

The object of the study is the functioning of control centers during emergencies.

Ukraine has faced large-scale emergency events caused by Russian aggression. The experience of crisis management in emergency events showed the need to find new solutions and improve the activities of emergency management centers at the State Emergency Service of Ukraine and GIS technologies in decision-making support systems.

The current paper has formulated a conceptual model of the work of emergency management centers at the Emergency Service of Ukraine; based on it, their main functions were formed. Identification of risks for objects that carry potential danger was carried out and a block diagram of object risk assessment was developed to improve the work of emergency control centers at the State Emergency Service of Ukraine. An approximate list of software and online resources for the operation of emergency management centers at Emergency Service of Ukraine is provided, which makes it possible to summarize the risks that are present in the given territory, isolate them, and pay special attention to prevent possible consequences from them.

Based on the computer software MARPLOT, CAMEO, and ALOHA, an example of response to an emergency event was described. In this case, the weather conditions, physico-chemical parameters of the dangerous substance, and the radii of the danger zones of its distribution and the number of people who need to be evacuated were taken into account. In practice, having this knowledge, a head of the emergency management center at the State Emergency Service of Ukraine will be able to effectively manage people without exposing them to danger, as well as conduct timely evacuation. The use of these programs makes it possible to reduce the time of hazard assessment and visualize them, which creates advantages over the existing methodology of the State Emergency Service of Ukraine in terms of speed of hazard assessment.

The results have made it possible to solve the problem of increasing the efficiency of the emergency management centers at the Emergency Service of Ukraine and to create the prerequisites for building a geo-information portal that could combine various methods and techniques on one platform

**Keywords:** crisis center, control centers, emergency event, geoinformation systems, MARPLOT, CAMEO, ALOHA, evacuation

# IMPROVING THE OPERATIONAL EFFICIENCY OF CONTROL CENTERS FOR EMERGENCY EVENTS BY USING GIS TECHNOLOGIES

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Received date 01.06.2023

Accepted date 07.08.2023

Published date 31.08.2023

**How to Cite:** Yemelyanenko, S., Kuzyk, A., Ivanusa, A., Behen, D., Koval, R., Morshch, Y. (2023). Improving the operational efficiency of control centers for emergency events by using GIS technologies. *Eastern-European Journal of Enterprise Technologies*, 4 (13 (124)), 37–49. doi: <https://doi.org/10.15587/1729-4061.2023.285938>

## 1. Introduction

At present, humankind is faced with various threats caused by natural phenomena and man-made accidents, which pose a threat to people and are categorized as emergency events. Under the conditions of martial law, urgent tasks for the State Emergency Service of Ukraine are the protection of infrastructure facilities, search and rescue of victims from under rubble, elimination of the consequences of bombings under conditions of a repeated threat. Management during an emergency is carried out under conditions of incomplete information and requires new approaches and

their implementation in emergency management centers at the State Emergency Service of Ukraine (hereinafter, Crisis Centers). Crisis management plays an important role in the protection of people and territories, and therefore it is especially important to ensure quick access to the necessary information and effective management of the process of elimination of emergency events (hereinafter, EEs) and their consequences. This is especially relevant in the presence of multiple threats caused by military activities.

The operation procedure of Crisis Centers is determined by the central executive body, which ensures the formation and implementation of state policy in the field of civil pro-

tection. In the event of an emergency, representatives of the relevant state authorities are involved in the work of Crisis Centers. The main aspects of the activities of Crisis Centers are listed in the Code of Civil Protection of Ukraine dated October 2, 2012, No. 5403-VI.

The main tasks of the Crisis Center are:

- management under the mode of daily functioning of subjects of civil protection provision;
- coordination of actions of management bodies and civil defense forces;
- implementation of round-the-clock duty;
- ensuring the functioning of the system for collecting, processing, summarizing, and analyzing information about the situation in areas of emergency events.

The State Emergency Management Center operates in the system of the Emergency Service of Ukraine at the national level.

However, at present, at regional levels, Crisis Centers are not always available and there are no uniform approaches to their construction, which is why they do not function properly, due to their actual absence. All analytical work is carried out in operational coordination centers of the State Emergency Service of Ukraine.

Therefore, studies aimed at the justification of the functioning of control centers in emergency events are relevant and should focus on GIS. It is important for adequate decision-making to visualize the processes related to emergency events and their elimination on the basis of GIS technologies as this will help improve the level of interaction and the ability to respond to possible threats.

Since 2014, Ukraine has faced large-scale emergencies caused by Russian aggression. The experience of crisis management in emergency events showed the need to find new solutions and improve the activities of Crisis Centers and GIS technologies in decision-making support systems. The results of research in this area will be useful for the EU countries and the European Central Pool, which Ukraine is a member of.

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## 2. Literature review and problem statement

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In the era of digitalization, the staff of Crisis Centers uses geo-information and information and telecommunication systems to make management decisions in the case of occurrence or prevention of accidents, catastrophes, and other emergency events [1, 2]. In [3, 4], the work of such centers is described, but the basic principles of the operation of Crisis Centers are not specified.

In connection with Russia's military aggression against Ukraine, the government is introducing the National Resilience System to ensure a high level of readiness of society and the state to respond to a wide range of threats. By the decision of the National Security and Defense Council of Ukraine dated June 4, 2021, Situation Centers were established. Currently, the principles of construction and requirements for Crisis Centers have not been formed at the legislative level. Works [5–7] analyzed the role of situational centers and emphasized that such centers should be united in a single protected network, with the possibility of quickly collecting information, analyzing it, and making decisions that are critically important for the state. However, these centers relate to the functioning of the Armed Forces of Ukraine.

In EU countries, the so-called “European Civil Protection Pool” [8] has been created – these are emergency

response groups with technical equipment to support emergency response measures.

When a disaster strikes and national resources are exhausted, aid can be provided to the affected country through the EU's civil protection mechanism (the European Civil Protection Pool). In the shortest possible time, immediate assistance is provided from the participating countries, which makes it possible to significantly reduce the consequences of accidents or disasters, and most importantly, to provide the necessary assistance in time to save lives and minimize losses. The European Civil Protection Pool allows better organization, more predictability and coordination of EU emergency operations. But the coordination of forces and means at the interstate level requires the same approaches to the decision-making processes that are carried out in the Crisis Centers of the EU and other countries, in particular Ukraine.

Emergency management in the UK is carried out on the basis of the National Risk Register [9], which includes information from many departments and agencies responsible for crisis management in the UK. The document has been published since 2008, in accordance with the provisions contained in the National Security Strategy (Great Britain) and describes the main categories of risks and methods of their prevention, as well as risk assessment [10]. The analysis is carried out by assessing the consequences and probability of the main threats in the next 5 years, while priority is given to threats that can have a direct impact on the state's activities. Every year, the British government conducts a risk assessment: National Risk Assessment – NRA (National Risk Assessment). This indicates the need to implement a risk-oriented approach to decision-making under the conditions of Crisis Centers.

