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TECHNOLOGICAL TRANSFER UNDER THE CONDITIONS OF DIGITALIZATION OF PRODUCTS AND PROCESSES

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Abstract. Technological development is largely determined by technology transfer, which is conditioned by the absorption capacity of new technologies, and new technologies are deeply digitized technologies. Success depends on creating basic digital skills, both technical and human, developing digital infrastructure, ensuring accessibility to digital technologies. In the context of Industry 4.0 technologies, the efforts to design products with pronounced physical-cybernetic elements are important, but especially those aimed at creating digital twins, gradually moving from intermediate variants of digital model and digital shadow. Digital twin creation models refer to the life cycle with emphasis on its stages. The paper proposes a digital twin model based on the technological function, in which the modification of the properties is manifested by restructuring the internal functions of the operator, operand and interface. The central place in this model belongs to the interface, which reflects the multitude of physical-technical processes at different scales of macro, meso, micro analysis characteristic of objects and processes in machine building.

Keywords: *technological transfer, industry 4.0, digital model, digital shadow, digital twin, technological function, technological interface.*

Rezumat: Dezvoltarea tehnologică este determină în mare măsură de transferul tehnologic, care este condiționat de capacitatea de absorbție a noilor tehnologii, iar noile tehnologii sunt tehnologii profund digitalizate. Succesul depinde de crearea competențelor digitale de bază atât tehnice cât și umane, dezvoltarea infrastructurii digitale, asigurarea accesabilității la tehnologiile digitale. În contextul tehnologiilor Industriei 4.0 importante sunt eforturile de proiectare a produselor cu elemente pronunțate fizico-cibernetice, dar mai ales cele orientate spre crearea gemenilor digitali, trecând treptat de la variante intermediare de model digital și de umbră digitală. Modelele de creare a gemenilor digitali se referă la ciclul de viață cu accentele pe etapele acestuia. În lucrare se propune un model de geaman digital bazat pe funcția tehnologică, în care se manifestă modificarea proprietăților prin restructurarea funcțiilor interne a operatorului, operandului și interfeței. Locul central în acest model aparține interfeței, care reflectă multitudinea de procese fizico-tehnice la diferite scări de analiza macro, mezo, micro caracteristice obiectelor și proceselor din construcția de mașini.

Cuvinte cheie: *transfer tehnologic, capacitate de absorbție, industrie 4.0, digitalizare, model digital, umbră digitală, geamăn digital, funcție tehnologică, interfață tehnologică.*

1. Introduction

All industrial revolutions resulted in the formation of leading and following economies, depending on their involvement in the creation and use of the emerging technologies characteristic of the revolutions. It can be seen that an important part of the world's countries remained outside the ongoing revolutions every time. Only after several decades does the gap close after the technologies become cheap enough. It is considered that there are about 30 developed countries, about 80 developing countries, including the Czech Republic, Hungary, Poland, Bulgaria, Romania, etc., and the rest - poorly developed, including the Republic of Moldova. This classification is important from the point of view of the development potential. The desire for development, including through technological transfer, must be supported by capacities to absorb new technologies, capacities that must be prepared technically-technologically (technoware), organizationally (orgware), informationally (infoware) and humanly (humanware). However, these capacities remain very different in today's modern world, even in the context of the digitization of economies.

According to the report of the United Nations Industrial Development Organization (UNIDO) for the year 2020 [1], in the field of advanced digital production technologies only ten leading economies (United States of America, Germany, Japan, China, Taiwan Province of China, Switzerland, France, United Kingdom, Republic of Korea and Netherlands) account for 90% of patents and 70% of digital technology exports. Another 40 economies follow (the followers), but with much lower values in the research/development and commercialization of digital technologies. Developing countries have technologies and technological systems characteristic of the Industrial Revolution 3.0 (3IR), sometimes in incomplete versions, and modernize to transform them according to the Industrial Revolution 4.0 (4IR).

The lack of capabilities to master the basic automation of 3IR technologies and information and communication technologies also makes it difficult for them to fully exploit the opportunities of advanced digital manufacturing technologies. The main challenges and opportunities for developing countries consist in the gradual integration of advanced digital technologies within the existing 3IR manufacturing systems, the modernization of production systems in the aspects where informational integration is possible. Other countries either have less activity or fail for various reasons to take part in the creation and use of these technologies.

It is found that a good part of the companies is still in the conditions of analog production. The transition to 4IR technologies depends on the conditions of the country and its industry. A key issue for countries where the majority of production is predominantly in the analog domain is how they can move up the technological ladder. Massive digital openness through non-industrial tools means that companies can skip a few generations or go straight to the most advanced ones. The differences between capabilities, endowments and technological efforts, between organizational characteristics and internal infrastructural and institutional conditions not only explain why some companies and countries manage to climb the digital ladder of technologies, but also demonstrate that advancement is possible [1]. The objective conditions of development, the effects of the scale of industrial factors, the effects of the state economic development policies of the Republic of Moldova place the country in the category of laggards, but the appropriate conditions for the adoption of these technologies by industrial companies can stimulate inclusive and sustainable industrial development and the achievement of the objectives of sustainable industrial development.

