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Towards innovation and development in ergonomic design: insights from a literature review

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Abstract

The paper examines the characteristics of changes that are intentionally introduced by humans into their living environment. It shows that technical and organizational changes without taking into account human factors criteria - and thus also ergonomic criteria - are the source of many losses. Moreover, the paper contains a discussion of the sequence of actions that lead to relevant changes in the existing reality. It also illustrates innovative engineering applications in the field of ergonomics, known as ergonomic engineering and more extensively – "ergologic" engineering. The importance of heuristic techniques in supporting creative thinking, indispensable in ergonomic design is shown. A discussion of economic development, which is determined by actions of an innovative character, is also presented.

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Keywords: changes; development; ergonomics; ergonomic innovations; human factor

1. Introduction

The concept of change is intuitively obvious: it is the result of deliberate actions, carried out by a human (people) or natural forces provoked by people (the effects of air pollution, the consequences of hydroelectric power stations construction), or the effects of forces of nature (volcanic eruption, earthquake, tsunami, ocean tide, solar radiation). It is a mean to adapt to new conditions (Kubr, 2002) and may concern – and do concern – all aspects of reality, including those which determine the lives and welfare of people (Golembiewski, et al., 1976; Neylor, 1996). Referring to humans and technology, three clearly distinct periods in the social acceptance of technology as

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an engine of change can be distinguished in the last century. At first, it was a period of unbridled and uncritical optimism, due to ground-breaking achievements such as the splitting of the atom, landing men on the moon, automation and robotization of manufacturing processes. It seemed that science coupled with technology can achieve almost anything (Brown, 1982). Afterwards, the change started to be viewed as predictable and dangerous (Botes, 2009), or even as dispelling misconceptions due to disappointment resulting from the lack of breakthroughs in food production and energy, the fight against diseases, improvement of the quality of life on a global scale, awareness of the causes and results of environmental losses (Brown, 1982). Finally, it has become a period of cautious realism: the understanding that material, energy and intellectual resources at our disposal are limited and that the need for their rational management requires an increasing depth and breadth of knowledge and imagination and ethical evaluations (i.e. a sustainable development strategy) (Steurer, 2008; Waas et al. 2014; Radjiyev et al. 2015). From these considerations it may be concluded that a lack of change signifies stagnation and is not a good scenario for the future (Hirschberger & Shaham, 2012) and in turn changes made for the sake of change often bring more harm than good (Chuang, 2006). The introduction of changes must therefore be based on knowledge, experience and preceded by deep reflection – all the more since modern technology as the fulfilment of scientific concepts is becoming increasingly invasive in nature in relation to the determinants of human life and the environment, on which we are almost entirely dependent (Hall & Hord, 2006; Wyrwicka, 2011; Saravia-Pinilla et al. 2016).

The issue of intentional change resulting from deliberate actions of people, who perform them on the basis of an accepted system of values, is of great interest. Relying on a recognized system of values and acting in accordance with them it forms the basis for an ethical evaluation of actions and their effects. In the qualitative assessment of change a special place is held by non-technical knowledge, including the humanities. Since technology is created by the people and for the people – by nature it is humanistic and on these grounds it should be assessed. On the other hand, it is important – particularly for engineers and economists – to be efficient in introducing changes, which is assessed according to praxiological criteria.

A final assessment of the quality of changes is possible only after their completion. Evaluations carried out earlier are prognostic and feature errors – which are larger, the longer the horizon (temporal, spatial, and factual) of prediction. The accuracy of prediction is increased by experience and verifiable knowledge about the effects of similar changes introduced earlier in similar fragments of reality. In order to implement any changes, they must first be planned (designed). This conceptual work must be based on decisional criteria belonging to a particular system of values. It is described by the concise definition: "design is the conceptual preparation of a relevant change" (Gasparski, 1978). This "relevancy" of changes can be fully achieved by using appropriate methods of design that take into account desirable quality criteria, for example:

- Concurrent design, which involves the co-participation of future users in the product design process (Parsaei & Sullivan, 2012)
- Universal design, which aims to design a technical object taking into account the characteristics of all people, including disabled users (Steinfeld & Maisel, 2012)
- Ergonomic design, where the structure of the design process is adapted to the nature of the designed object, i.e. the human – technical object system (Tytyk, 1991; 2001).

