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THE IMPACT OF DIGITAL TECHNOLOGIES INCORPORATING ARTIFICIAL INTELLIGENCE ON THE INDUSTRIAL DESIGN PROCESS (The impact of digital technologies incorporating elements of artificial intelligence on the industrial design process, as well as on the form, structure, and characteristics of modern technical systems of varying levels of complexity)

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Abstract

The article examines the impact of digital technologies incorporating artificial intelligence elements on industrial design and the evolution of technical systems. Transformations in design processes enabled by CAD systems (SolidWorks), virtual simulation, and TRIZ methodologies are analyzed. The laws governing the development of technical systems, Gudolin's classification, and the concept of the Ideal Final Result are reassessed in the context of digitalization. Using examples of liquid homogenization devices, the integration of digital modeling, new materials, and intelligent control systems is demonstrated. It is concluded that AI is becoming an active component of the innovation process, reshaping approaches to engineering design and patenting of technical solutions.

Keywords: *Technologies; Smart technologies; Smart manufacturing technologies; Current level of manufacturing process development; Classical methods of processing raw materials, digital technologies, and new composite materials; Non-contact electromagnetic resonance testing; High-speed metallization technology; The process of achieving the ideal final result; Auxiliary materials and tools whose combined use makes it possible to approach the achievement of an ideal final result; Globalization of manufacturing processes; The expansion of areas of application follows a fan-shaped pattern and gradually spreads to numerous related processes, including both manufacturing and all auxiliary operations and processes*

Introduction:

Until relatively recently, the majority of inventions were characterized by a rather localized scope, and the positive effects resulting from their implementation could be identified and evaluated with relative ease.

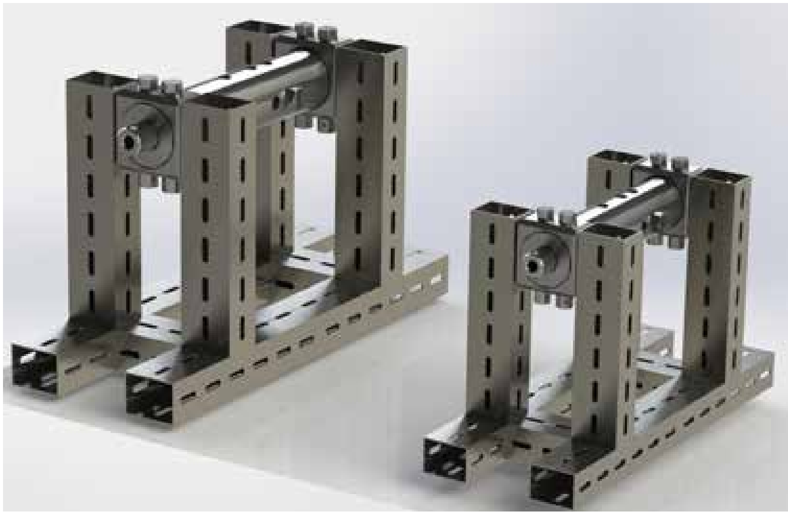
Today, due in large part to the significantly expanded capabilities of modern computer-aided design and engineering software, the outcomes of the design process make it possible to assess and classify the originality, novelty, and innovative value of newly developed technical systems with a substantially higher degree of accuracy, regardless of their level of complexity.

The integration of advanced digital technologies, including systems incorporating elements of artificial intelligence, machine learning algorithms, simulation environments, and virtual engineering platforms, has fundamentally transformed the processes of industrial design, engineering analysis, and technological innovation. Modern design tools allow specialists not only to develop complex technical systems but also to predict their operational characteristics, evaluate alternative design solutions, optimize resource utilization, and identify potential deficiencies long before physical prototypes are manufactured.