In the process of technological development in the machine building eterprises through transfer or through own research-development support, the perspectives opened by this Industry 4.0 concept will be taken into account. The perspectives are channeled by six design principles: decentralization, virtualization, modularity, interoperability, service orientation, real-time capability [2].

The pillar technologies of Industry 4.0 are determined by scientometric tools. In the paper [2], the following key technologies of Industry 4.0 are specified (Figure 1): autonomous and collaborative robots, augmented reality (AR), simulation/digital twins, horizontal and vertical integration, cyber security, the Industrial Internet of Things (IIoT), cloud computing, big data analytics. Artificial intelligence (often mentioned together with big data analytics), cloud manufacturing, M2M (direct communication between machines, devices) can be added to this list.

One of the most promising technologies of the Industrie 4.0 concept with an impact on the tasks to be achieved for engineers in the field of machine construction is the technology of simulation and digital twins. The reason is simple. Modeling and digital twins refer to products, processes, phenomena in the mechanical field, namely researchers in this field can solve the situations.

Research related to the creation and augmentation of digital twins is very intensive and covers several areas such as: product design [3, 4], assembly processes [5], mechanical manufacturing processes and through additive technologies [6, 7], mechanical machining [8-10], CNC machine tools [11, 12], cutting tools [13], materials [14], tribological phenomena [15] and others.

2. Technological transfer in the current industrial conditions in the Republic of Moldova

According to UNIDO, the industrial development of a country can be evaluated by the industrial capacity index [16]. Industrial capabilities represent the collective and personal skills, productive knowledge and experiences accumulated by industrial agents and companies to perform various productive tasks, absorb new technologies and coordinate production along the supply chain. The index of industrial capacity can be taken as a rough indicator of the basic capacities of countries in the field of production, which combines three dimensions: the ability to produce and export manufactured products, technological deepening and modernization and the global and/or regional impact.

The capacity to produce and export products manufactured by RM companies is low. The large and inefficient post-Soviet companies have been liquidated, and the new and modern ones are still few and, as a rule, small and medium. Technological deepening and modernization is focused on computer-aided design, CNC technologies, 4G communications with the near prospect of 5G, etc. and does not have a systemic character, but an insular one. The improvement of the situation on all three components can be achieved by realizing the path of European integration, through internal and international industrial collaboration. Thus, the industrial visibility of companies from the Republic of Moldova may be increasing, initially mediated by partners from developed and developing countries, then directly.

The development of car manufacturing companies operating in the Republic of Moldova is largely determined by technological transfer through direct foreign investment. Thus, branches of several companies from industrially developed countries such as: Italy, Belgium, Holland, Germany, Romania, USA, Spain, France etc. have been opened recently.

The activity of these companies is focused on product design and manufacturing. However, the emphasis is on design, so that the transfer of advanced digital technologies occurs through the human factor to the extent that the parent company is involved in the modernization of its own technologies. Some gap can be observed, but the use of licensed CAD/CAE/PDM/PLM computer programs, often from the servers of companies in developed countries, working in project teams, products designed according to the requirements of customers in industrially developed countries produces effects comprehensive digital. Smaller in scope are the manufacturing activities, but also in this field the corporate technological transfer related to the use of CNC programmable machines and licensed CAPP/CAM computer programs is positively manifested.

Industrial companies in the field of machine building face several challenges, which can also become great opportunities for the implementation of advanced digital technologies. Among them can be listed the basic capabilities, the modernization and integration of technological resources, the modernization of the digital infrastructure, overcoming the digital capacity gap, access to technologies and their accessibility [1].

1. *The basic capabilities*. The basic capabilities needed to absorb and implement advanced digital technologies are different for design and manufacturing companies. The design not only defines the functional-constructive structure of the object in question, but also determines the manufacturing and operating conditions, informationally determines the participants of the supply chains, etc. The product design serves as a major requirement, as a starting point for manufacturing. Manufacturing is more complex, because it gives a functional answer to the project requirement, the effort is physically multiplied by the value of the series, by the complexity of the product and its components. In manufacturing, the de facto participants of the supply and value chains manifest themselves physically and informationally. Thus, it becomes necessary to integrate new technologies with existing ones in complex technological systems.

