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TRANSFORMATION OF THE ENGINEERING THINKING OF COMPLEX SYSTEMS DESIGNER

The article analyses the professional thinking of designers of the new formation. The study aims to explore the evolution of approaches to designing complex systems and ensuring their viability, as well as to form principles of hybrid thinking on a transdisciplinary basis necessary for viable systems developers of the future.

Keywords: *safety, complex dynamic systems, viable systems, human factor, design thinking.*

Introduction

One of the priority problems of modern complex energy, technological, transport, and information systems and technologies is the problem of safety, which is closely related to stability and reliability [1, 2]. The complexity of its solution is due to the need to consider nonlinear processes of human-machine interaction in the 'man – technology – environment' system, which are often impossible to predict. It gives rise to the phenomenon of the human factor: when a theoretically reliable system in practice goes into a state of failure due to erroneous actions or psychophysiological failure of the operator. Technologies and equipment are not dangerous as long as they do not involve a person, their activities, and their decision-making. Modern technologies, methods, tools, and equipment alone do not guarantee safety without the proper functioning of people – developers, personnel, employees, their awareness, and transdisciplinary knowledge [1–4].

Ensuring the safety of systems, technologies, the environment, and people requires highly qualified personnel present at every stage of the life cycle of any system or technology (developer, designer, user, and other). The development of digital technologies, the implementation of artificial intelligence, and automation have provided unprecedented opportunities to obtain results in technology safety. At the same time, this created an illusion of safety, as confirmed by sad statistics, especially in transport systems. This inconsistency leads to increased requirements for selecting people to make responsible decisions. The emergence of Industry 4.0 and 5.0, digital ecosystems and digital workplaces, robots, cobots, and artificial intelligence have marked an intensification of the problem of training specialists, engineers, and designers [1, 2]. The activities of designers in new conditions require qualitatively new thinking, skills, abilities, and tools. On the one hand, the development of digital technologies, the implementation of artificial intelligence, and automation have provided unprecedented opportunities to obtain results in technology safety. On the other hand, digitalisation, automation, and advances in transport safety cause a false sense of security and safety. In particular, there are reports that the intensity of interactions in the transport environment today quite often does not correspond to the person's psychophysiological, cognitive, and physical capabilities. Failure to take into account the individuality of a person and their psychological and psychophysiological capabilities leads to statistics that in 87–93% of cases in road transport systems, the cause of accidents is the human factor. This problem is particularly acute for transport systems as highly complex technological and social structures aimed at ensuring the efficiency and safety of an entire sphere of human life. Risks increase if we do not account for the peculiarities of the nature of the human factor in the design, logistics, and operation of transport systems, 'driver – vehicle – road – environment' systems, and their elements. Therefore, ensuring the safety of the environment, humans, technologies, and equipment requires highly qualified people present at all stages of the life cycle of any system. Accordingly, the search for solutions in this area is very relevant.

Transport systems are complex technological and social structures focused on ensuring the efficiency and safety of transport operations and playing an essential role in the economy. They are actively developing and introducing new technologies to improve mobility, reduce their environmental impact, and provide users with a higher level of service. The problem of ensuring the safety of transport systems is in the plane of transdisciplinarity since transport technologies are interdisciplinary solutions and innovations to improve the transport systems' safety, efficiency, and sustainability in such fields as transport, human factors, infrastructure, management, and maintenance. The problems of creating and managing transport systems and technologies are very multifaceted. They require a broad worldview and convergence of knowledge, including safety problems (road accidents, vehicle safety, environmental safety); transport infrastructure problems (integration of different modes of transport and logistics); environmental problems of different directions; information flow management problems (data management, digital technologies, digital transformation); economic problems; social problems (person in the 'driver – car – road – environment' system, systems management). In other words, the creation and management of transport systems face various problems, including technical, organisational, social, and environmental aspects.

Today, the designers' creativity is transforming in a system of new technologies, revolutionary technological changes, and a radical revision of civilisational strategies. The emergence of Industry 4.0 and Industry 5.0, digital ecosystems and jobs, robots, cobots, and artificial intelligence have marked an intensification of the problem of training specialists, engineers, and designers of viable systems of the future [5]. Therefore, it is necessary to pay particular attention to developing educational environments to create such viable systems. It is imperative to form and develop a specific type of engineering thinking, which is the most crucial component of modern human activity: engineering, managerial, and social.

