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Review article

Systems engineering – synergy of science, knowledge and applied technology

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ABSTRACT

The following paper presents the theoretical foundations and selected practical applications of systems engineering. To begin with, the concept and subject of systems engineering is defined and embedded in the family of systems sciences. It also outlines the systems approach methodology applied in the systems engineering and the strong interdependencies that exist between systems theory and the practice of building systems applications. The matter of presenting selected categories of systems engineering, such as requirements engineering, environmental engineering, safety engineering, medical engineering, genetic engineering, management engineering, financial engineering, software engineering and social engineering was pivotal element of the paper. The paper has a form of a synthesis and an overview and contributes to further discussions within the framework of promoting a universal systems approach in the praxeological disciplines of the different categories of technical and non-technical, tangible and intangible, but always innovative and creative engineering.

KEYWORDS

system, engineering, science, concept, design, application, innovation

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1. The concept and subject of systems engineering

Engineering is the art of creating things (visions, concepts, designs) that are new and original and, at the same time, a pragmatic intellectual and experimental (research) activity that involves modelling, designing, constructing, modifying and maintaining useful and efficient solutions to solve practical problems. Modern engineering[1] is an interdisciplinary category, based on a synergistic application of current scientific knowledge and achievements of modern technology. This activity requires finding solutions to practical problems of varying

[1] The terms "engineering" and "engineer" derive from the French words *ingénieur* and *ingénierie*. These words in Franconian dialects occurring as *engigneor* meant constructor of war machines. The English derivation of*engineering* and *engineer*, although they sound similar, have completely different origins and do not derive, as one might assume, from the word *engine* (machine), but from the Latin *ingeniosus* meaning an enlightened and educated person.

nature, complexity, and degree of difficulty [1]. In a broader sense, engineering uses science and technology to drive the development of applied software (non-material) and hardware (material)technologies.

In a stricter (systemic) sense, engineering refers to the theoretical and practical application of the properties of science, knowledge, matter and energy, as well as abstract and real objects, to create innovative solutions, build new models and design original material structures (machines, equipment, products) designed for a specific purpose or as a solution to a specific problem.

Engineering is one of the creative disciplines, dealing with the designing innovative solutions and original products or structures, with a clear utilitarian purpose, which have not been invented yet. Hence, there is a strong resemblance to craft-related activities and also to art, especially – the applied art. The work of an engineer, craftsman and artist is quite similar. Arts and crafts, much like engineering, are based on creation, except that in engineering the most important aspect is scientific and technical knowledge, while in crafts it is the idea and experience that are of key significance, whereas in arts – talent and creativity. The activity of an engineer is, in other words, the art of creating innovative solutions and practical applications, with creativity and originality on the one hand and, on the other, a certain degree of risk, mainly functional [2].

The links between engineering in a praxeological sense and theoretical science have always been very strong, but engineering should not be equated with pure science, despite the similarity of the research methods used. When scientists see a problem, they ask *why* and try to find the most general solution. Meanwhile, the engineer wants to know *how* to practically solve the problem and *how* to implement the proposed solution. In other words – scientists try to explain existing phenomena, while engineers use available resources, not just scientific ones, to build solutions to new problems [3].

In the current era, the production of almost all usable products and technological solutions is preceded by various stages of systems engineering, and all of it starts with an identifying a social (economic) need or an finding a gap, such as a market gap. The result of this idea is – first and foremost – a virtual design, usually computer-based, and then an actual engineering object that fulfils all aspects of the assumed functionality and practical usability [4].

Since systems engineering approach is so useful and attractive nowadays, the world is witnessing an outpour of a wide variety of detailed engineering, often using only the media term "engineering". It should come as no surprise, then, to see such categories of engineering in colloquial contexts as, for example, cosmetic engineering, soul engineering, linguistic engineering, interior engineering, creativity engineering [2] and many others. Despite some formal and lexical controversies, such a high level of interest in the term "engineering" demonstrates, on the one hand, its social universality and, on the other hand, the high utility and potential benefits of a systems engineering approach. The central category of following discussion will be systems engineering, which a lot of detailed subject engineering is being developed today.

2. Scientific aspects of systems engineering

Systems (process) engineering belongs to the group of systems sciences, the essence of which is the study of different systems in their holistic view. What the systems sciences have in common is, above all, a scientific research methodology and a way of formulating and solving different problems [1]. These are the sciences of complex wholes (structures) and the laws that govern these structures (organisations). The universalist systems approach is highly effective in the field of systems engineering, referring to the art of designing, building and implementing innovative concepts and creative practical solutions, both in terms of design as well as implementation process. In the context of practical applications of systems engineering, there are four basic, particularly useful groups of systems sciences, which include: basic systems sciences, humanities-related systems sciences, technical systems sciences, natural systems sciences (Fig. 1).

Very often, engineering as well as basic and applied sciences work in a common application field producing excellent synergy effects. Scientists often decide to get involved in the practical application of their discoveries, thus becoming engineers. They also do so when constructing unique models, prototypes or measurement systems to help them in their research. Correspondingly, in the process of technological progress, creative engineers, with the help of devised research tools, often discover completely new rules and phenomena and become full-fledged scientists [5]. In the field of engineering, or rather the art of engineering, the roles of engineer-practitioner and scientist-researcher are mutually interdependent and intertwined.