2. *Modernization and integration of technological resources*. Design companies invest actively in new versions of computer programs and new applications. Computer programs, being the result of competition between software producers, are increasingly coherent and mutually compatible. The new versions of the programs are integrative (CAD/CAE/PDM/PLM), cover multiple needs with reference to engineering objects and processes and offer great possibilities for digitization through digital twins. Manufacturing companies already have older technology resources adopted and need to invest and learn how to modernize and integrate new digital manufacturing technologies into the already existing technology system. Front-end replacement of obsolete analog machinery and equipment with digital ones is expensive and rarer, because it requires significant

investments and radical changes. CNC numerical programming and CAPP/CAM computer programs are easier to access and assimilate, because they increasingly represent integrated product-process CAD/CAE/CAPP/CAM/PDM/PLM systems.

3. Modernization of the digital infrastructure. The new 4IR technologies require a substantial reliable and secure information and communication infrastructure to ensure real-time design and manufacturing. 4G resources are sufficient for the current state of communication needs. The 5G perspective is an imminently necessary one, especially for manufacturing companies with the multiplication of information flows characteristic of it through the use of physical-cybernetic technical systems (machines, equipment, instruments, measurements, products and components in progress, sensors, etc.) generators and users of processed and structured information.

4. Overcoming the digital capacity gap. Companies from developed and developing countries are persistently engaged in activities with advanced digital technologies. These islands of 4IR technologies may be surrounded by partner companies still using older technologies. Thus, there is a brake in the activities of leading companies and a danger of losing the competitive battle for companies with weak digital capabilities. If this digital capabilities gap is long-lasting and sufficiently extensive, the implementation of advanced digital technologies remains limited and insular. Moldovan companies in the field of design and those in the field of manufacturing with foreign capital are not susceptible to the formation of deep gaps, the activities being ensured by common computer programs with the basic companies and by corporate assistance. The major risk of a gap persists for domestic companies in the field of manufacturing, because they do not have enough modernization resources, both financial and properly qualified human resources.

5. Access to technologies and their accessibility. Advanced digital technologies represent major elements of intellectual property, so their dissemination represents a commercial act under conditions of rights protection. As a consequence, these technologies are effectively controlled by a limited number of countries, and their companies have non-commercial competitive advantages in its implementation and use. Companies from other countries rely on the import of these technologies under the conditions of dependence on the suppliers of hardware components and software applications. For local Moldovan companies, access and accessibility are imminently commercial, with the exception of open innovation or technological transfer situations supported by the state in the interest of all companies in the field or through projects. For Moldovan companies with foreign capital, access and accessibility have a corporate character and are ensured by the base companies. Practice demonstrates access and accessibility with a gap for companies in the field of manufacturing, digital manufacturing equipment is usually second hand. However, there is a tendency to improve these gaps.

The pandemic crisis situation of 2020-2021 has become an index not only of the usefulness of digital technological modernization, but also of the resilience of companies. Digitally advanced companies have organizationally restructured their activities, placing emphasis on results, on remote communication and not on presence and schedule [16]. In the field of industrial manufacturing, digitization and automation have become one of the major trends in technological innovation. The implementation of advanced digital technologies essentially influences all aspects of industrial development and profoundly changes the competitive advantages of companies.

All advanced digital technologies are constantly evolving. For companies from poorly developed countries (the Republic of Moldova) with low incomes, abundant learning is opportune, that is, the training of human factor's skills. The competences of the human factor become attractive for foreign companies that come with joint business projects and investments in computer programs, in technical insurance with computers, communication networks, CNC machines, new organizational versions of functioning are formed. Thus, the priority of education in the field of advanced digital technologies is established, which has the ability to launch technological transfer in various aspects. In companies from developing countries there are already digital applications that can be used as avenues for wider and deeper technology transfer.

The implementation of advanced digital technologies is a complex but real process. The given technologies are interdependent, so the frontal implementation of at least a few more closely connected technologies is required, or their implementation one by one with relatively delayed real positive effects. The current digital gap between companies is determined by the differences in size, capacities and availability, by the existence and operation of innovation and technological transfer support systems.

A special role in promoting modern technological transfer belongs to state structures, which must place more concrete emphasis on industrial innovation to stimulate the adoption of advanced digital technologies in engineering, to encourage investments in research/development and the diversification of industrial production with high added value, to increase the ability to respond to new product design and manufacturing requirements. Adequate technology transfer policies are needed to drive the deployment of advanced digital technologies while reducing the costs and risks associated with their adoption.

3. Technological transfer through the provisions of the Industry 4.0 concept

The concept of Industry 4.0 represents a complex immaterial object with a major influence on the development of technologies and on technological transfer. In figure 1, this concept of Industry 4.0 is represented schematically in interaction with technologies from the branch of machine construction. Intelligent manufacturing itself includes computer-aided design technologies, material object processing technologies and 4IR digital technologies.