For the designed relevant change to become an innovation it has to be implemented, introduced for general use and acceptable to users or customers. Desirable innovations are those that contribute to the growth of civilization: economically, socially, culturally – that is, those that increase the welfare of the people. The benefit of economic development is the increase in the relevant civilization variables: standard of living of society, scale and quality of production and public safety.

The main driving force that shaped society since the beginning of the Industrial Revolution is the ethics of growth. Prior to that the ethics of immutability dominated. One measure of the ethics of innovation should be its ergonomics – compliance with the principles of ergonomics as a sign of the humanization of technology. Growth (in the material sense), due to the depletion of resources (material, energy, human), cannot last indefinitely. It is necessary to adapt to the realistic possibilities that determine growth, that is – to change to the ethics of sustainable growth.

The paper gives an overview of changes that are purposefully introduced by human lives. In particular, it concerns introduction of technical and organizational changes where human factor criteria - and thus also ergonomic criteria are not taken into account what leads to many losses. Moreover, it presents ergonomic innovative engineering applications and heuristic techniques in supporting creative thinking, vital in ergonomic design. Finally, a discussion of economic development determined by actions of an innovative character is presented.

2. Innovation in ergonomics

2.1. Innovation in methodology

The main features of methodological innovation in ergonomics (in relation to other sciences) include: systemic approach, interdisciplinary nature of knowledge and humanocentrism (Tytyk, 2013). Other manifestations of innovation in the area of methodology can be seen in the treatment of the subject of research. Initially it was a human-machine system and elements of the close environment of the system (primarily environmental factors at work). This phase of development was later known as "first generation ergonomics" (Boff, 2006). This may suggest that it was a phase of development which belongs to the past and that it currently does not have any other meaning, beyond the historical. Such an opinion is not justified, even – false. If the subject of ergonomic considerations is treated in terms of a system, then in this case it is an elementary human – technical object system. The subject is an illustration of a single work station (Fig. 1), or any purposeful activity of a human using technical means, e.g. a person cutting bread with a knife, driver of a car or a turner at a lathe.

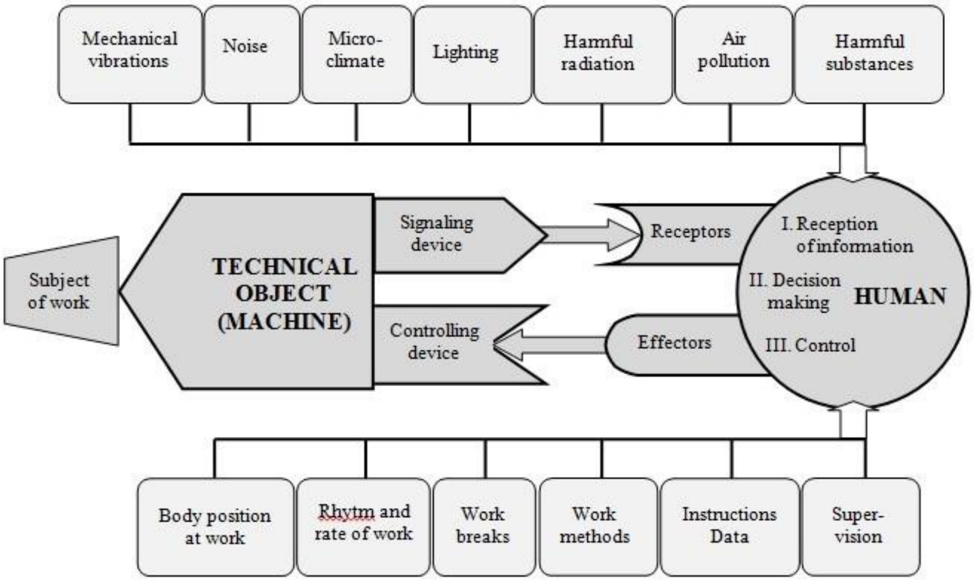


Fig. 1. Elementary human – machine system and his environment.

From these elementary systems are built systems with higher levels of complexity, e.g. production lines and cells, departments, enterprises, cooperating groups of people, etc.

Instead of talking about "first generation ergonomics" it is better to use the term "elementary systems ergonomics" – to not give the impression that such problems have been solved and are now obsolete (Tytyk, 2009).