A modern specialist today must compete not only with other people but also with artificial intelligence and robots. Therefore, we are talking about creating hybrid thinking based on ergonomic thinking and environmental consciousness, engineering thinking, which is fundamentally necessary for a modern specialist designing human-machine systems. The core elements of hybrid engineering thinking are the ability to see contradictions (logical, technical, physical) and a broad scientific worldview, which is impossible without interdisciplinary knowledge. It is only possible to achieve through a transdisciplinary approach to combining engineering sciences, information technology, psychology, bioengineering, neuro- and cognitive sciences, which allows for creating conditions for ensuring the safety, reliability, and sustainability of designed and operated complex human-machine systems [5–7].

In particular, emphasis should be on developing the ergonomic component of hybrid thinking for everyone whose activities concern the life cycle of a complex system. Ergonomic thinking is a whole system of views on the development of complex human-machine systems and the role of humans in them. It is an understanding of the complex processes of human-machine interaction; and an ability to predict risks and develop systems with a preliminary consideration of these risks. In the end, ergonomic thinking for a specialist of the present, and even more so of the future, along with ecological and critical thinking, is a sign of education and the foundation of a highly qualified specialist [3, 8].

It is necessary for an engineer to have a wide range of knowledge and skills and to have a multidisciplinary understanding to design complex systems. An engineer must understand a system approach and be able to analyse a system from the point of view of its functionality, structure, and relationships. Digitalisation, artificial intelligence, and the Internet of Things are all used today by engineers to create reliable and safe systems for people, society, and the environment. Therefore, the question of a person's thinking and knowledge is crucial.

Literature Review

Engineers' thinking has changed significantly over the past 100 years, driven by technological advances, social values changes, and cultural trends. In the early 20th century, engineers focused on mechanical and electrical design using classical methods and mathematical models. With the development of information technology in the second half of the 20th century, engineers became increasingly oriented toward computer modelling, numerical methods, and analytical programming. During this period, the concepts of a systemic and integrated approach to design also actively developed, which led to an increase in the complexity of engineering systems and their functionality.

From the history of the development of ergonomics, we know how the ideas of increasing the safety and efficiency of human activities, workplaces, and the human environment have transformed. Many ergonomists have devoted their research to human factors, neuroergonomics, and human error (J. Dul, R. Bruder, J. R. Fedota, R. Parasuraman, R. Mehta, J. D. Lee, and C. D. Wickens). In the 50s of the last century, Japanese scientists, in collaboration with American scientists, proved the need to create and develop a certain 'quality' thinking among all participants in the production process to ensure quality and technological breakthrough (W. Ed. Deming, P. Crosby, A. V. Feigenbaum, K. Ishikawa, G. Taguchi, Sh. Shingo, F. W. Taylor, and J. M. Juran). Also, increased demands on technology and the problem of its perception by humans led to the emergence of engineering psychology.

In 1990–2000, as a result of the analysis of the Chornobyl disaster and the role of safety culture there, the importance of developing a 'safety' mindset became clear. It became a painful discovery of the critical role of the human factor in the safety and development of the terrible events of the Chornobyl disaster and many other accidents and catastrophes. The development of organisational ergonomics and human factor engineering was necessary to master the human factor and improve the safety of complex systems in critical areas of life.

Researchers such as D. Biriukov, A. Martiusheva, Yu. Skaletskyi, L. Yatsenko, and A. Zaporozhets considered mastering the security culture by the population of Ukraine as an acute social problem. Many scientists and specialists in occupational safety, psychology, sociology, and other connected fields have studied the safety culture problem. British psychologist J. Reason significantly contributed to studying human safety factors and developed the 'accident ladder' model. American psychologists Ed. Deci and R. Ryan studied motivation and its connection with safe behaviour in the workplace. S. Dekker is a human factors and safety researcher who has written on human error and safety culture in air and other modes of transport. E. Hollnagel is a security and risk management researcher and the author of the 'next generation security management' theory. Research in this area takes place in various countries and includes both academic and practical aspects related to developing workplace safety policies and safety programs. During the same period, such areas as ergoecology and green ergonomics appeared in ergonomics. Their core principles are the study and analysis of the interaction of the human-machine system with the environment. For example, E. Hollnagel researches security, risk management, and human error analysis in work environments. R. Thomas, D. Redford, and P. Hughes are workplace safety and health experts.

The emergence of information technology ergonomics aimed to develop principles for creating digital ergonomic products. The following people devoted their research to this area: K. Mosier, researcher and consultant on cognitive ergonomics and human factors in information technology; E. Tufte, information design and data visualisation researcher; D. Norman, the author of 'Everyone's Design' who studies ergonomics and information technology.

