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Innovative Relations within the Software Application for Industry 4.0

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Abstract

The article deals with the preparation and definition of new relations within a software tool aimed at increasing the efficiency of production processes. These are three types of innovative concepts: Digital Master, Digital Technologist and Digital Twin that can be provided to customers separately, but also as integration into existing software in the production and logistics management process. By defining these relations within the developed software tool and its implementation into the production process, the automation and digitization of logistics processes in production facilities will reach a higher level that meets the requirements of Industry 4.0.

Keywords: Human-Cyber-Physical Systems, Digital Twin, Shop-floor

1. Introduction

This article deals with long-term research by the author, whose initial results were presented in 2007 [6]. This introductory publication presented an analysis of the then state of the art of computer-aided planning of discrete manufacturing processes. It dealt with the structure of the organization of the data model in terms of the classical approach and the specification of the requirements for the creation of a more universal model for production digitalisation.

The main aim of the study in the frame of the research programs is to increase the production efficiency by human weakness eliminating. The selected goals of the program are:

1. To find linkages and contrasts in digital twinning in cyber-physical systems in comparison with human-cyber-physical systems.
2. To characterize production-related human-cyber-physical systems with not materialize transformation.
3. To find possibilities to eliminate human in some traditionally human-cyber-physical systems.

The partially results of the publication were in form of the requirements for information systems: (1) Achieving a higher level of systematization of information systems (compatibly of data formats, the interconnection of all production processes in one IS, preparation for higher levels of automation); (2) Possibilities of flexible change of views and approaches within one IS; (3) options for choosing the philosophy of technological approach (Individual / Type / Group technology) in parallel within the IS; (4) enabling the secure interconnection of information channels of institutions of various types (micro-companies, SME´s, ... / research, development, production / ...); (5) secure information sharing through both vertical and horizontal elements of the structure.

The developed system was applied in real business conditions. Real-world use has necessitated a redesign of the system to a higher level of compatibility with other information systems and applications. The initial interconnections were performed with the CAM system, warehouse system and economic systems. Gradual development also brought with its requirements for the implementation of smart manufacturing features – a digital form of shop-floor manager and technologist.

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Nomenclature

CAM	Computer-Aided Manufacturing
DT	Digital Twin
IS	Information System
PS	Physical System
SSS	Shop-Floor Service System
SDTD	Shop-Floor Digital Twin Data
VS	Virtual System

2. Research fundamentals

The main difference between the author´s firstly developed CAPP system [6] and the then conventional systems was Multivariant Process Planning functionality. The functionality allows very flexible adaptation of produced segment (simple part, subassembly, assembly, final product) process plan in relation to changing production environment requirements to achieve the required goal (e.g., efficiency, shortening the production lead time, etc.).

By the functionality is possible to prepare more production strategies for every produced segment in advance, or to prepare new or modify previous process plan to the new one in a very flexible way.

Table 1. The classical structural technical concept of production system for the building of initial information system [6]

Production System Design								
Product Design			Manufacturing Design			Work-Study and Wage Structure		
Design Procedure	Design Methods	Value Analysis	NC Programming	Technological Structure Planning	Process Planning	Work Analysis	Work Measurement	Wage Scheme
Cooperative CAD / CAM systems			Developed Multivariant Process Planning					

The basic internal data structure of the developed system was oriented on the linear scheme of production system design (Table 1). This structure is based on the consideration of the separation of product design and creation of NC programs from the design of production processes and the collection of information from production. All data was stored and managed by the relational database system MS Access Professional (MDB – Microsoft Access Database.)

The developed Multivariant Process Planning system was applied in real production conditions for manufacturing of product consist of about five thousand parts. Testing in real conditions showed the biggest drawbacks of this solution - constraints given by the linear data model and the lack of efficient connection with the CAM software, warehouse, and economic systems of the company.

The next step of the creation of the information system for the production process was to change the philosophy of the linear data model to nonlinear (Figure 1). In this newly created model are used more complicated relationships among data records and optimize processes in more levels of the manufacturing process design.

For example, it is possible to compare basic parameters after preparing more concurrent variations of the manufactured segment production process.

