FORECASTING THE DEVELOPMENT OF EMERGENCY SITUATIONS: SCIENTIFIC APPROACHES, MODERN TECHNOLOGIES AND RISK ASSESSMENT

Daler Erkin-ogli Ismoilov
Shakhobiddin Sharofiddin-ogli To'khtamishov
Karshi State Technical University

Abstract: Forecasting the development of emergency situations is one of the most important directions in modern safety management and disaster risk reduction. Natural and technological emergencies can cause serious consequences for human life, public health, economic activity, infrastructure, and the environment. Their consequences often depend not only on the initial hazardous event but also on the speed of its development, the territory affected, the vulnerability of the population, and the effectiveness of preventive measures. Therefore, forecasting should be understood as a scientific process aimed at identifying possible emergency scenarios, estimating their development over time, and determining the potential scale of their consequences. This study examines the scientific foundations and practical methods used to forecast the development of emergency situations. Particular attention is given to statistical analysis, mathematical modelling, monitoring systems, geographic information technologies, remote sensing, and artificial intelligence. The study also considers the relationship between hazard probability, exposure, vulnerability, and potential consequences. Examples of forecasting floods, landslides, fires, earthquakes, and industrial accidents are discussed to explain how different methods can be applied depending on the nature of a hazardous process. The analysis shows that effective forecasting requires the integration of reliable information, continuous monitoring, scientifically justified models, and timely decision-making. The development of integrated forecasting and early warning systems can improve preparedness, reduce potential losses, and strengthen the protection of the population and critical infrastructure.

Keywords: emergency situations, forecasting, disaster risk, hazard assessment, mathematical modelling, artificial intelligence, monitoring, early warning systems, natural disasters, technological accidents

Introduction. Emergency situations are among the most serious challenges affecting the safety and sustainable development of modern society. They may arise as a result of natural processes, technological failures, environmental changes, or human activities. Earthquakes, floods, landslides, mudflows, droughts, extreme temperatures, forest fires, industrial explosions, chemical accidents, and transport incidents are examples of events that may develop into emergencies and cause significant damage.

The consequences of such events are not limited to the immediate destruction of buildings or infrastructure. They may also result in human casualties, injuries, environmental pollution, interruption of production processes, disruption of transport and communication systems, and considerable economic losses. In some cases, the consequences of an emergency may continue for months or even years after the initial event.

The development of information technologies has created additional opportunities for forecasting. Satellite observations, geographic information systems, digital monitoring devices, sensor networks, mathematical models, and artificial intelligence can process large amounts of information and identify changes associated with increasing danger.

However, technology alone cannot guarantee reliable forecasting. The quality of predictions depends on the accuracy of initial information, the scientific validity of the selected methods, the

characteristics of the studied territory or facility, and the ability of responsible organizations to use forecasting results in practice.

The purpose of this study is to examine the scientific foundations, methodological approaches, and modern technological possibilities for forecasting the development of emergency situations, as well as to identify the main factors influencing the reliability and practical effectiveness of forecasting systems.

Materials and Methods. The research is based on a theoretical and analytical examination of scientific publications, international recommendations, and methodological approaches related to emergency forecasting and disaster risk reduction.

The study considers natural and technological emergencies as dynamic processes influenced by environmental, technical, geographical, and human factors. The analysis focuses on the relationship between the initial hazardous event, the conditions affecting its development, and the possible consequences.

The following research methods were used.

Literature analysis. Scientific publications and international documents concerning emergency forecasting, disaster risk assessment, early warning systems, and modern monitoring technologies were examined. Particular attention was paid to studies comparing statistical, mathematical, simulation-based, and artificial intelligence methods.

System analysis. Emergency situations were considered as complex systems in which several factors may interact. For example, heavy rainfall may increase soil moisture, raise river levels, weaken slopes, and create conditions for floods and landslides. Similarly, technical equipment failure may lead to overheating, fire, explosion, or the release of hazardous substances.

