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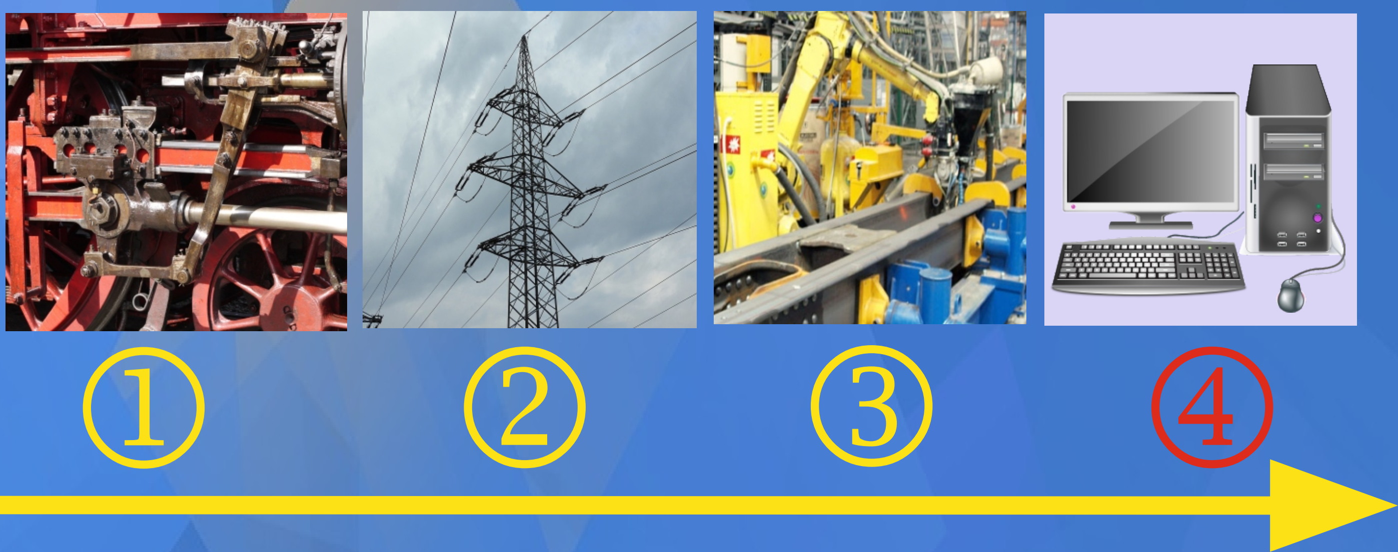


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# C O N T E N T S

## TECHNOLOGICAL BASIS OF "INDUSTRY 4.0"



## DOMINANT TECHNOLOGIES IN "INDUSTRY 4.0"



## BUSINESS & "INDUSTRY 4.0"



## SOCIETY & „INDUSTRY 4.0"

# CYBER-PHYSICAL MANUFACTURING METROLOGY MODEL (CPM$^3$)

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***Abstract:*** *The paper shows the concept of Serbian Industry 4.0 Model based on cyber-physical manufacturing metrology model (CPM$^3$) and an integrated approach to manufacturing quality. The paper presents two directions of research: Virtual optimization of CAI process parameters for the sculptured surface inspection and Intelligent model for Inspection Planning on CMM.*

**Keywords**: INDUSTRY 4.0, MANUFACTURING, ICT, MODELING, MANUFACTURING METROLOGY, QUALITY

## *1. Introduction*

Today's business structure is more complex and dynamic than ever before. The market requires rapid changes in the industry with new products, which directly reflects on the work of the factory. On the other hand, digitization and information technology (IT) provide new, unimagined possibilities, engineers in the design and planning. These two approaches have led to two concepts that have since emerged: the digital factory and digital manufacturing [1, 2].

Cyber-physical systems (CPSs) are enabling technologies which bring the virtual and physical worlds together to create a truly networked world in which intelligent objects communicate and interact with each other [3]. Together with the internet and the data and services available online, embedded systems join to form cyber physical systems. CPSs also are a paradigm from existing business and market models, as revolutionary new applications, service providers and value chains become possible [2].

