Steps, procedures, and methods of analysis and risk assessment of the coal industry enterprises

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Abstract
In this paper there was developed and implemented a mathematical model of the interpretation of the concept of "risk" with regard to the quantitative and qualitative effects of harmful environmental factors on living conditions, based on the statistical evaluation of the level of accidents coal mine, with the identification of the causes of accidents and construction of distribution function, as well as obtaining necessary statistical dependencies to significantly improve the safety of people.
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Ukrainian mines are extremely dangerous because of the extremely difficult geological and environmental conditions, temperature, which do not exist in other world coal basins. Two-thirds of Ukrainian mines are beyond methane, one-third - of coal dust. In addition, during their operation the technical backwardness of the domestic coal industry affects this.

According to statistics of the Ministry of Coal Industry in 2006 there were 38 accidents in Ukraine mines, in 2007 - 14 accidents, in 2008 - 18, and in 2009 - 40 accidents took place since the beginning of 2010 there already happened 10 of these phenomena. During the period from 2006 to 2009, more than 600 miners died. This situation necessitates the development of effective measures to prevent and control accidents.

This provision reduces the efficiency of the mining industry and requires a new approach to improve the situation. Experience of past years and the analysis of foreign experience indicates that some private events, as well as the development of local systems and separate security devices do not lead to a significant improvement of safety.

It is known that in the mining industry insuring of high-performance, cost-effective and safe working conditions is of particular importance due to the fact that the accidents at the mines lead to extremely serious social consequences, violate the rhythm of work, cause the losses of lives and require large economic costs to deal with them. Therefore, when the technical and economic analysis of economic activity of the coal companies, such interdependent aspects of production as: technical, technological, mining and geological, organizational, social, economic and political should be viewed in a single complex [1-4].

An important area to reduce the impact of injuries, occupational diseases and accidents is the use of appropriate preventive and precautionary measures. In the last decade this trend significantly weakened, due to the country transition from administrative to a market economy, which appeared not to be ready to invest for the operation of mines in new conditions. This situation can be remedied only by the help of technical and economic analysis of enterprises and appropriate sound management decisions.

We know that the basis for any analysis method is the criterion that allows to quantify the activity of the enterprises and to identify ways of improving the situation. One of those criteria for assessing safety in mines is the amount of risk, which is defined as the frequency of the practical implementation of a dangerous or harmful factors.

In foreign practice, the concept of “risk” has become widespread, and it is the ratio of number of human fatalities deaths to the total number of people engaged in the process of work, or any kind of activity. In our country, the safety assessment of the concept of “risk” is not yet widespread, although, in principle, the introduction of such concept is justified because to provide absolute security is practically impossible.

The first experience of safety management in the mining industry has been analyzed in the UK in 1992, together with representatives of the Polish Supreme Mining Management. The participants were also familiarized with the experience of safety management in the mining industry in Australia. It was also obtained a representation of a control system of health in the Netherlands. It was recognized that further increase of safety in the mining industry requires a qualitatively new approach to the issues related to occupational safety and health, including the appropriate methods of risk assessment training. Subsequently, the standard was developed on how to estimate the risk [5].

It should be noted that similar problems here in the domestic coal industry have become engaged only recently [6], however, they were not implemented. It is evident that a comprehensive approach to security management, i.e. implementation of the “risk assessment techniques”, is necessary.

In recent years, in technically advanced countries complex industrial facilities, including coal mines, hazardous gas or dust are measured using ergatic type of system “man - machine - environment”, with the use of new approaches based on such concept as “risk assessment”. And when these approaches are reliable, MTBF main and auxiliary equipment are not even of secondary importance, since it is the “risk assessment”, but rather the level and determine the conditions of safe work.

