# ON THE WAY FROM INDUSTRY 4.0 TO INDUSTRY 5.0: FROM DIGITAL MANUFACTURING TO DIGITAL SOCIETY

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***Abstract:*** *Nowadays the world is surviving the fourth industrial revolution named Industry 4.0, which combines physical world of real things with their "virtual twins". The man with his intellect, creativity and will lies beyond this ideology. Now the image of a new paradigm of Industry 5.0 could be seen. It involves the penetration of Artificial Intelligence in man's common life, their "cooperation" with the aim of enhancing the man capacity and the return of the man at the "Centre of the Universe". The paper outlines modern technologies – from IoT up to emergent intelligence, being developed in organizations where authors work. The convergence of these technologies, according to our minds, will provide the transformation from Industry 4.0 to Industry 5.0.*

**Keywords**: PARADIGM OF SOCIETY 5.0, RETURN OF THE MAN, EMERGENT INTELLIGENCE, EVERGETICS, ONTOLOGY AND KNOWLEDGE BASE, MULTI-AGENT SYSTEMS, INTERNET OF EVERYTHING

## *1 Introduction*

The breakthrough in new information technologies ensured the world to stand on the threshold of the 4-th industrial revolution, named «Industry 4.0».

During the implementation of concepts of "Industry 4.0" the technologies of design and production of difficult technical products cardinally changed. The view of a role of computers in control of the enterprises and, first of all, regarding to methods and means of industrial automation of the plants and factories which passed the way from use of sensors and automation of technological processes – to integration and visualization of data and intellectual support of decision-making by users, changes, too.

It is known that the term "Industry 4.0" was first publicly introduced in 2011 by a group of representatives of Germany business, political and scientific community. It was defined as means to achieve a competitiveness of the industry through the reinforced integration of "cyberphysical systems" (CPS) into productions [1]. At the same time, if 3-4 years ago the concept of "Industry 4.0" was viewed by many people as the next advertizing course, then now the interest in it has developed into real investments and results. According to researches of PwC the annual volume of investment into digital technologies within "Industry 4.0" will exceed 900 billion US dollars by 2020 [2].

It is necessary to note that still now the term "Industry 4.0" remains rather foggy and dim. The words of one of a production site manager with automotive manufacturer "Audi" could serve as a confirmation of this. He told that: "Even though Industrie 4.0 is one of the most frequently discussed topics these days, I could not explain to my son what it really means" [3].

In [4, 5] Industry 4.0 is determined as «an umbrella term used to describe a group of connected technological advances that provide a foundation for increased digitisation of the business environment». It is consistent with the definition of Industry 4.0 made by McKinsey as "the next phase in the digitization of the manufacturing sector, driven by four disruptions: the astonishing rise in data volumes, computational power, and connectivity, especially new low-power wide-area networks; the emergence of analytics and business-intelligence capabilities; new forms of human-machine interaction such as touch interfaces and augmented-reality systems; and improvements in transferring digital instructions to the physical world, such as advanced robotics and 3-D printing" [6].

There are usually identified four key components (CPS, Internet of Things (IoT), Internet of Services, and Smart Factory) and 6 major technologies (the Industrial Internet of Things (IIoT) and CPS, additive production (3D - the printing), BigData, an artificial intelligence (AI), Collaborative Robots (CoBot) and the virtual reality) to develop Industry 4.0 [3]. At the same time the main attention concentrates around technical aspects of their implementation. And the man, with his mental, creative and will abilities, lies beyond this ideology [7]. The only thing that is given a deal regarding human resources is possible changes of labor market caused by the Industry 4.0 [8-10].

Such situation is unsatisfactory and it finds reflection in a number of the articles devoted to the Industry 4.0. In particular, in [11] it is marked that «the world of work in Industry 4.0 will still be inconceivable without human beings» The author of [12] asks the fundamental issues «How can people and society benefit from Industry 4.0?»