Paper [11] describes the role of information and communication technology support in the coordination of actions during emergency response, focusing on the information level. Information coordination is usually based on national interaction mechanisms but is rarely supported by appropriate infrastructure or information and communication technology systems. In particular, the paper presents a prototype of a crisis information management system to support two tasks: incident notification and resource messaging. This system is based on open standards developed by the OASIS standards consortium. However, the work does not specify the principles of integrating the system into the activities of Crisis Centers.

Work [12] describes the process of managing crisis and emergency events, provides an overview of the legal framework and policy regarding crisis and emergency events. The authors describe the roles and responsibilities of the main actors involved in crisis and emergency response, drawn from their own experience, and discuss the management of communications during a crisis or emergency. But the importance of GIS technologies in crisis management is not highlighted.

Paper [13] focuses on the aspects of coordination during an emergency and highlights logistical and coordination problems, including asymmetric flow of information, its correct assessment and quick redirection of information. The roles and functions of the coordination center, the advantages of co-locating all the necessary services and departments in one room, the correct staffing of these premises and the use of mapping software are described. However, this information needs to be updated using modern GIS technologies.

The US Federal Emergency Management Agency (FEMA) [14] has emphasized the critical role of involving local communities, the private sector, and trained volunteers in disaster response and recovery. FEMA sees a need to

place more responsibilities on these groups. However, the cited work does not reveal the problem of uniformity of crisis centers and their software based on GIS technologies.

Therefore, for effective management decision-making, operative services must have clear algorithms of interaction among themselves to carry out management based on decision support systems provided with information visualization by means of GIS technologies.

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### 3. The aim and objectives of the study

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The purpose of this work is to improve decision-making processes by increasing the efficiency of Crisis Centers and software based on the analysis of probable threats and visualization of their spread and elimination. This will provide an opportunity to increase preparedness and improve the interaction of all involved agencies, and to make timely management decisions in the field of civil protection in emergency events.

To achieve the goal, the following tasks must be completed:

- to formulate a conceptual model of the work of the Crisis Center and the main functions of the Crisis Center;
- to identify the main risks and dangers in the work of Crisis Centers;
- to build a block diagram of risk assessment and minimization for a facility;
- on the basis of geo-information and information and telecommunication systems, visualize the emergency event;
- to state the principles of software selection for effective emergency management.

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### 4. The study methods

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The object of our study is the control centers for emergency events.

The subject of the study is the process of operation of control centers during emergency events.

The work uses a complex method of research, which includes analysis and generalization of scientific achievements in the field of GIS technologies, application of statistical data, their processing and display on the map. The methods of mathematical modeling, probability theory, and system analysis were also applied.

The hypothesis of the study assumes that the generalization of information on one resource could make it possible to quickly determine the scale of the accident and make important decisions for its localization and elimination. Interconnected programs ALOHA, MARPLOT, and CAMEO make it possible to quickly make forecasts of the development of emergencies and the spread of dangerous concentrations of toxic substances on the map, determine the scale of the accident for making management decisions.

For research, we chose one of the worst scenarios for modeling the process of spreading dangerous substances during an emergency and performed simulations of the consequences of an accident with an ammonia spill.

Existing procedure [15], which is used at the State Emergency Service of Ukraine, requires the involvement of significant resources, time, and expert groups; with the help of the above-mentioned programs, the necessary calculation can be made in a few minutes. A head of the guard at the State Emergency Service of Ukraine, while on his way to the place of the call, could predict the development of the accident and

determine the directions of response, which reduces the time for making management decisions, and accordingly could save lives.

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## 5. Results of research into the impact of GIS technologies on improving management decisions

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### 5.1. Conceptual model of the work of the Crisis Center and main functions

The functioning of the Crisis Center is the ability to respond to emergencies of a natural, man-made, and military nature, the interaction of all state authorities, operational and rescue units of the city, region, and other structures. The crisis center can be used as a center for forecasting, monitoring, management, and response of authorities and civil defense forces to emergencies in peacetime and during special periods.

The conceptual model of the work of the Crisis Center consists of four components (Fig. 1).

The first component is data collection, the analysis of a huge amount of data that includes information about emergencies, buildings, structural damage, casualty reports, impassable roads, numbers of forces and assets sent to respond, available equipment, and more. These data make it possible to calculate the real scenario of the development of an emergency based on information in the event of an emergency.

The second component is risk assessment, forecasting of possible threats inherent in certain territorial units, application of modern software for forecasting possible emergency scenarios, which has a direct impact on the level of effectiveness of the first response of the operational and rescue unit.

The third component is the management and coordination of response groups during the implementation of specific tasks for the elimination of emergencies: evacuation and rescue measures, disassembly of structures, localization of spills of dangerous chemicals, etc. Establishing communication is important in decision-making, it makes it possible to analyze the effectiveness of operational actions of response groups in a timely manner. Consistent and direct communication is an important component for response teams and management, which increases the effectiveness of the tasks assigned.

The fourth component is measures to eliminate the consequences of emergencies.

The crisis center ensures the rapid deployment of the operational group of the temporary commission of TEB and EE on issues of technogenic and environmental safety and emergency events and acts as a coordination center between all state departments and management bodies. There must be representatives of government departments and management bodies: the national police, disaster medicine, local authorities, the Armed Forces, and others. The crisis center ensures the establishment of cooperation and the procedure for the involvement of relevant management bodies in the event of an emergency.

The crisis center may consist of the following premises:

- analytical and coordination center;
- room for operational meetings;
- press conference hall;
- server room;
- auxiliary premises.

Functions of the Crisis Center:

- constant monitoring and comprehensive analysis of existing threats to the population and territories;
- assessment of the risks of occurrence and forecasting of emergency events;

- coordination of the actions of the relevant departments during emergencies and elimination of their consequences;
- development of decisions on prevention, overcoming, and minimization of emergencies;
- rational coordination of material and technical support;
- determination of emergency zone boundaries and emerging threats;
- implementation of constant forecasting of the zone of possible spread of an emergency event and the scale of possible consequences;
- organization of work on localization and elimination of the consequences of an emergency event, involvement of the necessary forces and means for this;
- organization and implementation of measures for life support of the affected population;
- organizing and carrying out, if necessary, evacuation measures;
- organization and coordination of radiation, chemical, biological, engineering, and medical protection of the population and territories from the consequences of emergencies;
- implementation of continuous control over the development of the emergency event and the situation at the emergency facilities and their adjacent territories;
- informing civil protection authorities and the population about the development of the emergency event and the measures being taken.