As a result, the process of creating innovative technical systems has become increasingly multidisciplinary, combining engineering, mathematical modeling, digital simulation, economics, logistics, and data analysis into a unified technological framework. This transformation has significantly increased the effectiveness of innovation activities while simultaneously raising the standards applied to the evaluation of novelty, technical originality, and practical applicability of engineering solutions.

Under these conditions, the influence of artificial intelligence–enabled digital technologies extends far beyond traditional design activities, affecting the structure, functionality, operational characteristics, and overall evolution of modern technical systems across a wide range of industrial sectors.

Figure 1. *Presents a design model of a device intended for the real-time homogenization of fuel mixtures*



As can be seen from the figure, the design process also simulates the characteristics arising from the selection of structural materials, as well as the properties of protective and decorative coatings applied during the design stage through the capabilities and modeling tools of the Solid Works software family.

The design process makes it possible to create entire families of technical systems, thereby providing additional time-saving opportunities and reducing the overall cost of engineering and design activities.

Today, as computer-aided engineering methods have become deeply integrated into the process of technical and technological decision-making – particularly those associated with the SolidWorks software family, which can reasonably be regarded as incorporating elements of artificial intelligence – the number of factors, characteristics, and developmental pathways associated with a technical solution, extending ultimately to the level of a technical supersystem, has become extremely significant. This creates a need for a systematic correspondence between technical solutions and the definitions, classifications, and identification methods applicable to the entire hierarchy of engineering systems, ranging from local technical solutions with unregulated technical and technological relationships (subsystems) to highly complex conglomerates of interconnected technical solutions forming supersystems.

It should be acknowledged that one of the first specialists to undertake the optimization of classifications for such categories of technical solutions was *Oleksandr Gudolin*, whose publications introduced a systematic approach to this subject by combining the methodology and principles of classical industrial design with modern methods of computer-program development and engineering modeling.

In the present article, the author seeks to correlate the fundamental conclusions and definitions presented in *Oleksandr Gudolin*'s publications with the specific methodology and decision-making framework employed in contemporary computer-aided engineering systems incorporating elements of artificial intelligence.

As the challenges associated with the development, modernization, and optimization of technology and engineering systems continue to increase in complexity, isolated local solutions no longer satisfy the requirements of customers and developers seeking to achieve an ideal final result. Practical reality increasingly compels organizations to pursue composite, integrative, and comprehensive solutions, in accordance with the terminology and classifications optimized by *Oleksandr Gudolin* in his contemporary publications.

The identification and classification of all categories and levels of technical solutions directly affect the possibilities for systematic protection of existing and newly created intellectual property. This applies both to effective and active subsystems and to technical supersystems functioning as accumulators and integrators of the properties and characteristics of their constituent subsystems.

Modern technological innovations are frequently generated through intensive collaborative brainstorming processes involving multidisciplinary teams of specialists whose collective objective is the achievement of an optimal or ideal final result. Under such conditions, significant challenges arise in organizing and managing the innovation process. These challenges are often caused by objective factors, including psychological, technological, and engineering stereotypes that influence the perception and evaluation of new ideas.

Both existing and newly emerging technical and technological solutions are commonly assessed through the prism of historical experience derived from the application of the laws governing the development of industrial technologies, machines, and mechanisms. Many of these principles were formulated during the previous century, when contemporary materials, advanced components, modern industrial electronics, digital technologies, and laser-based systems were either unknown or unavailable and, consequently, could not be incorporated into engineering practice.

Figure 2. *Clearly demonstrates the capabilities of computer-based scaling technologies, which make it possible to obtain various sizes and configurations of technical systems within a single design process*

As a result, modern digital technologies incorporating artificial intelligence create opportunities not only for the development of fundamentally new technical systems but also for the reassessment and refinement of traditional engineering concepts, thereby enabling the emergence of innovative technical solutions that were previously impossible to conceive, model, or implement.

This situation is further complicated by the fact that, in the United States and in most other countries, the recognition of a technical solution as an invention is based on a number of specific criteria – four criteria in the United States and three criteria in many other jurisdictions.