Comparative analysis. Different forecasting approaches were compared according to their purpose, information requirements, advantages, and limitations. This made it possible to distinguish methods suitable for short-term forecasting from those used for long-term risk assessment.

Mathematical modelling approach. The principles of describing hazardous processes through mathematical relationships were examined. Particular attention was given to the use of historical observations, changing environmental parameters, and probability-based estimates.

Risk assessment approach. The study considered the probability of a hazardous event, the exposure of people and infrastructure, and their vulnerability to possible consequences.

The research is theoretical and analytical in nature. It does not claim to present new experimental data or the results of field testing. The conclusions are based on the analysis and comparison of established scientific approaches.

Results. Scientific foundations of forecasting emergency situations. Forecasting the development of emergency situations is a process of scientifically estimating the possible future condition of a hazardous process using available information about its current state, previous development, and influencing factors.

It is important to distinguish between three related concepts: hazard identification, risk assessment, and forecasting.

Hazard identification means determining what dangerous events or processes may occur in a particular area or facility. For example, an industrial enterprise may be exposed to fire, explosion, chemical release, or equipment failure.

Risk assessment goes further by examining how likely an event is and what consequences it may produce. A hazard may exist without necessarily causing serious damage. The level of risk depends on the probability of the event and the exposure and vulnerability of people, infrastructure, and the environment.

Forecasting focuses on estimating how the hazardous process may develop in the future. It considers possible changes in intensity, duration, location, speed, and consequences.

These concepts are closely connected. Hazard identification provides the initial information, risk assessment determines the level of potential danger, and forecasting helps estimate how the situation may change over time.

For a more complete assessment, it is necessary to consider four basic elements:

- Hazard - a potentially dangerous natural, technological, or human-related event or process.
- Exposure - people, buildings, infrastructure, economic activities, and environmental resources located in potentially affected areas.
- Vulnerability - the degree to which exposed people or objects may be damaged by the hazardous event.
- Capacity - the available resources, knowledge, infrastructure, and organizational capabilities that help prevent, withstand, and respond to the emergency.

For example, two settlements may be exposed to the same flood. However, the consequences may differ significantly. A settlement with effective drainage, protective structures, reliable warning systems, and prepared residents may experience less damage than a settlement with weak infrastructure and limited preparedness.

Therefore, forecasting should not be limited to estimating the physical characteristics of a hazardous event. It should also consider the conditions of the territory and the ability of the population and institutions to respond.

Forecasting the development of technological emergencies. Technological emergencies differ from natural disasters because they are often associated with the operation of machinery, industrial processes, energy systems, transport infrastructure, and hazardous materials.

Their causes may include equipment failure, poor maintenance, human error, violations of technological procedures, electrical faults, overheating, pressure increases, and inadequate safety management.

One of the most important directions in this field is forecasting technical failures before they develop into serious accidents.

Industrial fire and explosion forecasting

Fires and explosions may occur when combustible materials, oxygen, and an ignition source are present under dangerous conditions.

In industrial facilities, the development of fire risk may be associated with:

- Increased equipment temperature.
- Gas or vapour leakage.
- Electrical short circuits.
- Accumulation of combustible dust.
- Failure of ventilation systems.
- Incorrect storage of flammable substances.
- Violation of technological operating procedures.

Monitoring devices can continuously measure temperature, pressure, gas concentration, smoke, and other parameters.

For example, if the temperature of a machine increases beyond its normal operating range while vibration levels also rise, the system may identify a possible technical malfunction. If this condition is combined with a gas leakage signal, the risk of fire or explosion may require immediate investigation.

However, individual sensor readings should not automatically be interpreted as proof that an accident will occur. The results must be evaluated using appropriate technical thresholds, operating conditions, and safety procedures.

Chemical and hazardous substance accidents

Chemical emergencies may result from leaks, spills, equipment damage, pipeline failures, or violations of chemical handling procedures.