The Crisis Center software should help operators perform the basic functions of forecasting, monitoring, and management. Operating systems and software used in the system of the State Emergency Service of Ukraine must be licensed and protected. Application software should be licensed, preferably with extended support and maintenance. In the case of using free application software, the source for its download must be the official website of the developer with an installed and valid SSL certificate at the time of download. It is not allowed to use the software if the developer is on the list of individuals or legal entities against whom the state of Ukraine has taken restrictive measures (sanctions).

Installation of software on users' computers in the system of the Emergency Service of Ukraine is carried out exclusively by specialists of divisions in the field of information and telecommunication technologies of the Emergency Service of Ukraine. Systems of management, processing, and display of multimedia information (video screen, video server, equipment for the operator's automated workplace, monitors and large-diagonal TVs).

The premises of an analytical and coordination center and the operational meeting hall must be provided with stable radio, video, and satellite communication with the control points and forces involved in the elimination of the emergency.

- Having analyzed the above-mentioned functions and work of situation centers [16–18], it is necessary to highlight the main capabilities of the Crisis Center:
- satellite, radio, and radio relay communication;
  - satellite and fixed Internet;
  - provision of video conference;
  - video broadcast of aerial reconnaissance using unmanned aerial vehicles;
  - online video broadcast from the scene;
  - ensuring the activities of management bodies;
  - government communication;
  - unification of all necessary information on one geo-informational portal.

**5. 2. Identification of the main risks and hazards in the work of Crisis Centers**

For specific objects that pose potential danger, it is necessary to perform an emergency risk assessment to predict possible consequences. The assessment can be carried out according to the relevant risks: individual, social, collective,

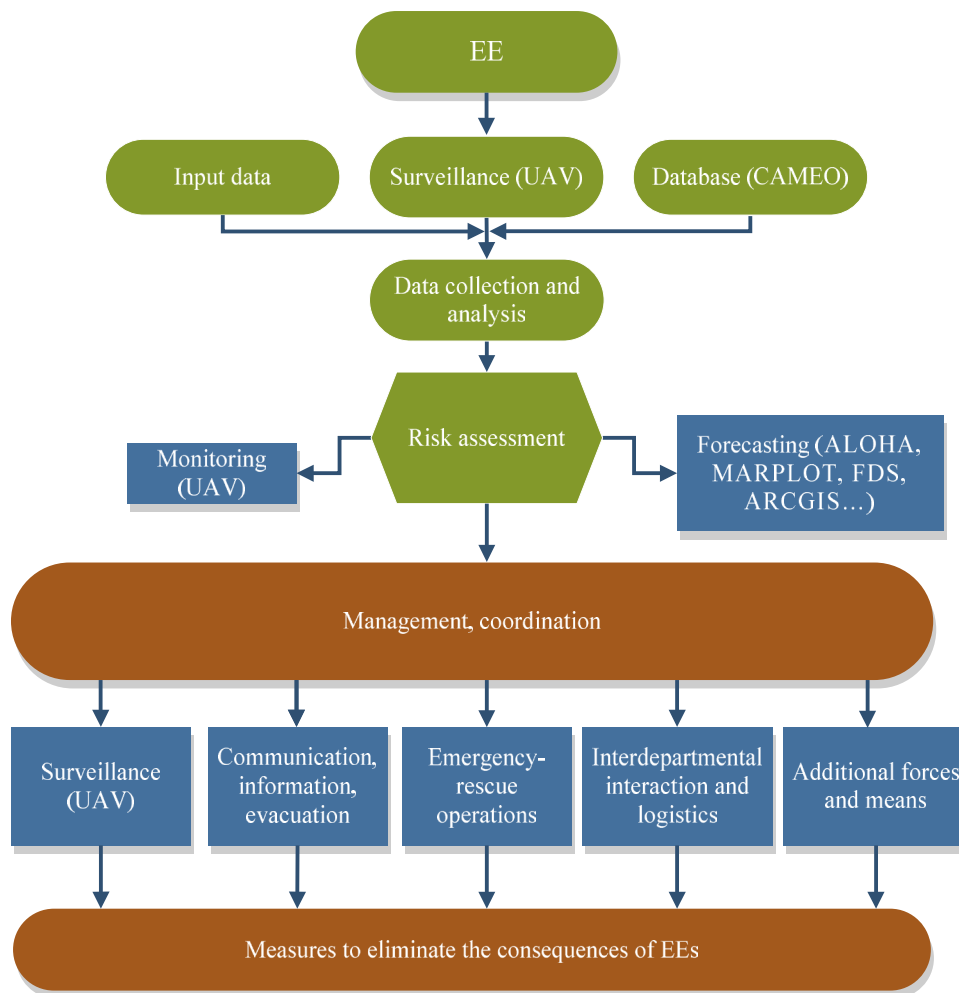


Fig. 1. Conceptual model of Crisis Center operation

territorial. Depending on the nature of occurrence and type of human activity, hazards are distinguished: domestic, man-made, natural, socio-political (Fig. 2).

An important component in risk assessment is the determination of possible negative scenarios and the construction of event trees that can lead to negative consequences. Also, when assessing risks, it is necessary to distinguish man-made, fire,

economic, and environmental risks (Fig. 3). Most emergencies are accompanied by the occurrence of fires, which in turn can lead to the loss of life, property or cause environmental damage.

Therefore, the identification of the main risks and dangers that the Crisis Center should work on will make it possible to investigate the main dangers inherent in this region (territorial community).