The fourth criterion used in the United States introduces a subjective element into the evaluation of technical solutions. It is this factor that contributes to the gradual development and consolidation of a psychological stereotype based on the classification of new technical solutions as either obvious or non-obvious.

The presence of a clearly expressed subjective factor inevitably introduces comparisons between the proposed technical solution and previously known design elements, technological approaches, and combinations thereof derived from earlier developments.

The familiarity of a particular solution and the details of its implementation cannot be considered an objective evaluation criterion, since decisions regarding the obviousness or non-obviousness of a technical solution fundamentally depend upon the knowledge, experience, and professional competence of the patent examiners responsible for its assessment.

In modern engineering designs and technological solutions, novelty is no longer merely the reflection of a single technical discipline. Rather, it is the result of the integration of multiple disciplines, including electronics, microelectronics, advanced materials science, fiber-optic technologies, laser engineering, computer modeling, and digital control systems. Consequently, the assessment of obviousness or non-obviousness requires analysis from numerous disciplinary perspectives, which can only be adequately performed through collaboration between highly specialized experts and specialists in multidisciplinary systems integration. As a rule, modern engineering design software, particularly software belonging to the SolidWorks family, enables the application of brainstorming techniques and the combination of various software capabilities for specialized design operations. These functions make it possible to address highly specific engineering requirements and performance characteristics associated with particular technical systems or groups of systems that ultimately form a comprehensive technical supersystem.

Naturally, much depends on the qualifications, experience, creativity, and analytical capabilities of the designer or software operator, as well as on their ability to interpret both conventional and unconventional technical parameters and performance indicators associated with a technical system functioning as a supersystem and incorporating numerous local technical systems operating as subsystems. At the same time, successful design and development activities require the ability to consider factors of unification and standardization while effectively combining them with original design solutions and innovative engineering features. The balanced integration of standardized components and novel design elements remains one of the key factors determining the efficiency, originality, and practical value of modern technical systems developed through advanced digital design technologies.

As illustrated in the figure, the current capabilities of the SolidWorks family of engineering design software make it possible to present a development not only as a complete assembly unit but also as a detailed set of individual components required for its assembly, including the visualization of each component and the complete assembly while taking into account the selected construction materials and their physical characteristics.

These capabilities, particularly when a development is intended to serve as a foundational technical solution for a future invention, require close coordination with the principles and methodologies of the Theory of Inventive Problem Solving (TRIZ).

TRIZ was originally conceived during the post-war period as a form of "exact science," despite the fact that even at that time an important debate existed within the inventive community regarding the fundamental importance of the individual inventor in achieving the declared Ideal Final Result (IFR), or its equivalent. The central question concerned whether the successful generation and selection of new technical solutions ultimately depended upon individuals capable of producing useful and practically viable ideas. Today, it can reasonably be argued that the individual can play a significant role only when equipped with appropriate intellectual tools, foremost among them advanced software systems.

Figure 3. *Presents an example of a modern engineering design solution for a real-time liquid-homogenization system operating within a pipeline without the use of chemical reagents or stabilizing additives*

At that time, it was widely believed that any qualified specialist or professionally trained engineer, provided with a coherent and effective methodology for solving inventive problems, would be capable of generating new ideas and transforming those ideas into practical results. Consequently, the newly established Theory of Inventive Problem Solving, developed on both scientific-technical and psychological foundations, was received with considerable interest by the professional community.

For a certain period, the laws, principles, and methods of TRIZ generally corresponded to the prevailing level of technological development and industrial capability. The first significant inconsistencies became apparent with the introduction of automated production lines, followed by numerically controlled machine tools, and later by the emergence of digital technologies combined with advanced materials science, composite materials, industrial electronics, and computer-aided engineering systems.