In engineering, the nature of scientific research and the applied research methods and tools is undoubtedly different from science. Firstly, the engineer often has to deal with phenomena that are theoretically well understood, but the associated problems are too complex to be solved in an unequivocal and accurate manner. Research in engineering is therefore focused mainly on finding effective methods to address these issues in a way that approximates, yet

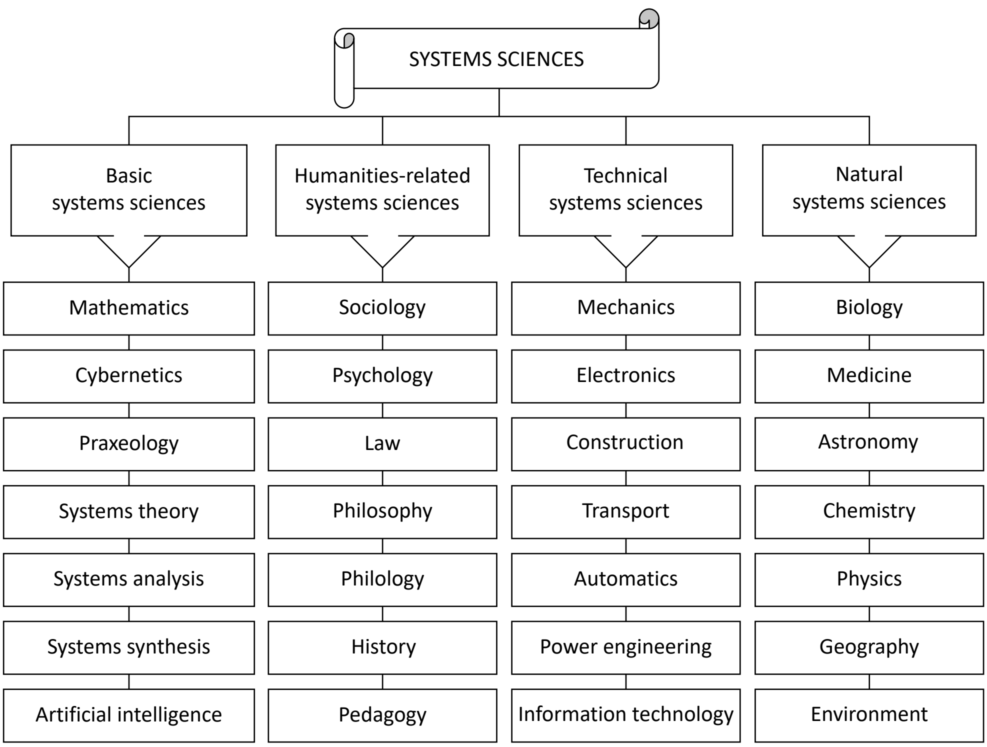

Fig. 1. Example structure of system sciences
Source: Author's own elaboration.

as accurately as possible, while still being safe and efficient[2]. Secondly, engineers use many "quasi-empirical" methods and tools in their research methodology, which are unknown to "pure" abstract science. It could also be argued that scientists build to learn, while engineers learn to build[3].

There is a feedback loop between engineering and science, manifested in the mutual stimulation of the development of the two disciplines. By discovering new phenomena, science makes it possible to design new improved methods and research tools, which in turn help to discover new phenomena and often – new scientific laws. The problem with calling engineering a science is also related to the fact that it is difficult to clearly define science as such, which is why engineering is very often included in the broad group of system sciences, which are of descriptive and comparative nature.

From the perspective of systems engineering needs and applications, systems science can be broadly divided into basic systems science and applied systems science. The basic systems sciences include systems theory, organisation theory, cybernetics, praxeology and economics. Because of the needs of the rapidly growing economies of the world, the oldest one has been determining the economic life since as early as the second half of the 18th century. Scientific management and organisation theory both have a long history. Cybernetics, systems theory and praxeology are much younger. Each of the basic systems sciences plays an auxiliary role in the systems engineering structure by stimulating its development according to the current state of knowledge. The essential distinctive feature of systems science is the study of certain organised wholes, acting purposefully and rationally (efficiently).

3. Methodological foundations of systems engineering

Systems (knowledge) engineering (System Engineering, Knowledge Engineering) has a variety of meanings, and most commonly refers to the design or analysis and synthesis of operating systems. It deals with the design of tangible and intangible concepts, structures and operating rules of various organisations (systems) and putting these designs into practice. The selection criterion in the design process is the praxeological efficiency and effectiveness of the designed system or organisation, which are analysed, for example, from the economic, social and environmental perspective [6]. Praxeological action systems engineering is the science of rational, organised, complex, controlled and purposeful action [3].

The scope of systems engineering therefore includes: a systems philosophy based on a systems holistic approach, systems theory including various models (identification, evaluation, optimisation) and applied engineering including systems analysis and synthesis [7]. From this perspective, systems engineering is universal and very general in nature, as it applies to all

[2] An example is the development of the finite element method and its implementation in computer programmes as a solution for calculating the results of differential equations, which have been known in the world of science for a long time.

[3] It is amazing how brilliant engineers of knowledge, science and technology the great figures of Antiquity were, not only of the ancient European culture close to us, but also of the age-old Chinese culture or the even more mysterious circle of Latin American civilisation, if without libraries, laboratories, accelerators, computers, the Internet, scientific conferences and symposiums, world EXPOs and, above all, without the consuming pressures of competition and globalisation and the absolute frenzy of the arms race, they created wonderful scientific theories, innovative projects and products so courageously ahead of their time and illuminating, with the authentic light of the human mind, the primordial darkness of Homo Sapiens' prehistory.

entities (systems) of action in their various phases of functioning. General systems engineering has a practical application in system-specific engineering, such as, for example, systems design engineering, systems manufacturing engineering, systems operations engineering, systems management (control) engineering or systems safety engineering [3].

The idea behind the term “systems” is to fulfil and signal that the object of engineering, e.g. the organisation, is viewed as a holistic praxeological system of efficient operation [8]. The very concept of a system denotes a complex set of interrelated and qualitatively different variables, relationships of which are partly deterministic and partly probabilistic. According to cybernetics, systems of interest to systems engineering fall into the category of relatively isolated open systems for exchanging information, energy and matter with the environment [9]. Systems engineering is therefore a response to the need, reported by professionals, to have effective techniques and procedures for influencing reality, within which the features such as the complexity of the organisation’s structure, the multiplicity of interacting elements and the impossibility of defining unambiguous cause-and-effect relationships between these elements are amplified [10].