Moreover, in spite of the fact that Industry 4.0 is only at the initial stage of the development and the main achievements can be expected not earlier than 2020-2025 [10], the image of a new paradigm of Industry 5.0 could be seen. It involves the penetration of Artificial Intelligence in man's common life, their "cooperation" with the aim of enhancing the man capacity and the return of the man at the "Centre of the Universe".

In this regard, probably, the more exact term instead of Industry 5.0 is "Society 5.0" (SuperSmart Society) that was offered in 2016 by Japan's most important business federation, Keidanren and being strongly promoted by Council for Science, Technology and Innovation; Cabinet Office, Government of Japan. [13]. Unlike the concept of Industry 4.0, Society 5.0 is not restricted only to a manufacturing sector, but it solves social problems with the help of integration of physical and virtual spaces. In fact, Society 5.0 is the society where the advanced IT technologies, IoT, robots, an artificial intelligence, augmented reality (AR) are actively used in people common life, in the industry, health care and other spheres of activity not for the progress, but for the benefit and convenience of each person [14].

The paper outlines modern technologies – from IoT up to emergent intelligence, being developed in organizations where authors work. The convergence of these technologies, according to our minds, will provide the transformation from Industry 4.0 to Society 5.0.

## *2 On the way to Society 5.0: directions and prospects*

This fig. 1 depicts the conventional "pyramid of sciences and technologies" which convergence, in our opinion, can provide the transition to Society 5.0. Distribution of layers in a pyramid to its top comes from the bottom in process of abstraction from the world of real objects (may be with some elements of AI), to concepts of Society 5.0, which can include the Evergetics – a new theory of intersubjective management processes in everyday life, and emergent artificial intelligence.

### *2.1 New types of distributed computers and "Swarm of Robots"*

These technologies are the hardware base for creation of the intellectual self-organized systems of different types.

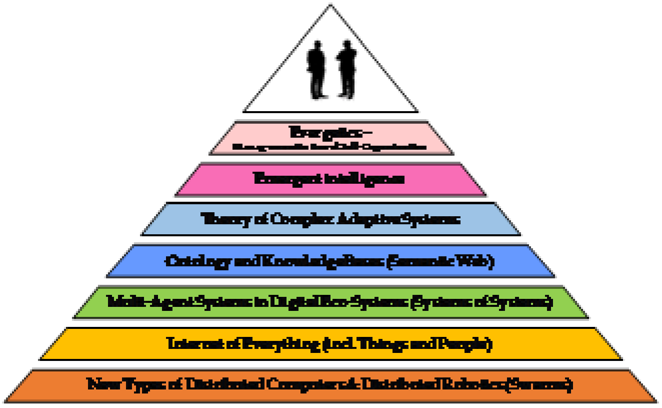


***Fig. 1*** *Convergence of sciences and technologies in Society 5.0*

The distributed computer networks have complex topological network design and provide multithreaded parallel and asynchronous computings.

"Swarms of robots" represent the self-organized groups of robots. And here we do not refer to the anthropomorphous robots only, but to the distributed smart technical systems. The intelligent gas-turbine engines with smart blades can be an example of this technology. In such engines each blade "agrees with neighbors" about its position (how it should be turned) in an air-gas path to provide optimum conditions of working medium (gas) flow and to prevent emergency state of the power plant [15].

These technologies also include the self-organized groups of small spacecrafts (nano- and piko- satellites) which, like the swarm of bees, can be multifunctional and flexibly configured in order to solve a particular problem, reliable and stable in the most different situations during the Earth observation, objects research in open space, telecommunication problem solving and other various tasks [16-18].

Another example is the "swarm" of pilotless tractors and other farm vehicles which are "… speaking with each other …" and are "… in constant communication among themselves, collaborating with each other" [19, 20], etc.

### *2.2 Internet of Things and People*

IoT (including industrial IoT (IIoT)) is intensively developing technology that complement traditional and usual to us Internet of people, and is an automation basis in Industry 4.0 and Society 5.0.