Returning to the optimized definitions and classification terminology relating to technical solutions and the technical systems containing them, developed by *Oleksandr Gudolin*, it should be noted that, even independently of their significance for TRIZ theory, the clear and unambiguous definitions proposed by him have substantially improved the preparation of such important engineering documents as Technical Specifications, Technical Requirements, and, on the basis of these documents, Technical Design Assignments for new and innovative developments, while maintaining the highest possible level of compliance with applicable standards at all levels.

It is equally important to consider the degree and levels of standardization and unification of components and subsystems within the hierarchy of technical systems. Such systems may function as subsystems relative to a higher-level technical supersystem while occupying the same hierarchical level as other subsystems. Consideration must also be given to the degree and level of integration of technical systems of equivalent hierarchical status into one another, since these relationships increasingly influence the design, development, optimization, and protection of modern complex engineering solutions.

In the context of contemporary digital design technologies incorporating elements of artificial intelligence, these classification principles acquire particular importance. They facilitate a more accurate understanding of the structure, evolution, and innovative potential of technical systems while improving the effectiveness of engineering decision-making, intellectual property protection, and the management of complex multidisciplinary development projects.

Figure 4. *Presents the same project shown in Figure 1, but supplemented with sectional views that provide a complete representation of the internal structure of the technical solution and the geometric requirements applicable to its individual components*

These capabilities do not exhaust the full functionality of modern computer-aided design systems; however, the application of TRIZ principles, definitions, and methods in combination with such software technologies can further increase the efficiency of innovative developments while simultaneously reducing both design costs and development time.

This raises an important question: what does TRIZ actually represent under contemporary technological conditions? How have modern high technologies, digital engineering tools, and advanced processor systems influenced its compositional and integrative capabilities?

These are only some of the issues requiring clarification. Equally important is the widespread tendency toward the detailed investigation of biological systems and biological or medical objects in search of effective analogues for future inventions, particularly within the field of biologically inspired mechanical engineering.

A significant question therefore arises regarding the relationship between such approaches and the laws, methods, and techniques of TRIZ and ARIZ (Algorithm of Inventive Problem Solving).

Today, the majority of highly effective and innovative inventions emerge from discoveries and systematic analyses of phenomena observed in nature. Biological systems increasingly inspire inventors to create complex integrative technical solutions capable of addressing unconventional problems through unconventional methods, many of which are derived from the principles governing the evolution and functioning of living systems. Owing to the capabilities of modern digital technologies, such concepts can be modeled, simulated, and evaluated systematically before the preparation of initial technical requirements and technical specifications for inventors and design teams.

Numerous examples of such developments can already be identified. More importantly, the process of creating new methods and styles of computer-aided design continues to evolve and expand in parallel with the constantly increasing capabilities of computer hardware, software platforms, artificial intelligence systems, and digital engineering environments.

For inventors and developers, one of the most important and challenging tasks has been the accurate determination of numerous parameters and relationships within technical systems, particularly in cases where no previous developments or engineering precedents existed.

The application of methods recommended by TRIZ, despite the absence of similar integrations in earlier developments, made it possible to create a fundamentally new product that approached the threshold of the Ideal Final Result.

This achievement immediately resolved a number of technical, innovative, and integration-related challenges and made it possible to obtain complete autonomy for the system under development.

Furthermore, the autonomous operating period of the system proved to be virtually unlimited.

Thus, overcoming a multidisciplinary engineering problem complex, combined with the elimination of a significant psychological barrier, enabled developers to address the remaining design challenges through the application of integrated, modified, and optimized TRIZ methodologies and techniques.

The integration methodology described above, applied during the synthesis of innovative technical solutions, has become the focus of numerous organizational, technological, engineering, and scientific initiatives.

In this context, it is noteworthy that on September 8, 2011, the United States Senate approved patent-reform legislation known as the America Invents Act. As the U.S. economy has increasingly evolved into an innovation-driven economy, its innovative nature has generated substantial new requirements for patent legislation. Moreover, the emergence of artificial intelligence elements within software systems and process-control platforms has created – and continues to create – a clear necessity for the systematic revision and adaptation of the fundamental laws governing the development of technical systems at all hierarchical levels.