Figure 2 presented the dependence of production costs on the size of the production for five different process plans of the same manufactured segment.

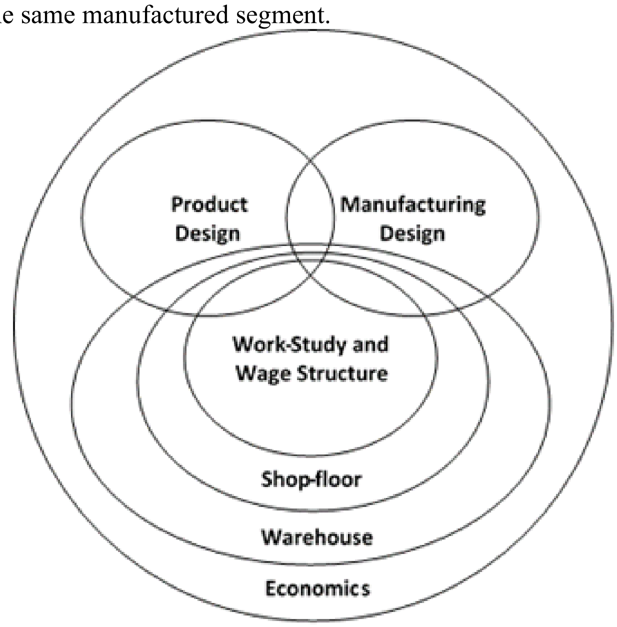

Fig. 1. Simplify scheme of the nonlinear data model for improved information system

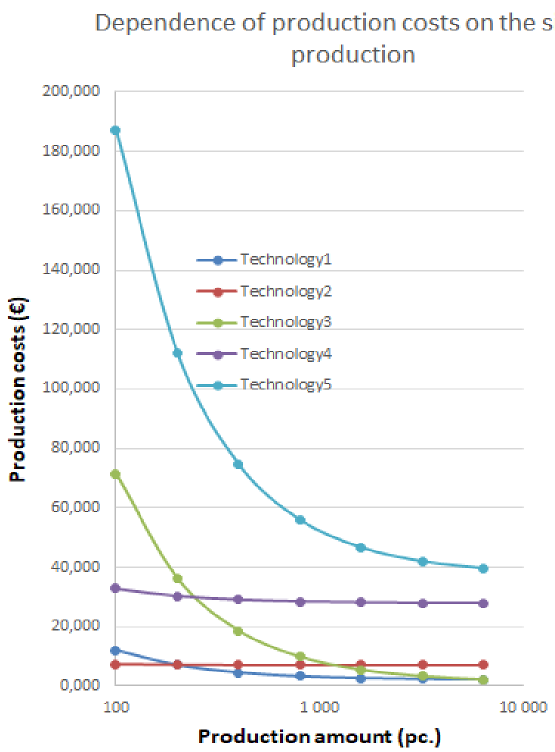

Fig. 2. Dependence of production costs on the size of the production for five different process plans of the same manufactured segment

The operation related level of the optimization is possible to use for looking for the best production factors under defined conditions for every created process plan. Figure 3 presents the optimization of cutting speed for an operation in the frame of the selected process plan.