As it is given in official Recommendation ITU-Y.2060 - Overview of the Internet of Things, IoT is a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies [21]. At the same time, generally, the "thing" means an «object of the physical world (physical things) or the information world (virtual things), which is capable of being identified and integrated into communication networks» [21].

In 2013 Cisco offered the term "Internet of Everything" (IoE), which is considered to be wider than IoT. Cisco determines IoE as "the networked connection of people, data, process and things. The IoE is made up of many technology transitions, including the Internet of Things" [22].

It is obvious that implementation of IoT (IIoT, IoE) requires development of a number of perspective technologies, including sensor (intellectual sensors, smart dust, …), telecommunication (RFID, NFC, Wi-Fi, 6LoWPAN, ...), etc. It will allow the "intelligence" to be encapsulated in a "thing" at a stage of its production. At the same time in Society 5.0 (as, however, and in Industry 4.0) IoT (IoE) should not be a technology for the sake of technology. Its opportunities should be directed to the benefit of the person, to improvement of quality of his life.

### *2.3 Multi-Agent systems and technologies*

Implementation of IoT (IIoT) technologies assumes transfer of computation to the virtual world ("cloud") where each "virtual" twin of objects of the real world acts according to the selected algorithm and rules. For communication of the real and virtual worlds intellectual agents are used. They can perceive information from the real world, make decisions and coordinate them with other objects or users in real time. At the same time real objects can independently work or be parts of more difficult objects (household things, the flexible production line, group of drones, etc.)

The multi-agent system in [23] is defined as a network of weakly connected solvers of private problems (agents) which exist in the general environment and interact among themselves for achievement of these or those purposes of system. Interaction can be carried out by agents in a direct path – by message exchange, or indirectly, when some agents consider the presence of other agents through changes in the external environment with which they interact.

Multi-agent systems and technologies can be applied to the solution of extremely difficult tasks (for example, planning and optimization of resources and knowledge acquisition of the class of Big Data and Small Data), and to creation of digital ecosystems ("the systems of systems") of the services capable to cooperate and compete among themselves, allowing the transformation of simple IoT in smart Internet of people and things (The Internet of agents).

### *2.4 Ontology and Knowledge Bases*

Ontology is a knowledge representation system about data domains [24-26]. As it is marked in [27], the ontology "is often understood as "the specification of conceptualization" … or even as a synonym of "a conceptual domain model" (more precisely, a set of the coexisting conceptual models)…" In the same source [27] it is said that "in the simplest case ontology is defined as "some general dictionary of the concepts used as construction bricks in information handling systems". Usually it describes hierarchy of the concepts connected among themselves by the categorizing relations" [27].

Ontological approach was widely adopted in the multi-agent systems, where ontologies actually are those knowledge bases of intellectual agents which contain both knowledge of specific data domain, and knowledge, belonging to methods of the decision-making [28]. On the basis of ontologies, agents have an opportunity to make search in knowledge bases and apply them to message exchange (for example, in the modern versions of languages of agents communication (ACL, etc.)) [23]

At the same time, according to [24], in case of integration of ontology and multi-agent system it is possible to select three qualitatively different from each other approaches:

– each agent stores the ontology containing knowledge and concepts available only to it;
– the ontology is unified for all agents and is stored on a centralized basis (as a rule, on the special agent);
– the ontology is partially unified, and partially – is distributed.

In [24] is also marked that application of ontologies in the multi-agent systems will provide standardization of knowledge representation, will simplify information exchange between agents and also "will allow in case of impossibility of communication between agents, which is often found in real projects, to recover or predict with some accuracy a behavior of other agent on the basis of the known parts of his ontology".

### *2.5 Theory of Complex Adaptive Systems*

The theory of complex adaptive systems appeared in the 90[s]. One of the most famous researchers in this area is J. Holland [29]. The kernel of J. Holland's theory is that irregular shapes of live systems arise from the adaptive behavior of simple one, and the adaptive behavior can be reduced to the sequences of micro-interactions with the environment of which consists a dynamics of more complex structures (for example, an anthill, a swarm of bees, flock of birds, etc.) [30].