To describe the subject of interest of ergonomics that is more complex than the elementary system human – technical object, the term "second generation ergonomics" (Pacholski, 2000) or "systems ergonomics" (Kleiner, 2006; Karsh et al., 2014; Wilson, 2014) was adopted. These terms are inappropriate, since they suggest a hierarchy of importance among generations, and tautological, because ergonomics by definition deals with (anthropotechnical) systems. Since the subject of interest are systems with a greater complexity than elementary systems, the term mesosystems and accordingly mesoergonomics (Greek: *mesos:* intermediate, middle) may be used (Karsh, 2006; Sanders, 2014).

The focus of mesoergonomics are systems of such a degree of complexity, as production lines and cells, working brigades, operator teams, hospital wards, universities, etc. The following features are characteristic of them:

- Aggregation of machines and other technical devices into larger units, with a large degree of complexity, requiring a team of people with relatively simple qualifications for their operation, and a dedicated team of people highly qualified for their maintenance,
- High operational independence of machines and aggregates, reflected in the automation of technological processes,
- Robotization of technological processes and auxiliary handling operations, causing human displacement from implementation processes and brings a lot of previously unknown effects – both positive and negative,
- Very large diversity of forms and content of work, from individual to team positions, from fixed-to-mobile positions, from simple and monotonous work to highly stressful work,
- Expanding the set of ergonomic criteria (diagnostic and design) to the social, sociological, economic, educational and cultural spheres.

The study of systems of such a complexity is difficult and burdened with low precision, given the substantial and significant contribution of factors immeasurable by an apparatus and amenable only to estimating judgments. Even more difficult and involving the risk of failure is the design of such systems. The designer has only incomplete and uncertain information that also may be inadequate and outdated at the time of executing the project. Implementation takes place at a certain amount of time after design decisions have been made, as a result the decision-making conditions (i.e. the design criteria) may change.

The development of modern ergonomics depends on the ability to solve problems on the meso scale. This creates particular demands for conceptual work concerning, among others, methods of diagnosis and ergonomic design, combined with an occupational risk assessment and measures aimed at ensuring an adequate quality of products and services. The results of this work should be addressed to the realities of life (not only professional) of various social groups.

It is easy to imagine the structure of systems with an even higher degree of complexity, made up of many elementary human – technical object systems (Fig. 2).

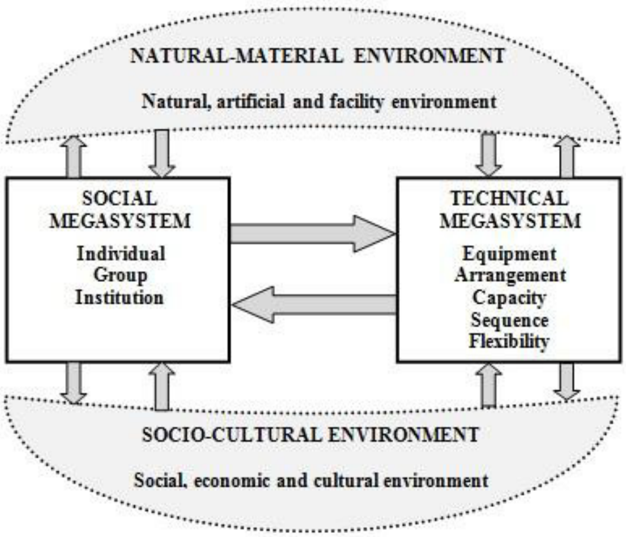


Fig. 2. Components of anthropotechnical megasystem.

They may be called “anthropotechnical megasystems” (Tytyk, 2013). In practice, this can be e.g. a manufacturing company, office, hospital, school, shopping centre, housing complex and even a giga system called a technological civilization. Here is the beginning of the realm of science called macroergonomics or “third generation ergonomics,” which is even closer to the management of complex systems (e.g. enterprises) (Hendricks, 2002; Pacholski and

Jasiak, 2011).

The environment of systems with a higher degree of complexity is different than that of the elementary or secondary systems: here factors belonging to economics, sociology, ecology, politics and culture come into play.

2.2 Innovation in research

Scientific research within the realm of ergonomics has both a basic and applied (practical, engineering) character. The first group of studies includes, for example, the study of human responses to various external environmental factors, the inquiry into the causes for and mechanisms of the appearance of events essential for human welfare that are derived from the area of technology. The second group includes – according to the definition of ergonomics as an applied science – a broad group of engineering measures known as diagnosis, „post-gnosis" and ergonomic design.