Rational and effective solutions to system problems require a certain knowledge potential, based on the current level of science, technology and engineering (Fig. 2). Hence, the term knowledge engineering is used interchangeably, emphasising the scientific nature of creative engineering. In this sense, the products and creations of knowledge engineering have the character of projects, i.e. objects that did not exist before, which most often bring a new quality to the world of theory as well as to social or economic practice [7].

If we view engineering as an interdisciplinary field of theoretical knowledge and practical activity, general principals of its operation have been formulated for the purposes of universal systems engineering, including the following specific principles [5]:

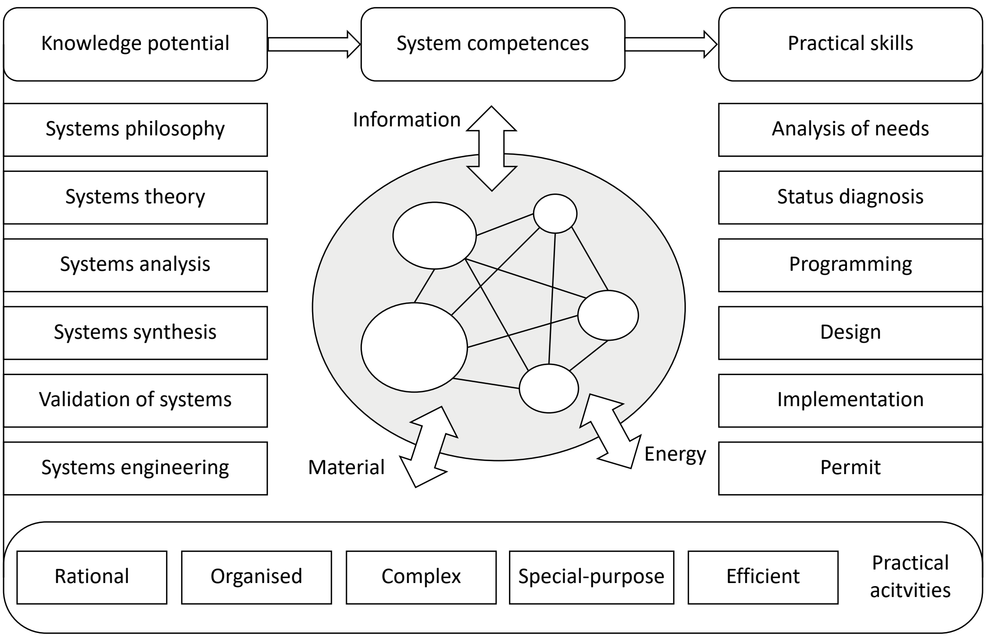

Fig. 2. Methodological concept of systems engineering
Source: Author’s own elaboration.

1. Wilber's principle of existence – at every level, reality consists of a totality of parts, or holons.
2. The principle of holism – the system as a whole has properties not revealed in any of its component parts (and vice versa).
3. The principle of emergence – new unknown before properties emerge from each organised whole, often at a different level.
4. The principle of sub-optimisation – if each system considered separately is geared towards maximum efficiency, the system as a whole will not achieve maximum efficiency.
5. The grey principle (indeterminacy) – no system can be fully understood.
6. The principle of hierarchy – complex phenomena are organised into multi-level hierarchies and each level integrates multiple sub-systems.
7. The Pareto principle (20/80) – states that 80% of results come from only 20% of causes. According to the interpretation of this principle, having fewer resources and effort, brings to the potential of producing much greater benefits or effects.
8. Resource redundancy principle – maintaining system stability under conditions of disruption requires redundancy of critical resources.
9. Relaxation time principle – system stability is only possible if the average disturbance succession time is greater than the system relaxation time.
10. Negative feedback principle – with active negative feedback, the system is invariant to a wide range of disturbances.
11. Positive feedback principle – with active positive feedback in the system, different final states can be obtained with the same initial conditions (multifinality).
12. Homeostat principle – the system will survive as long as its essential variables remain within acceptable limits.
13. Self-organisation principle – complex systems have properties of self-organisation and their structure and behaviour are the main result of the interaction of subsystems.
14. Survival principle – the ability to survive (live) is dependent on the right balance between the autonomy of the subsystems and their integration into the whole system, or in other words the balance between stability and adaptation.

The universal approach proposed by systems engineering integrates all basic system sciences into a methodologically mature and practically useful system of action, including: analysis and diagnosis of the actual state of affairs, theoretical concepts for improvement and development, efficient operating procedures, concrete model and design solutions, and standards and implementation requirements [11]. At the same time, systems engineering integrates the partial praxeological, cybernetic, organisational, functional and economic approaches into a single coherent system of action, pursuing a defined goal in a rational and efficient manner from the adopted evaluation criterion perspective [9]. In this context, it can be said that systems engineering is the science of the rational, organised, controllable and purposeful operation of a suitably complex abstract or real system.

4. Requirements Engineering

Requirements Engineering as a field of scientific research and practical activity emerged at the end of the 20th century in the process of analysing and formalising the complexity and security of information systems [12]. In its early stages, it was defined as the process of specifying requirements through an iterative process of analysing the problem, documenting the results in various forms of presentation and verifying the accuracy of the understood problem and it was assigned to the IT sector [13]. A more universal definition characterises requirements engineering as: the process of specifying, documenting and managing the requirements of the target solution [14].

The aim of requirements engineering was to build a formalised information model of the target system (product) within a detailed specification of its performance characteristics. This specification is made up of the documented requirements of potential users for the system under development. It is of descriptive nature and applies the need for a practical solution to a problem. One of the key aspects of requirements engineering is flexible and continuous communication between all stakeholders in the team developing a given project.

