival time of the first team;

Fire localization (LZ) - time of the checkpoint of the first localization report. In some cases, the head of extinguishing the fire announces the same time for all teams;

Liquidation (L) - time of the checkpoint of the end of the work by the last team;

Return (R) - time of the checkpoint of the last group that left the place of rescue operations;

Finalization (F) - The checkpoint time of the last rescue team's report on readiness for new response tasks.

$$T_r=t_o + t_i + t_d + t_{dm}+n_1*t_{tm}+m_1*t_a+m_1*t_w+m_1*t_{lz}+m_x*t_l+m_x*t_c+m_x*t_{rt} \quad (18)$$

where:

T_r - is the total response time,

t_o - the time stage of the response of the operator of the service 112,

t_i - the time stage of the collection of information by the operator of the service 112,

t_d - the time step of the response of the emergency response dispatcher,

t_{dm} - the time stage of decision making by the dispatcher,

t_{tm} - the time stage of information transfer to the dispatcher's emergency response units,

t_a - the time stage of the collection on the alarm of the emergency response forces,

t_w - time stage of travel on the way to the scene of the incident,

t_{lz} - the time stage during which the spread of fire was stopped,

t_l – the time stage, fixing the end of rescue operations,

t_c - the time stage of the collection of the applied response means,

t_{rt} - time step spent on returning to base.

n - department,

m - vehicle,

x - is the maximum quantity,

Analysis of the calculation of the response time to an emergency call, in which all stages of the response time are subject to mandatory standardization, demonstrates that only one stage has a variable value - this is t_{id} = the time spent on the way, the values of the remaining indicators are determined by the maximum values of time indicators approved by the internal documents of the services response. These include validity periods in the operator's and dispatcher's area of responsibility, where the reaction time is recorded in seconds:

$t_o = 10_{sec}$, $t_i = 50_{sec}$, $t_d = 10_{sec}$, $t_{dm} = 50_{sec}$ and $t_{tm} = 60_{sec}$.

The value of the time interval ($t_{collection\ on\ alarm} = t_a$) is equal to two minutes and is constant and it is determined by an internal order. It consists of the time of collection on alarm, putting on specialized equipment, and getting the rescue team into the vehicle.

$$T_{rc} = 10_{sec} + 50_{sec} + 10_{sec} + 50_{sec} + 60_{sec} + 2*60_{sec} + 15*60_{sec} = 1200_{sec} \text{ or } 20_{min}, \quad (19)$$

By summing the maximum values of the initial indicators, the value of the result obtained is optimized

$$T_{rc} = 300_{sec} + 15*60_{sec} = 1200_{sec} (20) \quad (20)$$

or

$$T_{rc} = 5_{min} + 15_{min} = 20_{min} \quad (21)$$

where: T_{rc} – emergency reaction time

The accumulated experience indicates that in order to reduce the reaction time and increase the response zone, it is necessary to keep in mind the revision of the processes taking place on the way to the scene of the incident. According to international standards, the reaction time should not exceed 20 minutes, if, according to calculations, the route is no longer than 15 km [10].

The proposed approach of timing can be applied and adapted to any type of response, regardless of the nature of the manifestation of the ongoing processes. It also allows for a detailed analysis of the efficiency in terms of the time taken to complete the actions of all participants in the response process, identify weaknesses, which, in turn, will lead to optimization and systematization of the response process, improving its quantitative and qualitative values of indicators.

Conclusions

From a science-based perspective, effective emergency response requires an initial detailed analysis

For this purpose, graphic models of algorithms for timing the main reaction processes have been developed, which allow a detailed analysis of the ongoing processes.

On their basis, algorithms for determining the size of the execution time of a single response process and its stages have been compiled.

Each time point is also described in detail, as well as the sequence of calculating the sizes of the response time stages. At the same time, calculations were made both for one unit and one response team, and for two or more units and emergency response teams.

As a result of the implementation of this approach, all participants in a single process are guided by the same standards, which made it possible to establish a clear boundary between their areas of responsibility.

Implementation and management in real conditions of the concept of a unified information system for emergency management based on the developed graphical models and algorithms, with a high probability, allows you to determine at what stage of time is the implementation of the response process to any specific type of emergency.

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