Regional Security: Analysis of the Emergency Management Effectiveness Based on the Scenario Approach

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Abstract. The paper analyses the effectiveness of the scenario analysis and modeling methods for solving the planning and operational control problems of in the processes of prevention and elimination of the causes and effects of man-made disasters, industrial catastrophes and emergencies. The scenario approach belongs to a class of object-oriented methods used to represent information about the state of a plant and an environment, which is necessary to generate control actions for the rescue measures and activities, as well as disaster management. The main feature discussed in this paper is a class of industrial safety management tasks based on the scenario approach which have to be developed as well as the general normative framework that allows to fundamentally change the approach to building models of an emergency. The research shows that in this case the procedure of forming the base model using a comprehensive analysis of existing technical regulations, norms and standards were quite effective. The results of modeling and scenario analysis of the processes, elimination of technological accidents consequences on transport infrastructure of metropolises are presented in the paper.

Key words: management, scenario analysis, man-made disaster, emergency, simulation, signed graphs.

1. INTRODUCTION

In the last decades, the world has witnessed a stable trend of substantial growth of material losses as a result of industrial catastrophes, emergencies and natural disasters. One of the main reasons for this, apart from global climate changes accelerating in the coming century and the saliently manifested synergetic nature of many industrial catastrophes, is the lack of willingness of warning management systems to the prompt, adequate and effective response to such events.

The main peculiarities of functioning of management processes in conditions of industrial disasters consist in the fact that an emergency (disaster) arises and develops suddenly and unexpectedly. Since its appearance in the management system poses the problems which essentially aren't inherent for the stationary mode of operation. Thus, that is especially important that the measures to counter the emergency development and elimination of its consequences should be taken without delay and been as efficient as possible. At the same time the fundamentally new problems arise in management systems, which have been complicated by the powerful stream of information that is required to examine and analyze promptly.

Analysis of management processes in emergency situations (ES) has allowed to identify a number of features compared to the daily activities mode. The most typical of them are given in the table 1 [1].

A management of prevention and dealing with consequences of technological disasters should cover the whole range of issues relating to emergencies, the most important of which are the stages of emergency forecasting, proactive planning and operational management of the liquidation of the causes and consequences of the emergency under high uncertainty.

The research is focused on the effectiveness of different methods for scenario analysis and modeling in the planning and operational management measures to prevent and eliminate causes and consequences of man-made disasters and emergencies.

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Table 1. Comparative characteristics of management systems

Daily activity mode	Management in emergency situations
Permanent mode of operation	Different operating modes
Strict structure and clear allocation of functions for a long period	The lack of a strict structure and a clear allocation of functions for a long period, flexibility, aggressiveness
The narrow functional focus	Broad and partially unpredictable scope
Monostructure	Polystructure
Regulated information flows	The dependence of the information flows on the current situation
Accurate information	Uncertain information
Redundant information	Insufficient information
The low rate of change	A high rate of change
Unpredictability of the situations	Unpredictability of the situations; orientation on past experience usually does not make sense
The principle of unity of powers and responsibilities	Combination of the principles of unity of command and the distribution of powers and responsibilities
Functional potential	Organizational capacity
The predominance of mostly socio-economic objectives and performance criteria	The objectives – efficiency and effectiveness in liquidation the causes of emergencies and their consequences; Criteria - minimizing the time to achieve the objectives, a minimum loss (victims) in liquidation of emergencies

2. PLANNING OF PREVENTION AND LIQUIDATION THE CAUSES AND CONSEQUENCES OF MANMADE DISASTERS AND EMERGENCIES

Unlike traditional planning and control systems [2], which are intended to solve strategic tasks for a long time period, the control system in emergency should operate in real time. Strategic tasks should be solved in a limited time interval promptly and continuously. In practice this also means periodic adjustment of the list of key strategic tasks and continuous monitoring of new emergency events. Moreover, a control system in emergency situations must be ideologically focused on the need, the possibility and the ability to operate in extreme conditions and to adapt quickly to changing conditions. The most important task of the control system under these conditions is not only operational, but also long-term planning for prevention and elimination of consequences of emergency situations on the transport infrastructure of urban agglomerations.

The principal features of the planning and management processes of eliminating the consequences of manmade disasters and emergencies are:

(1) partial predictability of serious problems and possibilities of their solution;
(2) partial predictability of places of appearance and development of emergencies;
(3) low predictability of the scale and the time of a disaster;
(4) unpredictability of adverse events and situations arising from the emergence and development of emergencies, i.e. availability of strategic surprises.

These conditions dictate the need for pre-emptive use of planning and management methods, based on anticipation of problems, situations and events, making flexible emergency solutions, oriented to the external system environment (natural environment, living conditions of population and staff of enterprises and organizations, socio-political situation etc.). Such methods can be effectively implemented in the unified modern concept of strategic and tactical planning and operational management.

Full planning and control cycle of risk of industrial catastrophes and emergencies, as well as the liquidation of their consequences include:

- forecast risk and severity of the consequences of emergency situation by generating scenarios;

- forming objectives and risk management criteria;
- strategic (long-term) planning of preventive measures;
- tactical (current) planning of alternative response to the emerging threat of disaster;
- strategic and operational management in emergency situations.

The risk of occurrence and development of ES of natural and industrial type is forecasted on the basis of constructed scenarios of these situations.

The concept of the scenario approach in control theory is to some degree new, though now has been used widely, especially in the analysis of strategic decisions in organizational management [3]. During the study of management processes the scenario of prevention of ES and liquidation the consequences of industrial catastrophes can be considered as a tool for formal analysis of alternative variants of ES development on a control object for the given objectives and criteria under conditions of uncertainty, when it is impossible to directly form a specific and detailed plan of measures on liquidation of ES consequences under the existing time constraints.

At its core, the scenario approach belongs to a class of object - oriented methods of presenting information on control object's state and environment, which is necessary to generate control actions for rescue measures and activities, as well as disaster management. In other words, the main task to be solved in terms of the scenario approach is to form the necessary data for preparation and making effective strategic and operational decisions, as well as a comprehensive analysis of the consequences of these decisions' implementation in a variety of conditions. Thus, a scenario of a problem situation development is needed as an intermediary between the stage of goal setting and the stage of formation and implementation of specific management decisions aimed at achieving the objectives for the prevention and liquidation of ES consequences.

In its content, a scenario of a plant's behaviour is a model of changes, which is related to appearance and development of an ES and is determined in discrete time with a given step.

The scenarios as a tool for management of complex systems belong to a class of so-called partial mathematical models, i.e. such models which include only the essential factors that can be formalized with an acceptable degree of accuracy.
The main application of such models is a class of tasks that can be reduced to finding both optimistic and pessimistic assessments of key quantitative and qualitative parameters of the objects and the processes when a particular set of management decisions is implemented.

In general, the scenario construction task may be stated as follows: a complex, dynamic, open, controlled, not fully observable system is given. Describe the possible ways of change in several alternative directions thus to provide the most complete picture of the possible future states and paths of the studied system development.
The process of scenario construction of industrial catastrophes and emergencies includes the following main stages [3].