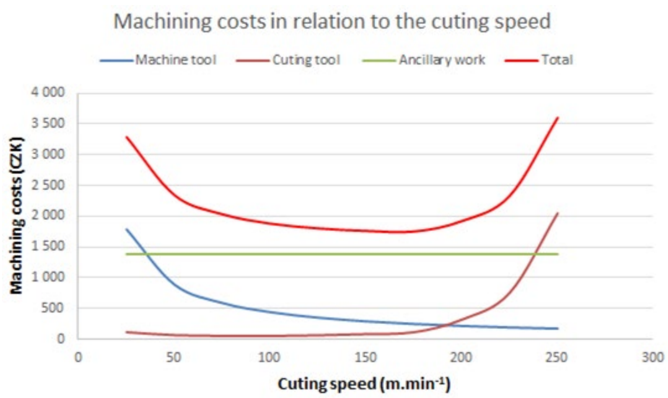

Fig. 3. Dependence of machining costs on the cutting speed

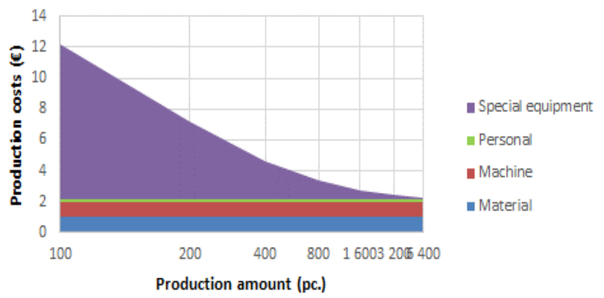

Fig. 4. Absolute share of production costs in production size for selected process plan

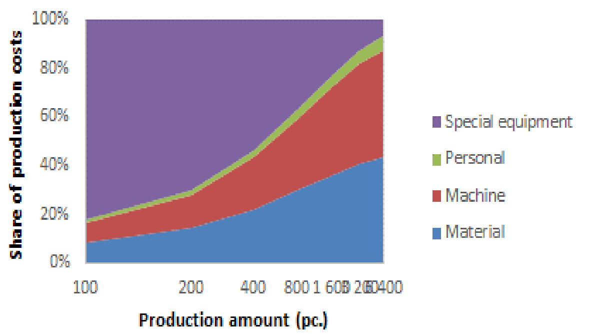

Fig. 5. Relative share of production costs in production size for selected process plan

Figures 4 and 5 present the share of production costs in production size for absolute, respectively relative interpretation. This version of the information system was created on ACCDB (Microsoft Access Database format). The main weakness of this version was in the low possibility of interconnection with a very wide variety of application used in a manufacturing environment. It is normal to have many possibilities to select from many CAD / CAM systems, many accounting software, many material flow control application, etc. for cooperation with the proposed information system.

The next logical step was a higher level of modularity of the system development. Significantly better use of computer capacity and production resources using a modular system is expected. This concept is based on a philosophy of relatively isolated production island. The concept can be a very good basement for the understanding of the elementary concept of production activities. But it has to be mentioned as a small part of the complex environment. Other very important features influencing the production system (without claim to completeness) are:

- Nature
  - Laws and regularities – Logical laws, Physical laws, Chemical laws
  - Sources – Material, Energy, Wasting
- Society:
  - People – Human resources, Level of knowledge
  - Standards – Ethical, Legal, Economic, Industrial
  - Assets – Capital, Lands, Buildings, Equipment, Networks
  - Information - Know-How, Data, Software
  - Transportation - tangible and intangible products
  - Partners - Suppliers and Customers
  - Market - Supply and demand laws

The modularity of the system was prepared in the way of preserving all good properties and functionalities of previous versions and creating of possibility for work of the system by dividing the system into the modules. Modules are organized in different layers of the system. The orientation of the layers depends on their type - for example, the information layer passes perpendicularly through the physical layers of production. The user can activate or deactivate the utilization of the modules for the production activities in accordance with real needs. The simplified data model of the modular information system is presented in Figure 6. The ACCDB format was selected for the real model building and testing of the information system.

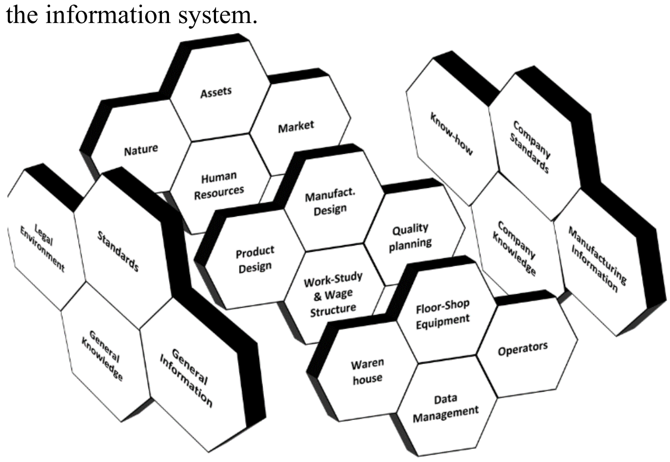

Fig. 6. Simplify scheme of the modular data model for information system

Based on the above research, the authors continue their work with an effort on production applications. In the area since the publication of the first article, very significant changes have taken place, which has been generated by the rapid development of several technologies (digital twins, big data, artificial intelligence analytics, cloud computing, industrial internet of things, cybersecurity, autonomous technique, etc.). [1]

In pursuance of the authors' analyses, the area of digital twinning appears to be very promising not only for technical objects but also for simulating personnel decision-making and action.

