# Cognitive Aspects of Ensuring the Safety, Dependability and Stability of a Dynamic System's Functioning in Extreme Conditions

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**Abstract.** Digitalization leads to the necessity of taking into account the cognitive aspects of human-computer interaction. Research of the complex dynamic system's functioning in extremal conditions are limited by the hidden interconnections of elements. The influence of the increasing complexity of interaction on ensuring the safety, dependability and stability of a complex dynamic system in extreme conditions is considered. The analysis of dynamic complexity from the perspective of interdisciplinary principles and laws made it possible to establish that taking into account cognitive aspects, as well as the person's psychophysiological state are critically important. Attention is drawn to the functional asymmetry of the cerebral hemispheres, the features of which lead to latent cognitive problems. Features of asymmetry are inherited or acquired during life. Their consequence is the violation of the basic communication interrelations in a complex dynamic system. This is reflected in the system's cognitive model, in which the influence of the human factor prevails. The key element of the model is the spatio-temporal inconsistency of relevant information flows, which complicates the analysis and selection of risk mitigation strategies. It is proposed to eliminate the actions of systematic security threats by applying an interdisciplinary approach. It is developed a structural-functional approach to the study and modelling of the elements functioning of the complex dynamic system. It is shown that such an approach to the modelling allows taking into account the person's psychophysiological state in real-time. The complex dynamic system's viability in extreme conditions depends on the spatio-temporal coordination of the elements functioning.

**Keywords:** Complex Dynamic Systems, Dependability, Viability, Human Factors, Cognitive Aspects, Spatio-Temporal Patterns, Parametric Geometrization, Visual Analytics.

## 1 Introduction

The relevance of complex dynamic systems (CDS) dependability forms a significant increase in the complexity of systems (information, technical, physical, biological), which leads to an increase in the number, significance and consequences of the realization of the risks. The interdisciplinarity of the problem is caused by the complex influence on the CDS dependability and safety of a person, society and the environment. It determinates the search for new ways, methods and means of risk mitigation to improve the dependability of the systems functioning taking into account the cognitive aspects of digitalization [1, 2]. The interest in man-machine interaction increased with the rising integration of cyber-physical systems and Industry 4.0, which develops according to exponential laws. Industry 4.0 was marked by the rapid adoption of digital technologies that removed the barriers between the physical and biological areas. The next technological revolution (Industry 5.0) links system dependability to man-machine communication. A key trend of Industry 4.0 is technology and dehumanization, will be changed. Industry 5.0 aims to increase the role of a person, his cognitive and intellectual abilities. The unification of human and machine, the emergence of cobots and the complication of human perception of new robotic systems led to the appearance of interest in humans' cognitive and psychophysiological abilities. [1, 2]. Statistical data on man-made incidents evidence the influence of environment and activity stress factors on them. Their analysis indicates that the main reasons for the occurrence of unpredictable events are the features of man-machine interaction, which are associated with the diversity, nonlinearity and blurring of information flows [3, 4]. Accordingly, the account of human cognitive capabilities in risk management getting actual [5].

In this regard, the research aims to the problem of the complex dynamic systems functioning from the standpoint of individuality influence of human factor on their dependability, safety and viability.

The goal is to explore the influence of the human factor on the complex dynamic systems dependability under extreme conditions, to develop means for declining and estimating the human factor.

The objectives are: a) to show possible ways to take into account the influence of the human factor on the complex dynamic systems' dependability at the design stage; b) to develop unified means for the study of cognitive aspects of complex dynamical systems' dependability under extreme conditions.

## 2 Research Methods

Despite the significant resources that are invested in ensuring safety, the negative consequences of man-made disasters are growing. One of the dominant reasons is the local features of the CDS elements' functional characteristics manifest in extreme conditions caused by external and internal factors. At the same time, the problem of ensuring complex dynamic systems' stability in different ways and approaches are tried to solve [6, 7], which combine intellectual analysis and processing of scientific data based on system analysis and methodologies of foresight and cognitive modelling [8-12].