(1) The possible moment of emergency and / or its consequences on the interval $[0, T]$ is divided into discrete times t_i with steps τ_i. The period T describes the time during which the damage is liquidated and the emergency stops its further development, depending on the scale of the damage and the disaster. Time instances correspond to control points of the ES development when control actions aimed to improve the situation are implemented. The step in a scenario is determined on the basis of the condition of effective using of forces and means, as well as the preparation of the necessary resources for countermeasures to the development of emergency.

(2) Formation of the initial conditions ($t = 0$) and the conditions under which emergency occurs and develops and the evaluation of losses (damage). On this stage the development of ES is simulated and the possible conditions of its course are described on the basis of initial and observed data. Concretize targets of countering, assess their effectiveness, determine limitations on the course and consequences of emergency situations as well as resources support. Define pessimistic preliminary assessment of

losses and damage of the disaster. Develop measures to counter the emergency in different variants of its development.

(3) Organization and putting into operation forces and means necessary to eliminate causes and consequences of emergencies, rescue and other urgent works in industrial catastrophes, depending on scale, character and amount of damage. It describes the process of mobilization and deployment of forces and resources, providing materials and food, emergency medical care, including the preparation for the reception of additional operational units, vehicles of all types, hospitals deployment points for the rehabilitation of victims, etc. Thus, at this stage briefly all the activities and resources are described as well as the forces and means necessary for an effective response to emergency situations.

(4) Formation of the current situation (at the time t_i) and the conditions of emergency situations, as well as the adjustment of the expected damage assessment, i.e. at this stage the current range of activities is described (similar to p.2). The situation and the most important indicators obtained at the time t_{i-1} are taken as initial conditions. Further the measures considering new conditions prevailing at a given moment are described. This process has to be described until the complete liquidation of the ES.

(5) Verify the completeness and reality of the obtained scenario and its correction for maximum adequacy to the real development of the ES. Scenario is checked by experts and is included into education and training.

(6) Formation for a given scenario of the actions course and operational plans for countering an ES. Based on the developed scenario a course of actions is being defined (a graph of goals and tasks with logic ‘AND’), preventive and operational action plans to reduce risk and damage in the form of many types of documents and descriptions (at the time t_i) which are distributed across the entire organizational structure for the execution. Thus, based on a scenario the general objective of the operation is formed, providing creation of the desired situation in the future. The formulated general objective is represented in the hierarchy of goals and called course of actions. Course of actions is a graph of goals and tasks, formed as a result of the decision-making on a complete graph of alternatives. There are two ways to form general objectives with the appropriate hierarchy of goals and tasks, and therefore two ways to form a course of action: from all the alternative scenarios the most probable one is selected and the general goal and the course of actions are produced in accordance with it; for each alternative scenario its own general goal is built with its hierarchy of goals and tasks (the variant planning). However, in all cases for each scenario several alternative general goals and courses of actions are considered.

A scenario formed this way allows to reflect the development of emergencies, develop a strategy of the organization and implementation of preventive and operational measures against emergencies, create strategic and tactical plans of actions to carry out a qualitative analysis of the impact, as well as to forecast data on the estimated losses and damage.

3. USAGE OF SCENARIO ANALYSIS IN MANAGEMENT OF PREVENTION AND LIQUIDATION OF EMERGENCIES

The basic feature of use the scenario approach in the planning and management of the prevention and liquidation of consequences of man-made emergencies is the need to expand its capabilities to conduct advanced comprehensive analysis of the current situation.

One of the most important features of man-made emergencies, as a research domain, is the sufficiently powerful normative base. Its development and improvement are continuously expanding over a number of areas, such as industry, transport, fire, radiation, chemicals, energy, environmental, social, public safety, security of life activity, certification of potentially dangerous objects, medicine disaster etc. It allows to improve efficiency of the scenario analysis methodology in the management of the liquidation of consequences of emergency situations and to change traditional methodology and technology of research of the simulation models.

At present the functional approach is widely used to study the problems of increasing efficiency of socio-economic systems. To study, for example, one or a few ‘close’ control functions is often not effective enough for solving the control tasks for the liquidation of consequences of man-made ES. The main reason for this is the need for a broader, comprehensive analysis of the situation and taking into account the synergistic nature of adverse processes and phenomena, which significantly expands the boundaries of the study subject area and thus reduces the efficiency of the traditional approach.

Using the functional approach in these conditions creates objective difficulties for combining expert knowledge in various subject areas into a unified picture. This doesn't allow to carry out a comprehensive analysis of states and tendencies of the situation development. This is caused by the difference of professional languages (terminology) of experts, contradictory procedures and discrepancy of expert assessments of the results, as well the lack of common tools and mechanisms for pooling expertise. This leads to great time required to collect basic data and expert assessments under sufficiently rigid restrictions on the time of decision making.

In addition, the traditional approach focuses on expert assessment of the current situation on a plant. This results in that a simulation model or at least its methodology basis is used. In this case, substantial expansion of domain area for a comprehensive analysis of the situation leads to difficulties with the assessment of the model’s adequacy, as well as with the validity of its borders and the level of detail.

The presence of a general and developed normative base allows to fundamentally change the approach to formation of ES patterns. It is more effective to form a basic model analyzing existing procedures and regulations, and further modify by the use of detailed information about the object’s specifics and the operational information about the development of the situation. This approach provides several quite apparent advantages:

(7) The use of technical regulations and norms as an information base can significantly improve the adequacy of the developed multi-factor model, since it is based on reliable data about the object of research. The quality of such model is guaranteed by multiple checks in the development, coordination and approval of technical regulations and norms.

(8) Efficiency of diagnosis of sources of vulnerability in the control object is increased for different kinds of threats, as well as accuracy of risk assessment. The risk is characterized by a relatively low probability of ES occurrence and by catastrophic consequences when it is realized.

(9) The complexity of model development is substantially reduced, because it is done on the agreed and (at least partially) formalized documents that contain extensive, reliable and, most importantly, relevant information for the research scenario.

(10) There are almost no serious problems of coordination and integration of expertise in the development of the base model, because, in fact, the most complex procedures of this type have been conducted in the development of regulations and their results can be directly used in developing of the model.

(11) Time spent on diagnosis and detailed analysis in the development of multi-factor model is reduced substantially, because the procedures of expert assessments, needed in the description of domain, carried out not on the full range of problems, and serve only to clarify the necessary details or analysis of emerging unexpected circumstances in the development of the situation.

(12) Using of normative base with a high level of detail gives possibility to conduct a study of a simulation model based on quantitative assessments and absolute scales. A simulation model allows to conduct experiments in real time and provides (1) increase of the validity of the generated scenarios of situation development, (2) precision of forecasts, formed on their basis, (3) as well as reliability of the evaluation of the effectiveness of management decisions.

(13) The most complex procedure of modification of a model is considerably simplified. It refers to an expansion and covering of adjacent domains and also allows to obtain complex strategic decisions, taking into account synergies in the development of ES.
(14) Using a normative base allows to simplify solutions of many technological problems of scenario study for complex systems, associated with the laborious procedures of operative change of the models of a managed object in a limited time, taking into account the dynamics of change of key factors and parameters, as well as their relationships.
(15) At last, perhaps the most important advantage of the widespread use of a normative base in the course of the scenario study is the possibility of an integrated approach to a solution of management tasks of prevention and liquidation of consequences of ES, allowing at the same time to consider the related but different in nature phenomena and processes. This allows effectively integrate in a single model the factors and threats of terrorism, as well as fire, radiation, chemical, energy and environmental security.

