Development of Risk-Oriented Thinking for Sustainable Functioning of the Technosphere

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Abstract. The increasing dependence of the mankind on technical systems makes us a "risk society." Therefore, in order to minimize consequences of anthropogenic activity those specialists who have access to complex technical systems need to develop advanced risk-oriented thinking.

The purpose of this study is to formulate and clarify the concept of "risk-oriented thinking" and substantiate integration of the systemic and the competency-based approaches. According to the authors hereof, the use of the Perrow model is the most effective educational condition of development of risk-oriented thinking in future engineers. Study results include both a definition of the "risk-oriented thinking" and criteria of the advanced risk-oriented thinking.

1. Introduction

Failures of complex technical systems may result in loss of human life, damage the environment, and destabilize the economy [1]. However, the contradiction between the need in training highly professional specialists in technology-related risk management and the absence of formulated training standards is becoming more and more obvious in the setting of the ongoing processes. Furthermore, the definition of the risk-oriented thinking and methods to develop such thinking remain understudied at the moment.

A definition of the risk-oriented approach is given by national standard GOST R ISO 9001-2015 "Quality management systems. Requirements" of the Russian Federation. In order to comply with requirements thereof, organizations need to plan and implements measures related to risks and possibilities [3]. If we define thinking as the cognitive activity of a human being, then the definition of risk-oriented thinking is basically reduced to understanding the processes that may promote actualization of risks in one type of an organization's activity or another. Furthermore, specialists in assuring public safety from various threats are focused on the following spheres at the moment: identification of hazards, risk assessment, prediction of emergencies, development of measures to mitigate risks and improve effectiveness of protection of population and territories, state regulation of risk mitigation, as
well as improvement and development of emergency control forces and means. In order to actualize all these spheres, specialists with developed risk-oriented thinking are required [4, 5].

2. Methodological background of the study

Given that technology-related safety is ensured by people with technical education, i.e. with a type of thinking characterized as "technical", their professional training must be based on the understanding of operation of both basic and the most complex technical systems. In our opinion, one of the most effective approaches to do that is the one that involves the use of the Perrow model.

According to the Perrow model [1], there may be two factors, the impact whereof may sufficiently significant to result in a failure of a complex technical system. A specialist with the advanced risk-oriented thinking is capable of determining the most vulnerable system or its part at the level of professional self-reflection.

The first factor determines the interaction of system's elements. There are both simple (so called "linear") and complex systems. Linear systems operate according to a clearly defined algorithm performing the set operations step by step. For instance, a conveyor belt's operation follows a clear sequence of actions. Therefore, when a system fails, the responsible specialist immediately understands where the problem is.

Therefore, specialists working with a complex technical system, especially if they are responsible for the safety of its operation, must have a highly advanced risk-oriented thinking based on profound knowledge of how the system operates and possible risks of the system's failures, especially because the operation of complex technical systems is for the most part out of unassisted sight. In that case, the specialist's work may be compared to walking a path on the edge of a precipice. In that case, all the human sense organs responsible for physical safety become activated (visual system, vestibular system, muscular system etc.) to avoid going to the edge of a cliff!

However, trying to manage a complex technical system, a man behaves like the one who walks along the edge of a precipice looking forward through binoculars, i.e. when we look through binoculars, we see large fragments of the path, but do not see the whole path. In that case, we would try to fragmentarily determine what to do focusing at the large element in our sight at the moment, trying to interpret it as a part of the whole picture of the impending danger.

Obviously, a specialist cannot get deep inside a complex technical system all the time to clearly analyze what is going wrong with each of its assembly units when a problem comes up. That is why with most problems specialists must be guided by indirect indicators. Let us recall horrible disasters that took place in Chernobyl and Fukushima. Obviously, one cannot send anybody to deal with the problems inside the reactor itself, and the picture of an accident forms out of readings of the functioning devices indicating pressure, water flow etc. As these readings do not provide a completely objective picture of an accident, there may be mistakes in the analysis of the situation made worse by the need to take into account the synergistic effect of failures of separate assembly units. That is why Perrow comes to the following conclusion: it is impossible to sufficiently understand complex technical systems to be able to predict all the possible consequences even of a slight failure.

Let us discuss now the second factor determining the probability of "loose" functioning. The primary condition is the rigidity of connection of elements: if the connection is rigid, the system features little looseness, therefore, a failure of one part slightly affects the other. On the other hand, if there is a large gap between parts, the system's survivability improves in the event of problems occurring in one of the elements.