Figure 5. *Illustrates the design of one of the fundamental components of the technical system presented in Figures 3 and 4. Unlike the previous design, this component is manufactured from a metal-ceramic material with a high carbon-carbon composite content instead of stainless steel*

Under these conditions, modern digital technologies incorporating artificial intelligence are not merely design tools; they are becoming active participants in the innovation process, influencing the generation, evaluation, optimization, integration, and implementation of new technical solutions and thereby reshaping the methodology of industrial design itself.

The figure demonstrates the advanced capabilities of comprehensive digital design simulation for all elements of the assembly. Where the external appearance and surface finish are critical to the subsequent operation of the technical system, such visualization provides maximum design information and enables a detailed representation of the assembly as a subsystem within a higher-level technical supersystem.

The author presents a representative example from contemporary engineering design practice. Catalogs and websites of leading manufacturers of standard components and assemblies now provide not only engineering drawings but also three-dimensional CAD models, for example, in SOLIDWORKS format. Designers can directly incorporate these models into their own technical solutions developed within the same CAD environment.

This approach fundamentally transforms the engineering design process by enabling the selection, evaluation, and integration of alternative components in real time while simultaneously incorporating supplier-provided engineering data as an integral part of the developing technical solution and its subsequent integration into all hierarchical levels of the technical system.

The author further discusses recent developments in patent legislation based on the "first-to-file" principle, under which patent rights are granted to the first applicant to file a patent application. This approach has significantly simplified the resolution of patent priority disputes by eliminating the need to establish inventorship during the examination process, although evidence of priority may still be introduced in judicial proceedings to challenge the validity of an issued patent.

This principle also has important organizational, investment, and psychological implications, influencing the working environment of technology development teams, the relationships between competing companies and investment organizations, as well as the role of component suppliers, which have become full participants in the engineering design process.

Today, the first-to-file system is applied in virtually all developed countries, including the United States.

However, apart from so-called hybrid inventions in the field of software, the fundamental issues remain unchanged. The recognition of software as patentable subject matter – despite the fact that software itself cannot be equated with a technical solution – has resulted in the issuance of numerous patents for applications that contain little or no genuine technical innovation.

The relative ease with which thousands of software-based and partially software-based patents have been granted has blurred the traditional criteria of technical operability and inventive novelty. As a consequence, and partly due to the resulting uncertainty experienced by investors, a parallel process has emerged in which patent litigation, rather than technological innovation, becomes the primary driving force. In this environment, the central figure is increasingly the patent attorney rather than the inventor, with the emphasis shifting from innovation to legal disputes.

Consequently, the challenges arising from contradictions and limitations within the **TRIZ** methodology are insignificant compared with the broader problems created – and to some extent stimulated – by the ambiguity and imperfections of modern patent legislation.

According to the author, the application of **TRIZ**, advanced analytical methods, computer modeling, and techno-dialectical synthesis to comprehensive technological forecasting may provide new opportunities for improving innovation processes, particularly in the fields of biotechnology and genetic engineering.

One of the undeniable strengths of **TRIZ** since its inception has been its attempt to apply dialectical principles to inventive problem solving through the identification and resolution of technical contradictions.

To achieve this objective, TRIZ introduced a specialized algorithm (**ARIZ**), consisting of a sequence of logical procedures designed to formulate an inventive problem as a system of contradictions and to provide recommendations for their resolution.

In addition, the TRIZ literature contains numerous illustrative examples and practical problems that possess significant educational and methodological value.

However, considering the current state of engineering design, an important question arises: **what if a contradiction, in its classical interpretation, does not actually exist?** In such cases, how can one resolve contradictions that are not present?

Partial answers to this question are provided by the latest capabilities of modern computer-aided engineering and design software.