4. SCENARIO ANALYSIS OF SAFETY UNDERGROUND STATION IN AN EMERGENCY SITUATION

Let us consider the task of scenario analysis of safety for potentially dangerous objects of urban transport infrastructure. The solution of this task is necessary in the process of planning and decision making on the prevention and liquidation of the causes and consequences of possible ES.

Here we must briefly recall the main principles and approaches to the design and study of models of the situation development, which provide the implementation of management decisions [3-5].

The process of modeling and synthesis of alternative scenarios of the situation development is carried out using the apparatus of functional signed graphs. The mathematical model of these graphs is an extension of the classical models of oriented digraphs. In addition, the model of digraph G (X, E), where the X – a finite set of vertices, and E – a set of arcs of the graph includes additional components. So, each vertex of the graph has the parameters $V = \left\{ v_i, i \le N = \|X\| \right\}$ and each arc of the graph has a sign, weight or functional transformation F (V, E).

As known, underground facilities of subways are the objects of high potential danger, that is related by a number of factors. The most important of them are:

- a large number of passengers served by the subway;
- high concentration of people inside trains, station premises and on inter-exchange transitions during peak hours;
- the possibility of panic and need of evacuation of large numbers of passengers;
- considerable depth of the tunnels and station facilities;
- a limited number of inclined tunnels and vertical shafts, coming to the surface;
- a large extent and a limited capacity of escape routes;
- difficult maintenance of smooth and safe evacuation of passengers from a train stopped inside a tunnel;
- presence of power grids under high voltage;
- high-speed of smoke pollution of tunnels and space stations, the complexity of reconnaissance and control of fires;
- the need for laying hose lines over long distances, taking into account the complexity of the layout and the availability of wagons;
- the impact of ventilation on gas exchange of fire;
- rapid increase in dangerous factors of fire values to a critical level;
- threat of deformation and loss of structural elements carrying capacity station etc.

In addition, metro stations and their environment are complex socio-technical systems, characterized by a significant amount of power, escalator, control-crossing, ventilation, climate, lighting and other kinds of process equipment; availability of premises of different categories for explosion and fire hazard, and fire resistance of load-bearing structures; a significant number of businesses for various purposes (kiosks, stalls, trade and promotional stands) to be placed in ground and underground hallways, in the transitions and on the platforms of underground stations, etc.

Consider the complex scenario models to predict the prevention planning and management, and liquidation of the causes and consequences of technological disasters and ES in the underground facilities. As an example, we will use a hypothetical ES initiated by a conventional explosion in a typical subway station of deep foundation, which Moscow has more than 70. This type of station is most typical for the Central Administrative District (CAD) of Moscow, which will be considered in the following model example. When constructing model the risk zone is limited to only outside of the station. To ensure generality of the model we also exclude from consideration peak hours of the metro, which represent the greatest danger from the point of view of the consequences of ES, as well as the busiest station and interchange nodes with the total daily load, considerably more than 50 million passengers (is known that the busiest station daily serves 100-150 thousand people). We assume that the number of people at the station at the time of a ES corresponds to its average occupancy and is about 800 people.

The designed simulation model consists of three parts:

(16) The security model of the station and the people;
(17) Model of the work of the Moscow City warning and ES liquidation system;
(18) Model of the power and means involved for liquidation of ES.

The model can be further expanded to include information about the route to the nearest metro station firehouse (FH). In particular, one can consider a situation related to difficulties in extension of the given FH due to the congestion of highways or other reasons. Also, data for the location of hospitals, in which the suffered people can come can additionally be used, as well as major socio-relevant and potentially dangerous objects, located near the considered metro station (if any).

4.1. The Security Model of Station and People

The model includes the following security issues:

(19) The safety of people;
(20) The safety of stay conditions;
(21) Mechanical safety;
(22) Fire safety.

If necessary, the number of security issues may be increased. Each of these aspects includes several related factors.

4.2. Model of the Work Stages of the Moscow City Warning and Liquidation of ES System (MCES).

The main stages of the simulated operation of the district-level MCES in the event of a ES in the subway stations are as follows.

(23) The first stage – the adoption of emergency measures:
- alerting the population;
- adoption of emergency measures to protect the public, victim assistance and localization of the accident;
- arrival of the operational group (OG) MCES;
- organization of a reconnaissance in the disaster zone;
- notification about ES and organization of an operational headquarter and the Commission on prevention and liquidation of ES and fire safety;
- clarification of tasks for MCES forces;
- alerting forces of MCES on the district level.

(24) The second stage – operational planning of emergency. Rescue and other urgent works:
- collection of information for the decision-making MCES;

- organization of work planning;
- organization of interaction between the involved forces.

(25) The third stage – liquidation of the ES:

- deployment of ES staff, organization of communication with the management bodies operating in the area of the emergency and the parent body;
- collection of executors and interacting of the management bodies deployed in the disaster area, clarifying the situation, the composition of forces, the action plan, the report for the elimination of ES;
- develop proposals of MCES for operational decisions;
- ensuring timely delivery of tasks to subordinates and interacting controls bodies;
- organization of information exchange about the situation, measures taken to interacting, neighboring authorities.

(26) The fourth stage – the implementation of measures on social protection and rehabilitation of areas affected by emergencies factors:

- complete deactivation, decontamination and disinfection facilities;
- repair of electrical, water, and gas utilities, communication lines, etc.

In addition to these activities in the first stage rescue and other urgent works are carried out (ASDNR), which include:

- search of victims, the evacuation of the focus of infection;
- conduct health suffered partial processing;
- delivery of the victims at the place of loading on ambulances;
- pre-hospital medical care, evacuation – transport sorting;
- delivery of the victims to special medical institutions;
- providing of skilled care.

The structure of the model takes into account that the activities of the individual steps are directly related to each other.

4.3. Model of Forces and Means Involved for Liquidation of Emergency Situations.

The list of factors is based on the information about the presence of forces and means of liquidation of ES, normative data about grouping MCES forces in 10 minutes after the disaster, and includes:

- technical services of subway;
- squad of the subway protection;
- operational groups of MCES;
- search and rescue team;
- police units of Internal Affairs (UVD) CAD;
- units of road – patrol UVD CAD;
- Public Joint Stock Company for Energy and Electrification of Moscow (Mosenergo);
- Joint Stock Company ‘Mosvodokanal’ (a company providing services in the sphere of water);
- supply and sanitation in the city of Moscow;
- Emergency gas service of Moscow (Mosgaz);
- forces of Emergency Medical Aid Center;
- forces of the specialized enterprises of fuel-energy sector of Moscow operation communication;
- collectors (Moskollektor);
- volunteer emergency rescue teams.

Additional factors in the model are the following peaks:

- activation of forces and means;
- arrival time of fire and rescue services;

- the number of people at the station.

The main arcs in the model are circular, which means a continuous activity of forces and means. If necessary, the model can be developed, replacing the factors of new structures (for example, drive factor and HRC can be replaced with a model fire fighting, etc.).

4.4. Joint Model of the Emergency Liquidation.

Topology of unified situational model, which is the unification of the previously discussed models, is shown in Figure 1. Consider baseline scenarios obtained by simulation of an emergency at the facility underground.