Innovation in research methodology in the first of the mentioned areas coincides with the development and improvement of research methods in the specialized sciences constituting ergonomics: physiology, psychology, medicine, anthropometry and is associated with the improvement of equipment and research methods (e.g. eyetracking, encephalography, electromyography, magnetic resonance imaging). Data processing is aided by increasingly applied analytical tools, such as the fuzzy set theory, expert systems, decision support systems and other tools of so-called artificial intelligence.

On the other hand, innovation in the second area of research concerns "corrective ergonomics" and "conceptual ergonomics" (Walker et al. 2010). An analytic induction process used to explain the causes and course of phenomena where only their effects can be observed, has been called "post-gnosis" (Hutchins, 2002). This is the very nature of methods of analysis of accidents at work, and to some extent – also of occupational risk assessments. Visible here is the strong research trend typical of engineering thinking: gaining insight into the causes and the most probable course of events (accidents, failures, emergencies) in order to eliminate or reduce the possibility of it repeating in the future, through implementing changes in technical and organizational structures.

A typical activity of engineering is perceiving design as a "conceptual preparation of a relevant change" (Gasparski, 1978). Methods of design employed in ergonomics underwent changes as a result of the development of general design methodology as well as from the development of methodological concepts in ergonomics and the subject of its research (Fig. 3).

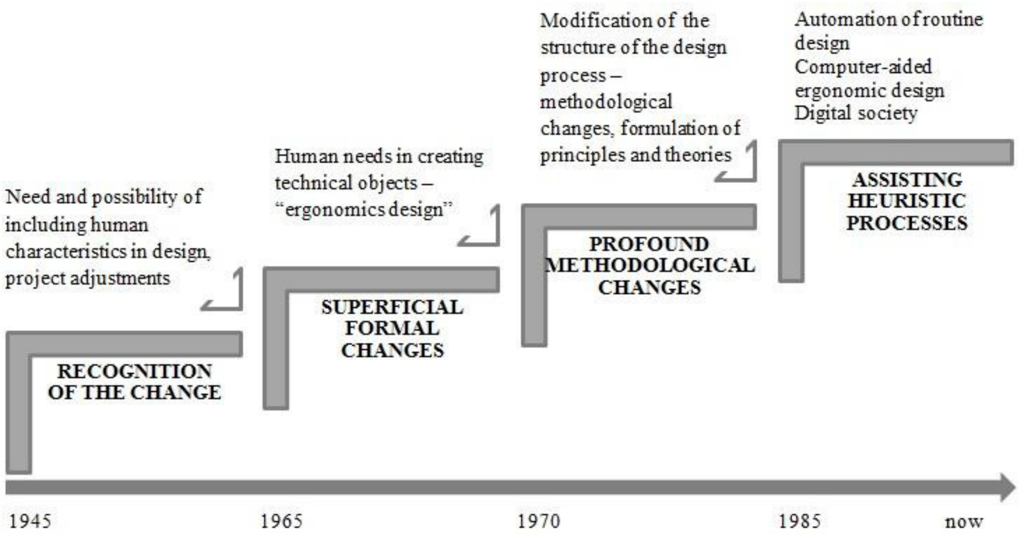


Fig. 3. Development of ergonomic design methods.

The characteristic of the (practical, applied) engineering sciences is that an extremely important part of their operation revolves around the processes of implementing relevant changes, otherwise known as design. In relation to ergonomic engineering, it is necessary to develop and apply distinctive methods known as ergonomic design. The process of designing technical sub-systems, which constitute the component parts of anthropotechnical systems, must be based on a specific way of creative thinking called “technical thinking” (Franus, 1978). The design of human sub-systems must precede the design of technical sub-systems and form the basis for decision-making regarding technical structures. This is the basic methodological assumption for the III stage of development of ergonomic design (Słowikowski, 2000; Tytyk, 2001) (Fig. 4).