A specialist with advanced risk-oriented thinking working in the sphere of safety control of complex technical systems must know and feel the difference in the functioning of linear and complex systems. Obviously, it is impossible to ensure perfect functioning of complex, rigidly connected systems, because replacement of assembly units and alternative methods work out only rarely, and there are frequent synergistic effects of system failures. An accident may develop very fast, and it will be very difficult to simply turn the system off, so the problem does not get out of control.
Let us return to the disasters at the Chernobyl nuclear power plant and in Fukushima. Safety assurance for these extremely complex and dangerous for the mankind technical systems requires numerous specific conditions. Even a slightest failure in the workflow, such as balance pressure valve jamming, may result in extremely undesirable consequences. Also, as mentioned before, we cannot slow a nuclear power plant down or suspend its operation. The rate of the chain reaction is rather high, and even if we stop it, the reactor will still retain a large amount of residual heat. That is why a lot depends on the expertise and advanced risk-oriented thinking of the specialists responsible for the system's safety. They must have professional reflexes similar to the reflexes of a person walking along the edge of a mountain trail, because in a critical situation one does not "look through binoculars" trying to scrutinize the problem in details - he or she needs to survive! Choosing the right time is essential.

As the problem rapidly builds up along with the meltdown of fuel rods and radiation leak caused by reactor overheating, there is no use in raising the level of cooling liquid after some long stretch of time. Such a decision must be made immediately and no matter what! Correct analysis of the situation will help to avoid a terrible disaster.

A different reaction could be expected from hazard analysis at an aircraft factory, where the manufacturing process is characterized by looser connectedness. There, most parts are assembled separately, which is why it is possible to control the emergence of problems and resolve them prior to the assembly. The most important thing is to prevent defects of aircraft assembly, as they may result in an inflight accident. This requires from specialists a risk analysis of possible consequences.

However, in both cases a specialist must understand how the technical object functions as a system and possess expertise in the sphere of operation of the given technical object.

3. Results

Obviously, neither technical system matches the categories defined by Perrow. It is also obvious that each case of problem analysis of the system by a specialist requires individual approach. However, when developing the risk-oriented thinking, a specialist may be guided by the following general points of reference: it is necessary to understand the level of complexity and rigidity of connection of elements and the risk of the synergistic effect of problems in an existing system. Let us consider the matrix in Figure 1.

Rigidly connected complex technical systems are in the upper part of the matrix, although, obviously, dams, though rather complex, are still less technically complex than nuclear power plants. They consist of fewer components and therefore have fewer accident risk zones.

In the lower part of the matrix there are rather primitive technically post offices and universities. Their activities are not very strictly regulated, and no failure of their operation could pose a critical threat to life and health.

![Figure 1. Perrow's matrix.](image-url)
Naturally, post offices are the simplest systems even in comparison with universities, the activities whereof are regulated by a complex bureaucratic mechanism involving numerous departments, boards, educational units etc. Universities perform various functions: scientific, educational, administrative etc. This is a complex system, though not technically, but administratively. Activities of a university are versatile and regulated both by administrative regulations and self-governing bodies. This may result in certain conflicts. For instance, a yearly contract of a university's management board with a lecturer may be challenged by a resolution of the faculty's or even the university's Academic Board, and there are multiple examples of such challenges. However, connections in system "university" are loose, which leaves ground for "maneuvering." Furthermore, the university continues to function; the faculties that are not involved in the problem directly may never even learn about it.

The most dangerous zone in the Perrow's matrix is the upper right quadrant. The systems there have complex and rigid connections, which may cause large-scale disasters. Failures of these systems spread in cascade, i.e. rapidly and uncontrollably, causing a "domino effect." We may recall here an extremely rapid destruction of the Sayano-Shushenskaya hydro power plant and the catastrophic consequences thereof. What is more, as the situation becomes worse, the external manifestations become more and more ambiguous. However hard one tries, it is difficult to definitely diagnose the problem; it is also possible to aggravate it solving not the underlying problem, but the one the specialist deems the most significant.

Fortunately, most accidents may be prevented, as their immediate causes are not related to the complexity or rigidity of connections. According to multiple sources, accidents are usually caused by unreasonable risk, disregard of warnings, communication problems, low professional expertise of the personnel and operator errors.

When developing the risk-oriented thinking, the Perrow model helps to develop the understanding of how to prevent accidents in complex technical systems characterized by high rigidity of connections and causing the worst damage. A specialist with well-developed risk-oriented thinking must understand that his or her understanding of the processes within a complex system may be wrong, and his or her own errors may lay over other failures in the worst possible way, while rigid connections of the system hinder counteraction to newer failures.

Let us consider a case of a failure to observe elementary rules, when a seemingly unnoticeable mistake is made out of simple lack of proper attention - a worker closes a wrong valve. This is a trifle failure that a system easily withstands, but if this is only one of many other failures within a complex and rigidly connected system, the consequences may be catastrophic.

Obviously, we cannot fundamentally change many systems, but we can use a systemic approach to risk analysis and improve professional competencies of specialists in safety assurance of complex technical system functioning to reduce the risk of accidents with harsh consequences.

4. Conclusion
Therefore, we may conclude that the risk-oriented thinking is a type of thinking based on the analysis and understanding of decision-making processes associated with the functioning of complex technical and techno-social systems on the basis of the risk-oriented activity. The criterion of the advanced risk-oriented thinking is the ability to analyze the largest possible number of probable options within a given period of time and to choose an option with the least undesirable consequences [6].

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