Scenario 1: 'The fire caused by an explosion and subsequent quenching'. At the first stage fire-fighting forces is done by underground workers (valid up to 20 steps). At first the human safety of the plant is growing. After 20 steps, gradually the all important characteristics become negative trend. Then, starting with the 100 steps of action of fire brigades and other forces alter the situation in a favorable direction (Figure 2).

Scenario 2: 'The spread of panic in liquidation of emergencies'. We consider the situation in which the occurrence of emergency situations and fire causes panic among the passengers in the station. Panic prevents the fire-rescue units and makes it difficult to search for survivors.
This situation corresponds to the following modification of the original model:

- increased weight feedback relationship 'Panic' **-->** 'Access *firefighters*' 10 times;
- addition of a new arc 'Access firefighters' **-->** (+1) **-->** 'Fire Propagation';
- increased weight feedback relationship 'Panic' **-->** 'Search *of victims*' twice.

Dynamics of the major factors is presented in Figure 3.

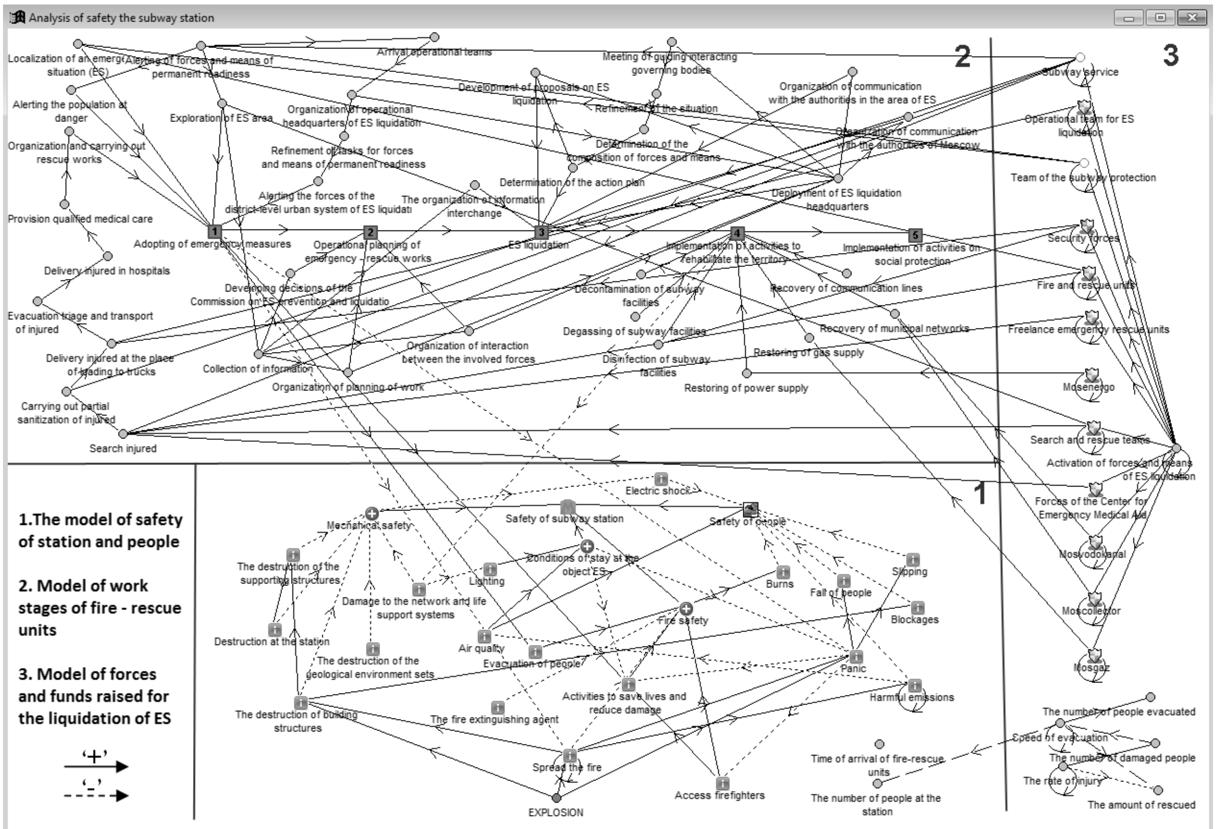

Fig.1. Joint model of the emergency liquidation

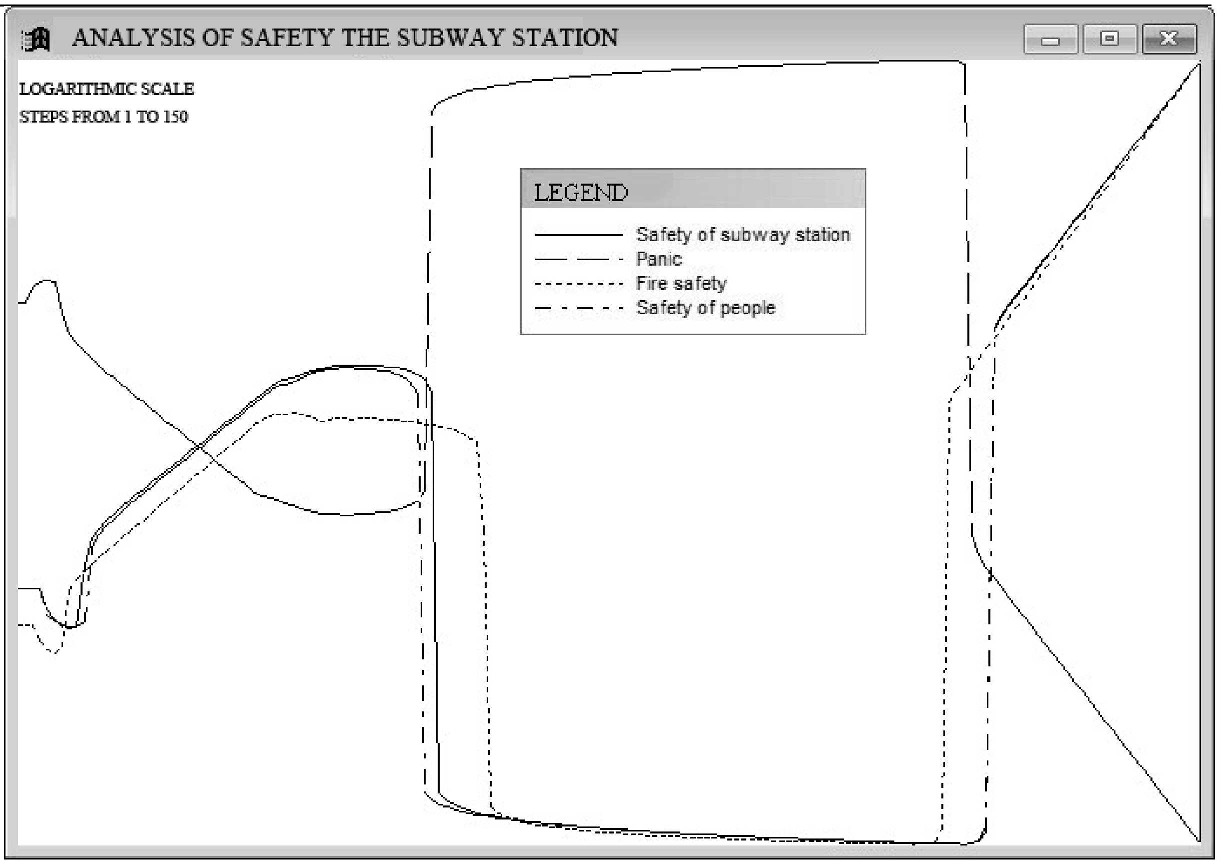

Fig.2. The fire caused by the explosion and subsequent quenching (scenario 1)