Today, there are no methods in Ukrainian coal industry, that would enable to assess the risks directly to the mines. First, about the risks and their evaluation were talked within such branches as nuclear power, aerospace, as the appearance of adverse events can cause the most significant damage here. In our country, relation to the risk assessment has changed dramatically after the accident at the Chernobyl nuclear power plant [7]. But with the development of science and technology and the increasing complexity of production processes, it becomes evident the need to apply the methods of risk assessment and other industries. Since our region is topical in issue of safe operation in the coal industry and, considering the number of accidents in the mines, hazardous gas or dust, and their consequences, then it begs the question for a long time the introduction of a risk assessment with a view to minimizing necessity and development of appropriate methods and normalizing documents.

What is the risk? To understand this, let’s return to the history of the “risk” concept. It is believed that the word «risk» is derived from the Arabic word «risk» or the Latin word «risiqum». The first means “something that is given to you and thereby you get the benefit” and has added value as a “random and a favorable outcome.” Originally the second one was referred to the challenge that sea reef threw to a sailor and had additional meaning as “accidental, but an adverse outcome.” Later, in the XII century, there already used Greek derivative from Arabic «risk», which meant a random outcome in general and did not imply any positive or negative value. Modern English «risk» has a clear interpretation of the «at risk» meaning " run into danger." In 1976, the Oxford Dictionary defines risk as "the probability bad menace consequences, loss and so on."

We see that with the passage of time the word changed from describing any unexpected outcome of the action to the value in the first place, describes the probability of its occurrence. Analytically, i.e. close to the numerical risk expresses the frequency of implementation of the dangers in relation to the possible number of them [6]. In general form:

$$R = \frac{N(t)}{Q(f)} , \quad (1)$$

where N - quantitative indicator of adverse events frequency per unit of time t;

Q - the number of risk objects subjected to certain risk factor f.

Normally, the risk of danger – is the value, which is less than one.

Thus, the expected (predicted) risk R - is the product of the frequency of implementation of the specific hazard f on the product of the probabilities of finding a person in the "risk zone" at different regulation process [6]:

$$R = f \cdot \prod_{i}^{n} p_i (i = 1,2,3,...,n) , \quad (2)$$

where f - number of accidents (fatal) from the ha-zard person^{-1} · year^{-1} (for domestic practice f = CZK • 10^{-3}, that corresponds to the value of the coefficient of frequency accident CZK divided by 1000);

$\prod_{i}^{n} p_i$ – the product of the probabilities of finding the employee "at risk."

Formation of hazardous and emergency situations – is the result of certain set of risks posed by relevant sources. Ratio of risk objects and adverse events allows to distinguish individual types of risks. Each type of it conditions the typical sources and risk factors. The risk can be also characterized by equation that includes the existence of threats, probability to avoid the risk and severity of risk [58]:

$$\text{Risk (R)} = E \times A \times S, \quad (3)$$

where E (Existence) - the probability that there is a certain risk;

A (Avoidance) - the probability that it is possible to avoid the risk;

S (Severity) - a category that determines the severity of the risk.

There are four main types of risk: risk in the work environment (man-made), calculated risk, pollution risk and unconscious risk (inherent). Technological risk - complex indicator, determined by the reliability of elements of the technosphere. It expresses the probability of an accident or disaster in the operation of machines, technological processes, construction and operation of buildings and structures [6]:

$$R_T = \frac{\Delta T(t)}{T(f)} , \quad (4)$$

were R_T – technological risks;

ΔT – the number of accidents per unit of time t on identical technical systems and facilities;

T – number of identical technical systems and facilities, subjected to the overall risk factor f.

Sources of technical risk: low research and development activities; unstable pilot production of new equipment; serial production of unsafe equipment; violation of the rules of safe operation of technical systems. The most common factors of technical risk: wrong choice of safety criteria areas of engineering and technology; choice of potentially hazardous structural schemes and principles of operation of technical systems; errors in determining the operating loads; wrong choice of construction materials; insufficient margin of safety; the absence in the plan of security equipment; substandard finishing construction, technology and (or) documentation on safety criteria; deviations from the predetermined chemical composition of constructional materials; poor accuracy of structural dimensions; violations of the thermal and chemical processing of details; violation of the regulations of the assembly and installation of structures and machines; the use of technology for other purposes;

violation of the passport (the project) modes of operation; untimely preventive inspection and repair; violation of transport and storage.

