Review of modern software complexes and digital twin concept for forecasting emergency situations in oil and gas industry

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Abstract. Technological processes complication leads to increase of accidents scale, this negatively affects people, environment and enterprise. In this regard, there is a need for good risk management, taking into account real state of a hazardous production facility. In this paper, is analyzed application of hazard analysis method “Tree of consequences”. The method is widely used for industrial safety of oil and gas facilities. The paper also provides an overview of some software systems that allow to visualize steps of risks analysis and to minimize calculation process based on 3D modeling. In oil and gas industry the FLACS software tool is used to simulate most well-known ignition and toxic emission scenarios in terrestrial conditions. It is possible to assess effect of hazardous or harmful substances on production facility in domestic TOXI-Risk software package. Phast Lite program is used to simulate consequences of accidents with ability to create danger in entire sequence of events from accident itself to damage. In addition, the article defines digital twin concept. The digital twin provides constant interaction and data exchange with a real object. This technology is promising for production management, for maintenance and for accidents prevention.

All industries are in constant development, new technologies are being created, processes are becoming more complicated to improve product quality, what in turn leads to increase of facility hazard level. Previously applied technologies at different stages of object life cycle lose their relevance.

Over the past few years, many destructive technological disasters have occurred in various industries. In connection with such situations, new approaches are being constantly developed in field of safety and risk management, which contribute to increasing safety of people and environment. Currently, hazards that can lead to negative situations are analyzed using various risk assessment methods.

According to regulatory documents, risk of an accident is a hazard measure characterizing possibility of an accident at a hazardous production facility and corresponding severity of consequences [1, 2].

When developing design documentation, documentation for technical re-equipment, industrial safety declarations, safety substantiating of a hazardous production facility, a plan for localizing and eliminating of accidents consequences, and also in order to develop measures to reduce the number of accidents, a risk analysis is carried out. A comprehensive risk analysis allows you to detect all
dangerous situations and develop preventive measures at both oil refining facilities and transportation facilities - main pipelines. [3]

The term risk combines both probability of an event and severity of its consequences. In the field of industrial safety, after identifying hazards, it is necessary to assess rate of any negative situation consequences. For this purpose, various methods of qualitative and quantitative risk assessment are applied. They contribute to proper organization of measures to reduce the level of a workplace danger. The most systematic and complex of these methods, at the moment, is the method of probabilistic risk assessment [4].

The purpose of a probabilistic risk assessment is to identify components that form risk, as well as to establish guidelines for developing measures to reduce it to society accepted level [5-7].

A probabilistic method of hazard analysis for technical systems helps to identify various paths of processes, building a "tree of consequences", or "fault trees" of technical devices and structures to form logical chains of unwanted results of safety requirements violation.

The result of risk analysis is accident scenarios used to assess accidents danger rate at industrial facilities and development of preventive measures.

The “tree of consequences” (the “event tree”) is a method for determining development of an emergency. The purpose of this method is to study the formation of situations (starting from an accident), taking into account the effectiveness of safety devices resistance to final state. As a result of studying all possible variations of situations and states that perceived as an emergency, are found.

For example, widespread forecasts of probable emergencies at oil pipelines arise due to complete depressurization of pipes and product ingress into atmosphere in critical mode [8]. An example of «tree event» for emergency consequences with depressurization of an oil pipeline is shown in figure 1.

An “event tree” makes it possible to foresee causes of emergencies and minimize costs of localization, elimination and also helps to increase the level of industrial safety.

All fundamental methods of risk assessment underlie the modeling of negative phenomena at a hazardous production facility.

A model is a visualization of a real process, knowledge structured in the established order.

![Figure 1. “Event tree” in case of accidents in event of depressurization of a main oil pipeline linear part.](image-url)
With the rapid development of new technologies, such as cloud technologies, the Internet of things, Big Data, artificial intelligence, the era of smart manufacturing is approaching, the key element of which is smart mathematical models and smart digital twins. The concept of digital twin as a virtual representation of a physical object has been used for over 30 years, mainly in space industry. For the first time, the concept of a digital twin was created by NASA Apollo. They made two identical models of a spacecraft, one was sent to space to fulfill its mission, the other remained on Earth for observation, a better understanding of situation and decision-making [9, 10].

In connection with world and industries digitalization, for example, in oil industry, there has been a rapid pace in development and application of this technology. A digital twin is a virtual prototype of a real object, it is not limited to data collection, at the stage of product development and manufacturing - it continues to collect and analyze data throughout entire life cycle of a real object, including using numerous sensors, forming a cyber-physical system [11, 12]. This technology is promising for production management and extension of safe operational resource, it is possible to analyze accumulated data, simulate object behavior under given conditions, predict faults, determine the most effective and adequate scenario for technological process and other activities. This is especially important for maintenance and repairs according to actual condition of the equipment.