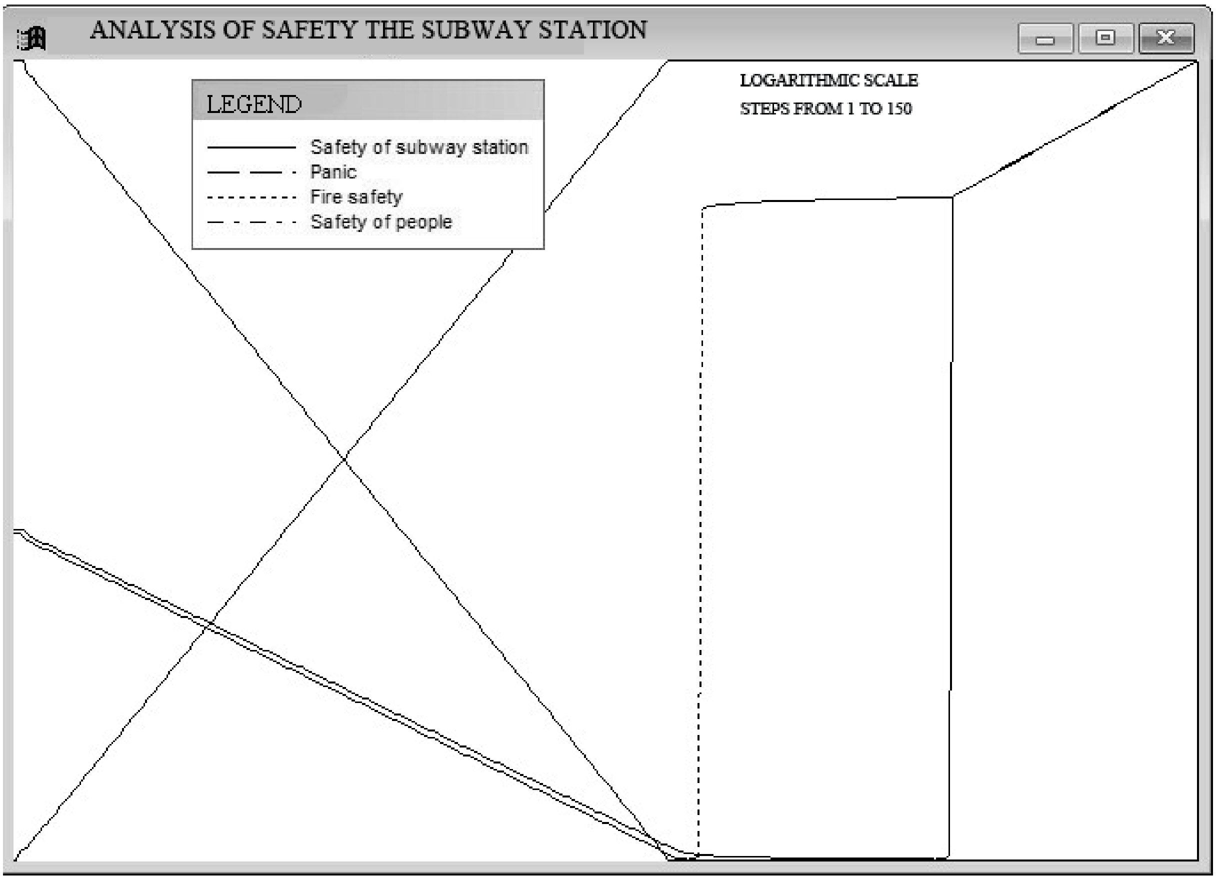

Fig.3. Spread of panic in liquidation of emergencies (scenario 2)

Initially, there is a decrease in the safety of people and station structures. Outbreaks of fire cannot be located and the fire spread process continues. Significant interference to the undertaken measures to extinguish the fire are the presence of people in the station, and not to reduce panic. A further negative development of the situation can lead to the appearance of the victims of the man-made disaster. Over time, due to held fire-rescue actions the fire safety factor first stabilized. It reduces the risk of destruction of bearing structures of plant facilities while reducing the spread of fire intensity. Accelerate the arrival of additional fire-rescue services accelerates the growth of the security of stations (in terms of the developed model), however, that is especially important, given the operational situation is after the onset of the fire victims.

Scenario 3: 'Efficiency of the actions the fire-rescue service on liquidation of emergency'. Under this scenario, the variant of the situation, in which the strong and well-coordinated actions of rescuers help reduce the panic, that is reflected in the following modification of the model:

- added a negative relationship 'The effectiveness of the fire and rescue services' --> 'Panic';
- added a nonlinear relationship 'Panic' --> 'The efficiency of the fire and rescue services' (link is positive if there is the panic growth and negative otherwise).

The simulation results are presented in Figure 4. As seen from represented in Figure 4 graphics dependencies, shortly after the arrival of the additional fire and rescue services the panic reduced. This increases the efficiency of fire suppression and leads to subsequent growth of human safety.

Scenario 4: 'Modeling of losses during working escalators'. The aim of this scenario is an analysis of the casualties among the passengers of the station as a result of a disaster. The basis for the building a model are the characteristics of the underground station. Carry out temporary normalization of modeling steps as follows: 100 steps = 10 minutes, that is 1 step = 6 sec. Accordingly, the fire and rescue services come into place on the emergency regulations in 10 minutes, i.e. after 100 steps.