The main risks (Fig. 2) can be described as a two-dimensional value, which consists of the accidents possibility and the volume of losses caused by the accident (effects) [8]:

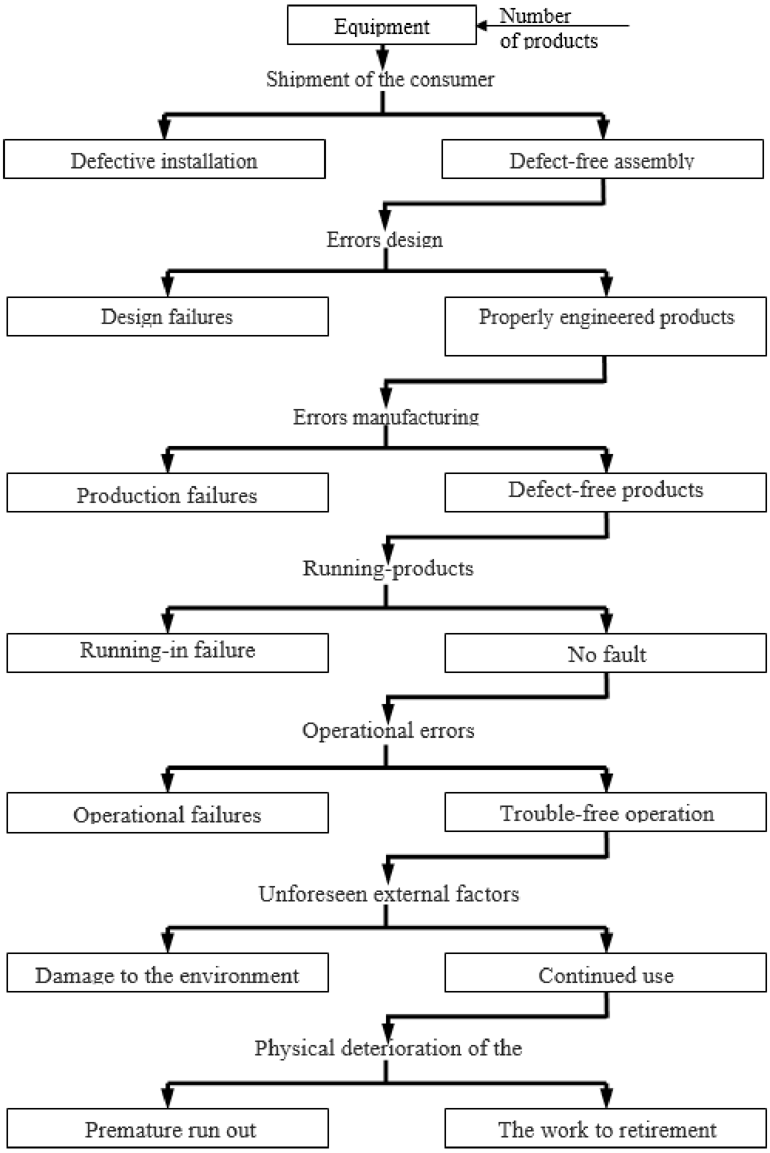

Figure 1. Model of the main factors of technical risk

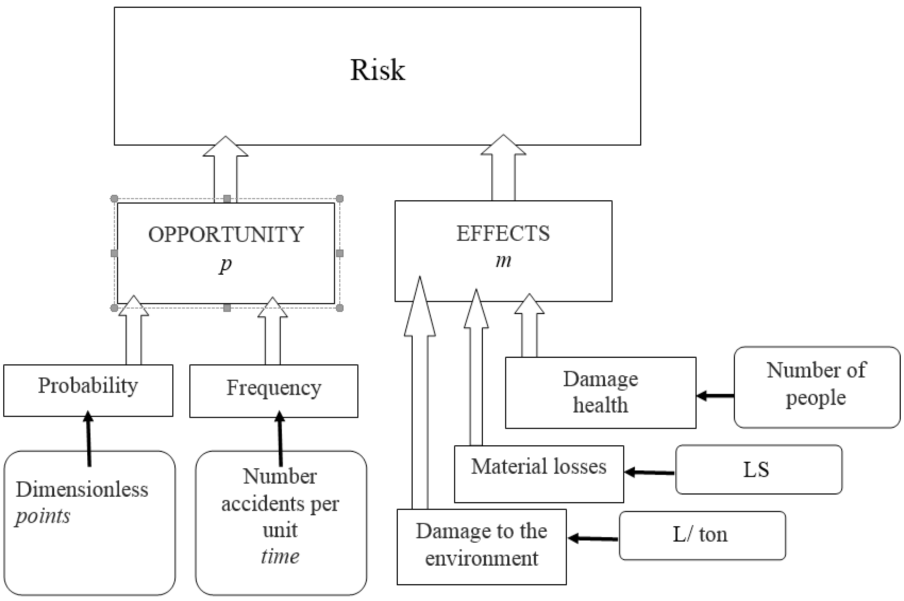

Figure 2. The components of risk

Model basic technical risk factors can be represented as a circuit shown in Fig. 1.

The risk in nature can be controlled, if it creates the legal basis for evaluation, methodological support and estimation procedure, as well as set specific requirements for the content of potentially dangerous objects in order to reduce risk.

Except the notion of "risk" there used a notion of "degree of risk" R, i.e., the probability of an unwanted event, taking into account the size of possible damage from the event. Degree of risk can be expressed as the mathematical expectation of damage caused by unwanted events:

$$R(m) = \sum_{i=1}^{n} p_i \cdot m_i , \tag{5}$$

where p_i – probability of occurrence of an event associated with the damage;

m_i – random variable damage caused to the economy, health, etc.

Risk probability is measured by its possibility or accidents frequency. The probability numerically is equal to the correlation of number of accidents to the possible number of events of the kind that contains the incident, i.e. the probability is the ratio of two numbers, and it has no units. The probability can not be less than zero (can not be a negative number) and can not be greater than unity.

Frequency of accidents is expressed by the number of accidents per unit of time or per unit of distance. It determines the unit of frequency of accidents, for example, the number of accidents per year, or the number of accidents per kilometer. Knowing the joining dependencies and probability, it is possible to calculate the frequency of accidents [2].