For each of the Industry 4.0 technologies taken separately, the other technologies represent the external environment, and the own elements (the partial technologies) represent the internal environment. In the systemic approach it is stated that "the internal and external environment of the system are continuous (the environment, in general, is continuous, and the division into external and internal environment is relative)", "the components of the system and the system as a whole are subject to development laws (...acts and manifests jointly in order to achieve well-defined objectives) and "the external environment represents the system's environment of existence from where it gets its resources, and the internal environment - the life environment" [17]. It can be concluded that the interaction between two technologies takes place with the participation of the external environment consisting of other technologies, so that the technologies in the environment can and do become development interfaces. An initial technology under the influence of the technological environment manifested through interface technologies becomes updated technology (Figure 2). And, since any change in the technological environment produces imbalance, a continuous systemic technological development is observed, caused and supported by the tools of Industry 4.0.

The modern development of machine building's traditional technologies is done through integrative phenomena and thanks to computer and communication successes. However, the essence of the characteristic and specific processes of different industries remains as substance, as core. In this way, the division of responsibilities of the fields of concrete industries, on the one hand, and the field of informatics and communication, on the other, takes place. The technologies mentioned in figure 1 are actually dual, containing both a processing tool and an instrumented object, but specific to the industrial branch.

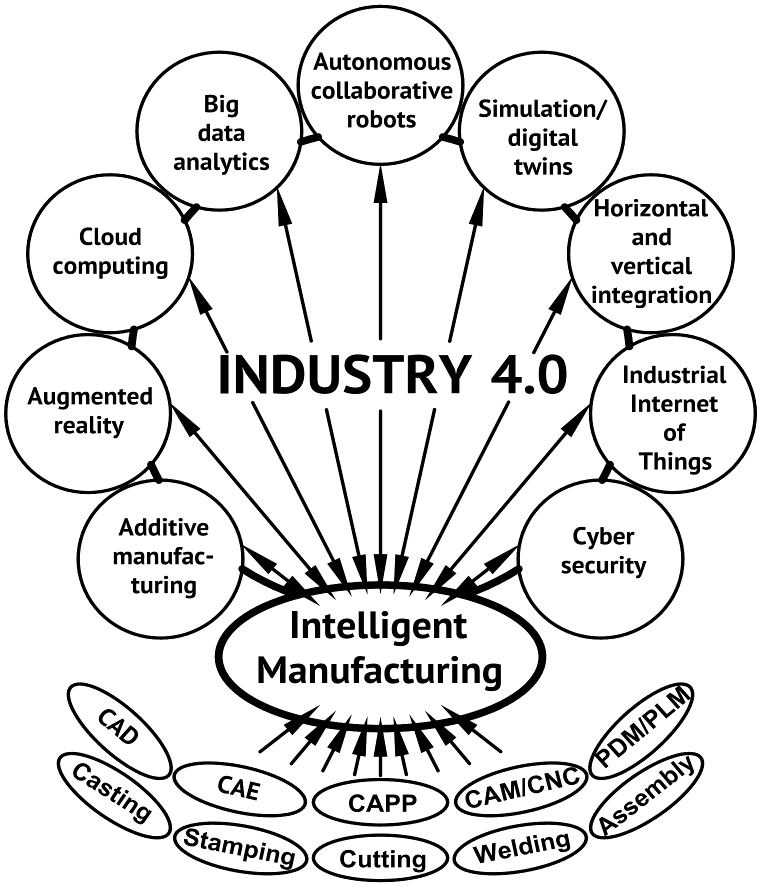

Figure 1. Intelligent manufacturing's technologies and tools.

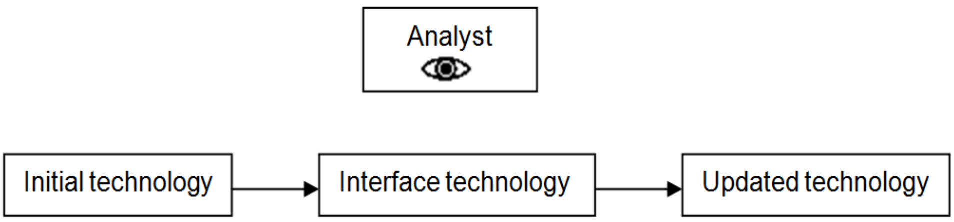

Figure 2. The development (updating) of technologies through interface technologies from the technological environment.

Both machine building and other industrial branches are represented in the new industrial concept by their own specific technologies. In the case of machine building, these technologies are: casting, molding, stamping, cutting, heat treatments, welding, assembly, etc. The essence of these processes is physical and technical. Operands are objects made of metal, of plastic, of composite materials etc. Operators are machine tools, equipment and tools that ensure predominantly mechanical demands often assisted by energetic ones. The design and management of processes are increasingly computer assisted (CAD, CAE, CAPP, CAM, CNC, PDM, PLM, etc.).