The complex adaptive system according to J. Holland [29] has properties of aggregation (hierarchy of elements when simple elements of lower level form elements of higher level – aggregates), nonlinearities, flows of resources (constant exchange with the environment and maintenance of internal level of conversion of the arriving resources), diversity (absence of an equilibrium status). J. Holland refers tagging (the marking providing visibility and identification of system from the outside), internal models (allow system to trace and predict the environment's dynamics) and building blocks (structural elements of system) to mechanisms of the adaptive systems' organization. At the same time J. Holland believes that these properties belong to any complex system.

Thus, it can be regarded that the theory of complex adaptive systems is a base of the multi-agent systems. It establishes a connection between multi-agent systems and non-linear thermodynamics when the solution of any complex task is reached during self-organization and is treated as "stable disbalance" (a temporal consensus).

### *2.6 Emergent Intelligence*

Emergent intelligence (intellectual resonance, swarm intelligence) is a phenomenon of unexpected properties whereby larger entities arise through interactions among smaller or simpler entities such that the larger entities exhibit properties the smaller/simpler entities do not exhibit [31].

In [32] emergence is determined as «global behavior of a complex system emerges from the interaction of agents and, in turn, constrains agent behavior». At the same time it is noted that «emergent behavior is unpredictable but not random; it generally follows discernible patterns (a new order)».

The key feature of emergent intelligence consists of dynamics and unpredictability of decision-making process by means of a large number of interactions (hundreds and thousands) which cannot almost be traced. Therefore the emergence property is often connected with multi-agent technologies which realize interactions of rather simple "smart elements" (agents) during their self-organization for the solution of a specific objective.

### *2.7 Evergetics*

Evergetics is the emerging postnonclassical science of intersubjective management processes in the society. "Evergetics" in Greek (Ευεργέτης) means "benefactor" and already in its title there is an orientation for "good actions" in management processes (decision-making). It distinguishes evergetics from classical management science and cybernetics, invariant to any values [33, 34]. At the same time D.A. Novikov ranks evergetics in his navigator on cybernetics as cybernetics of the third order for interacting subjects of control [35].

In [36] the author of evergetics professor V. Vittikh defined it as «…the science of management processes organization in a developing society, each member of which is interested in augmenting his cultural heritage he is producing, which entails a raise of cultural potential of the society as a whole and, as a consequence, an increase in the proportion of moral and ethical managerial decisions and corresponding to them benevolent actions in public life». On the V. Vittikh's opinion «this interdisciplinary science must rely on both humanities and social sciences, as well as on the Control theory, Informatics and on some other disciplines related to the category of the exact sciences. Such multi-disciplinary nature is due to the fact that the man in Evergetics is considered, on the one hand, as a subject, armed with methods and means to research situations and to make decisions how to settle them, and on the other hand, as the object of education, training, world outlook formation and skill to communicate with other people, etc.» [36]. At the same time V. Vittikh's evergetics does not reject traditional "system" approach to the control of socio-technical systems at all, but adds and expands its opportunities. [37].

The theory of intersubjective management processes [38] in which each active person can prove as the non-uniform "actor" realizing himself, "dipped" in some problem situation and ready to participate in its settlement together with other actors [39], is the cornerstone of evergetics. If you have a large number of actors the solution of any task is very laborious procedure and here the multi-agent systems, which provide a real-time (at the situation development) decision-making, can be used. At the same time the decision is made on the basis of the consensus which is based on mutual beliefs, compromises, concessions, etc. It creates a barrier to manifestations of violence, the evil, aggression and other defects because in processes of negotiations and decision-making people switch on value factors which cannot remove, but "smooth" these negative phenomena [40].