The second interpretation of the risk concept are the losses caused by the accident. It is an integral value, and it can also be calculated as:

- damage to health, for example, having calculated the time when professional pathology may occur as a result of the certain risk factors influence (hearing impairment, etc.);

- material damage, which is usually shown in monetary terms;

- damage caused to the environment, both in monetary terms (for example, the cost for cleaning the waters), and feedbacks how the environment affects the health of people (for example, the influence of the leakage of toxic substances on a certain number of people and their health).

Each accident: explosion, fire, leakage of toxic substances, etc. - may lead to a different number of patients with health damage of different severity and duration. If you do not take into account the factor of change of time and consider the case, where the losses caused by the incident are expressed as health damage, permanent in time, it becomes possible to display risk in three dimensions: the number of victims, dependence on the severity of damage and probability.

Three-dimensional graphic representation of the risk is shown in Fig. 3. The surface of the risk in this case reflects the possibility of all potential victims to get health damage of various severity. On the axis of the number of victims there laid off the possible number of victims, from one to the maximum number of people in risk zone corresponding to the scenario of the accident.

The severity of damage is expressed as a percentage, where zero percent damage corresponds to an event that does not affect people's health. Cross-section of a 100% risk of injury shows the probability that the result of the accident, «n» people died (Fig. 3).