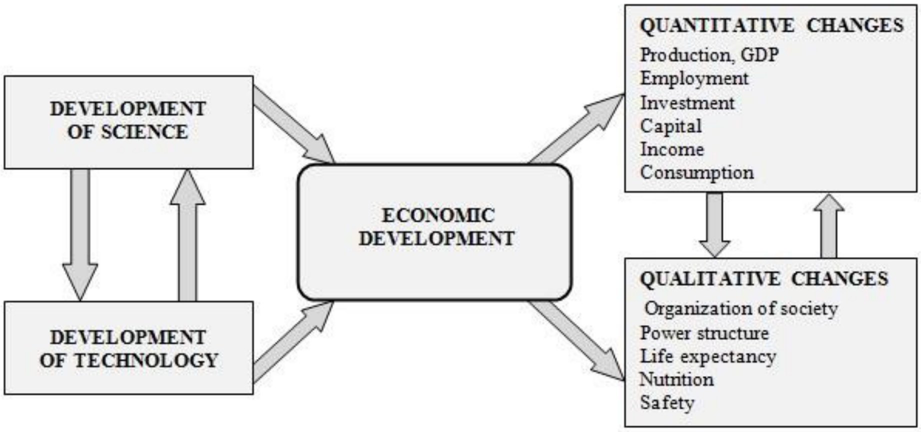


Fig. 4. Relationship between development of science and technology, economic development and the resulting changes.

Research on and the design of complex human – technology systems is an engineering task that is extremely difficult, responsible and risky. The larger the size and complexity of the system, the smaller the possibilities of diagnosis, simulation and relevant design. One way remains: to advance science, utilize the available knowledge, create technology thoughtfully and responsibly, evaluate the impact of actions prudently and correct mistakes, if it is still possible.

2.3 Innovation in the area of engineering applications

The statement that applied ergonomic research can be seen as “ergonomic engineering” appeared in the literature for the first time in the end of the 20 century (Kroemer and Kroemer, 1997). It refers primarily to the technical components of anthropotechnical systems, since this is an area with a wide scope for engineering measures such as implementing (desirable, positive) relevant changes based on an increasing knowledge of the psychological, physiological, anthropometric and cultural determinants of human activities, as well as on the construction and operation of machinery and manufacturing materials and techniques. Improving the “human component” of the anthropotechnical system takes place in parallel to the above and is the subject of educational, cultural, and training activities, and furthermore it is a consequence of improving the “machine component” of the constructed system of operation. Therefore, one could say that ergonomic engineering is a collection of engineering activities carried out on technical objects (existing in reality or virtually –in the design stage), in order to improve the level of their adaptation to the characteristics, capabilities, limitations and aspirations of the person operating them.

The fact that in ergonomic design “technical thinking” must be modified and enriched with humano-centric conditions and decision-making criteria, results in the necessity to create innovative technical solutions. It is a mechanism analogous to a principle known in organization theory which states that in order to effectively achieve a new goal, it is necessary to use novel methods. The new goal is a relevant anthropotechnical system (designed and implemented), while the novel methods are methods of ergonomic design.

The road to innovation in ergonomic design leads to a departure from traditional, already known technical solutions towards solutions that are original, innovative, not yet proven – but risky. The rejection of known, conventional methods for solving design and construction tasks is a compelling force to seek knowledge, use the imagination, look for analogies among other solutions from other areas of technology, or – what is very fruitful – from nature, and even from the realm of fairy tales and fantasy. The following heuristic techniques are helpful in launching creative thinking: brainstorming (A.F. Osborn), morphological analysis (F. Zwicky), synectics (W.J.J Gordon), algorithm (or theory) of inventive problem solving (H. Altshuller) ideal systems approach (G . Nadler) and others (Savransky, 2000). In all methods and techniques of creative thinking the following recommendations (of varying significance) exist:

- A person setting out to perform creative tasks must possess an inner conviction or even an internal obligation to carry out such operations; this attitude must be accompanied by the belief in the possibility of finding a solution and the high value of both the creative activity itself and its result;
- It is necessary to separate the creative exploration phase from the phase of detailed formulation and evaluation of solutions;
- Training and experience is necessary to use heuristic methods;
- It is desirable to skilfully use the diverse knowledge of many people, often completely unrelated to the subject of the search;
- Working in groups on solving tasks is more efficient and yields more innovative solutions than people working in isolation from each another; however, the synergistic effect may be disrupted by conflict within the group and a leader's inability to guide the group.