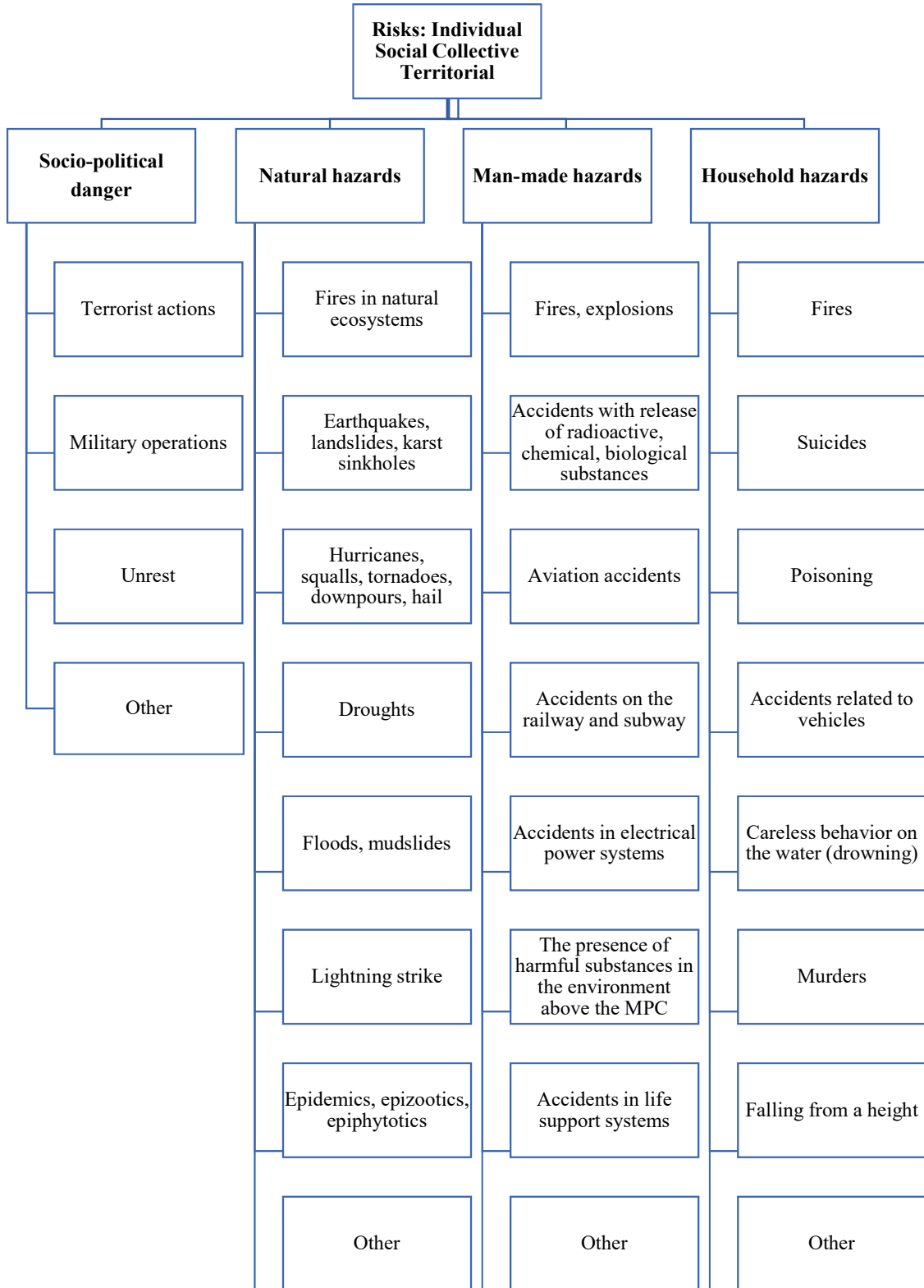


Fig. 2. The main risks and dangers that the Crisis Center should cover



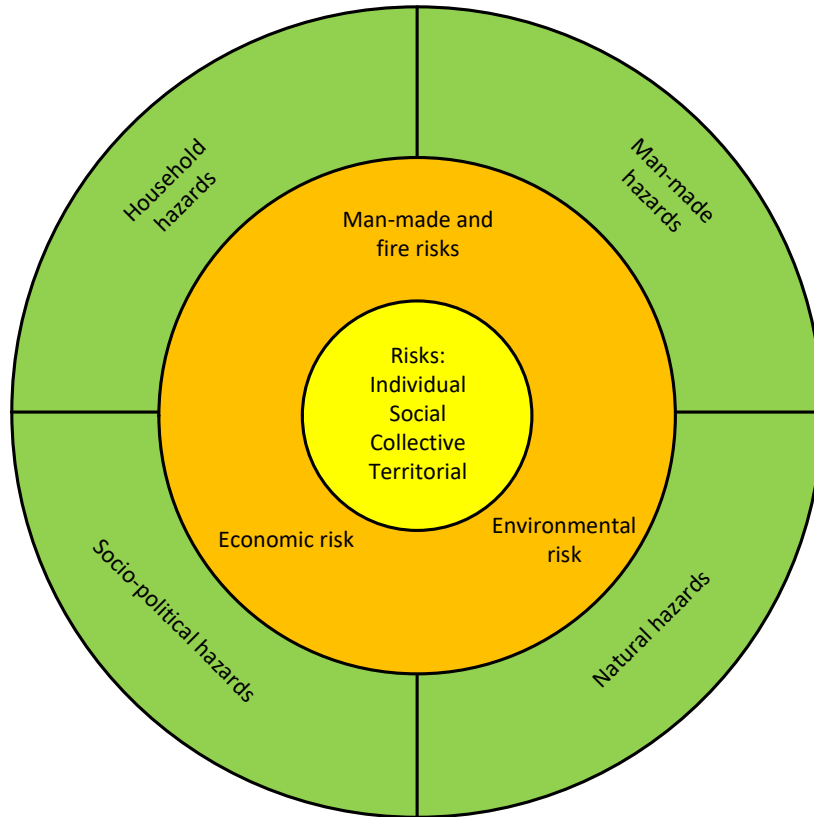


Fig. 3. Classification of risks and hazards

**5. 3. Flowchart of risk assessment and minimization for the object**

A risk assessment is carried out for each potentially dangerous facility. Analysis of the object’s hazards is necessary to identify and determine possible threats that are inherent in this object, to develop risk minimization measures (Fig. 4).

For each investigated object, data is collected, response plans are developed for threats of possible emergencies.

The scale and consequences of a probable emergency are determined on the basis of expert assessment, statistical data, forecast or results of model experiments conducted by qualified experts.

Classical approaches must be used for risk assessment:

$$R = P * S, \tag{1}$$

where *P* is the probability or frequency of occurrence of a negative event;

*S* is the consequences of a negative event (damages from fires, accidents, etc.).

In order to determine the probability of failure (*P*) at an industrial facility, it is necessary to determine the partial probabilities of all predicted events (reliability, failure of individual components of the system), the probability of a major accident will be equal to:

$$P = P_1 * P_2 * P_3. \tag{2}$$

A systematic approach to this task can be implemented using a tree of failures and/or errors and/or events.

Therefore, for the territorial unit covered by the Crisis Center based on a risk-oriented approach, it is necessary to draw up a risk matrix. The risk matrix should cover the main

dangers that are present in this area, especially fire and man-made risks and their consequences.

Table 1 gives a risk matrix that shows exposure levels and the probability of the risk occurring (in % probability that an incident will occur within one year multiplied by the exposure). There are three levels of risk: low (green), medium (yellow), and high (red).

The risk matrix serves to visualize fire risks and their consequences during large-scale accidents or catastrophes by means of GIS technologies. Visualization of an emergency event and information related to objects and the population in the zone of its influence on the basis of geo-information systems makes it possible to forecast its further development, establish threats to the population and make appropriate management decisions aimed at preventing its spread, minimizing consequences and material losses. Table 2 gives the main dangers, forces, and means that can be involved in the elimination of emergency events on the example of the Lviv united territorial community.