The consequences depend on the properties of the substance, the amount released, environmental conditions, and the location of exposed people.

Forecasting chemical contamination requires information about:

- Type and physical properties of the chemical substance.
- Quantity and rate of release.
- Temperature and pressure.
- Wind speed and direction.
- Atmospheric stability.
- Terrain characteristics.
- Location of residential and industrial areas.

Mathematical dispersion models can estimate the possible direction and extent of the movement of hazardous gases or vapours.

Such estimates can help determine potentially affected territories and support decisions about evacuation, sheltering, access restrictions, and the use of personal protective equipment.

Transport and infrastructure accidents. Transport emergencies may be associated with road accidents, railway incidents, aviation accidents, and failures in infrastructure systems.

Forecasting these events requires the analysis of traffic intensity, road conditions, weather, visibility, technical condition of vehicles, and human-related factors.

For critical infrastructure, such as bridges, tunnels, electrical networks, and water supply systems, monitoring and predictive maintenance can help identify technical problems before they lead to major disruptions.

Mathematical basis of emergency risk forecasting. Mathematical methods provide a structured way to describe and compare potential emergency risks.

One of the basic approaches is to consider risk as a combination of the probability of a hazardous event and the severity of its possible consequences.

A simplified expression is:

$$R = P \times C$$

Where:

R - estimated risk.

P - probability of the hazardous event.

C - severity of its potential consequences.

This expression is useful for initial risk comparison. However, it should not be treated as a complete universal model for all emergencies. In more detailed assessments, exposure, vulnerability, spatial distribution, and the ability to respond must also be considered.

For example, a hazardous event with a relatively low probability may still require serious attention if its potential consequences are extremely severe.

Similarly, an event with a high probability may produce limited damage if the exposed population is small and protective measures are effective.

For this reason, forecasting should examine both the likelihood of an event and the conditions that determine its consequences.

Another important aspect is the forecasting period. Depending on the hazard, forecasting may be divided into:

Long-term forecasting. Used to identify general trends and future risk conditions over several years or decades. It is important for territorial planning, infrastructure development, and investment in protective measures.

Medium-term forecasting. Used to estimate possible hazardous developments over several weeks or months. It can support seasonal preparedness, maintenance planning, and resource allocation.

Short-term forecasting. Used to assess the possible development of hazardous conditions over several hours or days. It is important for operational decisions and emergency preparedness.

Immediate warning and nowcasting. Based on rapidly updated observations to identify dangerous changes and issue warnings within minutes or shorter periods where technically possible.

The appropriate forecasting period depends on the physical nature of the hazard. Drought may require long-term monitoring, while a rapidly developing industrial fire requires immediate detection and response.

The role of monitoring and digital technologies. Reliable forecasting is impossible without sufficient information about the current condition of the environment or technical system.

Monitoring is therefore one of the main foundations of emergency forecasting. It involves systematic observation, measurement, recording, and analysis of parameters that may indicate the development of a hazardous process.

Modern monitoring systems use several technological solutions.

Sensor networks. Sensors can measure temperature, humidity, pressure, vibration, gas concentration, water level, and ground movement. Their readings provide information about changes in the monitored environment.

Remote sensing. Satellite images and aerial observations allow specialists to study large territories, identify changes in vegetation, monitor water bodies, and observe surface deformation.

Geographic information systems. GIS technologies combine information about terrain, infrastructure, population, environmental conditions, and hazard locations. They help identify areas exposed to possible emergency impacts.

Internet of Things. IoT systems connect sensors and monitoring devices through communication networks. Information can be transmitted to central monitoring platforms for continuous analysis.

Unmanned aerial vehicles. Drones can be used to observe areas that are difficult or dangerous for people to access. They are particularly useful for inspecting damaged infrastructure, monitoring fires, and assessing the consequences of floods and landslides.