Requirements engineering encompasses a series of mainly analytical, synthetic and utilitarian phases and activities, including: the identification of the formal basis and sources of requirements, the detailed specification and analysis of requirements, especially in terms of ensuring the high quality and assumed functionality of a given system. These tasks require project teams to have in-depth subject matter expertise, specialised skills and competences based on knowledge, technology and practice as well as experience [15].

So-called soft skills – verbal and non-verbal – are particularly relevant in terms of standards of requirements engineering, including the ability to negotiate constructively and discuss creatively to facilitate continuous improvement of end products at all stages of requirements formulation, implementation and modification. This means maintaining excellent interpersonal communication with the entire research team [16].

The use of requirements engineering procedures is based on the execution of a sequence of activities including: requirements identification and categorisation, requirements analysis and coordination, detailed requirements specification and documentation, and requirements validation and verification. A constant mode of reviewing and modifying requirements for new challenges and new tasks is of key importance. A very important aspect of requirements engineering are management-related activities, including: controlling, tracking and updating requirements specifications, flexible configuration and change management, and continuous stimulation of high quality in ongoing procedural activities [17].

A properly formulated requirements specification should be characterised by attributes such as: clear goals and objectives, completeness of the described requirements, consistency between the extracted tasks, and in addition, all extracted features should be fully verifiable by available methods and susceptible to various modifications and ongoing changes. The quality and completeness of the requirements specification often determines the success of the entire project and the target usability and efficiency of its operation.

The actual requirements of the users, the principals of the target application can be defined as a set of properties and attributes, as well as specific functionalities that determine the practical usability of the final design (system, product) [18]. The total set of requirements can be divided into: primary (main) characterising the actual needs of the user, and derived (secondary) resulting from the need for other requirements and attributes. Another division of requirements is functional requirements, which determine the goals and tasks set for the system, and non-functional requirements, which determine, for example, proper efficiency, reliability, security, including broadly understood security of the environment or, las but not least, compatibility and scalability of the solution.

Requirements engineering presenting certain principles to the highest degree is based on proven practices and various procedures and standards, mainly international ones. Almost every organisation has a defined methodology for designing, manufacturing and modifying its own products, which supports various aspects of requirements engineering. One of the good and proven practices is the industry norms and standards for the formulation of requirements. In times of globalisation, international norms and standards setting universal principles and canons for utilitarian requirements engineering, without limiting its scope to any particular interests of individual actors, are increasingly recognised. One of the most widely recognised sources of standards for requirements engineering in the world are the principles promulgated by the ISO (International Organisation for Standardisation) and IEEE (Institute of Electrical and Electronics Engineers) standards, which set standards for requirements in almost all areas of human activity. The ISO 9000 standard, for example, tackles the issue of quality management at, among other things, the various stages of requirements formulation within requirements engineering.

5. Environmental engineering

A very particular example of system engineering is Environmental Engineering, also known as ecosystem engineering, which is one of the more attractive and relevant disciplines developed within the natural and technical sciences and which includes formal, legal and organisational-technical undertakings aimed at maintaining the natural environment in a state of natural balance that lets it maintain its ability to self-regulate and self-purify [19].

Environmental engineering encompasses engineering projects (design, implementation, operation) aimed at maintaining the state of equilibrium of the nature and facilitating its capacity for self-regeneration and self-purification and the successive restoration of natural resources. Environmental engineering provides the scientific basis for the rational management of nature's resources and the prognosis, assessment, prevention and remediation of the negative consequences of destroying these resources. An important objective of environmental engineering is to educate the public about the introduced organisational and technical measures and their consequences [20].

Due to the enormous threats to the environment caused mainly by intensive human activity, environmental engineering offers numerous methods and tools aimed at restoring this balance. Environmental engineering encompasses scientific and research endeavours as well as practical engineering activities that guarantee the sustainable development of our civilisation in full symbiosis with the environment [21].

Highly increased human economic activity – mainly industrial, agricultural and construction – and the huge expansion of the technical civilisation have caused great devastation to the natural environment and led to the disappearance of nature's capacity for self-protection and continued evolutionary survival. Environmental engineering is determining new standards for the harmonious functioning of modern civilisation as well as the laws of nature, aiming to restore the imbalance of both. It encompasses such diverse issues and research directions as wastewater and waste disposal and recycling, agricultural land reclamation, water supply, protection of the air and atmosphere and of water bodies and watercourses, as well as continuous monitoring and forecasting of the level of risks and the status of safety and sustainability [22].

An extremely important part of environmental engineering is the study of the human impact on the climate and the various, mainly climate-related, consequences associated with it, the most prominent example of which is the greenhouse effect and the spectre of rapid climate change and catastrophes that come with it. Environmental engineering also focuses on studying the impact of various extraordinary events – accidents, disasters or civilisation-crushing catastrophes – on the level of natural safety and developing the necessary defence mechanisms to eliminate the consequences of these events.

6. Safety engineering

Another aspect that deserves special consideration is the universal category of Safety Engineering, formally considered a part of Systems Engineering, which has a large number of generic subcategories and, in the most general terms concerns the safety of entities and objects operating within the space of civilisation [23]. Safety engineering is the totality of technical and organisational activities undertaken to identify hazards and to estimate, reduce and monitor risks to health, life, property and the environment. Safety engineering combines issues related to the safety of structures, machinery and technical equipment with management, IT and technical operations. Interdisciplinary safety engineering is primarily associated with the area of technical sciences and, more recently, in the area of social sciences [24].

In broader terms, security engineering is a discipline the of which aim is to develop, improve and disseminate methods and measures that increase the efficiency in terms of protecting the people, the environment and the civilisation assets through:

- prevention of security threats (natural, civilisation-related, public and during the exploitation of artefacts),
- preparing actors and the security system for emergencies,
- responding to the negative effects of the emerging threats to human security and the environment.