Table 1

		Risk criteria assessment matrix		
By exposure to risks	Numeric value, %	By the likelihood of risk		
		Low probability	Medium probability	High probability
		1	2	3
High level of impact	3	3* (1×3) (yellow zone)	6* (2×3) (red zone)	9* (3×3) (red zone)
Medium level of impact	2	2* (1×2) (green zone)	4* (2×2) (yellow zone)	6* (3×2) (red zone)
Low impact	1	1* (1×1) (green zone)	2* (2×1) (green zone)	3* (3×1) (yellow zone)

Note: \* – product; (...) – the color of the zone is indicated in brackets

Table 2

The main dangers, forces and means that may be involved in the elimination of emergencies in the Lviv united territorial community

Dangers	Services																			
	Lviv Mayor	Head of Regional State Administration	Chief State Sanitary Doctor	Head of the Main Department of the Ministry of Internal Affairs of Ukraine	Head of the Main Department of the State Emergency Service of Ukraine	Commander of the troops of the operational command "West"	Head of Lviv Regional Prosecutor's Office	Head of the Western Regional Department of the State Border Guard Service of Ukraine	Director of Housing Department	Director of the Department of Social Protection	Director of the Department of Civil Protection	Director of the Department of Health	Director of the Department of Ecology and Natural Resources	Head of Transport and Communications Department	Head of the Main Department Derzhprodsposhimsluzhba	Director of the Department of Development and Operation of the Housing and Communal Economy	Director of Fuel and Energy Department	Department of Communications and Internal Policy	Department of Economic and Technical Support	Department of Fuel and Energy Complex
Socio-political																				
Terrorist actions	k	d	d	p	p	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Hostilities	k	d	d	p	p	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Riots	k	d	d	p	p	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Other	k	d	d	p	p	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Natural																				
Fires in natural ecosystems	k	d	d	d	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Earthquakes, landslides, karst abysses	k	d	d	d	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Hurricanes, squalls, tornadoes, downpours, hail	k	d	d	d	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Drought	k	d	d	d	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Floods, mudslides	k	d	d	d	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Lightning strike	k	d	d	d	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Epidemics, epizootics, epiphytotics	k	d	d	d	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Other	k	d	d	d	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Man-made																				
Fires, explosions	k	d	d	d	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Accidents with the release of radioactive, chemical, biological substances	k	d	d	d	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Aviation disasters	k	d	d	d	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Railway and subway accidents	k	d	d	d	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Accidents in electric power systems	k	d	d	d	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
The presence in the environment of harmful substances above the MPC	k	d	d	d	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Accidents in life support systems	k	d	d	d	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d
Other	k	d	d	d	p	d	d	d	d	d	d	d	d	d	d	d	d	d	d	d

In Table 2, the following designations are accepted: k – coordination, (management); p – rescue operations (elimination of emergencies); d – auxiliary.

The problems of preparedness for actions in emergencies and response to them mainly relate to the interaction between the relevant operational units of civil protection and departments. Despite the multifaceted and wide range of accidents and disasters, many of which pose a significant threat (fires, earthquakes, floods, hurricanes, etc.), the suc-

cess of their elimination depends on making quick management decisions in emergency events and on the readiness and proper functioning of Crisis Centers.

The crisis center will be effective only when modern GIS technologies are applied, which are concentrated in one portal, interaction are established between the relevant civil protection units and departments, and communication is established for quick data exchange when making decisions.

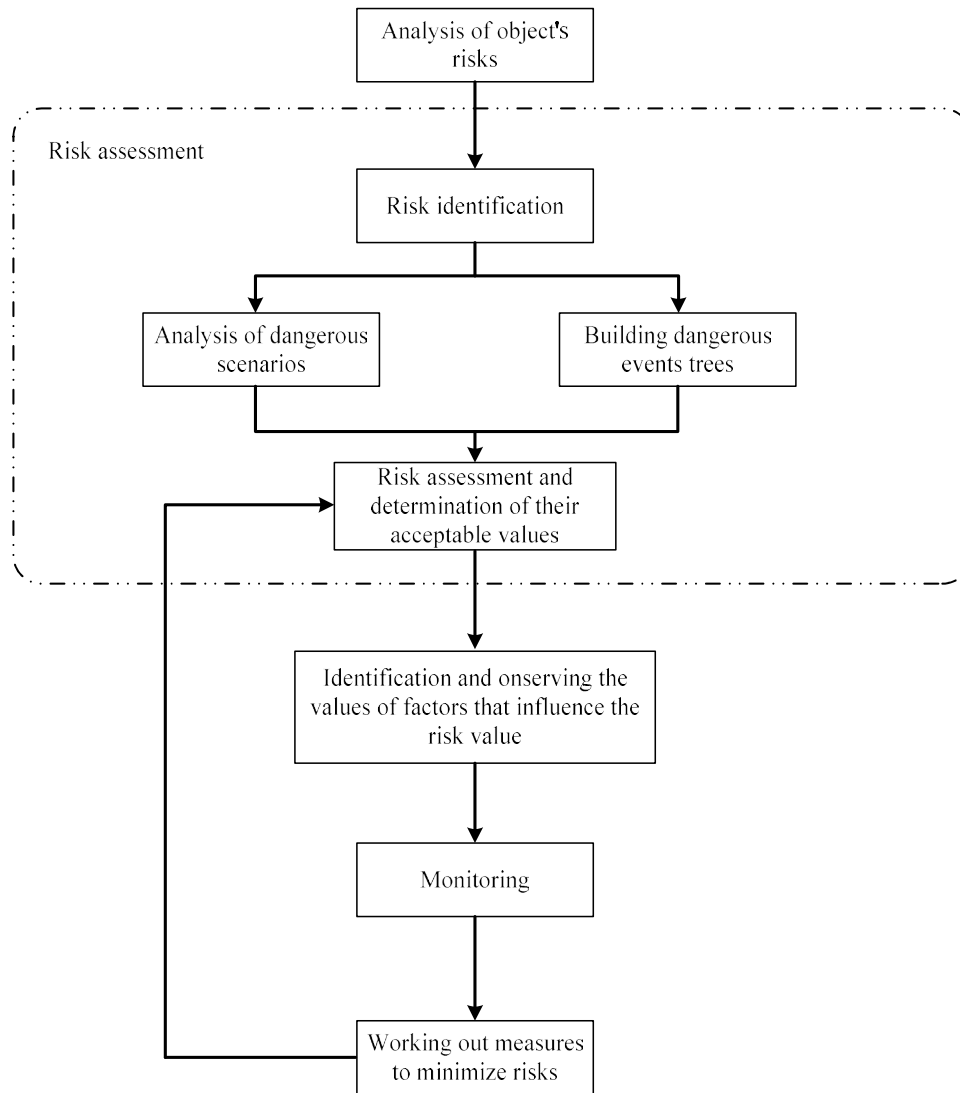


Fig. 4. Flowchart of risk assessment and minimization for the object

**5. 4. Emergency visualization based on GIS technologies**

In order to visualize fire risks and their consequences during large-scale accidents or catastrophes, it is necessary to use geo-information technologies based on GIS systems. Visualization of an emergency event on the basis of geoinformation systems allows forecasting the further development of the emergency, establishing threats to the population, and making appropriate management decisions aimed at preventing its spread and minimizing the consequences. Another important issue for the proper functioning of the Crisis Center is the database and the speed of its processing. In fact, this database can be in the form of a complex geo-information system, which will make it possible to quickly use the data to forecast the consequences of emergency events of a natural, man-made, or military nature at the stage of preventing their occurrence.