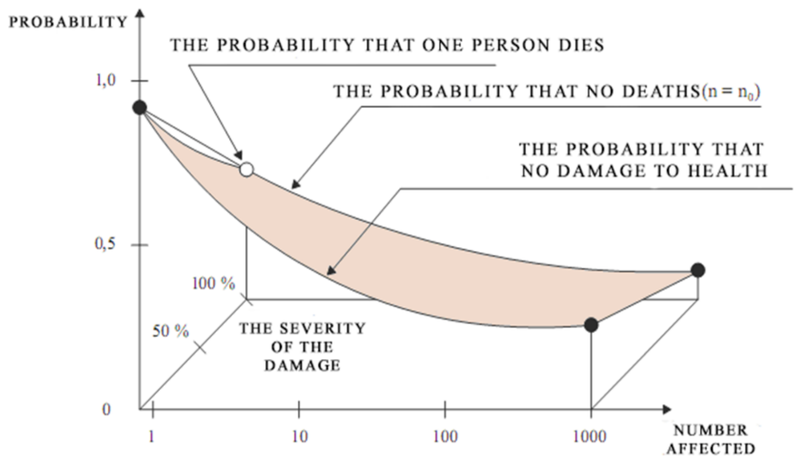

Figure 3. Three-dimensional graphic representation of the risk

The study of risk involves the use of analytical methods at the level of systems that take into account the components and subsystems, and consider their probability of failure and the consequences of these failures. Herein there used quantitative, qualitative or semi-quantitative approaches to evaluate the probability of failure and their implications for technical systems [5]. Systematic approach allows the analyst to appropriately and easily evaluate the safety and risk of complex systems for various standard operating and emergency conditions. The results of risk analysis can also be used in making decisions that are based on the analysis of «cost - benefit».

Factors, creating danger and requiring evaluation, may be different. This is mainly physical factors (noise, vibration, ionizing and non-ionizing radiation, temperature, etc.), mechanical factors, the presence of chemical or biological active substances, ergonomic, psychosocial, organizational, and other factors, as well as equipment, work practices, technology etc. The main risk factors of the working environment can be grouped as follows (Fig. 4):

Assessment of risk – is the process whereby the risks for the system modeled and quantified. Assessing risk involves obtaining qualitative and / or quantitative data for use in risk management. Risk analysis and assessment involves the identification of hazards, assessment of the probability of events and impact assessment. Here are answers to the questions:

-What the adverse can happen?

-What is the likelihood that this will happen?

-What are the consequences of this event?

The answer to these questions implies the use of different methods of risk assessment.

Chemical factors
- Corrosive substances - Irritants - Narcotics - Asphyxiants - Carcinogens - Aerosols and dust - Organic solvents - Chemical elements and compounds of general toxic effects

Physical factors
- Microclimate - Noise - Ultrasound - Infrasound - Vibration - Electricity - Static electricity - Lighting - Ultraviolet radiation - Infrared - Laser radiation - Electromagnetic fields - Ionizing radiation - High and Low Pressure

Biological factors
- Fungi - Bacteria - Viruses

Mechanical factors
- Moving machinery, conveyors, elevators and others.

Psychosocial and organizational factors
- Aesthetics labor - Stress at work and others. - Preventive measures conducting to the maintenance of health (rest breaks, the prevention of fatigue, etc.)

Ergonomic factors
- Lifting and moving heavy objects - Drudgery - Workload - Operating voltage - Fundamentals of biomechanics and anthropometry

Figure 4. Risk factors of working environment

Methodological support for risk analysis - is a set of methods, techniques and software tools allowing to fully identify hazards and assess the risk of an emergency, the source of which could be an industrial facility. Meeting the requirements for methodological support of hazard and risk analysis is necessary to improve the accuracy and objectivity of the results of the study of hazardous industrial facilities, as well as to improve the efficiency of development activities to prevent emergencies.

Risk assessment – is an analysis of the origin (appearance) and the scale of the risk in a particular situation. Despite the differences in approaches to the sequence of steps in the process of risk management, there are three common to all documents constituting of the process: information on occupational safety, risk analysis and the resulting control of occupational safety. Risk analysis is based on information gathered and determines the measures to control the security of the technological system, so the main task of risk analysis is to provide a rational basis for decision-making with respect to risk (fig. 5). Risk analysis – is the systematic use of available information to identify hazards and assess of risk for individuals or population, property or the environment [9].