Today, the digitalisation of work operations directly affects occupational safety issues. Digital technologies have changed the safety requirements, which has led to the emergence of a new labour concept, 'Work 4.0'. In today's digital transformation age, engineering thinking is becoming increasingly multidisciplinary and integrated. Engineers widely use machine learning, artificial intelligence, and data analytics to optimise design, resource management, and decision-making. In addition, a vital trend is to emphasise sustainability, safety, and social considerations in design.

Over the past 20 years, increased requirements for the organisation of the process, the presentation of information, and its perception by humans have led to an increase in the complexity of human-machine interaction problems and, as a result, to the development of neuroergonomics and digital ergonomics. Today, there is already talk about information perception problems due to increased demands on human decision-making and modern features of thinking generated by clip thinking, distance learning, and cognitive distortions of the individual [5, 7].

That is, we see that the constant increase in requirements for technology, people, processes, and systems was not able to solve safety problems, and some technological innovations led to the development of their new aspects (as the problem of automation led to the emergence of new human operator errors) [5, 7]. Also, returning to the roots, V. I. Vernadsky, regardless of the boundaries of individual sciences, laid the foundations of a transdisciplinary approach, which is very important for education in the digital world. Transdisciplinarity is the basis for the transition to predictive safety management at various levels – environmental, economic, technological, and social [5–10].

Aim and Objectives

In this regard, the article aims to analyse the evolution of approaches to the design of viable systems and the formation of the principles of hybrid thinking of designers on a transdisciplinary basis.

Objectives of the study are:

– forming principles for the development of metaergonomic thinking to optimise the activities of designers;

– drawing attention to the problem of training developers of human-machine systems and creating a knowledge system that is adequate to the complex demands of the twenty-first century.

Discussion of Results

Problems of ensuring the viability of complex systems. Industry 4.0 and the transition to Industry 5.0 entail developing and operating highly complex human-machine systems. New issues, a new level of human interaction with robots, artificial intelligence, and decision-making will create new risks, such as new requirements for humans for the functioning of complex human-machine systems, cognitive distortions and errors, and failure of a person as an element of the system due to information complexity. Digitalisation and automation lead to a constant growth in the number of information sources and the diversity of information flows, which increases the complexity of their understanding (identification, definition, visualisation). As a result, it complicates managing and understanding complex systems, the manifestation of the phenomenon of human factor, accidents, and catastrophes. Indeed, at all life cycle stages, the safety of complex systems directly depends on selecting relevant information, cognitive perception, and analysis by the decision maker.

The problem of the safety of complex human-machine systems remains a serious challenge, especially for transport systems. Negative statistics of road accidents and transport events, poor infrastructure, lack of advanced technologies in transport systems, non-compliance with safety standards in the production and operation of vehicles, and environmental and social risks are all indicative of a low safety culture in this area and the need for systemic changes. It is clear that the safety and stability of human-machine systems directly depend on the person: their psychophysiological characteristics, cognitive capabilities, motivation, and motives of behaviour. It means that safety depends on the ability to manage the human factor, which is a complex transdisciplinary problem [1, 3, 4, 6, 7].

There are several approaches, methods, and strategies to reduce human error risks and ensure the viability of complex systems. For a long time, the prevailing approach was an individual-based one, which focused on the mistakes of individual people: that is, the assumption was that all problems were due to 'bad' people (their illiteracy, negligence, inexperience). However, decades of analysis of aviation and human-made accident statistics have shown the effectiveness of the predictive approach and strategic thinking in the design of complex systems. The strategy for preventing operator errors relies on eliminating errors in the system already at the design stage, and the predictive approach allows us to foresee their occurrence. Thus, the focus has shifted from the human performer to the human designer. In other words, creating fault-tolerant systems results from using a systems approach, which ensures increased resistance to human errors. In this way, we attempt to foresee the worst possible scenarios and predict opportunities to avoid their development. Japanese experience and quality theory have shown that organisational culture is crucial, forming the general concept of safety culture, and training is its basis.

That is why the key to creating viable systems and managing human factors is the presence of specific systems engineering thinking in the designer of human-machine systems. Its characteristics include a holistic perception of objects and phenomena, their connections, and the ability to 'see' risks and predict trajectories and consequences. In addition to mastering the necessary professional knowledge, the designer of human-machine systems must learn to overcome the inertia of thinking, identify and resolve technical contradictions, generate non-standard technical ideas, and master the skills of multivariate problem solving and its objective assessment [5, 6, 9].