The task of safety engineering is to minimise the possibility and magnitude of negative impact potential hazards can have on people, the environment and civilisation assets (property). The mission of safety engineering is to plan, design, organise and operate safety systems and technologies in order to prevent and mitigate negative effects of technical objects and natural phenomena on the environment in order to protect human life and health and all the assets of civilisation.

Safety engineering emerged due to the need to counteract threats directed against the safety of people, technology and the environment. Modern civilisation is exposed to natural hazards (earthquakes, hurricanes, avalanches, floods, droughts), technical hazards, mainly failures and catastrophes related to technical facilities (nuclear power, transport and communications, construction, chemical industry), and destructive human activity (social unrest, conflicts and wars, terrorism, sabotage). Biological, medical and pandemic threats have recently become significantly more active out of all natural hazards.

The idea behind system safety engineering is to guarantee the maximum safety of people, technology and engineering in all its dimensions. It is about protecting our modern civilisation, which is filled with artefacts of human activity. These tasks are, by principle, carried out within the realm of engineering, chiefly civil and technical safety engineering. Technical safety engineering deals with the design, construction, operation and decommissioning of technical facilities especially in terms of minimising their negative impact on the overall safety environment encompassing the natural, social and technical environment of modern civilisation. Civil safety engineering deals with the reducing and removing negative effects (damage) caused directly by natural hazards, technical failures and disasters and deliberate destructive human action, which is also considered an element of public safety engineering [26].

Since security is such broad concept, a corresponding category of security engineering can be assigned to just about any area of socio-economic life. For example, transport safety engineering discusses the issues of road, rail, maritime, aviation, aerospace safety engineering, as well as pedestrian safety engineering. Safety engineering is almost a paradigm in the spheres of construction, mining, metallurgy, energy, as well as agriculture, forestry, etc. The International Occupational Safety and Health (OSH) Standards play integrative role here, which provide an excellent practical application of universal safety engineering principles in all areas of professional practice.

Fire safety engineering, which includes fire safety and fire protection, also take an important place in safety engineering [24]. The concept of fire safety can be defined as: a state eliminating the threat to human life or health through the system of legal standards and technical fire safety measures as well as the implemented fire prevention activities. Practical fire protection, on the other hand, assumes the implementation of measures aimed at protecting life, health and property or the environment from fire, natural disaster or other local danger by: preventing the occurrence and spread of fire, providing means and resources to fight fire, carrying out rescue operations.

Fire safety engineering is a tool used in fire protection to design and assess the fire safety of specific facilities. It involves the application of engineering principles and rules and expert judgement, based on scientific knowledge of fire phenomena, fire impacts and human reactions and behaviour. In practice, fire safety engineering starts with the definition of fire protection objectives. The following interrelated fire safety objectives can be distinguished: protection of health and life, protection of property (including historical assets), protection of the environment, ensuring continuity of operations.

Ultimately, fire safety engineering provides the opportunity to design and assess the level of fire safety using an engineering approach based on quantifying the course (development) of a fire phenomenon and predicting human behaviour in the context of factors affecting people's health and lives, their property and the environment. The social mission of fire safety engineering is, firstly, to protect life, property, the environment (social and natural) and historical heritage, secondly, to determine the degree of fire danger and the risk of fire and its consequences, and thirdly, to delegate the optimum protective and preventive means and measures necessary to limit the effects of fire within the specified limits.

The issue that security engineering is most concerned with so-called soft (innovative) engineering involving sensitive spheres of social, political or economic life – most often on an international and global level. In this field, the theory and practice of national, internal, public, social, as well as political, military or international security engineering is being developed [26]. Due to the observed climate change, there is a lot of talk today about environmental and climate security engineering. In the last year, in the face of the sudden attack of the COVID-19 pandemic, health security and the various preventive and precautionary measures that had to be introduced using the theory and practice of extensive pandemic security engineering have become a the top-priority matters. Almost the entire global pharmaceutical industry has directed its efforts towards producing an effective vaccine against SARS COV 2 viruses in the shortest possible time with the highest health safety standards.

7. Medical engineering

A very particular set of social expectations in the face of enormous scientific and technical progress are currently being brought by and fulfilled by Medical Engineering along with many of its varieties and types. This is because engineering and technology share significant analogies and similarities with biology and medicine. Both disciplines are about solving problems with knowledge, intuition, experience and creative heuristics. Moreover, they share the same pragmatism, driven by the need to create effective solutions and efficient applications, mainly in the form of tools and instruments, even before scientific explanations have been assigned to given phenomena.

Biomedical Engineering is part of the bioengineering sciences. It represents an amalgamation of knowledge and experience that is located at the intersection of technical, medical and biological sciences. The marriage of medicine and informatics has proved particularly attractive, resulting, for example, in bioinformatics, medical informatics, medical imaging, telemedicine, image processing, physiological signal processing, biomechanics, biomaterials or 3D modelling. Clear examples of the application of this knowledge are improvements in the manufacturing and operation of medical equipment, diagnostic devices, imaging devices, laboratory and medical laboratory equipment, as well as new generations of drugs and other therapeutic agents that support healthcare services at all stages of diagnosis, treatment and prevention [27].

A particularly attractive substitute for medical engineering are biomaterials that solve many medical, ethical or even moral dilemmas. A huge field in this area still exists in the design of artificial organs. The training of specialists to operate and service computerised biomedical equipment is covered by clinical engineering. The field of bioengineering needs high-level professionals specialising in the operation and use of medical equipment, as well as experts in the software of this equipment with strictly medical knowledge. Genetic engineering, or the various biotechnologies, is currently in the process of rapid development, and an entire branch of bioengineering for medical applications has emerged.

8. Genetic engineering

Genetic engineering (GE), which dates back to the 1970s, still raises many hopes, but just as many question. The genetic code of viral DNA and bacterial DNA was artificially combined in the U.S. laboratories in the 1970s. This groundbreaking experience triggered the development of genetic engineering, which integrates the genetic material of different organisms to alter their hereditary properties. It involves introducing a specific stretch of DNA from another organism (the donor) into the cells of the organism, the characteristics of which we wish to change (the recipient) [28].