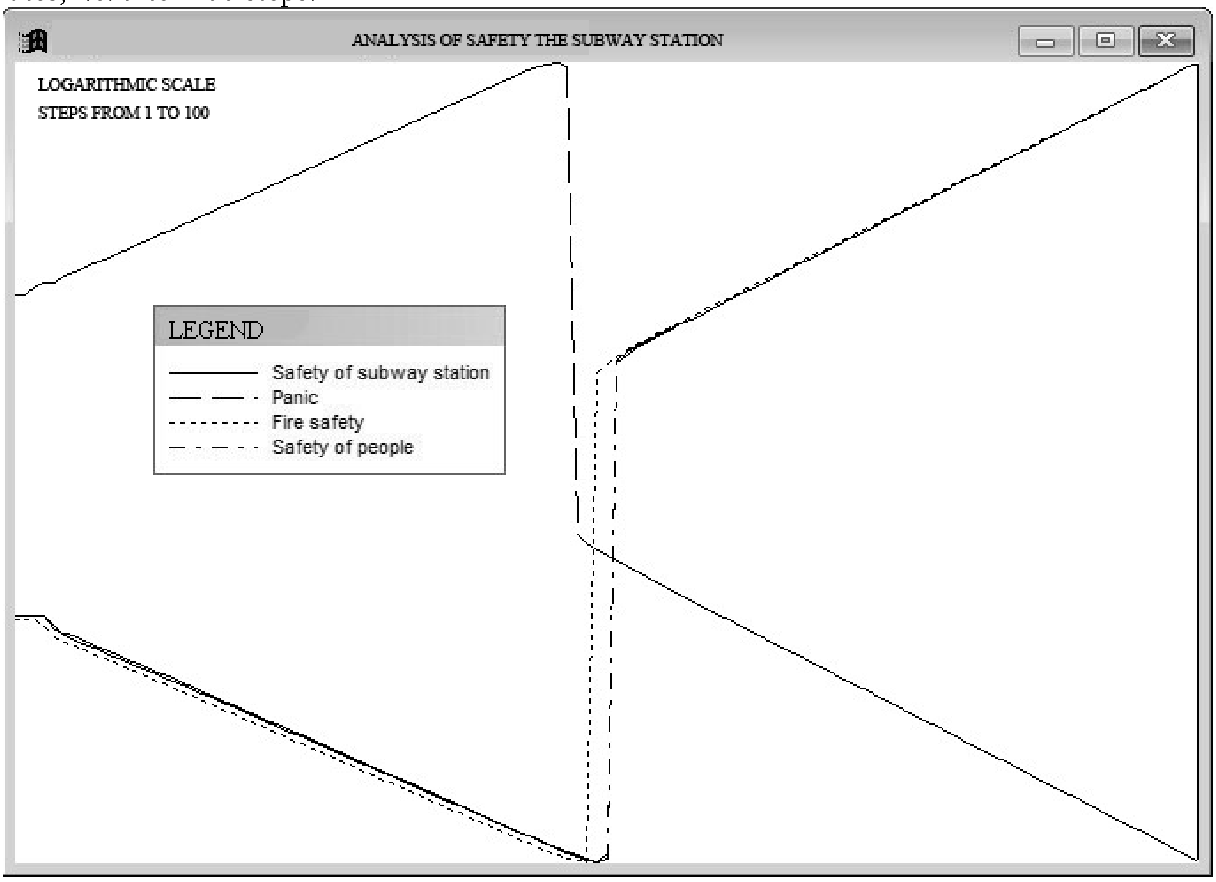

Fig.4. Efficiency actions the fire - rescue services on liquidation of emergencies (scenario 3)

The activity of metro services unit for the protection of underground rescue people is 20 steps = 2 min. In the period from 20 to 100 steps (4.8 min.) the assistance in rescuing on their own is limited. As before, it is assumed that metro stations are around 800 people. This corresponds to an average workload of the station. Assume that the escalators on all saving time is not damaged, and the only way to save. The speed of the escalator is the motion on the rise – 3.0 thousand people / hour. Thus, the rate of evacuation is 5 people / sec. It should also be noted that the speed of evacuation decreases with a decrease in the safety of people. Moreover, the evacuation of injured people is slower than healthy people. The evacuation of everyone injured takes twice more time. Every 6 sec. (Step 1) add one injured.

Under these initial conditions the following modification of the model is conducted:

(27) New factors are added:

- ‘The number of people at the metro station’,
- ‘Evacuation speed’,
- ‘The rate of destruction of people’,
- ‘The number of evacuees’,
- ‘The number of injured’,
- ‘The number of rescued without injuries’.

(28) New relationships are added:

- ‘Evacuation speed’ --> (-1) --> ‘Number of people at the station’,
- ‘Evacuation speed’ --> (+1) --> ‘Number of evacuees’,
- ‘Evacuation speed’ --> (+1) --> ‘Number of rescued without injuries’,
- ‘Destruction speed’ --> (+1) --> ‘Number of affected’,
- ‘Destruction speed’ --> (-1) --> ‘Number of rescued without injuries’,
- ‘The rate of evacuation’ --> (5, if the safety of the people is increasing 2 or otherwise) --> ‘Evacuation speed’ (circular arc).

(29) The conditions of factors activity:

- ‘Evacuation speed’ is active, if the number of people at the station is greater than zero,
- ‘Destruction speed’ is active, if the number of people at the station is greater than zero.

(30) Initial impulses:

- --> ‘Evacuation rate’ +1;
- --> ‘Destruction speed’ +1.

The simulation results are presented in Figure 5 (qualitative results) and Figure 6 (quantitative results). The simulation results show that as a result of works on ES liquidation 800 people are evacuated, 271 is injured (get damaged), and 529 people escaped without injury.

Scenario 5: ‘Modeling of losses during non-working escalator’. The modification of the previous model: the speed of evacuation is 3 person / sec. The rate of evacuation of injured persons 2 / sec. evacuation speed cannot be negative. Qualitative and quantitative simulation results are shown in Figure 7 and Figure 8, respectively.

As a result of work on ES liquidation on the results of the simulation of the 800 evacuated people were injured 447 people, 353 people escaped without injury. The results were almost twice as bad. Furthermore, the evacuation time increased to 12 minutes.

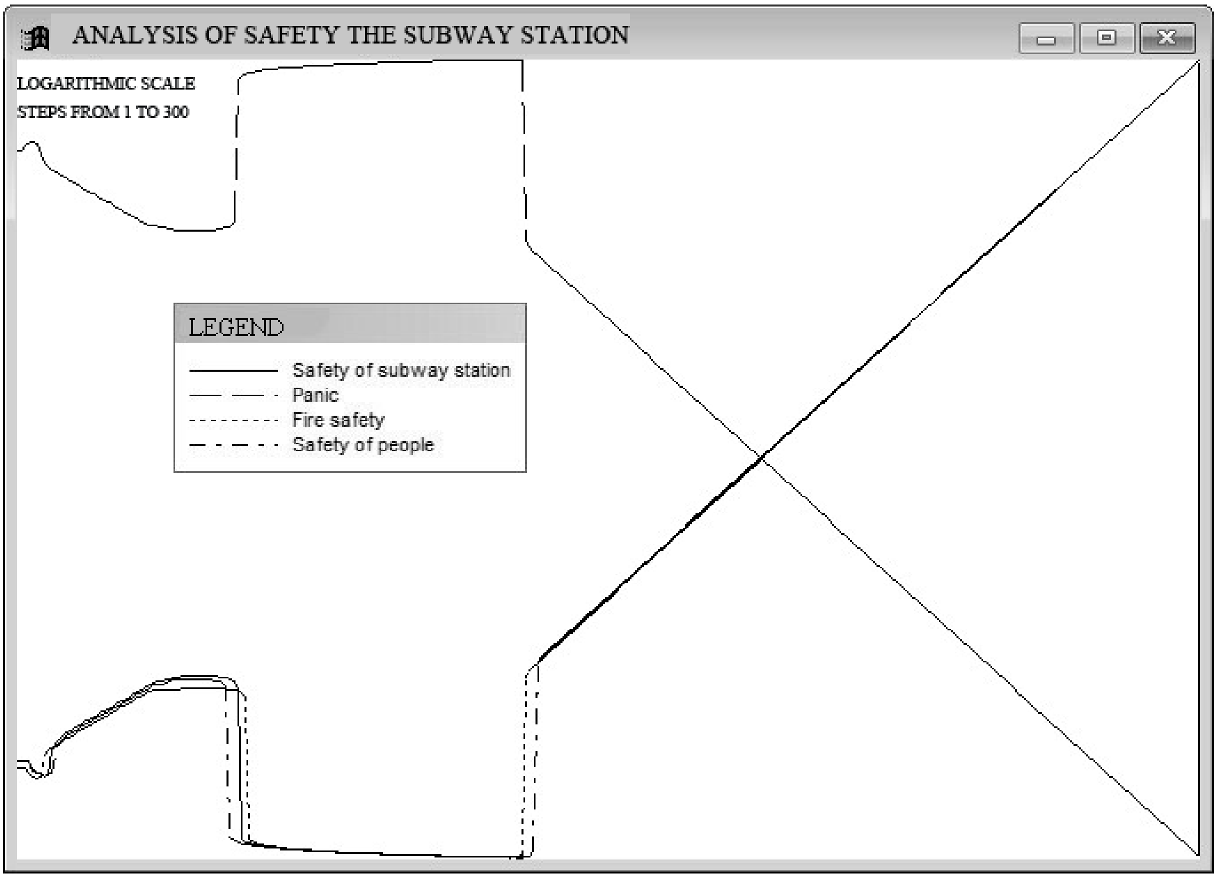

Fig.5. Modeling of losses during working escalators (scenario 4, the qualitative results)