### 2.1 Viability as CDS Emergent Property

CDS include a large number of elements, which determines the variety of emergent properties of the system. These properties are advisable to consider from the standpoint of their influence on the system's dependability and safety. The CDS' emergent properties and the hidden relationships in it determine its dynamic stability, which A. Bogdanov called vitality [13]. He showed that unstable or unreliable elements can form a viable, stable and dependable whole, due to their emergent properties. Further, this idea was developed in the works of W.R. Ashby, S. Beer, R. Espejo, R. Harden, Razumovsky, Khazov [14-21]. Thanks to them, the theory of viability was developed for most types of CDS. Viability as a system's emergent property determines its functioning in extreme conditions and explains the existence of the "human factor" phenomenon and a large number of failures in complex systems controlled by a human. Thus, improving the CDS dependability depends on understanding the role of a person, his cognitive, behavioural and psychophysiological characteristics. Viability determines the system functioning in extreme conditions and explains the existence of the "human factor" phenomenon and a large number of failures in complex systems controlled by a human. Thus, improving the CDS dependability depends on understanding the role of a person, his cognitive, behavioural and psychophysiological characteristics. Note that taking into account the cognitive aspects of the CDS' viability in extreme conditions is important for the development of systems for intelligent support for systemic decision making and predictive analytics [22-26]. Thus, **the set of methods that we used to study CDS are the extreme principles of natural science** that underlie the theory of CDS viability.

### 2.2 Strategies for Managing CDS' Dependability

At the moment, CDS dependability management strategies are based on standardization. Updates and the appearance of new international standards demonstrate the importance of certain procedures to ensure dependability. So, additions appeared in the ISO 9000 standards series related to the control and management of the human factor. Along with the changes in the employe's working place, ergoecology develops, it is introduced the standards indicating the need to control and take into account the human factor – ISO 45001 (Health & Safety), ISO 31000 (Risk management). Finally, the IEC 60300 (Dependability management) standard combines management systems and system dependability analysis and is designed to reduce the risks of design (systematic) errors that are directly related to human activities. It is devoted to the procedures, the implementation of which should increase the dependability indicators of technical systems, most of which are directly related to human and the manifestation of the human factor. Thus, the lack of attention to the problems of man-machine interaction leads to an increase in the negative consequences of the human factor manifestation, which led to the need to introduce changes in safety standards. It should be noted that the dependability management strategies are based on the Japanese concepts of quality assurance: Total Quality Management, lean production, Six Sigma, Kaizen and KAIRYO, Gemba kaizen, Method 5S (Seiri, Seiton, Seiso, Seiketsu, Shitsuke), structured function QFD - (Quality Function Deployment), Re-engineering and EFQM Excellence Model. All of them directly use the principle of total control over human actions to avoid mistakes. And this is the problem because a human in the system should not make decisions that are not provided by the regulations. And it does not work in difficult and extreme conditions. Human activity according to clear instructions and the lack of opportunity to make independent decisions are rigidly ordered system, which over time tends to degrade. That is why the above models of man-machine systems do not work today, do not give the same result as it was several decades ago. **We used a number of standards ISO 9000, ISO 45001, ISO 31000, IEC 60300 to study the CDS.** It allowed us to analyze the operation of the CDS both from the standpoint of safety theoretical provisions and in real work conditions.

### 2.3 Account of the Influence of the Cognitive Distortions

The CDS dependability today directly depends on the human: his knowledge, perception of information, the presence of cognitive biases or distortions [27, 28]. There is a causal relationship between the CDS dependability and the human factor. According to the theory of practical bias by Scott A. Snook, the expected properties of a system always differ significantly from the obtained result [29-31]. The calculated dependability of the system is based on three basic assumptions: the absence of problems with software and hardware, the necessary training of a human and the observance of the rules by him. However, it is unreal to ensure three conditions at the same time. In this case, an inevitable shift towards real indicators occurs, the main reason for which is the influence of the human factor. At the same time, the application of human factor engineering to the development of CDS can reduce this “practical bias” and bring the result closer to the predicted one. Thus, the third method that **we used to study CDS is Scott A. Snook’s “practical drift” theory**.