The problem of the viability of human-machine systems in complex conditions is directly related to the peculiarities of the interaction of elements of different natures within the framework of one system. They depend on the individuality of the functional state of the system elements and the hidden connections between them, which give rise to systemic problems. It leads to information redundancy and complexity. The UN recognises digitalisation as one of the four main threats that humanity faces shortly. Indeed, digitalisation creates not only space for the development and improvement of human-machine interaction but also problems that require study, such as an increase in the likelihood of technological failures and human-made disasters, the threat of cyber attacks, and automation problems closely related to the human factor. Digitalisation and automation create a false sense of security and the feeling of being able to solve any complex issue with the help of artificial intelligence. The consequence of digitalisation and changes in the perception of information is fragmentation and illusion of knowledge, clip thinking, and cognitive distortions [5, 7, 9, 10].

Therefore, interdisciplinary solutions using cognitive psychology and ergonomics, computer science and control engineering, and human factors engineering are required to design effective viable systems. After all, the basic concept in human factor engineering is human error, which today is perceived not as a cause but as a consequence of unsystematic training and process organisation. According to Scott A. Snook's 'Practical Bias' theory, the actual viability of complex systems differs significantly from expected ones as it stems from assumptions that are difficult to predict precisely because of the influence of human factors (Fig. 1).

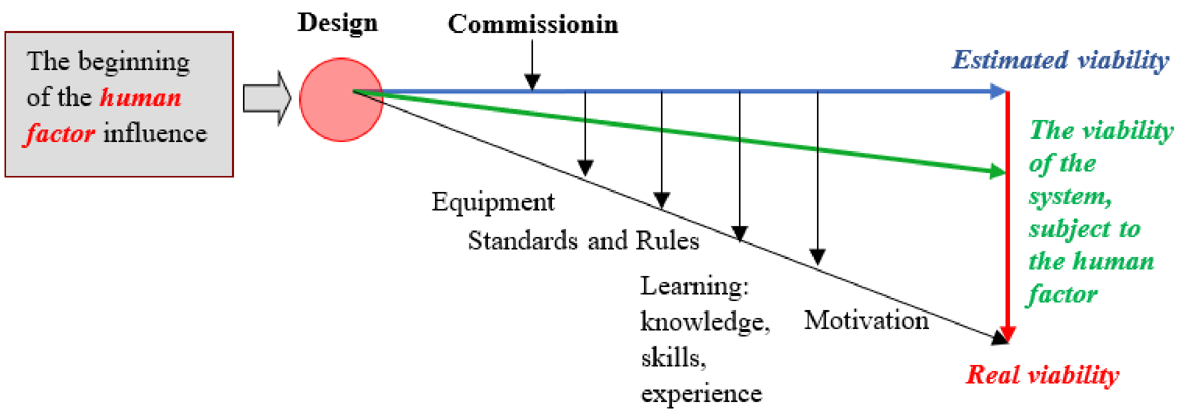

Fig. 1. Practical displacement of the expected parameters of the viability of a real system

Such a shift in real properties is inevitable in the system. Accounting for the influence of the human factor can reduce this ‘practical bias’ and bring the result closer to the predicted one.

In other words, people introduce unpredictability into the system through their mistakes, ignorance, and lack of safety culture. Human error at any stage of the life cycle of a system or technology is one of the main reasons for the occurrence of risky events. Designing a viable system involves identifying potential hidden failures and creating a structure where human error is impossible and does not pose a threat. At the same time, the major problem is the training of specialists considering current and future challenges.

Design thinking of a designer as the path to creating viable systems.

Features of design thinking. It is increasingly common to discuss design thinking based on cognitive abilities, experience, predictive and practical knowledge, and a designer’s skills [10–13]. Let us note that design thinking is a methodology for solving complex problems of a different nature – engineering, business, and others – based on a balance of creative and analytical thinking. In his book ‘Change by Design’, Tim Brown described the tension between the triad of ‘feeling, intuition, inspiration’ and ‘rational, analytical, systemic’ that underlies design thinking [13]. Note that this problem-solving approach reflects the essence of human life, interpersonal relationships, and self-discovery because, in all these areas, a person has to make choices and seek a balance between the sensual and the rational. Accordingly, the formation of design thinking in a modern person is the path to a more developed, perfect society. Design thinking is necessary to achieve the crucial goal of aligning human needs, resources, and technical and technological capabilities. Design thinking relies on being intuitive, identifying patterns, and creating ideas based on emotionality and functionality [12–14]. It is both science and creativity, emotional and rational, physical and mental.