Genetic engineering is a set of methods, thanks to which it is possible to modify the genome of living organisms. From a technical perspectives, this opens up extraordinary possibilities. It is possible, for example, to produce bacteria that will produce substances such as insulin or interferon, which have important applications in medicine. This method can also be used to grow frost-resistant plants or the plants with the ability to produce their own pest control substances. In the most general terms, genetic engineering involves: isolating fragments of genetic material from a cell, making changes to the genetic information, transferring DNA fragments into the cells of another organism and duplicating (cloning) genes and whole organisms. The development of genetic engineering has been possible thanks to the strong developments in genetics and molecular biology over the past decade or so. Genetics did not begin to emerge and develop until the mid-70s, which involved the discovery of the structure of DNA and the development of electron microscopy methods.

Genetic engineering methods currently have a wide range of applications in the manufacture of many medicines, such as insulin and some vitamins. This is of great practical importance. In the past, before the insulin biosynthesis method was developed, insulin was obtained from animal pancreases. This was a very expensive method, as the amount of insulin obtained from one pancreas was small and the process of secretion was expensive. Genetic engineering is also used for the production of so-called transgenic organisms [29]. It is also important in the development of genetics. This is because it helps to learn more about the functions performed by specific genes. Genetic engineering brings us much closer to solving the mystery and mechanism of life as a form of appropriate programming of the genetic code. Nowadays, attempts are being made to use cloning methods to save endangered species. Public discussions on genetic engineering often focus on the danger of releasing previously unknown life forms into the environment.

Genetic engineering is widely used in many scientific fields, both theoretical and practical. It is used extensively in medicine, agriculture, forensic and judicial science, archaeology, evolutionism. Currently there are attempts to modify, for example, plants so that they produce more abundant harvest (eradicating world hunger), contain more vitamins and nutrients and, for example, would facilitate introducing vaccines against certain diseases (reducing vaccination costs).

Genetic engineering is an extremely promising and up-and-coming technology that, in addition to its obvious benefits, also has a certain baggage of drawbacks and uncertainties. It offers hope for a better life in the future – higher yields, healthier food, cloning of endangered organisms – but in order to use safely, appropriate ethical rules and legal standards need to be developed and the necessary long-term and reliable research needs to be carried out. Meanwhile, pharmaceutical and biotechnology companies seeking to make as much and profit as possible and also – as fast as possible – sometimes choose to ignore it and consciously take dangerous shortcuts.

9. Management engineering

The praxeological branch of systems engineering is Engineering Management, which traditionally belongs to economic sciences. Management, i.e. the reduction of uncertainty in action by making sound decisions for action, is not just limited to coordination, supervision and control, but also covers the functions of planning, directing, designing, implementing and the constant pursuit of change [30]. Organisations that operate in a fast-paced environment require innovative operating concepts, constant transformation and continuous improvement of management methods. Traditional management methods were geared towards harmonising simple and unique activities today are proving ineffective in the face of today’s ever-changing situational challenges [31]. Management, which, up to this point, has been focusing mainly on standard simple and repetitive activities (planning, organising, stimulating, controlling), is giving way to agile and unique management, implemented in a turbulent world of constant challenges and changes.

Management engineering, referring to the broadly defined theory and/or practice of knowing and deliberately changing and controlling processes or systems, is a reflection of contemporary developments in business (manufacturing). It is associated with a very specific way of thinking geared towards improving mainly production and manufacturing processes, the result of which is a new product, or a process or product that is better than the previous one. In economic terms, it aims to integrate information, material and human resources, including design, manufacturing, control and transport and storage processes into one comprehensively managed production system [32]. In this respect, management engineering, often equated directly with production management, plays a crucial role in the modern manufacturing technology.

Management engineering in terms of manufacturing is conceived as the management of technical functions such as research, design, manufacturing (found in any company with modern technology), as well as − the management of broader functions such as marketing, logistics, product and service production, distribution and trade, and the management of upstream development projects and production companies. This management-related activities are carried out in an environment of market competition, high technology and rapid changes in manufacturing and operating techniques. A popular market trend nowadays is end-to-end product management, i.e. from the generation of requirements for a new product, through the design phase, test production, market launch, distribution, to market withdrawal and replacement with a new product or its next generation.

Universal management engineering is developing in line with the needs of the modern market economy, stimulating the improvement of organisational processes and contributing significantly to production efficiency. Over the last few years, the transformation of economic orientation from manufacturing to market (business) orientation has forced entrepreneurs to seek new ways to improve in order to be able to keep their companies afloat in the highly competitive market for goods and services. Increasing uncertainty caused by dynamics of the ongoing changes has necessitated the continuous development and implementation of new concepts and approaches to planning, organising and controlling production processes and systems across almost every industry. The rapid and effective response of company boards and managers to the dynamic needs of the market economy is a marker of modern times, and this challenge is being faced in a very efficient manner by modern management engineering [33].

10. Financial engineering

The new 21st century has seen the birth and rapid boom of Financial Engineering[4] based on selected methods of modern applied mathematics and theories of finance, banking and macroeconomics in general [34]. Its purpose is to analyse financial market derivatives through analytical valuation (forecasting) methods for specific indicators in order to minimise various types of risks, e.g. financial, stock market, credit and also business risks.

Financial engineering is a field of modern finance that provides tools to model and forecast events in financial markets and to quantitatively manage the risks associated with financial investments. The statutory objectives of financial engineering include: compiling of complex investment strategies, price forecasting of financial instruments, design, analysis and creation of financial instruments, valuation of financial instruments, risk management of financial investments. In pursuing these objectives, econometric and mathematical techniques are

[4] A new branch of financial mathematics pursued also as a specialisation in mathematics or management science has been created for the rapidly growing financial engineering and its global products, mainly in the stock market, insurance and banking sectors.

used for the modelling and forecasting of events in financial markets. Financial engineering is, therefore, a field that combines knowledge of finance, applications of mathematics and methods of IT and econometrics.