Numerous current manufacturing strategies can be recognized to prepare for the future industrial environment. These strategies were created under different environments, but all of them focus to reach intelligent manufacturing.

For all of these strategies is crucial to reach fusion between the physical world and the digitalized one by sophisticated interconnection and interoperability. [4]

The authors of this paper started innovation the information systems on knowledge and experiences from their previous work done. [6-8] They selected the structural technical concept of the production system (Table 1) with new relationships that reflected a modern production environment. The concept remained retained because the shop floor is an elementary unit of manufacturing. All the necessary production activities - previous preparation and finishing the product - are concentrated right here. Shop-floor can be defined as an industrial operation-critical system of industrial automation. The current and future industrial automation is very closely interconnected with cyber-physical systems for the synchronization of processes between the computational and physical environment of engineered systems. [10]

Digital twins are crucial for the efficient run of cyber-physical systems as management platforms able to simulate and visualize physical system by processing sensor or actuator data from the physical systems and able to synchronize both sides of the system – physical and digital, too. [1]

Digital twinning philosophy was selected as a central part of the new information system design of described project of authors because it is a very efficient way of physical and virtual space fusion on the shop-floor.

The concept of Digital Twin is a complex topic developing over thirty years and still in progress. The evolution of Digital Twin can be shortly described [3]:

- Information Mirroring Model;
- Digital Simulations, 3D Printing;
- Intelligent & Connected IoT Services;
- Mixed Reality, Cognitive and Artificial Intelligence.

Digital twin application can be seen mainly in [9]:

- The production processes - optimizes the management of production lines and processes. It focuses primarily on productivity increasing;
- Logistics - solves the harmonization of logistics processes and logistics resources into one comprehensive, harmoniously functioning unit.

Historically firstly proposed models of digital twin - consisted of three components: the physical entity, virtual entity, and connection - are not able to accommodate the new requirements from applications, technology, modelling, simulation, etc. An extended model of a digital twin is expanded by the data of the digital twin and the services at the minimum. [11]

The digital twin practical application can be illustrated by basic problem solving [9]:

- an undesirable event occurring in the production or logistics process, such as downtime, and at the same time recommendations on how to deal with it, how to prevent such situations;
- how to organize, optimize the sequence of orders processing so that production concerning the current plan produces as many products as possible;
- when to replace the tool because it has reached the end of its life, etc.

It is very prospective to classified digital twins into three levels toward different applications [11]:

- unit level - to address the corresponding issues like monitoring, fault prediction, and maintenance of a single piece of equipment;
- system level - for applications that need to deal with different units;
- system of systems (SoS) level - for complex relations, combinations, and associations.

The application of Digital Twin in production is characteristic of wide complexity and needs of synchronously interacting. For this special application is used the term "Digital Twin Shop-Floor". It is mostly implementations consist of four basic features [11]:

- **Physical Shop-Floor** able to realize interconnection and interaction
- **Virtual Shop Floor** – a digital mirror of the physical one – to simulate the physical shop-floor with a high level of mirroring exactness of four aspects: geometry, physics, behavior, and rules
- **Shop-Floor Service System** – supporting the management and control of the physical system and the operation and evolution of the virtual system;
- **Shop-Floor Digital Twin Data** - mainly consists of physical system data, virtual system data, service system data, and fused data of the previous three parts.

3. Human in the Cyber-Physical Systems

Nowadays Digital Twins applied for production activities are on the third stage of the evolution path of the shop-floor acting philosophy. They generally offer interaction between virtual space and physical space. This interoperability acting is expected to be replaced by interaction and convergence of virtual space and physical space in the future. [11]

The human-cyber-physical system definition for purpose of this research is: systems entwined people, physical objects, data, and digital technologies.