Design thinking is a specific way of solving and looking at a problem. It is the key to solving complex problems, creativity, and innovation in science – for finding similarities between different things; in art – when searching for differences between similar things; in design – when creating a possible whole from impossible parts. In essence, design thinking is an approach to solving problems crystallised in design and combines a holistic, user-centred approach with rational and analytical research – all intending to create innovative solutions [11–14].

Eco-ergonomic thinking. Our works [3, 5, 7, 8, 14] show a need to pay particular attention to developing specific eco-ergonomic thinking, an essential element of safety culture. A required feature of eco-ergonomic thinking is recognition of the exceptional priority of environmental problems and problems of human-machine interaction relative to all other human activity problems.

Ergonomic thinking, combined with a human-centric approach and environmental thinking, creates space for a safety culture. The human-centric approach, on which ergonomics, engineering psychology, usability, UA/UX design, and a dozen disciplines at global engineering universities rely, is the basis for risk-oriented thinking. The concept of a human-centric approach focuses on a person, a worker, a manager, a consumer, and their desires and capabilities. It allows us to understand the processes of human-machine interaction, predict risks in these systems, and plan the development of systems with a preliminary consideration of these risks.

Strategic thinking and vision. The development of design thinking in terms of identifying risks, predicting, and forecasting consequences is strategic thinking and vision. Forward-thinking and strategic foresight are the basis for solving future problems and designing systems of the future and human activity in them. This way of thinking implies developing and searching for all possible scenarios of event development and preparing for them despite their likelihood. It is a technology that creates competitiveness and efficiency, safety and reliability, viability and resilience of systems and environments. This thinking type underlies the creation of reliable aviation, energy, and economic systems.

Hybrid thinking and hybrid worldview. Hybrid systems have entered our lives. To study modern human-machine systems, since 1992, the concept of a hybrid intelligent system has been in use as a tool of synergetic artificial intelligence, which makes it possible to simulate the effects of interaction, self-organisation, and adaptation observed in systems where nature, man, and technology are closely intertwined.

Hybrid thinking and a hybrid worldview are the next steps in the philosophy of perception of the world around us and the design of hybrid systems within it [13–15]. The 21st century has brought hybrid thinking, warfare, and learning due to the increasing complexity of systems and problems. Ray Kurzweil [15], in the talk ‘Get Ready for Hybrid Thinking’ and in the book ‘How to Create a Mind’, connects human intelligence with artificial intelligence, describing the phenomenon of brain virtualisation. The global environmental and social challenge is a crisis of values, ideas, views, and knowledge and, therefore, first and foremost, a crisis of education [15].

Hybrid thinking is a concept that involves combining different types of thinking and approaches to problem-solving to achieve more effective results. It combines the elements of analytical, creative, systematic, critical, and intuitive thinking. It emphasises the need to use a variety of ways to solve problems instead of limiting yourself to a single approach. The development of hybrid thinking is only possible with harmony/ balance between the emotional and rational and the formation of synergy between creativity and productivity. Today, it is already clear that the best performers for solving nonlinear problems under conditions of uncertainty are people with hybrid thinking.

Examples of hybrid thinking are analytical-creative thinking (the ability to analyse information analytically and at the same time apply creative methods to find innovative solutions), critical systems thinking (the ability to evaluate a situation critically and at the same time consider it from a systemic point of view, taking into account relationships and consequences), transdisciplinary thinking, and integration of rationality and emotionality (combining logical, rational thinking with emotional intelligence to make more balanced and informed decisions). This concept highlights the importance of flexible thinking and adaptability to different scenarios and conditions.

The multidimensionality of hybrid thinking includes:

– the ability to integrate different ways of thinking, jump between them, and coordinate them to achieve a universal goal (Milan Guenther);

– the ability to integrate and switch between different ways of thinking (Sascha Bardua, 2018).

– conscious blending of different opinion branches to discover and develop opportunities previously invisible within the status quo (Forbes, 2009).

Effective thinking system. The synergetic effect comes from combining types of thinking into a single system, the effective thinking system [16]. In 2009 [13], Brown described design thinking as ‘a human-centred approach to innovation that draws on the designer’s toolkit to integrate the needs of people, the capabilities of technology, and the requirements for business success’. According to Herek Loei, design thinking integrates desirability (human aspect), viability (business aspect), and feasibility (technical aspect).

They complement each other to achieve successful results in solving complex problems by co-creating more meaningful, human-centred experiences. Fig. 2 shows the onion model of the hierarchy of thinking types.