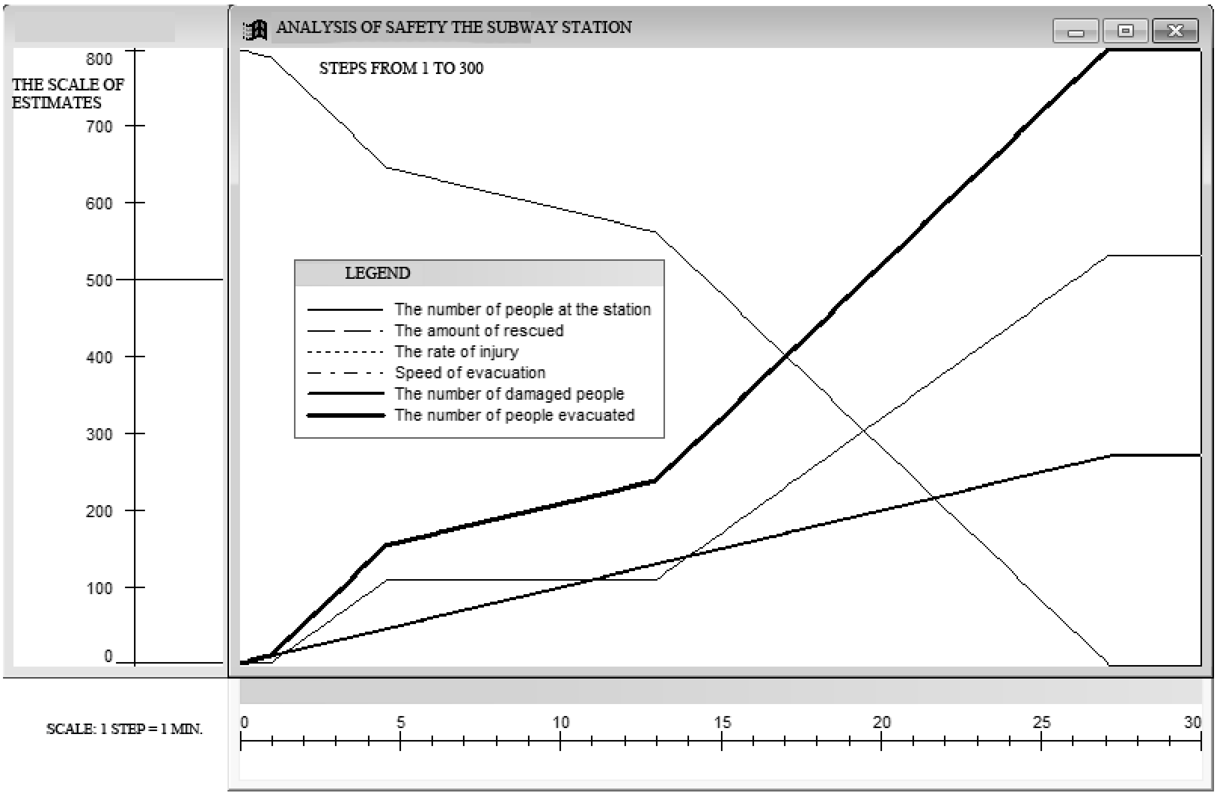

Fig.6. Modeling of losses during working escalators (scenario 4, the quantitative results)

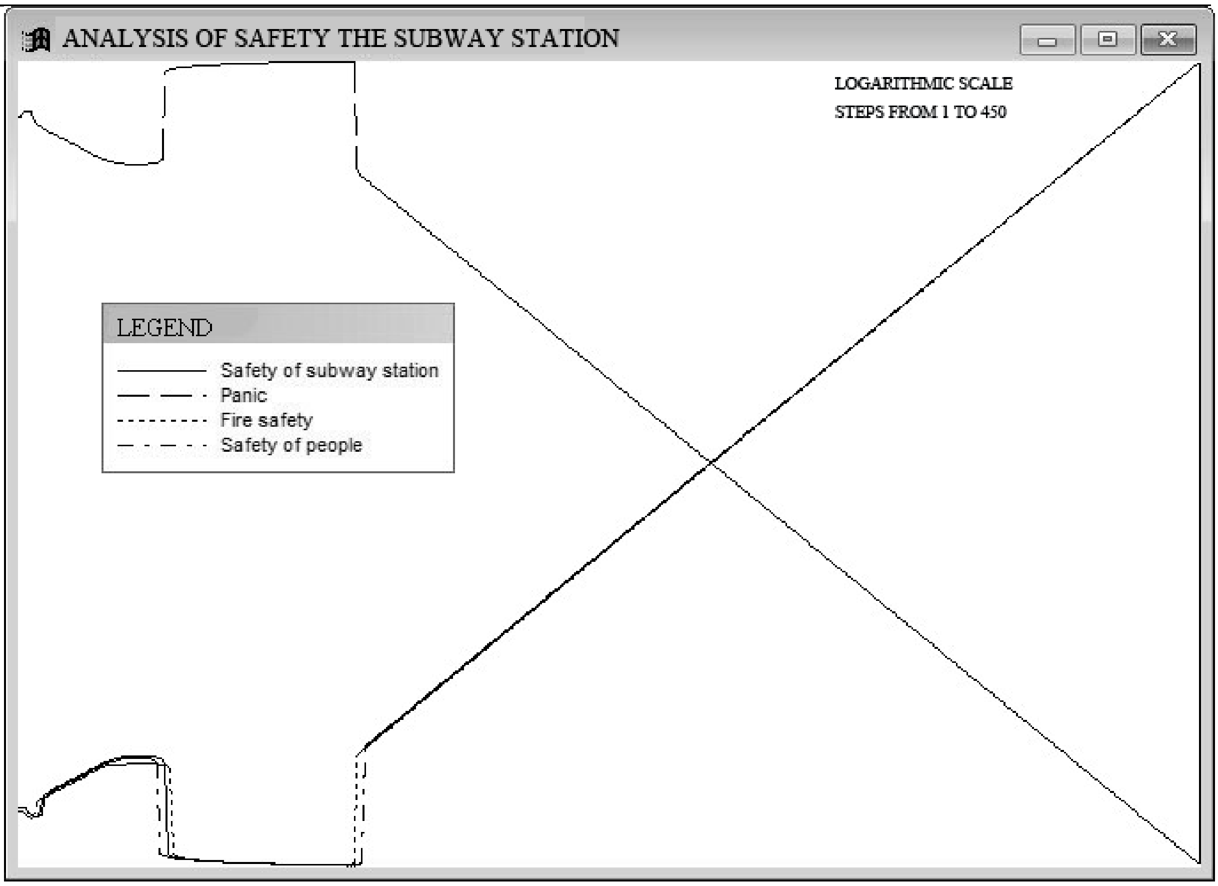

Fig.7. Simulation of losses during nonworking escalators (scenario 5, the qualitative results)