The main advantage of these technologies is their ability to provide more complete and frequently updated information. However, their practical value depends on reliable communication, regular maintenance, accurate measurements, and proper interpretation of the collected data.

Development of integrated early warning systems. Forecasting produces practical results only when its information is communicated to the people and organizations responsible for taking action.

An early warning system is not simply a device that detects danger or sends a notification. It is an integrated arrangement of risk assessment, monitoring, forecasting, communication, and preparedness.

International approaches commonly identify four interconnected components.

First component: Knowledge of disaster risk.

This includes information about the types of hazards, their possible locations, historical frequency, exposed population, infrastructure, and vulnerable groups.

Without understanding the actual risk, it is difficult to determine which parameters should be monitored and where warning systems should be installed.

Second component: Detection, monitoring, analysis, and forecasting.

This component includes observation stations, sensors, satellite information, mathematical models, and forecasting procedures.

Its purpose is to detect changes in hazardous conditions and estimate their possible development.

Third component: Warning communication and dissemination.

Forecasting information must reach the relevant population and responsible organizations in a timely and understandable form.

Warnings may be distributed through mobile communication, sirens, radio, television, internet platforms, and official emergency communication channels.

The warning should explain the type of danger, the potentially affected area, the expected time, and the recommended actions.

Fourth component: Preparedness and response capability.

People and organizations must know how to respond to warnings. This requires evacuation plans, emergency training, rescue resources, protective equipment, and regular exercises.

The absence of this component may significantly reduce the effectiveness of an otherwise technically advanced forecasting system.

Integrated approach to forecasting the development of emergency situations

Based on the analysis, forecasting can be organized as a continuous process consisting of interconnected stages.

Stage 1. Identification of hazards. Potential natural and technological hazards are identified for a specific territory, industrial facility, or infrastructure system.

Stage 2. Collection of initial information. Historical records, environmental observations, technical data, maps, and information about exposed population groups are collected.

Stage 3. Assessment of current conditions. The current state of the environment or technical system is compared with normal operating or environmental conditions.

Stage 4. Selection of forecasting methods. The forecasting method is selected according to the type of hazard, available data, required accuracy, and forecasting period.

Stage 5. Development of possible scenarios. Several possible scenarios are prepared, including normal, adverse, and severe conditions.

Stage 6. Estimation of potential consequences. The possible effects on people, buildings, infrastructure, economic activities, and the environment are assessed.

Stage 7. Preparation of warnings and preventive measures.

If the estimated risk reaches a level requiring action, responsible organizations prepare appropriate warnings and preventive measures.

Stage 8. Continuous updating of forecasts. New observations are used to update the forecast and evaluate whether the hazardous situation is becoming more or less severe.

This approach demonstrates that forecasting should not be regarded as a single calculation performed once. It is a continuous process that changes as new information becomes available.

Discussion. The analysis shows that forecasting the development of emergency situations requires an integrated scientific approach. No single method can provide equally reliable results for all types of natural and technological hazards.

Statistical methods are useful for analysing historical patterns and identifying recurring conditions. Mathematical and physical models help explain how hazardous processes develop. Scenario-based methods allow specialists to compare possible outcomes under different conditions. Monitoring technologies provide current information, while artificial intelligence can support the analysis of complex datasets.

The choice of method must therefore be based on the characteristics of the specific emergency.

For example, flood forecasting requires meteorological and hydrological information, while industrial accident forecasting depends on equipment parameters, technological conditions, and the properties of hazardous substances. Earthquake risk assessment requires geological and seismic information, although the exact time and magnitude of an individual earthquake cannot currently be predicted reliably.

An important scientific issue is the difference between forecasting a hazard and forecasting its consequences. Predicting that heavy rainfall will occur does not automatically determine which settlements will be flooded. The final impact depends on the condition of rivers, drainage systems, terrain, protective structures, population distribution, and local preparedness.