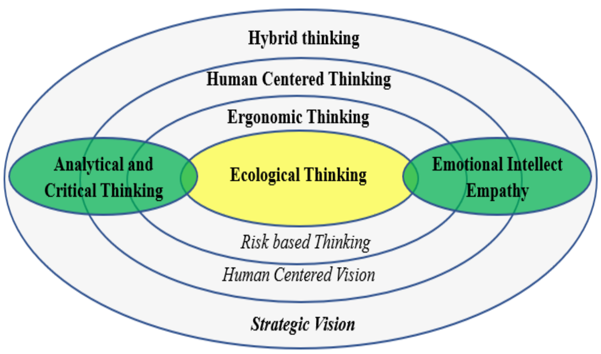

Fig. 2. The onion model of the hierarchy of thinking types

Consequently, convergence of knowledge and application of interdisciplinary approaches and strategies are needed to ensure the safety of modern systems (human-machine, socio-technical). It is necessary to develop new design thinking and new tools to learn to think, live, and act under the new conditions of the time. After all, the beginning of the 21st century was associated with a change in paradigmatic attitudes in education. The focus has shifted from just technology to people. An integral system of views on the development of complex human-machine systems and the role of humans in them is crucial. Technical systems are increasingly becoming cognitive, and the peculiarities of human thinking, methods of learning, and cognition have turned out to be very important.

Transformation of design thinking to create viable systems.

Development of metaergonomic thinking. Efficient and competitive design today is impossible without complex systems thinking [17–19]. However, when designing complex systems (control systems, technology, equipment, furniture), the developer must first see the people and their functioning/ existence/survival in this system. In an era of rapid development of technologies and capabilities, metaergonomic thinking as a specific type gives today an advantage and competitiveness to designers and planners [18, 19].

Design thinking integrates desirability (the human aspect), viability (the business aspect), and feasibility (the technical aspect). Fig. 3 shows the structure of metaergonomic thinking. The central idea is to maintain a balance of ecological principles (existence in an ecosystem), ergonomic principles (human activity in an ecosystem), and human factors principles (error and decision-making).

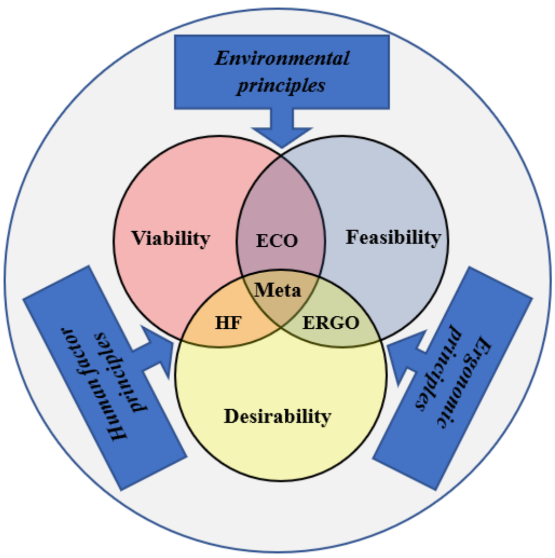

Fig. 3. Metaergonomic thinking system framework for creating viable systems

Today, more and more attention goes to the formation of design thinking in the learning process based on the designer's cognitive, predictive, and practical knowledge and experience [5, 11, 14, 17]. The methodology for solving engineering, business, and other problems requires a balance of creative and analytical approaches. Interestingly, design thinking opens up new non-standard solutions to complex design problems of humans and society's existence.

Metaergonomics contains a triad 'ergonomics – human factors engineering – engineering psychology' [5, 7, 10, 11]. It focuses on designing and optimising activities in extreme environments that require critical thinking.

Under normal conditions, the optimisation of activities proceeds according to the laws of mutual adaptation and transformation. The current state of ergonomics is associated with a shift in emphasis from adapting technology to humans to forming a human-machine symbiosis.

The basis of modern metaergonomics is no longer only the adaptation of the system to the capabilities and limitations of a person but a whole system of views on the development of complex human-machine systems and the role of humans in them; this is an understanding of complex processes not only of human-machine interaction but also of human-robot interaction; the ability not only to predict risks in these systems but also to purposefully go one step ahead and predict possible challenges and plan the development of complex systems taking these challenges into account. The human operator should be selected, trained, provided with information, provided electronic support, supervised, and removed where justified and possible. The system's design must be viable and resistant to human states, actions, and intentions. In other words, the viability of complex systems depends on the designer, not the one who ensures the functioning [5, 7, 10–12].