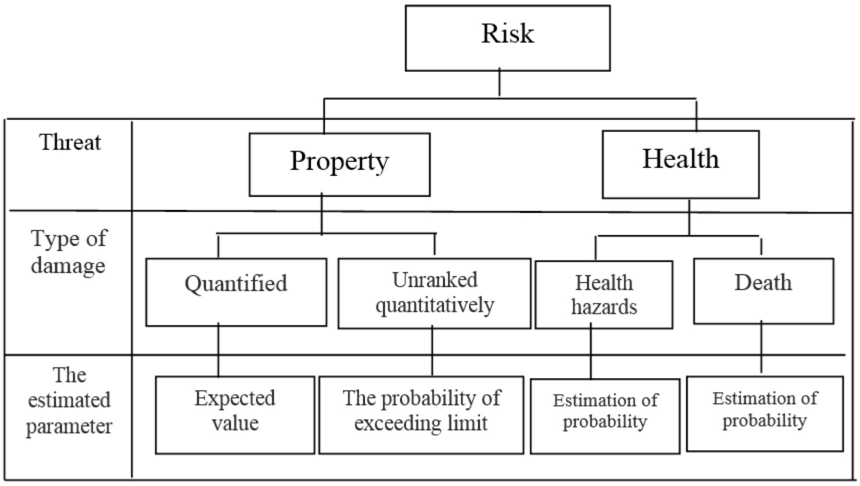

Figure 5. The scheme of risk assessment

First, any analysis of risk begins with the planning and organization of work. Therefore, the first steps are:

- Specify the reasons and problems that caused the need for risk-analysis;
- Determine the analyzed system and give a description;
- Choose the appropriate command for analysis;
- Identify sources of information on the safety of the system;
- Specify the source data and the constraints causing the limits of risk analysis;
- Define clearly the purpose of risk analysis and risk acceptance criteria.

The next step of risk analysis - is the identification of hazards. The main task – is identify (on the basis of information on this subject, the results of expertise and experience of such systems) and describe clearly all the dangers inherent in the system. Preliminary assessment of the hazards in order to select further areas of activity is carried out:

- Cease further analysis in view of the insignificance of the dangers;
- More detailed analysis of risk;
- Make recommendations to reduce risks.

In principle, the process of risk analysis may be terminated at the stage of hazards identifying.

After hazard identification, one proceeds to the step of risk assessment, where identified hazards should be evaluated basing on the criteria of acceptable risk, in order to identify hazards with unacceptable level of risk, which is the basis for the development of recommendations and measures to reduce the dangers. Herein the criterion of acceptable risk and the risk assessment results can be expressed qualitatively (in the form of a textual description) or quantitatively (e.g. as the number of accidents or accidents annually) [5].

According to the definition, risk assessment includes analysis of the frequency and impact analysis. However, when the consequences are negligible or frequency is extremely low, it is enough to estimate one parameter. To analyze the frequency there commonly used:

- Historical data corresponding to the type of system, the facility or activity;
- Statistics on accidents and safety equipment;
- Logical methods of analysis “event trees” or “fault trees”;
- Expert evaluation, taking into account the opinions of experts in the field.

Impact analysis includes an assessment of impacts on people, property or the environment. In order to predict the consequences it is required to have disturbance models, to understand of their essence and essence of used damaging factors, as it is necessary to evaluate the physical effects of adverse events (fires, explosions, toxic emissions) and to use criteria of defeat of studied objects of influence.

At the stage of the risk assessment one should analyze the possible uncertainty of the results, due to the inaccuracy of information on the reliability of the equipment and personnel errors and the assumptions used in the calculation models of emergency process (Figure 6).