The depth and level of detail achievable during even the preliminary design stage make it possible to perform a complete cycle of computer modeling and simulation of the device's operating process using initial conceptual models, without the need to manufacture physical prototypes for experimental testing.

Furthermore, eliminating the need for a dedicated budget to validate conceptual designs significantly reduces development time while allowing substantially greater resources and effort to be devoted to the synthesis, optimization, and further development of innovative technical solutions.

These capabilities also fundamentally transform the psychological and professional relationships between technology developers, equipment designers, and investors. The traditional concern over costly design errors is greatly reduced because comprehensive computer modeling and simulation enable potential deficiencies to be identified, analyzed, and corrected at an early stage while simultaneously suggesting more efficient alternative directions for the further development and optimization of the project.

Let us consider the following laws governing the evolution of technical systems:

1. The Law of Completeness of the Parts of a Technical System.
2. The Law of Increasing the Degree of Ideality of a Technical System.
3. The Law of Human Elimination from a Technical System.
4. The Law of Coordination of the Rhythms of System Components.
5. The Law of Energy Conductivity of a Technical System.
6. The Law of Uneven Development of the Parts of a Technical System.
7. The Law of Transition from the Macro-Level to the Micro-Level.
8. The Law of Increasing the Degree of Substance-Field Interactions.

Let us also adopt the modified classification of technical systems proposed by *Oleksandr Gudolin* in his publications:

- Technical System
- Local Technical System
- Advanced Technical System
- Global Technical System
- Intelligent Technical System

The **Ideal Final Result (IFR)** is defined as achieving the desired outcome or solving a problem without increasing the complexity of the technical system while minimizing the consumption of resources, including financial costs, development time, materials, clean water, and other essential resources. From the perspective of environmental protection, the concept of the IFR encompasses all resource-efficient, waste-free, and environmentally sustainable technologies.

The formulation of the Ideal Final Result begins with identifying the primary useful function of the technical system – that is, answering the fundamental question: **"Why was this system created?"** For example, the primary purpose of a mobile telephone is to enable communication in the absence of a fixed-line telephone. Accordingly, the Ideal Final Result is the ability to establish instantaneous communication with any person anywhere in the world, a capability that has been substantially advanced through modern Internet technologies.

Under contemporary engineering conditions, the formulation of the IFR serves several essential objectives.

First, it establishes the design objective and determines the direction of technological development. Today, the validity of selecting this objective can be verified through advanced computer simulation and digital modeling, allowing engineers to predict system output parameters and evaluate their variations in response to changes in the characteristics of standard components incorporated into subsystem architectures. These component models are increasingly supplied directly by manufacturers as validated digital engineering models.

Second, it minimizes unnecessary trial-and-error during the search for engineering solutions. Modern computer models of technical systems enable designers to generate, evaluate, and simulate numerous design alternatives while varying the performance characteristics of all subsystem components throughout the hierarchy of the overall supersystem. As a result, the number of experimental iterations required during conceptual development is reduced to a practical minimum.

Third, it ensures a high level of quality for the final engineering solution. Here again, priority is given to computer-based simulation of production processes and operating cycles, enabling comparative evaluation of system performance, reliability, efficiency, and other qualitative indicators before physical prototypes are manufactured.

The concept of the IFR is closely associated with that of the **ideal technical system** – a system that does not physically exist while its intended function is nevertheless fully performed. Although such an ideal state cannot always be achieved in practice, it serves as the ultimate direction of technological development.

Accordingly, engineering efforts are directed toward increasing the **ideality** of technical systems, defined as the ratio between the useful functions performed by a system and the total resources required for its design, engineering, manufacturing, operation, and maintenance.

Naturally, the formulation of the Ideal Final Result must remain fully consistent with applicable technical standards, regulatory requirements, industry specifications, and engineering codes. While these constraints inevitably limit the degree of design freedom, they simultaneously ensure the practical feasibility, safety, and regulatory compliance of innovative engineering solutions.