### 2.4 Systemic Problems that are Induced by the Human Factors

The human factor as a source of problems is present in all aspects and stages of the life cycle of complex systems. Human is a source, receiver and analyzer of information, and he ensures the reliability, security and stability of the system. The essential challenges of digitization that directly affect complex systems and technologies safety are: features of man-machine interaction in extreme conditions; increasing information complexity of systems (technical, physical, biological); human cognitive abilities (individuality of perception, imagination and thinking), as well as cognitive distortions under stress. The human factor takes place on the stages: creation of complex systems and technologies; selection of relevant information; information processing, analysis and generalization based on previously set or formed evaluation criteria; decision-making based on the analysis of information and image-conceptual model; execution of the decision using a certain sequence of actions. To study the safety and reliability of CDS functioning in extreme conditions, **we adapted methods of systems analysis of the structure of the relationships based on Ishikawa diagrams**. This is the fourth method we used to study CDS.

## 3 Results and Discussion

### 3.1 Identification of Dominant Factors Influencing the CDS Reliability and Safety in Extreme Conditions

Thus, the human factor is a cause and a result of system problem in CDS operation at the same time. It is the reason because of systems and technologies are developed without taking into account certain human characteristics. It is the result since the limitation of human cognitive abilities leads to dangerous situations. Analysis of standards ISO 9000, ISO 45001, ISO 31000, IEC 60300 and statistics of the results of their practical application showed that the safety and reliability of CDS depend on standards, rules, algorithms and programs **only theoretically**. In reality, the neuroergonomic, psychophysiological and psychological aspects of human perception of information play a significant role. An adapted version of the Ishikawa diagram demonstrates this statement. (see Fig. 1) [32]. **The adapted diagram is the first result of the research.**

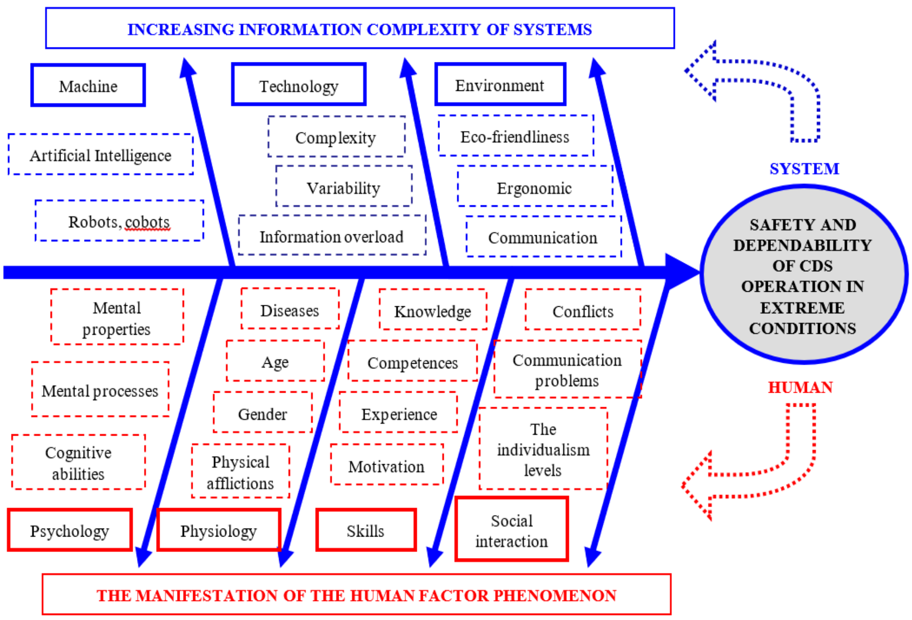


**Fig. 1.** Factors affecting CDS dependability and safety in extreme conditions (an adapted version of the Ishikawa diagram).

### 3.2 CDS Cognitive Model

Functional asymmetry of the cerebral hemispheres leads to latent cognitive problems that are genetically inherited or acquired during learning and activity. They manifest in difficult conditions of functioning and cause the manifestation of the "human factor" phenomenon. As a consequence, there is a violation of the basic communication relationships "human – human" and "human – hardware, software and environment" in complex systems controlled by a human. A cognitive model of a complex system in which the influence of the human factor prevails reflects this (transformed SHEL model) (see Fig. 2).