4. Digitization - the basic factor of technological development in machine building

The pillar technologies of the Industry 4.0 concept are of different origins, but each of them essentially contributes to the informational integration of all processes. For any object or process, the integrating factor is the digitization of the its life cycle. In this sense, the "Simulation and digital twins" technology is of the greatest interest. The process of simulating and of creating digital twins is, in fact, a development of what in specialized literature is called Continuous Acquisition and Life-Cycle Support (CALS) developed in the USA in the 1990s.

The concept of a digital twin of existing physical objects or processes was proposed by Grieves in 2002 (University of Michigan) for product lifecycle management (PLM) and include the three elements [18]:

1. Physical object or process in a real space.
2. Virtual object or process with set of virtual subsystems in a virtual space.
3. Links through data and information between the virtual and real physical spaces together with the respective objects.

From a chronological point of view, the relationship of physical objects and processes with their virtual (digital) aspects is one in development and is manifested by the level, the measure of integration. According to [18], several stages can be characterized:

1. The physical space predominates, everything depends on it.
2. The virtual space appears, is growing and improving.
3. Physical and virtual space interact.
4. Physical and virtual space interact more and more and tend to converge.

The transition from stage two to stage three was determined by the implementation of the concept of computer integrated manufacturing (CIM), CNC digitization of machine tools, computer-aided development CAD/CAE/CAM of products. The industry is currently going through the third stage through the emerging technologies of the Internet of Things (IoT) and Big Data analysis, which facilitate the interaction between physical and virtual spaces. The launch of the fourth stage is determined by the development of the Digital Twins (DT) concept, which uses intensive interaction in both directions (phisical - digital, digital - phisical) thanks to informational and cyber-physical systems.

One of the first clear definitions of a digital twin was given by NASA: “A Digital twin is an integrated multi-physics, multi-scale, probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its flying twin” [19]. A digital twin is a virtual representation of machines, products, processes, any system in the real world based not only on the spatial image, but also on the data provided over time by information systems, the Internet of Things (IoT), sensors, etc. The digital twin enables better understanding, analysis, performance improvement, proper maintenance of industrial systems and products.

Digital twins can be created and completed in two different situations. In the first situation, the physical object is designed with modern computer-aided tools, so that from the very beginning it also exists in the digital version with a level of detail determined by the computer program used. The models are continuously updated through changes based on the data generated directly by the physical objects [20, 21]. The second situation refers to the situation when the virtual version is not available, also because the existing physical object was designed with classical tools. Thus, the completion of the digital twin is produced in augmented mode, starting from image recognition or captured characteristics of the physical object.

Depending on the nature and direction of the data flow between physical and virtual systems, the notions of digital model, digital shadow and digital twin can be defined [19].

The digital model of an existing physical object or process does not provide for the automatic exchange of data with the physical object, so that the digital model once created is not able to reflect the changes over time of the physical object (Figure 3a).

In the case of the digital shadow, there are flows data generated by the physical object both automatically and manually directed to the digital object so that it is updated with new information from the real world (Figure 3b).

In digital twins, data flows are automatic and bidirected. A change to the physical object is automatically reflected in the digital object and vice versa. Thus, the digital object allows the formation of the data necessary to control the functioning of the physical object appropriate to the external and internal situation. The foundation of the digital twin is the connection of the physical and the digital (Figure 3c).

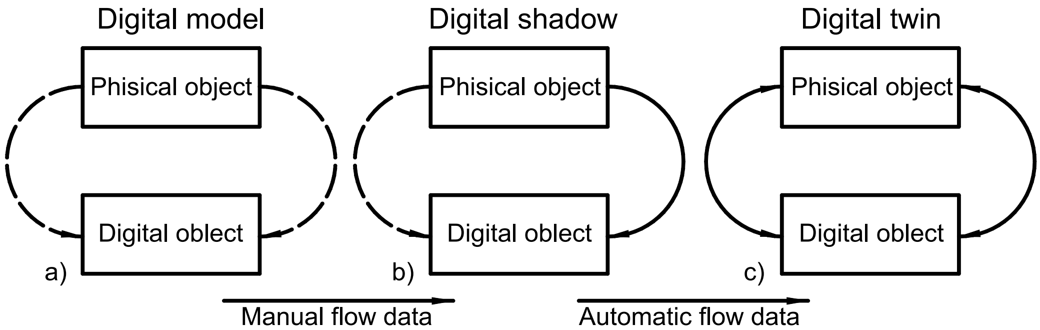

Figure 3. Digital model (a), digital shadow (b) and digital twin (c) [22].

The simulation differs from the digital twin in that it characterizes the future states of the physical object based on the initial set of data and hypotheses [23]. The digital twin interconnects physical and digital object data and forms the datasets for simulation. Thus, simulation in the context of digital twins becomes a practically continuous process [19, 20].