To this end, modern geo-information systems are used, which allow online or offline assessment of damages and consequences of possible emergency events and forecasting of possible damages. For effective crisis management during an emergency, one of the software examples is the CAMEO software suite [18], which includes:

- CAMEO Data Manager – database and information management tool;

- CAMEO Chemicals – Table of chemical reaction data and reaction prediction tool;

- MARPLOT [17] – mapping app for response, planning, and local operational tasks;

- ALOHA [19] – zones of spread of dangerous atmosphere during accidents with chemically hazardous substances.

For example, a typical scenario of an emergency event and the work of the Crisis Center on its elimination are considered. On the territory of the city of Lviv, there was a traffic accident involving a passenger car and a tanker truck, which was transporting a chemically dangerous substance (1.67 tons of ammonia).

As a result of the collision of the car with the tanker, a hole appeared in the tanker truck in the form of a round hole, as a result of which the tank was depressurized. A hole with a diameter of 50 cm was formed in the lower part of the horizontal tank and a spill of a chemically dangerous substance (ammonia) took place, without its subsequent ignition.

With the help of the ALOHA program, the damage zones of this emergency were calculated. These zones are divided into certain sectors, which are marked by different colors: red, orange, and yellow. The radius of the affected zone, taking into account the weather conditions, is about 3.5 km (Fig. 5).



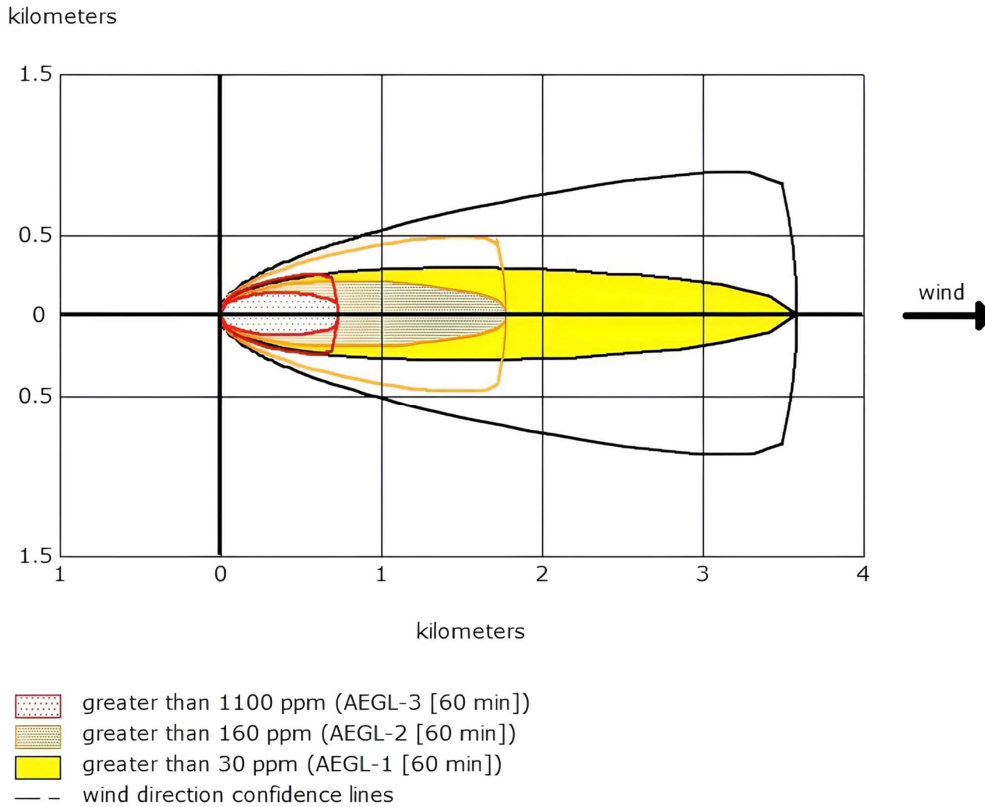


Fig. 5. Assessment of affected areas in the ALOHA program

With the help of the ALOHA and MARPLOT software, it is possible to determine the number of people who directly fall into the affected area and require further evacuation (Fig. 6, Table 3).

The data obtained as a result of calculations using the ALOHA, MARPLOT, and CAMEO programs (Table 3, Fig. 6) showed that the perimeter of the red zone will be: 1.72 km, the area: 0.160 km<sup>2</sup>, and the number of people who will fall into this zone that must be evacuated immediately: 2,229 people. Perimeter of the orange zone: 3.83 km, area: 0.580 km<sup>2</sup>, number of people who need to be evacuated: 3,973 people. The perimeter of the yellow zone: 9.08 km, the area: 4.58 km<sup>2</sup>, the number of people who need to be evacuated: 17,452 people. That is, it is necessary to evacuate 17,452 people in these areas. The

evacuation zone may change depending on weather conditions. In the case of changing wind, evacuation zones are modeled in the form of a circle with corresponding radii, which will significantly increase the number of people who need to be evacuated.

The use of ALOHA, MARPLOT, and CAMEO Data Manager allows real-time use of data for immediate emergency assessment even offline. In the absence of the Internet, it is possible to assess the risks of the spread of dangerous substances, and under conditions of martial law it is extremely relevant. This method makes it possible to take into account the direction and speed of the wind, weather conditions, physico-chemical parameters of the hazardous substance, and determine the number of people who directly fall into the affected area and require further evacuation.