Transformation of thinking. The activities of developers/designers should create a safe, effective, and resilient environment. That is why design education is critical for innovation, competition, growth, and development. The impact of algorithms and artificial intelligence in modern society has created a new reality that negatively affects mental health, thinking, human cognition, and interpersonal communication. The transdisciplinary approach [7, 18] will contribute to the deconstruction of disciplinary knowledge through the convergence of specific sciences and technologies, namely:

– formation of hybrid design thinking (bionics, engineering psychology, among others);

– formation of balanced creative and critical thinking;

– expansion of worldview (disciplines such as metaphysics, metaergonomics, topology);

– mastery of the principles of risk forecasting (human factors engineering, viability theory, risk theory, environmental and ergonomic directions).

To design complex dynamic systems that are efficient, viable, and sustainable, one needs to be confident in the following aspects of hybrid thinking:

– Technical Thinking: to implement technically complex solutions, developers must have deep knowledge of technology, programming languages, architectural patterns and development tools, ecology, and ergonomics;

– Business-oriented Thinking: developers must contribute to creating a product that meets business requirements and provides value;

– Systems Thinking: understanding system relationships and the overall system structure;

– Hybrid Design: ability to combine different styles to achieve the optimal balance between flexibility and performance;

– Ability to Innovate: developers must be open to new technologies, ideas, and approaches to create competitive products that meet today's demands;

– Interpersonal Skills: effective communication with other team members, customers, and end users. Communication is a core element in the successful development of complex systems.

Hybrid thinking to create complex systems requires adaptation to different requirements and contexts. Creating viable systems necessitates the integration of various technologies and methodologies and constant approach updates per changing requirements and capabilities [7, 10, 12, 18, 20–24]. Having a hybrid developer mindset means being able to:

– evaluate the system as a whole and identify vulnerabilities and security risks. Think in the direction of finding weak points and potential points of attack. It allows one to create systems in which components interact securely, taking into account possible attacks and threat scenarios;

– be focused on analysing potential risks from the very beginning of the design and provide for potential threats, work to prevent attacks;

– introduce new security technologies that require constant training and adaptation;

– communicate, as the effective exchange of information allows resolving problems.

Thus, the hybrid thinking of developers, their training, and awareness play an essential role in creating complex technical systems with high security. Security becomes integral to development when developers have specific mindsets and skills. Fig. 4 shows a five-level model for the growth of 'engineering maturity' of a designer of complex dynamic systems in the transdisciplinary training process.

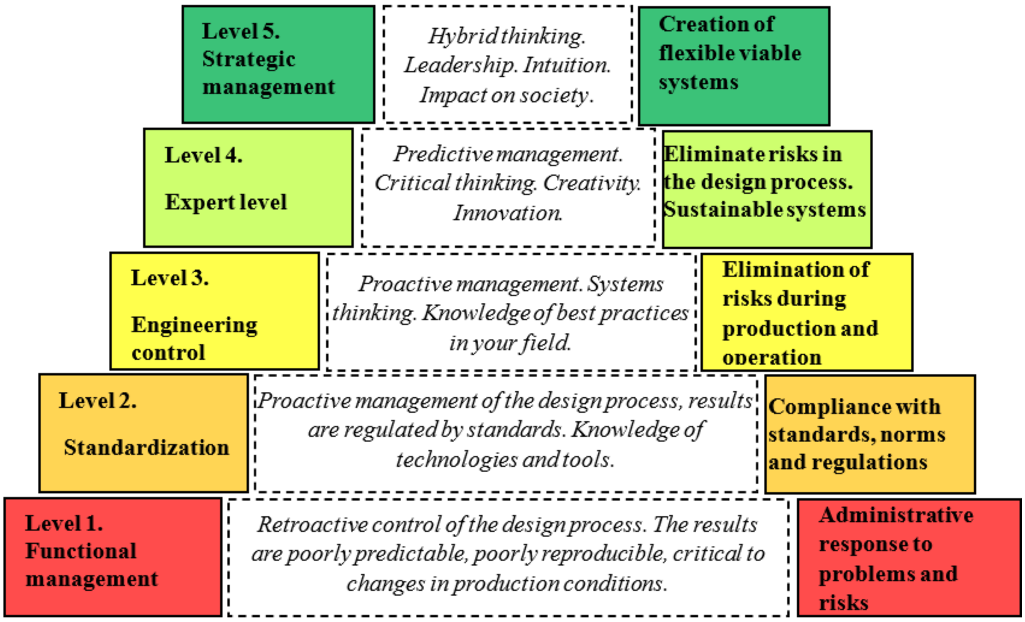

Fig. 4. Five-level model for the growth of 'engineering maturity' of a designer of complex dynamic systems