The effectiveness of these methods and heuristic techniques is demonstrated by the fact that they have been useful in solving technological antinomies and obtaining several inventive solutions from the field of ergonomic engineering, which acquired patents or utility models (Tytyk, 2001).

3. Development and innovation

Economic development is a long-term process of changes taking place in the economy. It includes both changes in quantity and quality. Quantitative changes concern an increase in production, employment, investments, amount of functioning capital, income, consumption and other economic values characterizing the economy from the quantitative side (economic growth). They are accompanied by qualitative changes, which concern the organization of society as well as structural changes. Economic development results in changes in the creation of Gross Domestic Product and changes in employment structure.

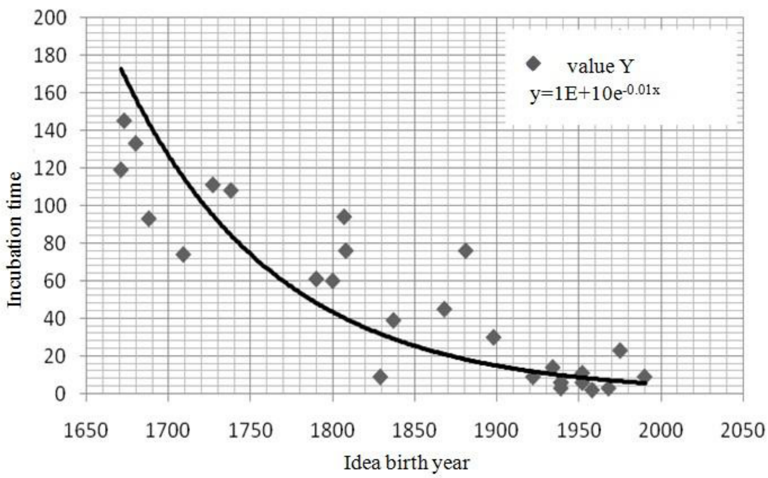
Economic development is currently not possible without the development of technology which, in turn, is not possible without the development of science (Maddison, 2014). From the point of view of the quality of life of human societies, a generally positive impact can be observed of the development of economy, science and technology on the nutritional status of people, the infant survival rate, prolongation of life expectancy, health, comfort of life, work safety, etc. At the same time, the development of technology and the accompanying economic development and prosperity are paid for by the costs that are incurred in other areas: unemployment rises, while in many professions there is a lack of skilled workers; the occurrence of detrimental changes in mental and emotional characteristics, in social bonds, recognized values and authorities, and above all – the main cost is borne by the natural environment, animate and inanimate. The effects of changes in the environment inevitably affect us, the perpetrators of these changes too, because we constitute a part of the natural environment.

Modern science cannot exist without sophisticated research technologies, and its fruits are largely used immediately to create innovative techniques and technologies. The issues in technology are shaped mainly by the needs of the market (civilian and military), and their satisfaction requires the involvement of a broad knowledge base, that is, the development of basic and applied scientific research. It indicates a complete interdependence, symbiosis of science and technology. A manifestation of these relationships is the utilitarian nature of research carried out at scientific institutions, as well as the robust research and development (R&D) departments in major industrial companies on the market.

People have been working on technical innovations slowly and fairly evenly throughout the period of evolutionary creation of their civilization. However, over the last 200 – 300 years there has been a significant and accelerating development, a snowball effect after reaching a so-called critical mass. In the last 100 years, changes concern not only the level of technology, but also the lifestyle and cultural, ethical and moral values. It appears that the desire to alleviate humankind of its toil was and is dictated by economic and humanitarian considerations (in that order). It is also an important reason for the development of technology – almost as important as the human lust for power and wealth and the propensity for aggression.

It is extremely difficult to gather the most important achievements in science and technology obtained from the second half of the 20th century, and in particular – in the last 10-15 years. A fundamental difficulty is created by the "curse of overabundance." According to "Moore's Law," named after the Intel co-founder, the number of significant achievements of mankind doubles approximately every 5 years (with this period constantly getting shorter). Due to the vast number of scientific discoveries and inventions made in various, previously known or newly emerging areas, it is difficult to assess which of these achievements are important and will be significant in the future. This lack of foresight means that many achievements are overemphasized or form only a short episode in the development of certain areas of science and technology (as was the case with hot air balloons as a method of transport), while on the other hand, others are initially underestimated (e.g. vacuum tubes in computers, the Internet, mobile phones).