The entwinned system can be found by name "Intelligent Digital Mesh" in other publications. They are defined as systems enabled by digital models, business platforms and a rich, intelligent set of services to support digital business. [2]

Human element in the systems can be presented in forms: physical entities; thinking and feeling entities; and social networks (physical and computational). [5]

Many case studies aimed at implementation of digital transformation pointed to the requirement to use not pure technocratic approaches in this movement. According to these studies: people, activities and digital technology are closely entwined and need to be addressed together with a holistic approach; strong leadership from the top is essential for Digital Transformation; do not use technobabble and the buzzwords for the transformation, clear Digital Transformation objectives and strategy; the foundations of the Digital Transformation Program such as Program

Governance, Program Management and Program Performance reporting; the Program plan and the corresponding detailed business case for change; the availability of digital skills; collaborative procurement; establishing communication channels with other members of transformation. It is very important to understand and meet customers' current everyday needs and expectations, too. [10]

Actual research focuses on the possibility to change human in some positions in the production chain. For the first observation according to the above research goals were selected two typically human production positions in classical mechanical engineering plants: Process plan designer ("**Technologist**"); and Shop-floor manager ("**Master**")

Both of these positions required a very educated and experienced personality capable be flexible and inventive. The main characteristic of general human is a relatively high level of error rate, not very stable level of performance, linear thinking, small computational capacity, and other typical weakness. In contrast to the weakness are human cognition, abstractions, creativity, flexibility, etc. Replacing physical people involved in the production process mainly through their intellectual abilities (thinking and feeling entity) can generate many unpredictable problems in such a system.

Nowadays manufacturing system is generally looking for capabilities of increasing quality and efficiency level. The ability to replace human weakness in the above positions and preserving all the benefits of the human intellect can fulfil the capabilities.

The progress in information technologies of the last decade allows utilizing all of reached digital advances to build very complexly and fast responding computerized systems. These systems are capable to restyle common technological structures, production methods, and production outline.

The scheme in figure 1 a) shows the basic inputs and conditions of human processing of the task in a very simple form.

The crucial part of the investigation is how to transfer unique human intellect capabilities in the Human-Cyber-Physical Systems to the simplified Cyber-Physical System – figure 1 b).

Artificial Intelligence is the most important digital technology in the frame of the project from human capability transfer to cyber system point of view. It is required to build the system architecture and technical framework which will be able efficiently to solve the production-related task.

In the initial stages, a human will have to be actively involved in the system, and as the system gradually learns, its activities will be dampened. The learning period of the system will be actively focused on a strategy to achieve specific production goals in optimal conditions. Artificial Intelligence systems need to learn from the information flows of the production activities – requirements, collected information from sensors, etc. to analysis and decision-making.

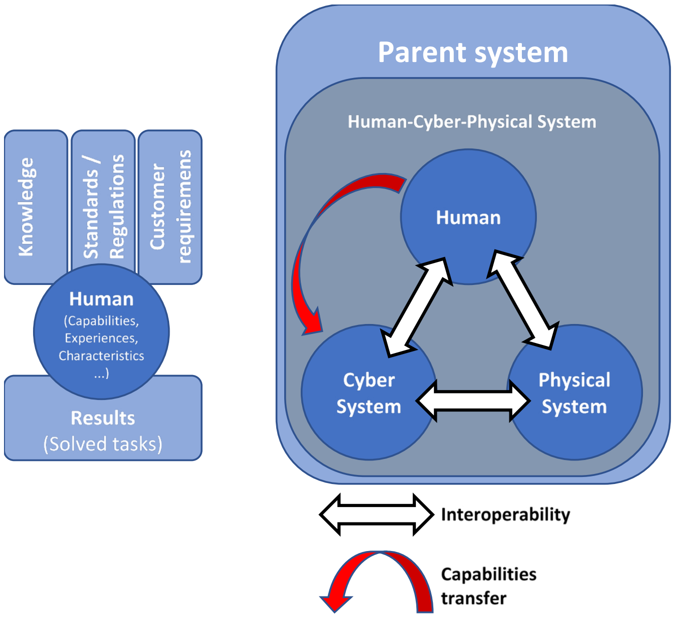

Fig. 7. Simplify scheme of: a) inputs and conditions for human task processing; b) Human-Cyber-Physical System transforming

Illustration scheme of Human-Cyber-Physical System of Floor-shop manager in the developed modular system is in Figure 8.