Consequently, modern forecasting should increasingly focus on impact-based information. This means that forecasts should explain not only what hazardous event may occur but also what the event could mean for people, infrastructure, and economic activities.

Another important issue is uncertainty. Every forecast is based on available information and assumptions. Even well-developed models cannot eliminate all uncertainty because natural and technological systems are influenced by many changing factors.

For this reason, forecasting results should be presented with appropriate levels of confidence and clear explanations of possible limitations. Decision-makers should understand that a forecast is a scientific estimate, not an absolute guarantee of a future event.

The use of artificial intelligence also requires careful consideration. Machine learning can improve the processing of information, but its effectiveness depends on the quality and representativeness of the data. It is particularly important to test models using independent observations and evaluate their performance in real operating conditions.

For Uzbekistan, these scientific and technological approaches are relevant to the forecasting of floods, mudflows, landslides, droughts, extreme temperatures, fires, and industrial accidents. The country's geographical and climatic conditions require attention to both natural hazards and risks associated with industrial development and infrastructure.

The development of integrated monitoring and forecasting systems should therefore include the following priorities:

- Improvement of the quality and accessibility of monitoring information.
- Integration of meteorological, hydrological, geological, and industrial safety data.
- Development of digital risk maps for vulnerable territories.
- Application of scientifically validated mathematical and forecasting models.
- Improvement of communication between responsible institutions.
- Training of specialists in modern forecasting and risk assessment methods.
- Regular testing of warning systems and emergency response plans.

The practical significance of forecasting is determined not by the number of technologies used but by whether the information helps prevent casualties, reduce damage, and improve preparedness.

Conclusion. Forecasting the development of emergency situations is an essential scientific and practical direction in modern safety management. It makes it possible to identify dangerous changes,

estimate possible emergency scenarios, and prepare preventive measures before serious consequences occur.

The study establishes that emergency forecasting should include not only the identification of potential hazards but also the analysis of their development mechanisms, influencing factors, affected territories, and possible consequences for the population and infrastructure.

Statistical analysis, mathematical modelling, scenario-based forecasting, expert assessment, and artificial intelligence provide different but complementary opportunities for studying hazardous processes. Their effectiveness depends on the correct selection of methods and the availability of reliable information.

Monitoring technologies, including sensors, satellite observations, geographic information systems, and IoT platforms, improve the continuous collection of information. These technologies make it possible to detect abnormal changes and provide data for updating forecasts.

Artificial intelligence can strengthen forecasting by identifying complex relationships in large datasets. However, it should be considered a supporting technology rather than a replacement for scientific assessment, professional experience, and established emergency management procedures.

The analysis also demonstrates that forecasting and early warning must operate as a unified system. Information about an approaching hazard becomes practically valuable only when it reaches the relevant people and organizations and leads to timely preventive action.

In this regard, the following conclusions can be formulated:

- The development of emergency situations is influenced by multiple natural, technological, environmental, and human-related factors. Their interaction must be considered during forecasting.
- The reliability of forecasting depends on the quality of initial data, the scientific validity of the selected model, and the continuous updating of monitoring information.
- Different types of emergencies require different forecasting methods. A universal model cannot fully describe all hazardous processes.
- Mathematical modelling and scenario analysis provide opportunities to estimate the possible intensity, duration, spatial development, and consequences of emergencies.
- The integration of monitoring technologies, geographic information systems, remote sensing, and artificial intelligence can improve the speed and quality of forecasting.
- Forecasting results should be connected with early warning, emergency preparedness, evacuation planning, and preventive safety measures.
- Further development of integrated forecasting systems in Uzbekistan can contribute to reducing disaster risks, protecting human life, and improving the safety of industrial facilities and vulnerable territories.

In conclusion, forecasting the development of emergency situations should be considered not merely as a technical procedure but as an important element of a comprehensive safety management system. Its main purpose is to transform scientific information into timely preventive decisions and practical actions that reduce the likelihood of human casualties and material losses.

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