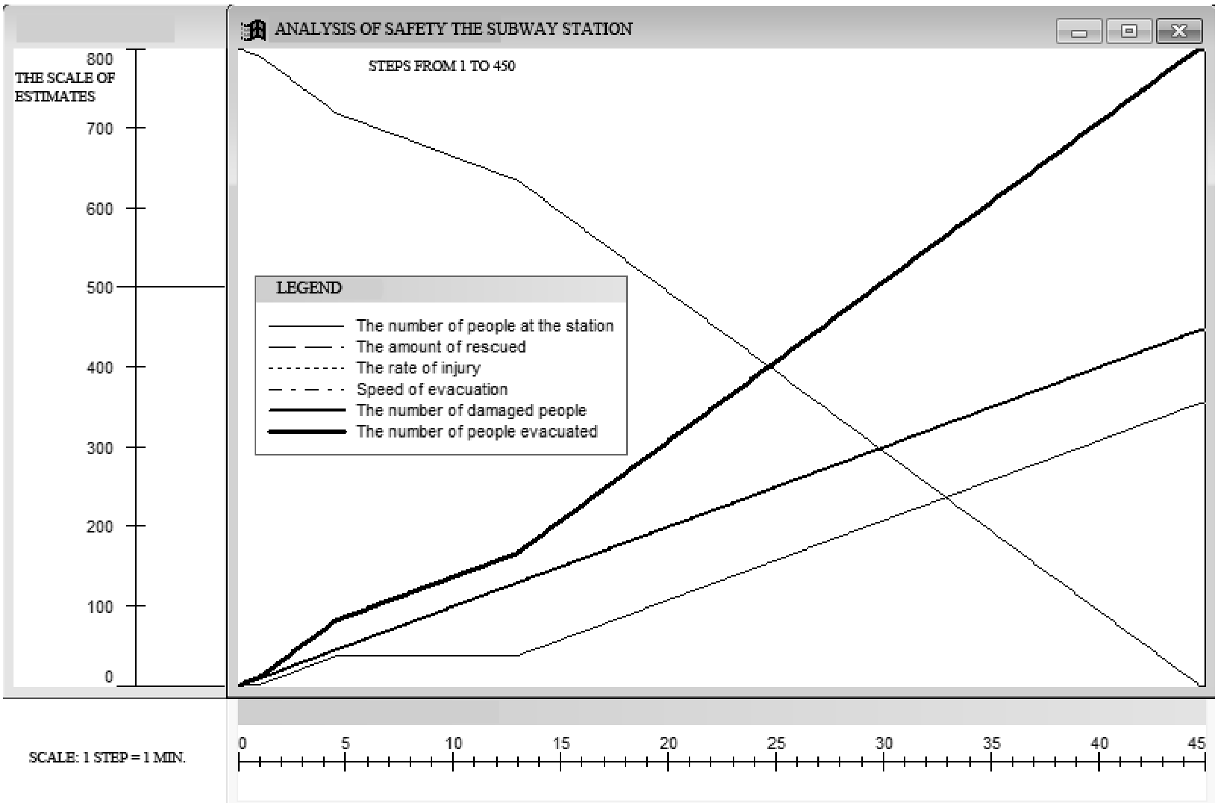

Fig.8. Modeling of losses during nonworking escalators (scenario 5, the quantitative results)

5. CONCLUSIONS

The main feature discussed in this paper, a class of industrial safety management tasks based on the scenario approach is to have developed and the general normative framework that allows to fundamentally change the approach to building models of emergency. Studies have shown that in this case the procedure of forming the base model using a comprehensive analysis of existing rules and norms were quite effective. In the second stage – modifications of the model taking into account the detailed information about the specifics of the object of study and the incoming operational information about the nature of the emergency. Using the normative base in the process of forming the simulation model allowed in the generation of alternative scenarios of situation development to base not only on qualitative but also on quantitative indices. This improves the accuracy and reliability of the scenario analysis results, and the quality and efficiency of decisions made in the process of liquidation the ES consequences.

The developed methodology of advanced scenario analysis allows to solve a wide range of process management tasks of prevention and liquidation of consequences of technogenic catastrophes and emergencies. The proposed methods provide the complex multidimensional study of alternatives of an emergency at the given target criterion under conditions of uncertainty. The main advantage of this approach is the ability to predict the behavior of the simulated object through the formation of alternative development scenarios. This approach allows to make conclusions about the most likely and appropriate directions of dynamic processes development, their stability, and other significant characteristics on the basis of information about the structural features of the study domain. The practical application of scenario approach enables a comprehensive analysis of the current situation at a given time horizon, to form the short-term and long-term forecasts of its development and to counter the emerging threats, to assess the effectiveness and consistency of distributed in time and space strategic and tactical management decisions for the prevention and elimination of consequences of emergencies and man-made disasters and catastrophes.

Modeling and scenario analysis of a wide range of safety of potentially dangerous for transport and infrastructure, residential and industrial buildings, etc. It comprises:

- diagnostic analysis and evaluation of the situation;
- the development of the object model, the choice of performance criteria and an assessment of their relative importance;
- generation of possible development scenarios;
- assess the scenarios developed (primarily management processes of prevention and liquidation of consequences of ES), and selecting the best of them for a given criterion of efficiency
- continuous analysis of monitoring information on the situation and making the appropriate changes in the structure of the models on the basis of the data obtained;
- assessment and selection of management actions on liquidation of emergency situations and improve safety;
- dynamic analysis of the possible consequences of control actions;
- collection of the results of the implementation of scenarios and assessment of data.

The opportunity to develop the methodology of scenario analysis and modeling is certainly not limited to the examples given in this paper – they are much wider. Currently, one of the most promising directions of development of the proposed methodology is unification of planning and scenario modeling. This area, which requires a separate study, involves the selection, analysis and certification of standard subclasses of potentially dangerous objects on the basis approved by the Ministry of the Russian Federation for Civil Defense, Emergencies and Liquidation of Consequences of Natural Disasters (EMERCOM of Russia) classification, which includes five basic classes, technological accidents which may are the source of federal (cross-border), regional, territorial and local emergencies respectively.

Unification (the reduction of all the variety of plans, control and monitoring actions to quite a limited set) should enable the development and use of standard tools and resources planning and management processes of prevention and liquidation of consequences of ES, as well as a large community of semantic and information content of the standard (basic) plans. On the one hand, it provides the ability to use quite limited set of information elements, and on the other hand – a significant invariance for the different levels of government and departmental affiliation, which should simplify the implementation of agreed plans of the system in various modes.

Development of theoretical and applied research in this field will provide an opportunity to solve a wide range of practical problems of planning and management processes of prevention and liquidation of consequences of emergency situations at the facility, municipal, regional and federal levels.

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