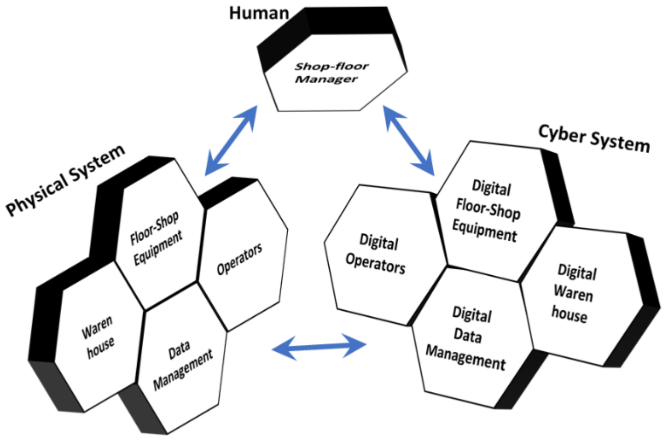

Fig. 8. Scheme of modular information system relationships for Human-Cyber-Physical System of Floor-shop manager

The system needs not only information transfer from the superior system, but transfer to the superior systems, too. It will be necessary to optimize input data structure for the cyber-physical system. The production approach paradigm change will require changing manufacturing data provided by the superior system.

The question of digital twin constituting arises after solving the above research steps. The digital twin is inevitable for the efficient run of the newly defined system replacing human experience and intellect.

At this point, the question of transferring knowledge learned by the system to other systems comes into play. The big challenge is how to solve so enormous variation of input and conditional variation of the discrete production. For example – we know about 40,000 engineering materials; every of the material can be provided in hundreds of forms (plates, sheets, beams, …); every form of material can be differently treated; it is possible to select more technologies for the manufacturing of every part; it is possible to create tens of production plans for every selected technology; it is possible to select many machine tools and tools for every manufacturing operation; etc. This area is very open for future preparation standardization for rules and conditions of such system working to be able to share (and to transfer, of course) learned knowledge.

The proposed innovation of the developed modular information system is in creation relationships and data structures for implementation of Human-Cyber-Physical System modules into.

The use of such a module can be very useful if it is created with regard to the ability to learn not only from the business environment of application, but also from the surrounding systems of similar focus.

4. Conclusions

The human production positions in the plants are too hard to replace with cyber or cyber-physical systems. These positions are typical of the need to use a combination of human experiences and intellect to make "good" decisions. Positions "Shop-floor Manager" and "Process Plan Designer" are mentioned in the contribution as the most suitable example of real production conditions.

All successful persons in these positions are based on a very high-quality level of personal (knowledge, experiences, skills, persistence, resilience, etc.) and interpersonal (communication and communicative, responsibility, flexibility) traits.

The most important point of the digital production system is running on right information. Therefore authors innovated previously tested versions of information system by Human-Cyber-Physical System functionality of Floor-shop manager and Process plan designer. Effective transfer of personnel characteristics of professionals in these positions is one of the most important tasks at the digital twinning research point. The outputs of the research pointed to more typical characteristics of this philosophy:

- The necessary of the composite structure of the information system
- Obligatory human participation in learning of the system
- System ability to incorporate human experiences into the learned knowledge
- System constitution will require changes in information and structure provided by the superior system
- The standardization of the structure of learned knowledge for the possibility of transfer to other systems

The application of these characteristics is made possible by creating a modular concept of the information system. Modularity maintains the consistency of the information system while enabling the involvement of flexible and efficient process optimization tools. All the above knowledge and experiences reached by the research described in this contribution will utilize for fulfilling of next project steps. The next logical step is testing of the newly developed system are:

- Creation or application (in accordance with the following research) of appropriate classification of knowledge base structure;
- Creation of knowledge base capable to flexible share (import and export) of knowledge;
- Applying an efficient tool for personnel knowledge transfer to the knowledge base.

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