High levels of automation come as standard in the smart factory: this being made possible by a flexible network of CPSs - based manufacturing systems which, to a large extent, automatically supervise manufacturing processes. Flexible manufacturing systems which are able to respond in almost real-time conditions allow in-house manufacturing processes to be radically optimized [4]. Manufacturing advantages are not limited solely to one-off manufacturing conditions, but can also be optimized according to a global network of adaptive and self-organizing manufacturing units belonging to more than one operator.

## *2. Cyber Physical Manufacturing Systems (CPMSs) - Basic Concept*

Developed and implement "advanced manufacturing concept" as a base for Cyber - Physical Manufacturing Systems (CPMSs), will be to evolve along five directions [4,5]: (i) on – demand manufacturing: Fast change demand from internet based customers requires mass-customized products. The increasing trend to last-minute purchases and online deals requires from manufactures to be able to deliver products rapidly and on-demand to customers; (ii) optimal and sustainable manufacturing: Producing products with superior quality, environmental consciousness, high security and durability, competitively priced. Envisaging product lifecycle management for optimal and interoperable product design, including value added after-sales services; (iii) human - centric manufacturing: Moving away from a production-centric towards a human-centric activity with great emphasis on generating core value for humans and better integration with life, e.g. production and cites; (iv) innovative products: From laboratory prototype to full scale production – thereby giving competitors a chance to overtake enterprises' through speed, and (v) green products: for example Manufacturing Strategy 2020/30 [1, 2] needs focused initiatives to reduce energy footprints on shop floors and increase awareness of end-of-life (*EoL*) product use, and there are framework for CPMSs. The merging of the virtual and the physical worlds through CPSs and the resulting fusion of manufacturing processes and business processes are leading the way to a new industrial age best defined by the INDUSTRIE 4.0 project's "smart factory" concept [4].

Smart factory products, resources and processes are characterized by CPSs; providing significant real-time quality, time, resource, and cost advantages in comparison with classic manufacturing systems [3]. The smart factory is designed according to sustainable and service-oriented business practices. These insist upon adaptability, flexibility, self-adaptability and learning characteristics, fault tolerance, and risk management.

## *3. Our Research in the Field of Cyber Physical Manufacturing Metrology Model (CPM$^3$)*

In our Laboratory for Production Metrology and TQM on Mechanical Engineering Faculty, Belgrade, now we have following researches areas: (i) Digital Manufacturing – Towards Cloud Manufacturing (base for CPMs), (ii) Intelligent model for Inspection Planning on CMM as part of CPM concept (IMIP), and (iii) CPMS – CPQM our approach. In this paper we shall show some research results for third direction.

Digital quality, as a key technology for CPMs represents virtual simulation of digital inspection in digital company, based on a global model of interoperable products (GMIP). GMIP represents the integration CAD-CAM-CAI models in the digital environment. The essence of this research is solved the concept of metrology integration into GIMP for the CMM inspection planning [5,6], based on Cyber-Physical Manufacturing Metrology Model (CPM$^3$).

Feature-based technology and STEP standard could be considered as a main integrator in terms of linking the engineering and manufacturing domain within various CAx systems. To specify the part data representation for a specific application, STEP (ISO 10303) uses Application Protocols (AP) [7,8]. Beside STEP APs, the following standards and interfaces are important for CAI. A vendor-independent Dimensional Measuring Interface Standard (DMIS) provides the bidirectional communication of inspection data between systems and inspection equipment, and is frequently used with CMMs. It is intermediate format between a CAD system and a CMM's native proprietary language.

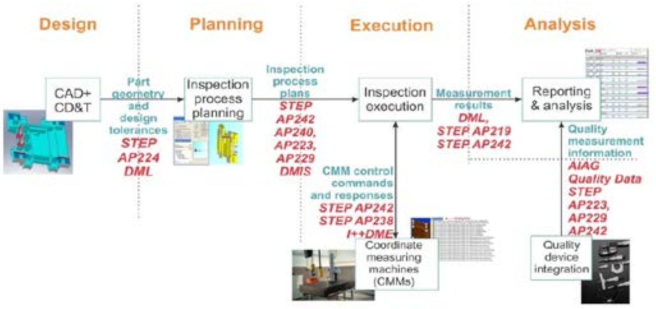



**Fig.1**. *CMM interoperability model* [7]

Dimensional Markup Language (DML) translates the measurement data from CMMs into a standardized file that could be used for data analysis and reporting. I++ DME-Interface provides communications protocol, syntax and semantics for command and response across the interface, providing low level inspection instructions for driving CMMs [4], Fig. 1.