The increasing pace of discoveries and inventions makes it difficult to make a qualitative assessment. It is illustrated on Figure 5 showing the shortening of the so-called invention incubation time which is the time that elapses from the appearance of a concept of a technical solution to its practical implementation in the form of a working device.



No	Invention or discovery	Birth	Application	Incubation period
1	Telescope	1671	1790	119
2	Mech. arithmometer	1673	1818	145
3	Bicycle	1680	1813	133
4	Steam engine	1688	1781	93
5	Hot-air balloon	1709	1783	74
6	Camera	1727	1816	111
7	Hydraulic machines	1738	1846	108
8	Sewing machine	1790	1851	61
9	Dual-fuel engine	1800	1860	60
10	Engine aircraft	1807	1901	94
11	Mech. typewriter	1808	1884	76
12	Electric engine	1829	1838	9
13	Telephone	1837	1876	39
14	Radio	1868	1913	45
15	Space rocket	1881	1957	76
16	Televison	1898	1928	30
17	Radar	1922	1931	9
18	Transistor	1934	1948	14
19	Nuclear reactor	1939	1942	3
20	Nuclear bomb	1939	1945	6
21	Lamp computer	1939	1945	6
22	Integrated circuit	1952	1958	6
23	Industrial robot	1952	1963	11
24	Laser	1958	1960	2
25	Microprocessor	1968	1971	3
26	Nanotechnology	1975	1998	23
27	Genetic engineering	1990	1999	9
28	Personal computer	1975	1981	6
29	Mobile phone	1973	1983	10
30	Internet	1984	1991	7

Fig. 5. Evolution of the time of invention incubation (Adapted from (Tytyk, 2001)).

The clear trend towards shortening of the incubation time of inventions means that the creators and users of innovative technical measures have less and less time (and opportunities) to verify all the effects that will come with the use of these inventions.

It usually happens that the positive, desired effects turn out to be exaggerated while the negative, side effects – underestimated. History will show which of the discoveries and inventions from the turn of the 20th and 21st centuries will prove to be the most impactful for future generations. In the near future society will have to deal with problems on a global scale: garbage production, global warming, ozone depletion, migration of the population, overcrowding, lack of drinking water, lack of energy, microbiological and psychosomatic diseases, etc. There will never be a lack of reasons to develop science and technology – hopefully in a direction that gives future generations of humans, animals and plants a chance for survival.

Such a high intensity of changes observed at present in ecosystems is caused by at least three general trends:

- The development of techniques and technologies (the amount of resources and their technical advancement) is exponential in a function of time;
- Environmental pollution (of air, water, soil) accumulates, which leads to exceeding the natural absorbency and resilience of the ecosystem to substances and energy and disrupts the mechanisms of circulation of matter and energy in nature;
- Global human population growth rises exponentially.

The third of the above mentioned phenomena is the result of complex and diverse processes. Population growth is observed mainly in poor countries, which do not have a developed technology and economy. They command only 15% of the global economic income, while their population is 77% of the global population.

Negative phenomena in ecosystems originate primarily as a result of human technological activity. In order to understand these phenomena, ergologic sciences on the interface between technical, ergonomic and ecological issues should be developed. The development of ergologic engineering is the only reasonable path towards creating technology that will allow the human species and other inhabitants of the planet Earth to survive. Describing the direction of development of such sciences is not easy. We remember that the forecasting methods used by the Rand Corporation in the 60s of the 20th century yielded results of a value comparable to divination from tea leaves. Despite these experiences, for over 30 years the richest countries: United States, United Kingdom, Germany, the Netherlands, Japan, Australia and New Zealand developed a certain idea of systems analysis called “foresight,” aimed at, among others, the assessment of global market and technology trends, that would allow to identify generic technologies and the associated lines of research that will have a long-term impact on economic and social development of future generations. Of particular interest to researchers are the changes that are deeply interfering with reality, revolutionary changes known as disruptive innovations.

4. Conclusions

One could give countless examples of negative changes in the environment brought about by human activity. The conclusions suggest themselves: if we want to survive as a biological species, we must better understand the natural laws by which ecosystems operate – and we must learn to respect them, to integrate human activity into natural mechanisms without interference. This motto can be regarded as the manifesto of ergologic engineering, as the tool of an economy steered towards the ideals of sustainable development.

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