In the context of digital twins, the approaches related to the methods of analysis, design and simulation of objects and processes as subsystems are changing. It is a natural reflection, most modern engineering objects and processes being extremely complex, so it is logical to have multiple teams of experts from different fields working in parallel. The subsystems operate on the basis of the different physical laws and at different dimensional scales (macro, meso, micro, nano) and, consequently, they can hardly be integrated into a common model [24].

The main function of a digital twin is the combination of approaches based on modeling and on collected data to obtain a virtual forecasting tool that can evolve over time. In this sense, the digital twin offers the possibility to solve technical problems in engineering applications. The reduction of uncertainties related to the application of knowledge in decision-making is achieved by using the data objectively recorded by the physical twin, through real or representative laboratory tests. It is important that the data recorded and delivered are characteristic of twinned structures. In the organizational aspect, the digital twin uses a hierarchical format, a fact that facilitates the integration of objects and processes of different physical origins and on several dimensional scales. The goal of overcoming organizational obstacles is also pursued by improving connectivity through logical interfaces for the various calculation and simulation models [24]. Figure 4 shows model V of product development on the stages of the life cycle in the traditional version (a) and in the version that also includes the digital twin cycle (b).

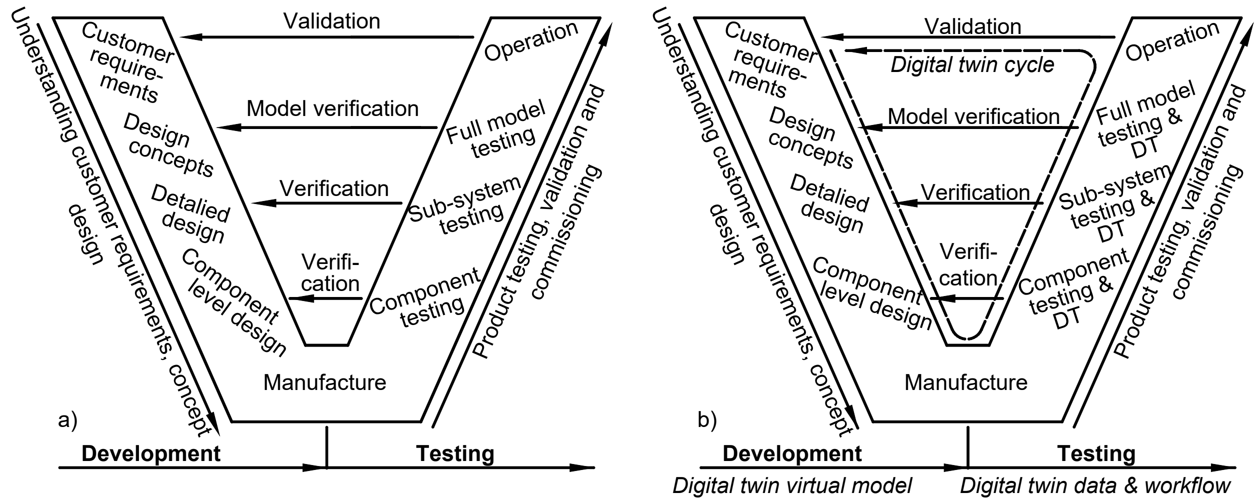

Figure 4. V model representing the life cycle of the product: a) traditional model, b) model that also includes the cycle of the digital twin (DT) [24].

Simulations and the creation of digital twins refer to objects and processes, products and technologies to the same extent. The digital twin includes information - factors (representing influences or potential influences) adequately and objectively determined by the work team and accumulated during the stages of the life cycle.

Based on the same factors, models of objects/processes or their components are created for simulations. Defining the factors is a complex process, which is based on knowledge and experience.The complexity of selecting and defining factors is related to the fact that factors can be obvious and implicit, systematic and random, can manifest independently or in connection with other factors, can manifest synergistically, etc.The origin of the factors is very diverse and refers to the transformation couples: needs – requirements, requirements – functions (use values), functions – physical-technical principles, physical-technical principles – constructive variants (structures), constructive variants – technical parameters, technical parameters – processes, processes – technology, technology – manufacturing, manufacturing – testing, testing – exploitation, Figure 5.