### *3.1. Virtual optimization of CAI process parameters for the sculptured surface inspection*

Fig. 3. shows the working process with the integration of design, production and coordinate inspections. Master Assembly represents the mechanical assembly with all associated parts. This assembly consists upper and lower tools and wind turbine. The experiment was done on the lower side of the Mold Turbine Blade (MTB, shown in Fig. 2.

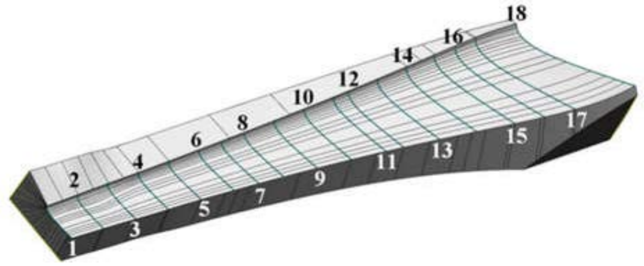



**Fig.2** *Nominal geometry of Mold Turbine Blade* [8]

Computer aided manufacturing (CAM) or Computer aided inspection (CAI) is executed in a separate part-file that consists the original geometry of the part. Only this way it is possible to make changes on the original geometry that can reflect on some of the engineering activities.

Part file CAD/CAM is usually obtained as STEP AP203 or AP214. It represents the basis for the preparation of manufacturing technology. At the same time a geometry inspection is being prepared so that when a part is manufactured, its inspection can be implemented on the coordinate measurement machine (CMM).

As an output from CAD/CAM, STEP AP203/214 is obtained which is the input for PC-DMIS Wilcox. S/W Wilcox PC-DMIS uses its integrated translator to convert it into DMIS format. At this stage GD&T and the motion of measurement probe are defined. Based on the acquired measurements, DMIS output was generated which can be a printed report or STEP too, but now with measured geometry. This STEP can be loaded again into a CAD/CAM system or some other coordinate system for inspection, and contents for the same part of DMIS file give procedure CMM inspection.

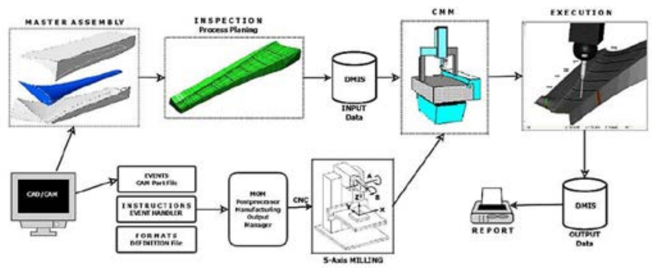



**Fig.3**. *Process with the integration of design, production and coordinate inspections for Turbine Blade Mold* [7]

Our research [8] aims to contribute to the development of a virtual inspection of freeform surfaces, in terms of the investigation of CAI parameters' effects on the quality of the inspection process.

In order to assess the effect of CAI control factors (Number of Control Section, Number of Measured Points, Uniform distribution and distribution with Geometric progression) on the quality of measuring process (measuring accuracy and measuring time), a virtual experiment has been performed for a sculptured surface part in PLM software environment. The measuring accuracy is presented by the distance error and the angle error, and the measuring time is presented by the measuring path length. The results of analysis performed using RSM (Response Surface Methodology) are: Number of Control Section and its square term are significant for the distance error; all three control factors and/or their square terms and interactions are significant for the angle error; for the measuring path length only Distribution Method (Uniform and Geometric Progression) is insignificant. Finally, the optimal CAI factors setting was obtained for the observed freeform surface part. Although the analysis has been performed for the selected part (MTB) that was taken as a reference, these findings could serve as guidelines for the setting of CAI parameters in inspecting sculptured surface parts. Besides, in this approach, the inspection curves were fitted using a cubic spline.

### *3.2. Intelligent model for Inspection Planning on CMM*

The development Intelligent model for Inspection Planning on CMM (IMIP) for prismatic parts involve following activities: (i) development ontological knowledge base presented in [9]; (ii) local and global inspection plan, and (iii) optimize path of measuring sensor. Output from the local and global inspection plan (LGIP) is initial measuring path. The first element LGIP's is sampling strategy or model for the distribution of measuring points for features, and second element define the principle for collision avoidance between work piece and measured probe. By modifying the *Hemmersly* sequences, we define the distribution of measuring points for basic geometric features such as plane, circle, cylinder, cone, hemisphere, truncated hemisphere and truncated cone presented in figure 4.