Basic scheme of assessment in a simplified form may be displayed as follows (Fig. 7):

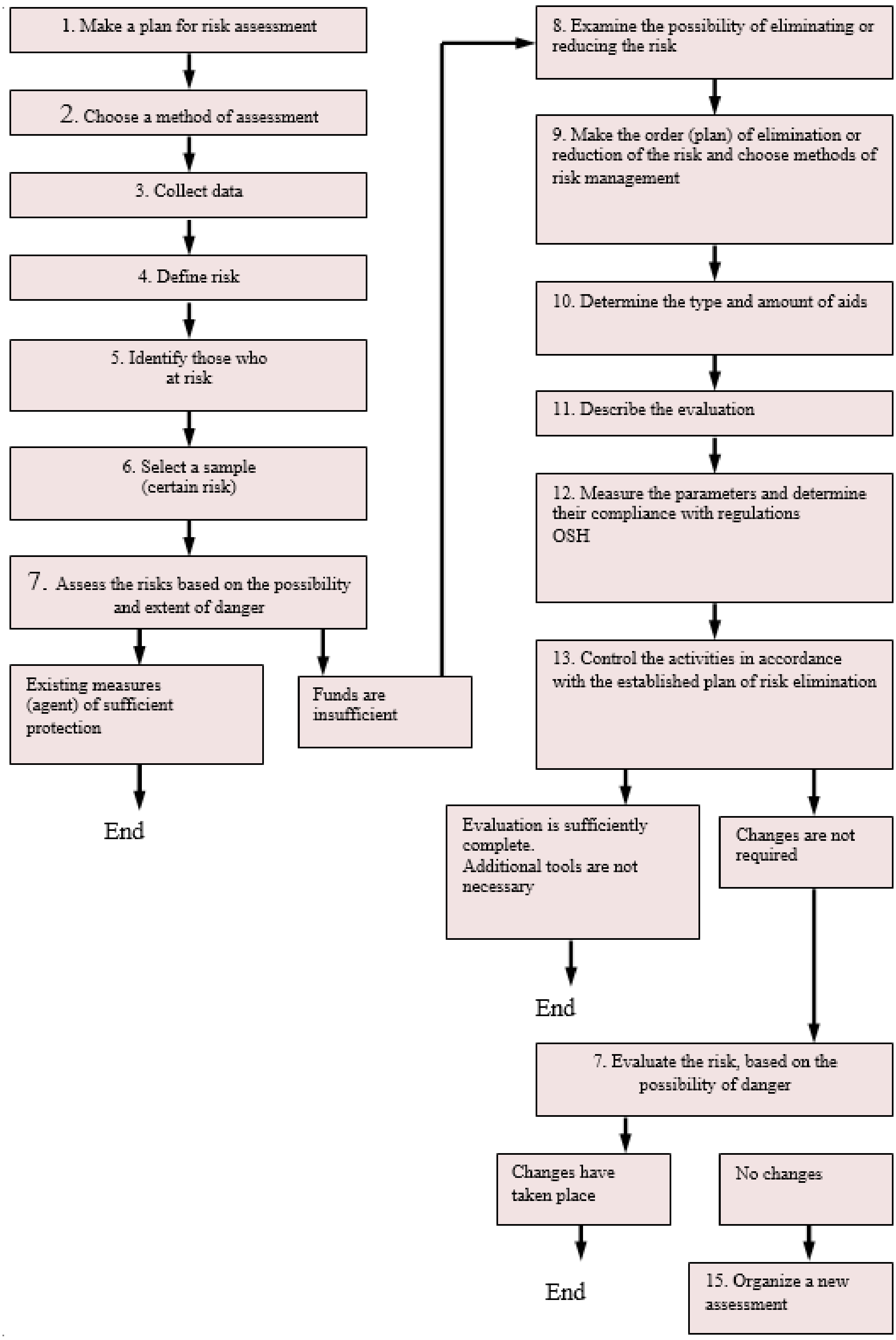

Figure 6. Stages of risk assessment [60]

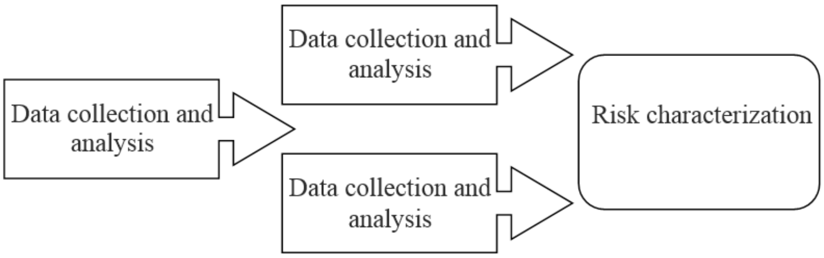

Figure 7. Simplified scheme of risk assessment

Uncertainty analysis – is a conversion of the original parameters and suggestions used during risk assessment, into the uncertainty of the results. The largest volume of safety recommendations is produced using high-quality (engineering) methods of risk analysis, allowing to achieve the main objectives of risk analysis using a smaller amount of information and labor costs.