Financial engineering enables reliable forecasting of prices and risks in financial markets. It studies modern methods of investment risk management using statistical and mathematical models and, above all, offers a wide spectrum of abilities in the valuation of complex financial instruments. It is possible to improve the efficiency and safety of business operations through the skilful distribution of risks; by precisely identifying their sources and applying effective risk management methods. A very important financial engineering tool is the handling of sophisticated financial and banking products, such as bank options, new shares and bonds, various funds, the use of shareholdings, futures contracts, which increase employee motivation and customer trust [35].

In the end, the application of various financial engineering mechanisms causes the competitiveness of the company to grow, the quality of its services and products to improve and with it – so do the sales and final profit. Physical process models and, more recently, computer simulation models are also widely employed as a very flexible tool for marketing or financial research. Financial engineering can also be understood as a way of financing business ventures that use different combinations of financial instruments, forms and institutions. Such activities are sometimes also called a “financial assembly”[5].

Financial engineering tools first found a large-scale application in the early 1990s. We are now living in a time of an avalanche of information and an enormous surge in the number of collected data, the skilful use of which can lead to an increase in the quality of life for all, as well as bring huge profits to those who are able to use it well. As for the worlds of IT, economics, finance and engineering, they are integrating on an unprecedented scale. With the development of information technology, the computing power of computers and the increasing globalisation of markets, the importance of this discipline continues to grow [12]. Financial engineering specialists are in high demand on the labour market. The importance of financial engineering is expected to grow and its future is linked to the application of advanced AI-based methods.

11. Software engineering

Software engineering belongs to process engineering, which deals with all aspects of the production and use of computer software: from requirements analysis and definition, through preliminary and technological design, to the usable implementation and evolutionary development of the finished software. While IT deals with the theoretical aspects of software production, software engineering focuses primarily on the practical side[6]. Software engineering can be defined as technical knowledge concerning all phases of the software life cycle with the aim of making a high quality product, i.e. software [36].

[5] One of the negative products of modern financial engineering based largely on virtual accounting and bookkeeping and electronic e-Cash was, in a way, the recent financial crisis (2009) triggered by an uncontrolled outflow of blank bank loans with no financial security on the part of the borrower. As a consequence, the basic control instrument of financial engineering, i.e. the risk analysis of the banking services market, has been completely ignored and disregarded.

[6] The term “software engineering” was first coined in the late 1950s/early 1960s (but officially 1968 and 1969 are cited as the birth of the discipline, with two NATO-sponsored conferences taking place in Garmisch and Rome respectively).

Advanced engineering methods are applied in modern computer science, which is an interdisciplinary discipline at the intersection of mathematics and logic, physics and electronics, information and communications theory, precision mechanics, materials science. In order to cope with the overwhelmingly dynamic environment of scientific and technological progress, it has developed a number of its own research methodologies known as detailed engineering, which include in particular: software engineering and computer engineering. Software engineering can be defined as the technical knowledge relating to all phases of the software life cycle with the aim of making a high quality product, i.e. software [37].

Software engineering is the utilitarian knowledge and practical skills useful for building computer programmes, especially large operating systems, which includes the development of a software application, various programming methods, practical aspects of commissioning and testing, and documentation development. Another responsible direction of software engineering applications is the proof of correctness and functionality of computer programmes and issues of program transferability to other installations. Knowledge of the principles of programming engineering helps in the process of efficiently building reliable software, also automatically via other software systems.

The scope of software engineering largely overlaps with that of IT project management, the implementation of which can be simplistically treated as practical software development. The success of the entire venture depends on this stage of the IT project, while at the same time, at this stage, it is possible to correct any detected problems in a flexible way and systematically adjust the requirements increasing the quality of the final product [12].

For the purposes of software engineering, a specific methodology has been developed for software production, according to which we distinguish the following phases of the software production process: specification of assumptions and requirements, technical and technological design, software implementation and integration, testing, implementation and operational use. Software engineering has developed a number of tool notations and languages to support the software development process. Nowadays, languages supporting object-oriented programming have become popular – the most important one out of all of them is the UML (Unified Modelling Language). The Yourdon structured method was used in the past. Currently, the most popular software production models are, for example, cascade model, prototype model, incremental model, parallel model, extreme programming or spiral model [36].

The broadest term is information systems engineering, which is the art of creating, developing and maintaining applications that meet specific user requirements. On the other hand, a certain subcategory of programming engineering is information engineering, also known as knowledge engineering, which refers to building advanced knowledge bases, mainly for the expert systems, assigned to the sphere of artificial intelligence. The primary task of knowledge engineering is the collection and formalisation of expert knowledge, according to the form of usage rules of modern expert systems.

12. Social engineering

Social engineering, also known as societal engineering or sociotechnics, plays a huge role in shaping global relations in today's global village. Used for years in political science, sociology and marketing, Social Engineering is a set of techniques to achieve specific goals through the deliberate manipulation of the society [38]. The person who uses social engineering believes that the goal they are pursuing is more important than the truth or the independence of thought of those being manipulated. Sociotechnics appeals to people's emotions and tries to put their minds to sleep [39]. Often, the manipulators try to convince the recipients of their message of their ideas, in doing so they even resort to detracting the recipients from reality, because they think that the purpose of their activity justifies it. Social engineering can also be used for the benefit of society. An example of this is the instilling of positive, humanitarian ideas in the upbringing process.