Thus, the transformation of the thinking of a modern specialist to create effective viable systems requires the formation of hybrid transdisciplinary thinking, which means:

– Transdisciplinary education to understand the connection between various system components;

– Experience: working on real projects develops skills in solving real problems;

– Flexibility of thinking: one needs to adapt to changes and look at problems from different points of view;

– Systems Thinking: one needs to consider the system as a whole and understand the structure, connections, and internal and external environments;

– Development of technical and engineering intuition;

– Stimulating creative thinking: searching for new and innovative approaches; skills of generating ideas and solutions;

– Technical leadership training: one needs to not only be able to solve technical problems but also effectively command and manage development processes;

– Ethics and Responsibility: developing moral thinking is essential to creating socially and culturally sensitive systems;

– Adaptability and Learning: continuous learning is vital as technology changes;

– Leadership and Motivation: developing leadership and self-motivation skills is imperative.

Transforming the thinking of a modern specialist to create effective viable systems requires hybrid solutions – a combination of technical and non-technical skills, as well as an understanding of the systemic aspects of problems and their solutions [7, 9, 10, 14, 18, 22, 24].

Conclusions

The solution to the problem of ensuring the viability of systems lies in the intersection of human factors engineering and dynamic systems engineering. It is necessary to develop a new hybrid, meta-ergonomic thinking and new tools to learn to think, live, and act under the new conditions of the time.

The development of digital technologies, the application of artificial intelligence, and automation have provided unprecedented opportunities to ensure technology security. Since the digitalisation of technologies, automation of complex dynamic systems, and the unique capabilities of Industry 4.0 in a linear world do not work in a real hybrid subject environment, a solution to the security problems of complex systems requires the framework of a transdisciplinary approach. We analysed the evolution of approaches to complex systems design and ensuring their viability to form the principles of hybrid thinking on a transdisciplinary basis, which is necessary for developers of future systems. We suggested a five-level model for the growth of the 'engineering maturity' of a complex dynamic system designer. We also proposed the principles of the formation of hybrid thinking on a transdisciplinary basis and the principles of the development of metaergonomic design thinking to optimise the activities of a developer of complex systems.

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ТРАНСФОРМАЦІЯ ІНЖЕНЕРНОГО МИСЛЕННЯ ПРОЄКТУВАЛЬНИКА СКЛАДНИХ СИСТЕМ

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Розвиток цифрових технологій, використання штучного інтелекту, автоматизація надали безпрецедентні можливості для отримання результатів у сфері безпеки технологій. Водночас це створило ілюзію безпеки, що підтверджується сумною статистикою, особливо в сфері транспортних систем. Така суперечливість спонукає науковців і промисловців розробляти нові, прогресивні, більш безпечні технології та ставить дедалі суворіші вимоги до відбору людей, які приймають відповідальні рішення. Поява Industry *4.0 та 5.0, цифрових екосистем та робочих місць, роботів та штучного інтелекту ознаменувала загострення проблеми підготовки фахівців – проєктувальників складних систем. Забезпечення безпеки потребує високої кваліфікації людини, що присутня на кожному етапі життєвого циклу будь-якої системи чи технології (розробника, проєктувальника, користувача та ін.). Зокрема, формування в проєктувальників якісно нового гібридного мислення, а також відповідних навичок, умінь, засобів.*

Стаття присвячена аналізу професійного мислення проєктувальників складних систем нової формації. Проаналізовано комплекс проблем, що стосуються специфіки процесу формування необхідного сьогодні типу інженерного дизайн-мислення як засобу адаптації до технологічної революції. Основною метою роботи є аналіз еволюції підходів до проєктування життєздатних складних систем та формування принципів гібридного мислення проєктувальників на трансдисциплінарній основі. Завдання роботи: формування принципів розвитку метаергономічного мислення для оптимізації діяльності проєктувальників; привернення уваги до проблеми підготовки розробників людино-машинних систем та створення у них системи знань, адекватної складним запитам сучасності. Запропоновано п'ятирівневу модель зростання «інженерної зрілості» проєктувальника складних динамічних систем. Запропоновано принципи формування гібридного мислення на трансдисциплінарній основі та розвитку метаергономічного мислення для оптимізації діяльності розробника складних систем.

Ключові слова: *безпека, складні динамічні системи, життєздатні системи, людський чинник, дизайн-мислення.*