However, quantitative risk assessment methods are always very helpful, and in some cases are the only valid ones, in particular, to compare the hazards of various nature or especially dangerous examination of complex technical systems. Development of recommendations on reduction of the risk (risk management) is the final stage of risk analysis. Recommendations may find existing risks acceptable or specify the measures to reduce the risk, i.e. measures for its control. Risk management measures may be of technical, operational or organizational nature [5].

On the basis of research [6], a common risk assessment procedure can be written in the form (Fig. 8):

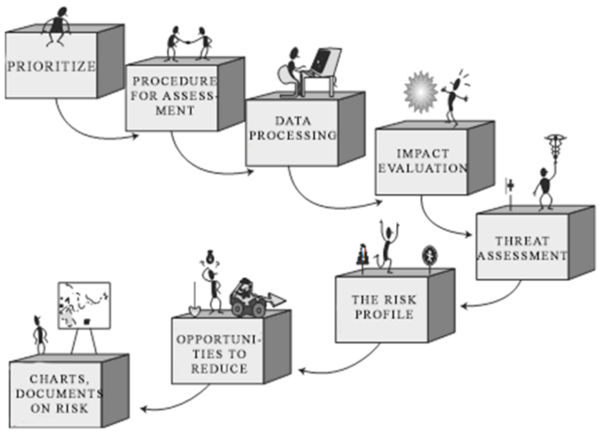

Figure 8. The general procedure for risk assessment

Let us consider the concept of tolerable risk. Acceptable risk - it is normalized (determine by GOST) criterion, allowing to work with this level of security, when the probability of risk is reduced to a minimum, or the consequences of risk (with its large probability) are minimal. If we use more rigorous assessment of the scale, then the only acceptable risk refers to the probability p, equal to zero, and workplace safety is fully guaranteed. In real operating conditions, such is not usually because there is at least a small but definite risk probability, that is $p > 0$.

Since the risk is always possible, zero risks are almost impossible, but in any case it is necessary to strive to reduce the risk to a minimum. If the risk is assessed as valid, it can be assumed that the protective measures (funds) to further enhance security are not necessary, especially if these objectives require large material means [10].

Thus, the development and implementation of mathematical models of interpretation of the concept of “risk” with regard to the quantitative and qualitative effects of harmful environmental factors on living conditions, based on the statistical evaluation of the level of coal mine accidents, the identification of the causes of accidents and the construction of the distribution function, as well as obtaining the necessary statistical relationships, will significantly increase the effectiveness of the security of people. Through the presentation of the mine as a ergatic system “man-machine-environment” and the development of appropriate mathematical models it will be possible to identify the hazard and the probability of its occurrence, to assess the risk based on the possibility and severity, to define the categories of acceptable risk, as well as damage caused by the appearance of danger, make calculation of risk and identify risks that can be avoided or minimized. This will allow to determine the adequacy of measures to protect and select the method of reducing risk and to analyze the «cost-benefit». The totality of these actions will lead to the development of technical and organizational measures to improve work safety in coal mines. The main purpose of the introduction of risk analysis and techno-hazards is to identify “weak” places for subsequent optimization of security measures, resource justified reduction of risk of accidents and injuries that lead to an increase in the overall safety of the coal mines. The system can be implemented and adapted to any industry and any industrial facility, considerable technological complexity.

The widespread adoption of similar measures, risk analysis and assessment in the mining industry abroad has led to a significant reduction in injuries and deaths at work of the coal mines, as well as improved efficiency.

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