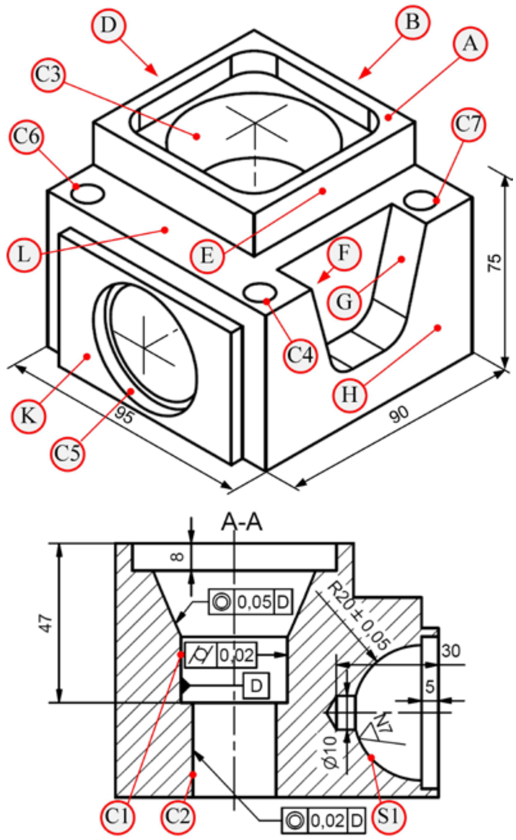



**Fig.4** *The features of the real part: plane - A,B,D,E,F,G,H,K,L; cylinder – C1,C2,C4; cone – C3; sphere – S1*

Each geometric feature is uniquely determined by the local coordinate system $O_F, X_F, Y_F, Z_F$ and a set of corresponding parameters. These parameters could belong to the following types: diameter (D, $D_1$), height (H, $H_1$), width (a), length (b), normal vector of a feature (**n**), fullness vector of a feature ($\mathbf{n_p}$). The vector **n** determines the orientation of a feature in the space. The fullness parameter is defined by a unit vector of the X-axis of a feature. The fullness vector and the normal vector define the direction of a measuring probe access in generating the probe path.

For example, the equations for calculation of measuring point coordinates for cylinder are:

$$s_i = R\cos\left(-\frac{\pi}{2} - \frac{2\pi}{N}\cdot i\right)$$

$$t_i = R\sin\left(-\frac{\pi}{2} - \frac{2\pi}{N}\cdot i\right)$$

$$w_i = \left(\sum_{j=0}^{k-1}\left(\left[\frac{i}{2^j}\right]\mathrm{Mod}2\right)\cdot 2^{-(j+1)}\right)\cdot h$$

where, $s_i$, $t_i$, $w_i$ correspond $x_i$, $y_i$, $z_i$ respectively and $h[mm]$ is the height of a cylinder.

In Figure 5 are presented distribution points, windows of simulation for plane and cylinder and optimizing path by solving TSP using ants colony.

The simulation is based on three algorithms: Algorithm for Measurement Points Distribution (AMPD), Algorithm for Collision Avoidance (ACA), and Algorithm for Probe Path Planning (APPP).

Application of ACO in a coordinate metrology is based on the solution of TSP, where the set of cities that the salesman should pass through with the shortest possible path corresponds to the set of points of a minimal measuring path length [10]. Precisely, the set of cities corresponds to the set of points, and the salesman corresponds to the measuring probe. Since it is necessary to avoid collision between the workpiece and a measuring probe during measurements on CMM, the mathematical model must be developed to present distribution of points for basic geometric primitives and for their unique description.

The model is based on the following equation for calculation of the measuring probe path during the measurement on N measuring points:

$$D_{tot} = \sum_{i=0}^{N-1}\left(\left|\overrightarrow{P_{i2}P_{i1}}\right| + 2\cdot\left|\overrightarrow{P_{i1}P_i}\right| + \left|\overrightarrow{P_{i1}P_{(i+1)2}}\right|\right)$$

In order to obtain a measuring path, a module ‘Manufacturing’ and its sub-module ‘CMM’ in Pro/ENGINEER® (version Wildfire 4.0) was used. The coordinate system of a workpiece during the inspection corresponds to the workpiece coordinate system used for the inspection on CMM. Figure 4 shows the measuring path for the inspection of a hemisphere diameter, as well as a part of the generated CL file.