The importance of digital twin technologies in matters of industrial safety and production management is recognized in energy sector, as it is planned to create digital twin of nuclear power plants. This will allow not only collecting and effectively applying data on operation of each individual piece of equipment, but will also create opportunity for modeling and predicting behavior of objects in various modes. Gazprom Neft, also showing interest in this technology, created digital twins of the catalytic cracking gasoline hydrotreatment unit at the Moscow Oil Refinery and the primary oil refining unit at the Omsk Oil Refinery [13].

To build a comprehensive twin model, numerical methods for modeling physical processes in object materials are used. It helps to predict the response of product to operational loads, for example, using the Finite Element Analysis (FEA) method. Using this method, you can simulate behavior of complex systems by breaking them into many elements (cells) small enough to consider their properties as homogeneous. The method is widely used to solve problems of deformable solid mechanics, heat transfer, hydrodynamics and electrodynamics [14].

Currently, in connection with scientific and technological progress, there is a need to use special software products for emergency situation consequences modeling. With the advent of more powerful computers, new programs arose.

Consider the foreign software package FLACS.

FLACS is a software tool which purpose is to simulate in land environment (dispersion, fire, and explosion) the most famous ignition and toxic emission scenarios. It is widely used for oil and gas refineries, as well as in nuclear industry, in facilities with potential for dust explosion and in many other areas. Modeling using CFD (Computational Fluid Dynamics) can predict consequences much more accurately and thereby take into account the influence of all contributing and mitigating factors [15, 16].

The use of 3D modeling for risk assessment provides additional capabilities, for example, predicting smoke dispersion, testing hypotheses during incident investigations, visualizing results in three dimensions, determining gas location, optimized separation between equipment, passive fire specification and protection, placement of safety equipment [17].

Figure 2 shows an example of FLACS-Risk output: a new three-dimensional visualization of explosion overpressure risk [18].
Figure 2. An example of three-dimensional visualization of explosion overpressure risk.

It is possible to evaluate results of hazardous or harmful substances influence on production facility in domestic TOXI + Risk software package (developed by STC PB CJSC, Moscow) [19].

The program is an alternative solution for calculating an accident consequences scenarios. It is also possible to build a risk zone and calculate risk indicators (individual, collective, social).

The TOXI + Risk feature is another way to consider:

• distribution and parameters of technical structures and facilities at risk (people, environment, equipment);
• emergency scenarios and their formation likelihood.

The software package provides an opportunity to generate spread area of hazardous substance released in atmosphere as a result of an emergency and to visualize results of calculations on surrounding area plans, to assess the number of people who are in zones of exposure to hazards affected by various emergency scenarios. As a result, it is possible to construct a potential risk field, an example of which is shown in figure 3 [20].

Figure 3. An example of a potential risk field.
Phast Lite software tool (developed by Det Norske Veritas) is used for analyzing consequences of an accident. This software allows you to analyze accident scenarios with the capabilities of threat modeling, which allows studying development of events from the initial (accident) to the final (damage) stages. Phast Lite is designed to analyze emergencies risks at all stages of design and operation. The basis of software tool is modeling various scenarios of emissions of harmful and dangerous substances [21].

Phast Lite software allows you to get:
- reliable results of hazard analysis;
- ample opportunities to create detailed reports and diagrams for convenient visualization of results;
- widespread use of hazard analysis software in the workplace. It is possible to simulate various sources of emissions, for example, depressurization of pipelines, ruptures of vessels etc;
- assessment of a whole range of production hazards [22].

The program also allows to visualize the contours of excess pressure during an accident. An example of visualization is presented in figure 4.

![Figure 4. An example of visualization of overpressure contours.](image)

In general, programs discussed above make it possible to imitate a “real space” in the place of hazardous or harmful substance uncontrolled release, establish emission parameters, and visualize the results of risk calculations [23].

The article discusses modern software systems used in the field of industrial safety at hazardous production facilities of oil and gas industry. The development of optimal set of models will create a clear view of negative situations, providing a correct forecast for development of situations and visually present accident consequences.

Each software product is focused on simulating certain situations, modeling ignition scenarios, assessing the impact of hazardous and harmful substances on production, and so on. Based on their work on 3D modeling, they help minimize calculation process and provide a comprehensive understanding of situation to consider all possible accident scenarios. With the correct use of programs, a better approximation of model to actual situation is provided, and a deeper account of analyzed parameters.

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