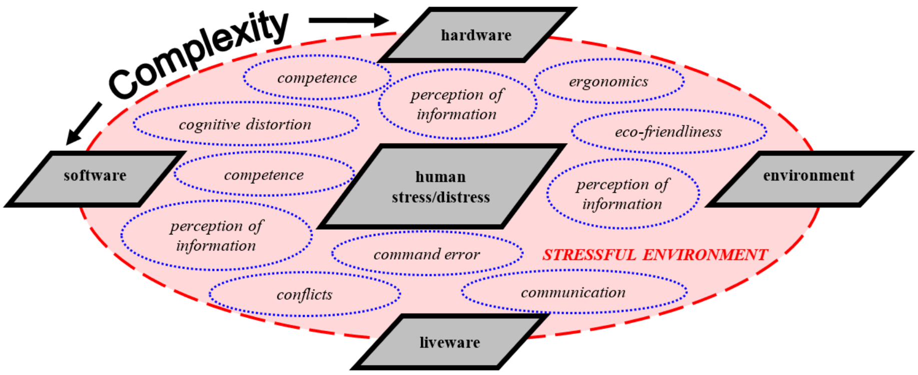


**Fig. 2.** CDS cognitive model.

The presented model is built on the basis of practical results of the application of the CDS viability theory principles and provisions of Scott A. Snook's "practical drift" theory for the research of CDS.

The basis of the problem is CDS, which often finds itself in extreme conditions. A key element of the problem is the spatio-temporal inconsistency of all information flows, which significantly complicates human decision-making. Thus, the main reasons for the decrease in the complex dynamic systems viability in extreme conditions are the problems of perception of nonlinearity, ambiguity and increasing complexity of information interaction. **The cognitive model of hidden relationships, in which the human factor predominates, is the second result of the research.**

### 3.3 The Strategies of Risk Management and Improving CDS Reliability

1. Distribution of random and systematic threats and risks. Eliminating systematic threats by using standards and creating viable systems based on human factors [29, 30].

2. Training of future complex dynamical systems developers. A transition to convergent learning with an emphasis on understanding the features of man-machine interaction is needed. The transition model can be represented as follows (see Fig. 3).