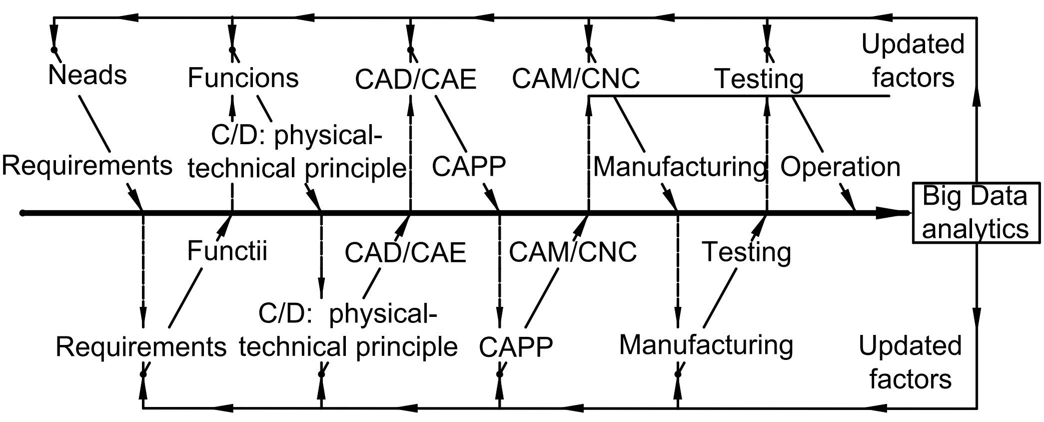

Figure 5. Updating the technology factors of the product's life cycle stages.

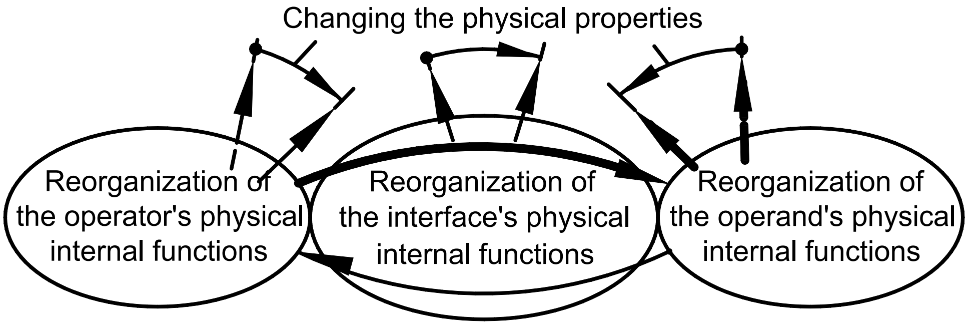

Figure 6. Changing the physical properties of the operator, operand and interface by reorganizing their internal functions.

Representation through transformations allows the process character of the life cycle to be highlighted. Unlike the V model represented in figure 4, the transformation by couples approach can be represented by the technological function model (Figure 6) [25].

The result of the technological function are the changes in the properties of the operand, the operator and the functional interface. These changes are produced by reorganizing the internal functioning of the mentioned objects with external functional effects of each of them.

The interaction between operator and operand occurs through functional interfaces. The number and character of the interfaces depends on the fizico-technical conditions considered and on the physical-technical phenomena resulting from the interaction.

Figures 7 and 8 show, respectively, digital shadow and digital twin models based on the technological function model and the interpretation of these notions according to [22].

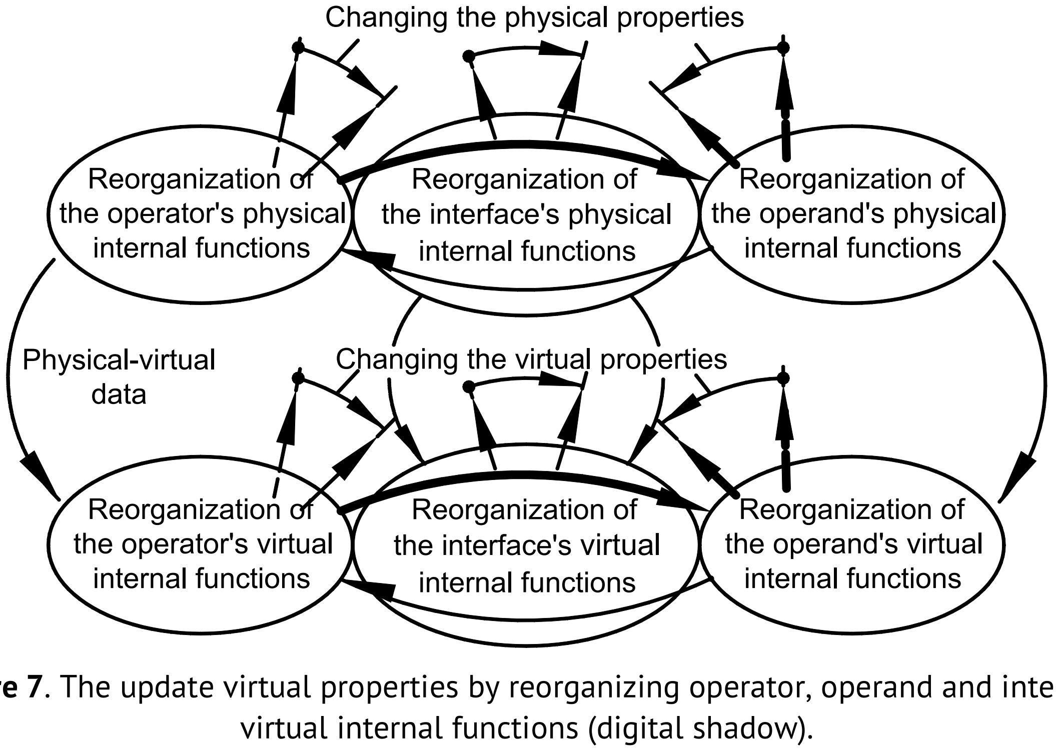

Figure 7. The update virtual properties by reorganizing operator, operand and interface virtual internal functions (digital shadow).