The foregoing considerations provide the basis for re-examining the fundamental laws governing the evolution of technical systems from the perspective of today's capabilities in computer-aided engineering, digital design, advanced manufacturing technologies, and modern operational methodologies.

The Law of Completeness of a Technical System

A fundamental prerequisite for the viability of any technical system is the presence and minimum operational capability of all its essential components. Since the operational performance of these components can now be reliably verified through computer modeling during the design stage, their minimum functional capability can be accurately assessed during system development. Consequently, in modern engineering practice, compliance with this law is largely ensured before the product reaches the market and rarely presents challenges beyond routine maintenance during subsequent operation.

The Law of Energy Conductivity of a Technical System

A fundamental condition for the viability of a technical system is the uninterrupted transfer of energy throughout all of its components. Compliance with this law can likewise be accurately verified through computer modeling by selecting only those components whose performance fully satisfies the required energy transfer characteristics. For modern computerized technical systems, the law of energy conductivity constitutes one of the fundamental principles governing reliable and efficient system operation.

The Law of Coordination of the Rhythms of System Components

A necessary condition for the viability of a technical system is the coordination of the operating rhythms, frequencies, and periodic behavior of all system components. In contemporary engineering, compliance with this law is achieved through computer simulation and digital coordination of the operating characteristics of every subsystem, including components controlled by programmable processors and industrial controllers.

The Law of Increasing the Degree of Ideality

The evolution of technical systems proceeds toward increasing their degree of ideality. Comprehensive computer modeling and simulation of all system components under both static and dynamic operating conditions make it possible to optimize not only the performance of individual subsystem combinations but also the overall ideality of the complete supersystem within integrated engineering projects.

The Law of Uneven Development of System Components

The components of a technical system evolve at different rates. The more complex the system, the greater the disparity in the development of its individual parts. However, under today's conditions of global technological integration, it has become possible to select both primary and auxiliary components that represent comparable levels of technological maturity, thereby minimizing developmental imbalance among subsystems within the supersystem and throughout the subsequent hierarchical levels in which the supersystem itself functions as a subsystem.

The Law of Transition to a Supersystem

After exhausting its own developmental potential, a technical system becomes integrated into a supersystem as one of its constituent elements, with further development occurring at the supersystem level. In modern engineering, where flexible computer control systems and Internet-based data exchange are widely implemented, the transition of a subsystem into a supersystem is increasingly determined by the computational capability, processing speed, and functionality of embedded computer systems.

The Law of Transition from the Macro-Level to the Micro-Level

The evolution of a system's working elements proceeds initially at the macro level and subsequently at the micro level. With processors, programmable controllers, supervisory computers, and Internet-connected monitoring systems participating throughout the design, manufacturing, and operational stages of a technical system, the traditional distinction between macro- and micro-level processes becomes increasingly indistinct. Under such conditions, a system functioning as a subsystem may effectively operate as a supersystem when connected, for example, to cloud-based information storage and distributed control environments.

The Law of Increasing the Degree of Substance-Field Interactions

Technical systems evolve toward increasing the number and complexity of substance-field interactions. The widespread incorporation of computerized monitoring and control systems creates numerous additional substance-field relationships, including direct and feedback communication channels, as well as information, control, and monitoring signals exchanged throughout every hierarchical level of the technical system. This significantly increases the degree of substance-field interaction while simultaneously expanding the number of functions that can be monitored, controlled, and optimized.

Conclusion

In future publications, it will be appropriate to return to specific examples of contemporary engineering developments in light of the above observations concerning the laws governing the evolution of technical systems, while also considering the modified definitions and classification of technical systems of varying structural and technological complexity proposed by *Oleksandr Gudolin* in his published works. These updated interpretations provide a more comprehensive framework for analyzing modern engineering systems operating within highly integrated digital design, manufacturing, and control environments.

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