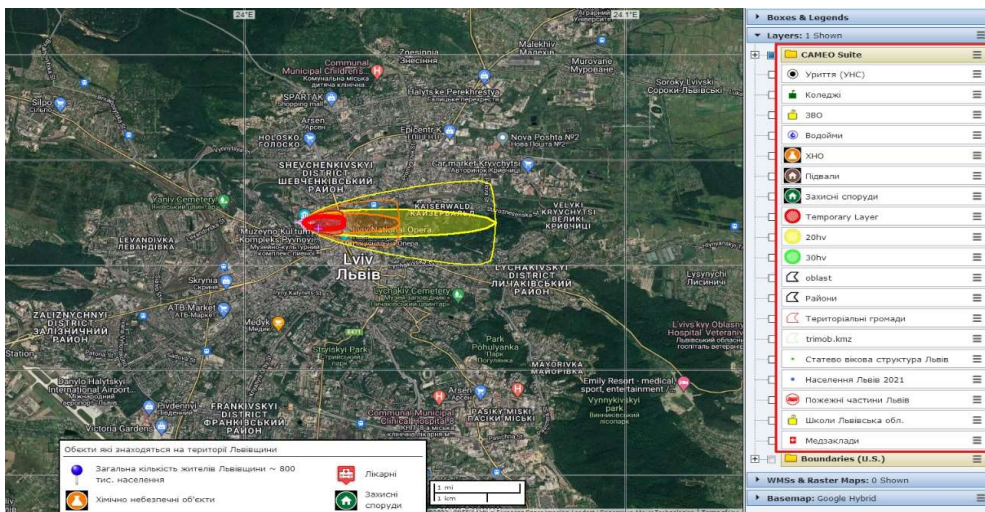





Fig. 6. Prediction of the damage zone during a traffic accident using the example of Lviv

Table 3

Areas affected by emergency

Zone name	Key options by Aloha	Key parameters for Marplot
 Red zone	737 m, 1100 ppm=AEGL-3 (60 min)	Perimeter: 1.72 km. Area: 0.160 km <sup>2</sup> . Number of people to evacuate: 2229 people
 Orange zone	1771 m, 160 ppm=AEGL-2 (60 min)	Perimeter: 3.83 km. Area: 0.580 km <sup>2</sup> . Number of people who need to be evacuated: 3973 people
 Yellow zone	3541 m, 30 ppm=AEGL-1 (60 min)	Perimeter: 9.08 km. Area: 4.58 km <sup>2</sup> . Number of people who need to be evacuated: 17452 people

**5. 5. Principles of Crisis Center software selection for effective emergency management**

The software of the Crisis Center should be based on modern GIS technologies and provide an opportunity to perform the following tasks:

- coordinate-time and navigation playback;
- monitoring of weather, geophysical phenomena, floods, state of the atmosphere and water resources;
- monitoring the ecological state of water bodies (river network, lakes);
- detection of temperature anomalies (fires) in forest areas;
- forecasting the spread of fires in natural ecosystems and others;
- monitoring the condition and activity of potentially dangerous objects;
- analysis of the consequences of man-made disasters and natural disasters (floods, floods, fires, explosions, hurricanes, etc.);
- tracking the results of localization and elimination of the consequences of natural disasters and man-made accidents;
- identification of prerequisites for the occurrence of emergencies;
- monitoring the course and consequences of emergencies (fires, floods, storms, etc.);
- forecasting precipitation and weather conditions using satellite data and GIS technologies, forecasting, and tracking the state of drought and fire-hazardous areas in natural ecosystems;
- assessment of the risks of emergency occurrence in public facilities (facilities with mass presence of people), critical infrastructure facilities, high-risk facilities, and other facilities.

In order to better understand the development of emergency events and predict the possible consequences that may arise, the selection of software for the needs of the Crisis Center was carried out (Table 4). Software, government websites, websites of international organizations, and others were used for its formation.

To perform specific tasks related to calculations and modeling of phenomena and processes, it is also advisable to use licensed software programs in the Crisis Center: ARCGIS, ENVI, COMSOL, MATLAB, and others, which can perform visualization of results and ensure their speed. It is necessary to develop the necessary scripts for use in software packages in order to create convenient algorithms and solve practical tasks of civil protection services in the territory served by the Crisis Center.

Table 4

Indicative list of software and online resources for the work of the Crisis Center

No.	Task	Name of software or online resources
1	Dangerous toxic substances in the atmosphere	
1.1	Modeling of the danger zone of spread of toxic substances in the atmosphere	ALOHA [19]
2	Earthquakes	
2.1	Earthquake data display	USGS Latest Earthquakes
3	Flood	
3.1	Hydrological prevention	Hydrometeorological Center website [20]
3.2	Forecasting and mapping areas of probable flooding	FMGlobal NatHaz Map
3.3	Flood risk maps	The website of the State Emergency Service of Ukraine [21]
4	Weather	
4.1	Current state and weather forecast	Hydrometeorological Center website [20]
4.2	Meteorological alerts	
4.3	Cloudiness (Satellite observations)	
5	Radiation	
5.1	Radiation situation	Hydrometeorological Center website [20]
6	Operational situation	
6.1	GPS tracking of equipment and personnel	OpenGTS Project [22]
7	Risks of fires in public buildings	
7.1	Calculation of the time of blocking escape routes by fire hazards	CFAST, FDS [23]
7.2	Evacuation, fire hazards	FDS+Evak [23]
8	Cartographic editors to visualize the possible consequences of emergencies	
8.1	Visualization on the map	MicroGIS, QGIS, ARCGIS [24], MARPLOT [17]

For the effective operation of the Crisis Center, it is necessary to create a geo-information portal [1, 2], which will combine the created models and algorithms on one platform and will be maximally adapted to the needs of the Crisis Center staff.

Summarizing the above functions and tasks of the Crisis Center, as well as their implementation, it should be noted that an important element in crisis management is the proper

visualization of phenomena and processes carried out on the basis of GIS technologies [25, 26]:

- modeling and forecasting the spread of fire flames, spillage of chemically hazardous substances, destruction, etc.;
- managing emergency elimination;
- risk map;
- emergency monitoring;
- evacuation measures (evacuation zones, number of people, objects located in evacuation zones, etc.);
- damage assessment of critical infrastructure structures;
- location of operational rescue units and determination of the time of arrival at the place of occurrence of the emergency and the conduct of rescue operations;
- creation and maintenance of various databases, access to databases of other services and authorities;
- study of the stability of critical infrastructure to natural disasters;
- assessment of the stability of public facilities (with a mass presence of people);
- monitoring the ecological state of water bodies, natural ecosystems, forests, etc.

Therefore, to perform the above functions and tasks of the Crisis Center at the initial stage, you can use ALOHA, MARPLOT, and CAMEO Data Manager to visualize the results of calculations. However, the wide range of tasks and functions that the Crisis Center must perform requires the creation of a geo-information portal based on modern technologies to combine all capabilities on one platform.