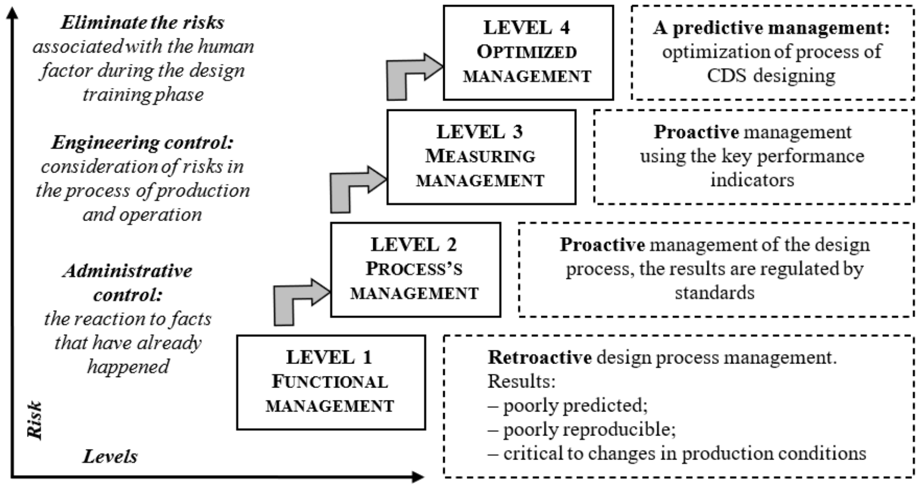


**Fig. 3.** An engineering training levels of a complex systems designer.

3. Interdisciplinary view on the "human factor" problem. An important moment in the "human factor" management is the collection and analysis of data on the CDS functioning. At the same time, when studying the CDS behaviour in extreme conditions, an additional question arises: the unification of the means of obtaining, processing and displaying information flows from each of its elements in one space. For today, using of a significant number of unrelated parameters, indicators and criteria from different areas in the study of the CDS functioning proved ineffectiveness. Thus, because the CDS dependability and safety directly depend on the human factor at all stages of the system's life cycle, then only an interdisciplinary view on the human capabilities in CDS creates the necessary basis for improving CDS' dependability and safety. In this case, interdisciplinarity means the intersection of such areas in the CDS study, as a person's psychological and physiological capabilities, his social capital, the technical perfection level of equipment and so on. This approach allows reducing the human factor impact through: study of the human perception cognitive features of information, according to the results of which it is possible to carry out a rational redistribution of the CDS functions; Determining the characteristics of the CDS behaviour in extreme functioning conditions; Taking into account a person's potential opportunities and existent limitations; Development of a person's professional skills based on an individual approach to learning. The interdisciplinary approach to the study of the "human factor" creates the conditions of managing by him [29-33]. From the above, the third result of the research follows: the use of methods of the human factor engineering allows to influence the most unpredictable factor in the functioning of the CDS. This means the possibility to manage risks, which will increase the reliability and security of the system as a whole.

4. An application of strategic proactive management principles by the "human factor". Today, for human factor management individual and system approaches are used. According to the individual approach, dangerous actions occur primarily due to

aberrant mental processes and countermeasures aimed primarily at reducing unwanted changes in human behaviour. According to the system approach, errors are a consequence of system problems in the system's organisational structure. Obviously, the most effective mechanism for the "human factor" managing can be created using both approaches. In this case, the role of the individual approach is to study the human activity cognitive aspects, and the system one is in the study of CDS behaviour in extreme conditions [29-33]. In fig. 4 shows the interrelations in the case of the implementation of the human factor proactive management and ensuring the CDS viability.

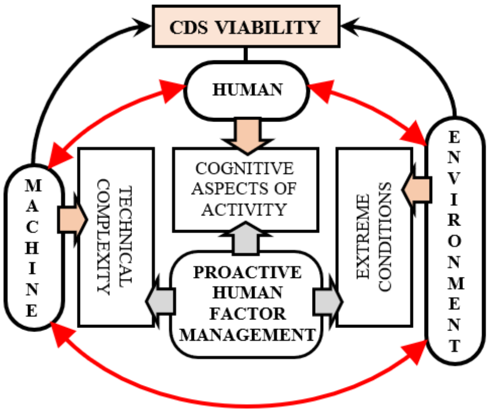


**Fig. 4.** Interrelations in the CDS in the case of human factor's proactive management.

The interconnectedness and cyclicity of the stages research and analysis of CDS dependability is shown in Fig. 5.

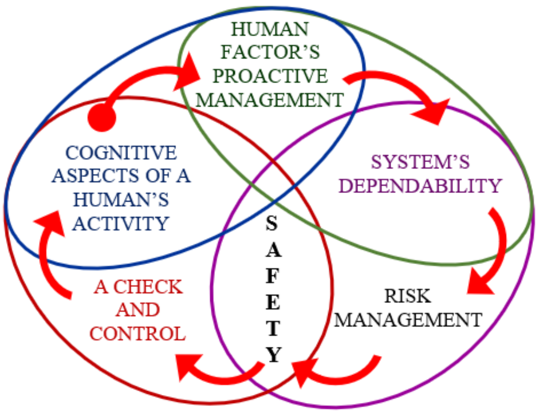


**Fig. 5.** Cyclicity of the stages of research and analysis of CDS dependability.

The starting point is the study and analysis of the human activity cognitive aspects. The research results determine the choice of methods for the "human factor" proactive management. The practical implementation of the selected management methods determines the degree of CDS dependability, which, in turn, leads to risks mitigation arising in the extreme conditions of CDS functioning. Improving the CDS dependability and risks mitigating arising during its functioning determine the level of system safety. The final stage is a check and control of the obtained results. Then the cycle is repeated until the required level of CDS dependability and safety is achieved. **The application of the principles of strategic proactive management of the “human factor” is the fourth result of the research.**