As an example, the information that must be processed to create a digital twin of the product can be described:

- the set of user needs that must be satisfied by the product;
- the set of requirements for the product;

- the set of (external) functions of the product;
- the physical-technical principle of operation, of the principle scheme;
- the CAD model of the product assembly with the specification:

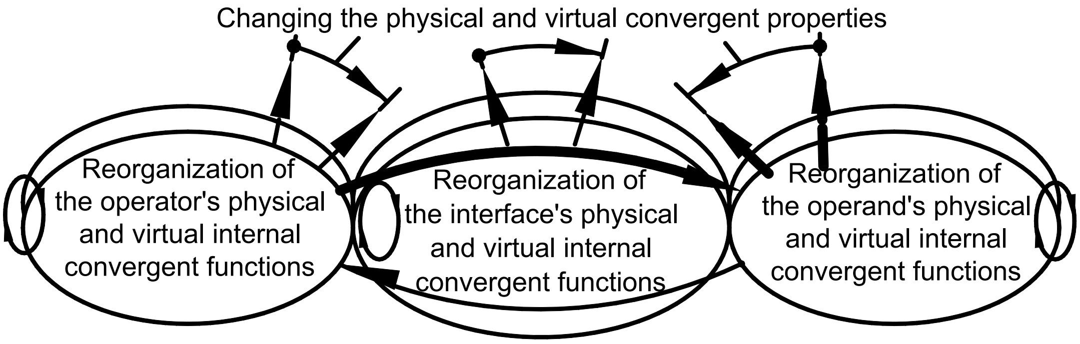

Figure 8. Synchronizing the change of physical and virtual properties by reorganizing the physical and virtual internal functions of the operator, operand and interface (digital twin).

- ✓ informational origins of complex components (subassemblies);
- ✓ adjustments, dimensions and tolerances, gauge dimensions, etc.;
- ✓ the materials of the parts and the heat treatments with references to the respected standards regarding the representative properties important for the operation in conditions of resistance, rigidity, thermal regimes, wear, etc.;
- ✓ the regime parameters of the sliding and restoring torques;

- CAE models and simulation results:
  - ✓ product functionality;
  - ✓ the operation of the product and/or its assemblies;
  - ✓ resistance, rigidity, reliability of components, etc.;
- CAPP models and the description of the elaborated process parameters;
- the characteristics of machine tools, of other machines involved in technological processes (model, functional parameters, precision, etc.);
- the characteristic of cutting tools, of other tools involved in technological processes (model, code, functional parameters, precision, etc.);
- CAM/CNC models and description of machining parameters;
- the results of the technical control of the parts, testing, trials with the concretization of fits, etc.;
- the parameters of the packaging, storage and transportation conditions;
- parameters in real time of functionality and operating recorded by sensors and information systems, etc.;
- regime and maintenance parameters;
- liquidation regime and parameters.

From the point of view of maturity, the digital twin's technology is an emerging one, it is one that has significance in many aspects of engineering, it can offer new solutions to the current and potential problems faced by the engineering of complex objects and processes.

5. Conclusions

- Currently, technological transfer has become largely oriented towards the digitization of products and processes and depends on: the level of basic technical and human digital capabilities, the level of modernization and integration of technological resources, the level of modernization of digital infrastructure, the level of accessibility to new digitized technologies, etc.

- The pillar technologies of the Industry 4.0 concept are diversified by function, but form a systemic whole, so that for strategic success it is necessary to implement them also in a systemic regime.
- Technological development resources are limited for small and medium-sized companies, so it is necessary to set certain priorities. Since several companies in the Republic of Moldova are foreign-owned and mixed, they operate with modern technologies, and for the markets of developed countries, technologies for simulation and creation of digital twins and design of products with high physical-cyber content can be prioritized.
- Technologies for simulating and creating digital twins are sufficiently complex, so the path to digital twins can be traversed, gradually passing through intermediate variants of digital model and digital shadow.
- Models for creating digital twins refer exclusively to the product life cycle, with the emphasis being placed on the finalities of the life cycle stages.
- The paper proposes a digital twin model based on the technological function, in which the modification of the properties is manifested by the restructuring of the internal functions of the operator, the operand and the interface. The central place in this model belongs to the interface, which reflects the multitude of physical-technical processes at different scales of macro, meso, micro analysis characteristic of objects and processes in machine building.

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