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## 6. Discussion of results of the study of the impact of GIS technologies on the improvement of management decisions

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In contrast to [5], the software required for forecasting, monitoring, and responding to emergencies for prompt management decision-making regarding its elimination is considered. This becomes possible thanks to the creation of a conceptual model of the work of control centers at the State Emergency Service of Ukraine, which consists of four components (Fig. 1). Attention is focused on the second component – risk assessment, forecasting of possible threats with the use of modern software, which has a direct impact on the level of efficiency of the first response of the operational-rescue unit.

In order to identify the main risks and dangers that should be covered by the Crisis Center, the classifications are proposed (Fig. 2, 3), which make it possible to assess the risks for objects that carry potential danger. A risk assessment is carried out for each investigated object that poses a potential danger, which is shown in the block diagram (Fig. 4).

Analysis of the object's hazards is necessary to identify and determine the possible threats that are inherent in this object, to develop risk minimization measures. For each investigated object, data is collected, response plans are developed for threats of possible emergencies.

The definition of risks is carried out according to classical approaches (1), (2), which makes it possible to build trees of failures and/or errors and/or events, and for the territorial unit covered by the control center of the National Emergency Service of Ukraine, it becomes possible to draw up a risk matrix. The risk matrix should cover the main dangers that are present in this area, especially fire and man-made risks

and their consequences. On the basis of the Matrix of risks and GIS technologies, it is necessary to establish threats to the population and make appropriate management decisions aimed at preventing emergencies in the emergency management centers of the State Emergency Service of Ukraine. Table 2 shows the main dangers, forces, and means that can be involved in the elimination of emergency events on the example of the Lviv united territorial community.

Table 3 and Fig. 6 show an example of a typical scenario of an emergency event and the work of the emergency management center of the State Emergency Service of Ukraine regarding its elimination. The data obtained as a result of calculations using the ALOHA, MARPLOT, and CAMEO programs showed that the perimeter of the red zone will be: 1.72 km, the area: 0.160 km<sup>2</sup>, and the number of people who will fall into this zone, who must be evacuated immediately: 2229 people. Perimeter of the orange zone: 3.83 km, area: 0.580 km<sup>2</sup>, number of people who need to be evacuated: 3,973 people. The perimeter of the yellow zone: 9.08 km, the area: 4.58 km<sup>2</sup>, the number of people who need to be evacuated: 17,452 people. That is, it is necessary to evacuate 17,452 people in these areas. The evacuation zone may change depending on weather conditions. In the case of changing wind, evacuation zones are modeled in the form of a circle with corresponding radii, which will significantly increase the number of people who need to be evacuated.

In contrast to existing methodology [15] used by the employees of the State Emergency Service of Ukraine, which requires a significant amount of time to assess and forecast the consequences of the spill (emission) of dangerous chemicals during accidents, with the help of the ALOHA, MARPLOT, and CAMEO programs, you can make the necessary calculation in a few minutes and visualize EE development. At the same time, it is possible to determine the directions of response, which reduces the time of making management decisions, which will, accordingly, save lives.

For the effective operation of the emergency management centers of the State Emergency Service of Ukraine, it is necessary to create a geo-information portal [1, 2] based on the example of the work of the above-mentioned programs for use in the activities of the State Emergency Service of Ukraine. Table 4 provides an approximate list of software and online resources for the operation of control centers in the National Emergency Service of Ukraine and defines the main tasks and functions that must be performed in it. Therefore, a geo-information portal for the implementation of tasks and functions of control centers in the National Emergency Service of Ukraine can be created on the basis of modern technologies to combine all possibilities on one platform. A wide range of software of the Crisis Center will help to better identify problematic issues of regions and territories, dangerous objects in order to prevent possible emergencies.

The disadvantages of our research include the fact that for modeling a flood, a fire in natural ecosystems or for a separate object, it is necessary to use other programs that are not compatible with ALOHA, MARPLOT, and CAMEO. However, the use of ALOHA, MARPLOT, and CAMEO programs in the activities of the State Emergency Service of Ukraine will help replace the portal and on the basis of the above-mentioned programs to evaluate and perform forecasting of the consequences of the spill (emission) of dangerous chemicals during accidents or take as a basis for the creation of a geo-informational portal.

This study has a development potential, especially during the period of martial law, when the control centers in the Emergency Department of the State Emergency Service of Ukraine must interact with similar centers in Ukraine (situation centers of the Armed Forces of Ukraine) and EU countries, modernize hardware and software, information bases, and communication tools in a timely manner. In particular, by means of GIS technologies. It would be better to join forces and rename the emergency management centers of the State Emergency Service of Ukraine into Situation Centers of the State Emergency Service of Ukraine. In the future, it is necessary to develop a single concept of the functioning of Situation Centers of Ukraine for all agencies and provide access to certain necessary information in the event of an emergency. Special attention must be paid to access to the activities of such centers in order to prevent the leakage of information. Creation of a single portal or platform based on modern GIS technology will help improve interaction between relevant government departments and civil defense units.

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## 7. Conclusions

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1. A conceptual model of the work of the Crisis Center and the main functions of the Crisis Center were formulated. This model consists of four components: data collection and analysis, risk assessment and forecasting of possible threats, management and coordination, disaster relief measures. Its peculiarity is that it is oriented for the use of modern GIS technologies for forecasting possible emergency scenarios, which has a direct impact on the level of efficiency of the first response of the operational and rescue unit. The work of the Crisis Center should include the rapid deployment of the task force of the temporary commission of the TEB and EE and act as a coordination center between all government departments and governing bodies.

2. The identification of risks should cover the main risks of specific objects that carry potential danger, take into account the relevant risks: individual, social, collective, territorial – to forecast the consequences of possible and possible dangers.

3. The developed block diagram of risk assessment covered by the Crisis Center makes it possible to generalize the

risks present in the given territory, isolate them, and pay special attention to prevent their possible consequences. This becomes possible due to the fact that data is collected, risks are assessed, and response plans are developed for threats of possible emergencies for each investigated object that poses a potential danger.

4. Based on the results of modeling the process of assessing the risks of the spread of hazardous substances during an emergency, using the example of a traffic accident with an ammonia spill (1.67 t) that happened on the territory of Lviv, regularities were established regarding the quantitative characteristics of people entering the affected area. In particular, it was established that when simulating an accident with an ammonia spill, at least 17,452 people on an area of 4.58 km<sup>2</sup> will fall into the evacuation zone. Knowledge of this information will allow effective management of emergency elimination.

5. To choose the software of the Crisis Center, the following key requirements must be taken into account: visualization, speed, licensed software, etc. This is due to the fact that for the effective operation of the Crisis Center, it is necessary to create a geo-information portal that will combine the created models and algorithms on one platform and will be maximally adapted to the needs of the Crisis Center staff.

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## Conflicts of interest

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The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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## Funding

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The study was conducted without financial support.

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## Data availability

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The data will be provided upon reasonable request.

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