Structural-functional approach to the complex dynamic systems studying and modelling. Currently, there is no universal approach to the study and modelling of CDS functioning in extreme conditions. A specific feature of any approach is that it must rely on the notion of system, as well as use the general patterns of CDS’ construction, functioning and development. However, common for all approaches to systems research is the determination of the regularities of the system’s functioning and the system structure’s models synthesis through decomposition. Analysis and synthesis of the model the researched system should solve problems in practice. For this, it is necessary to analyse the functioning of all CDS elements including the operator in the polydisciplinary cognitive space that is proposed in the study [34]. The visualisation in the dynamic events space presented in the study made it possible to connect the following ideas: N. Wiener on the spatio-temporal ordering of the signal structure [35]; Packard and Takens on the reconstruction of the functioning model from a one-dimensional measured signal [36, 37]; Forester on feedback loops and response delays in system dynamics [38].

The synergy of these ideas is most evident in the uniqueness of the dynamic events space [39]. It is due to: interconnected dynamic parameters (state-speed-acceleration); geometric interpretation of the least action principle formulations; energetic interpretation of the least action principle.

Their complementarity simplifies the synthesis of models, the analysis of which can use fundamental laws and principles, as well as thermodynamic criteria. Information about the CDS viability is contained exactly in the individual features of its functioning [39, 40]. The structural-functional approach is based on the connectiveness of the dynamic events space [39-42]. It is due to the following facts: morphologically different dynamic systems are functionally subordinate to the same principles of physics and biomimicry; different dynamic systems operate according to the same laws; cognitive simplicity is inherent in models in the space of dynamic events; it is possible to visualise dynamic processes that obey the principle of detailed balance; reconstruction of the transformation of the 3D model is accompanied by natural decomposition.

Therefore, the approach is based on the interrelation between local distortions of the fractal signal of the object functioning of study and the features of its dynamics. That is why cognitive visualisation of different nature and scale dynamic processes in the same space underlies the cognitive approach to predictive analytics for safety purposes [40, 42]. In the space of dynamic events, the latent spatio-temporal features of fractal signals become available for cognitive analysis and synthesis. This allows you to identify relevant sources of information and predict their work in difficult conditions.

**Cognitive graphics of the CDS elements functioning.** It is proposed to visualise the dynamic structure of information flows of various nature in the parametric space of dynamic events to ensure physical, functional and information safety. In this space, a scalar time series (signal) of any nature is transformed into a topological 3D model. Its orthogonal projections are space-time signatures. Our researches [3, 36, 37, 42, 43] evident that **these signatures can be transformed into patterns. This is the fifth result of the current research.** The use of extreme principles of dynamics and biomimicry for the synthesis and analysis of 3D models of the CDS functioning of different nature has a high innovative potential.

## 4 Conclusion

The article analyses the interdisciplinarity and cognitive aspects problems of safety, dependability and stability CDS functioning in extreme conditions that are caused by digitalization and increasing dynamic complexity. A variety of concepts that reflect different aspects of dependability are analysed. It is shown that the system viability is the emergence property, which is important for modelling the CDS elements functioning of a different nature, including a human under external influence.

The leading role of the human factor in CDS safety, as well as its dependence on the increasing dynamic complexity of modern systems, lead to insufficient predictability of man-machine interaction. Predictive analytics directly depends on the diversity, nonlinearity and blurring of information flow, the perception of which depends on the person's psycho-functional state. It is shown that increasing the CDS viability in extreme conditions is in the plane of using the methods of human factors engineering in the design of the dynamic system, as well as in the synthesis and analysis of their models. The viability and dependability of dynamic systems are most dependent on various aspects of the human factor that manifest themselves at all stages of the CDS life cycle. At the same time, it is important to eliminate the action of systematic safety threats by applying an interdisciplinary resource approach based on proactive management.

It is shown that for the implementation of monitoring and forecasting the CDS functioning there is a necessity for the development of interdisciplinary tools for predictive analytics. These include a structural-functional approach to modelling the complex system behaviour and state. It was proposed a smart technology in the basis of which 3D visualisation of information flows in the parametric space of dynamic events. This technology makes possible to study and model the CDS functioning, including the assessment of the person's psychophysiological abilities in real-time. It is shown that the methodology of human factors engineering and the development of structural-functional approach to modelling make possible to foresee the problems of physical, functional and information safety, which reduces the risks of cognitive distortions.

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