Social engineering, on the one hand, seeks to study objective social states, views and moods and, on the other, to skilfully improve the mentality and characters of specific social groups through the effective use of various socio-technical procedures. Through proven and tested and effective socio-technical methods, "social engineers" seek to influence the acceptance of suggested norms, views or values, especially those that are shared by, for example, authorities or power elites [40]. This is why it is not uncommon, despite the fact that they formally apply scientific methods, e.g. sociological or psychological tools, for them to sometimes obtain paranormal results, tainted with elements of manipulation and autosuggestion.

Since the dawn of time, certain methods of social engineering have been used unconsciously by leaders to empower people living in harsh conditions. Some religions have always unknowingly used social engineering to reinforce a positive impact on the believers and give them the strength and delusion to endure the hardships of everyday life. However, in the 20th century, advanced social engineering became a tool for human destruction. Totalitarian regimes have used social engineering on purpose to stupefy the people they rule over in order to maintain discipline, obedience and, above all, power. Manipulation often led to the surge of negative feelings such as fear, aggression and hatred. Known from the darkest corners of history, fascism, communism, the Holocaust or the Gulags would not have been possible without the use of social engineering methods to guarantee mass support for these cruel ideologies.

Social engineering is not objective and neutral knowledge. It is linked to specific techniques of manipulation, autosuggestion and so-called personal marketing, as well as to politics, prevailing ideology or other trends, e.g. world or religious trends. Therefore, its objectivity and effectiveness depends not only on the knowledge, qualifications and dispositions of the "social engineers", but also on their intentions, the principles they believe in or the moral and ethical norms they recognise as their own [4]. This is why they introduce subjective adjustments into their research agendas to ensure the desired convergence of results with their own views or the suggestions of a particular community.

Conclusions

Contemporary knowledge and technology engineers solve a variety of theoretical and practical problems that require efficient solutions that are not particularly clearly defined at the outset, so several alternative solutions are usually also possible. Engineers must therefore evaluate a number of alternatives in terms of their functionality, safety, economics, etc. and, on this basis, select the best solution that fulfils the assumed initial requirements.

Creating a suitable mathematical model is usually an essential tool that and an engineer can use to effectively analyse and test potential solutions. Despite the use of various mathematical optimisation algorithms, engineering is usually fairly content with merely sufficient (acceptable) solutions[7]. Knowledge engineering is definitely closer to a "pure" theoretical

[7] After analysing a number of existing patents, Genrich Altshuller, the creator of the famous invention algorithm, presented an idea that at a "low level" engineering solutions are based on trade-offs, while at a "higher level", the engineer's work is about selecting the best solution that eliminates the main difficulty of the problem.

science than technology engineering, but scientific and technological progress, and thus the development of civilisation, is fundamentally determined by the state of technology and the level of material goods, which are the results of praxeological technical engineering, i.e. “the producer”.

Computers and the useful methods and tools of computer science are an integral tools of modern engineering. They provide support for engineers at every stage of their work – from design through production, testing, implementation to operational use, improvement and servicing. The widespread use of computers to design and directly support production processes has led to a dramatic increase in the efficiency of economic processes and – as a matter of fact – to the massive overproduction of all material goods and services. At the engineering design stage, in many cases thanks to the computer modelling and simulation it is no longer necessary to design and test costly one-off prototypes, now replaced by virtual entities. The specialised software also offers the engineer a rich database of proven solutions or ready-made standards commonly used in day-to-day operation.

The great social systems that have been operating smoothly for centuries have been the basis for the development of the civilisation world in specific epochs and eras of civilisation. Even in ancient times, there were great state empires the existence and development or expansion of which were based on the achievements and accomplishments mainly of the system sciences in a broad sense. The most spectacular example of the application of unnamed system engineering in the history of Europe was the Roman Empire, whose political, military and socio-economic power was based, on the one hand, on universalist Christian philosophy and, on the other, on the achievements of science and technology of the time. An outstanding example of this was the administrative system based on prefects and the intense development of a communication network integrating vast areas of the Empire, which – in its heyday – covered an area of more than 2 million square kilometres, where political and administrative power was exercised very effectively.

To recapitulate, it can be stated that in order to effectively and efficiently manage and manage large real systems – political and social or economic, it is first necessary to recognise and master the basic laws governing the operation of these systems, and then to have a sufficiently high level of processing tools and technology to guarantee the effectiveness of practical activities occurring within the material culture (design, construction infrastructure). This requirement, even in the age of the Internet, is the unchanging paradigm of the engineering approach in all of its theoretical aspects and applications.

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Author contributions

All authors contributed to the interpretation of results and writing of the paper. All authors read and approved the final manuscript.

Ethical statement

The research complies with all national and international ethical requirements.

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Inżynieria systemowa – synergia nauki, wiedzy i technologii stosowanej

STRESZCZENIE W pracy przedstawiono podstawy teoretyczne i wybrane aplikacje praktyczne inżynierii systemowej. Na wstępie zdefiniowano pojęcie i przedmiot inżynierii systemowej, którą osadzono w rodzinie nauk systemowych. Nakreślono też metodologię podejścia systemowego, wykorzystywaną w nurcie inżynierii systemowej i silne współzależności, jakie istnieją między teorią systemową a praktyką budowania aplikacji systemowych. Szczególny wysiłek został skupiony na prezentacji wybranych kategorii inżynierii systemowej, takich jak: inżynieria wymagań, środowiska naturalnego, bezpieczeństwa, medyczna, genetyczna, zarządzania, finansowa, oprogramowania i społeczna. Praca ma charakter syntetyczno-przeglądowy i stanowi przyczynek do dalszych dyskusji w ramach propagowania uniwersalnego podejścia systemowego w nurcie prakseologicznych dyscyplin różnych kategorii inżynierii technicznej i nietechnicznej, materialnej i niematerialnej, ale zawsze innowacyjnej i kreatywnej.

SŁOWA KLUCZOWE system, inżynieria, nauka, koncepcja, projekt, aplikacja, innowacyjność

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