All mentioned above allows to assert with confidence that evergetics as a science about management processes in socio-technical systems, is aimed on use of knowledge, will and energy of people, disclosure of their talents for the benefit and convenience of each person. It completely corresponds to the concept of Society 5.0. Therefore in fig. 1 evergetics is placed on top of "a pyramid of sciences and technologies" in Society 5.0 on which a man leans.

## *3 Scientific and technical backlogs: eligibility and development*

The key sciences and technologies that make possible a transition to Society 5.0 and that were briefly introduced in section 2, are and will be in researchers' and IT-developers' focus in the nearest and distant future. The organizations represented by authors are not an exception. We have all necessary competence and experience in development of similar systems, being pioneers in many of the directions sited above. At the same time, in the considered context, our main interests and achievements are concentrated on the development of multi-agent systems, ontological data analysis and evergetics.

Multi-agent systems and technologies are being developed in Samara more than 25 years (since 1990) [41]. Initially there was directivity on the development of new methods and tools for solving of complex problems based on the principles of self-organization and evolution (the fact that "the emergent intelligence" is called). In particular, successful examples of development of the multi-agent systems were connected to models of networks of needs and opportunities (NO-networks) and method of the conjugate interactions for resource management in real time. This approach was developed in V. Vittikh and P. Skobelev's works [42, 43].

According to this approach the NO-networks are created. There can be marked agents (roles) of the needs and opportunities, by determination representing entities with opposite interests which work within virtual "market" of system and can both compete and cooperate with each other [41]. At the same time the role of needs bears in itself knowledge of the "future", and an opportunity role – knowledge of the "past". Such approach allows to view the different processes of the solving of complex multicriteria tasks of resource management of any nature (static or moving, separated, renewable, etc.) absolutely from the new side. In this case they are considered as a process of self-organization with detection and the conflict resolution between agents by negotiations with concessions for achievement of consent (consensus) by them [40].

The methods and multi-agent systems realized on their basis were used for the solution of a wide range of tasks – from clustering and understanding of texts up to dynamic resource management of the space, transport systems and the industrial enterprises [44-51]. Their industrial implementation proves efficiency of the developed approach and defines perspectives for the solution of a wide range of complex tasks within the concept of Industry 4.0 and further Society 5.0.

As it was already noticed, the organization of knowledge system about data domain and methods of knowledge deployment in the multi-agent systems is carried out on the basis of ontologies which allow to describe the heterogeneous, multicoupling and incomplete knowledge that can contain incorrect information and be connected not only hierarchical, but also by network structures, etc. [26]. Pioneer works in the field of ontological data analysis were made by S. Smirnov [25, 52-54]. He made an essential contribution to the solution of one of the significant problems in this area: the automation of formation of ontologies of data domains on the basis of measurements [55]. The technique of detection of conceptual structure (the formal ontology of experimentally researched data domain) offered by S.V. Smirnov is based on the analysis of the formal concepts [54]. He generalized the standard object-and-features data model and used for its processing the multiple-valued vectorial logic.

It is also necessary to mark that the formal ontologies can be a theoretical and technological framework for implementation of the bases concepts of created theory of intersubjective management processes – evergetics [56] (it was described in detail in item 2.7). In particular, for identification of a sense of a problem situation for the actor it is possible to use a method of ontological data analysis. The basis of this method is theoretically well reasonable analysis of the formal concepts. And the communicative semantic model of a problem situation, that is necessary for all actors, can be received as a union of actors' subjective ontologies.

## 4 Conclusion

The provided review shows that the growing popularity of digital economy and uncountable number of practical applications have created a strong basis for development of Industry 4.0 technologies already now and in the long term can serve as the launch pad for creation of Society 5.0. And the evergetics which returns "ordinary" people from everyday life to the world of intellectual systems and gives the chance to use personal intellectual resources of each person and to do the habitat attractive to people, "area of an attraction", but not a zone of their temporary residence, can form a theoretical basis for this "future society".

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