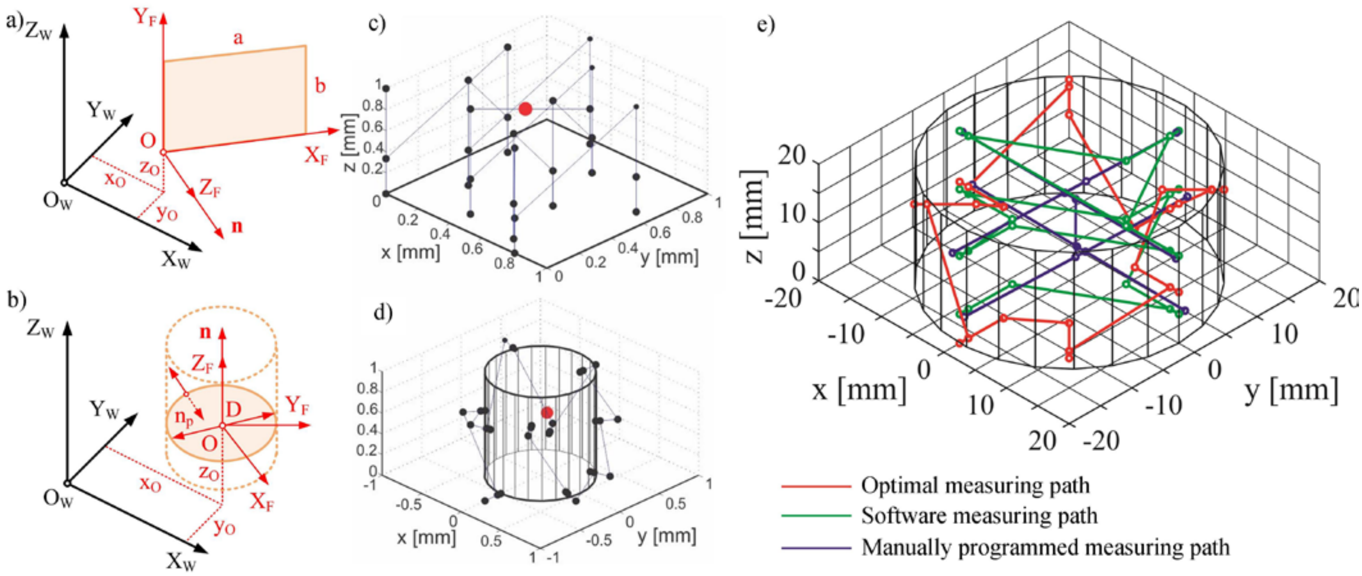



**Fig.5** *The features of the real part: plane - A,B,D,E,F,G,H,K,L; cylinder – C1,C2,C4; cone – C3; sphere – S1*

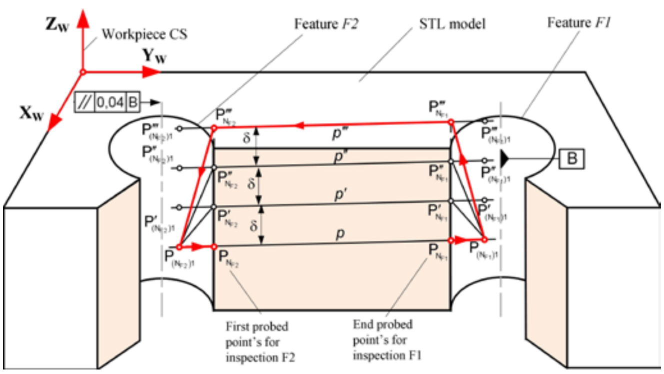



**Fig.6** *The principle collision avoidance*

Based on STL model for the presentation of PP geometry, the tolerances of PP, the coordinates of the last point $P_{(N_{F1})1}$ of a feature F1 and the coordinates of the first point $P_{(N_{F2})1}$ of a feature F2, the simplified principle of collision avoidance between work piece and probe at parallelism tolerance inspection is presented in Figure 6.

For each triangle in STL file, the belonging plane equitation is formulated. If triangle vertexes are $T_1, T_2, T_3$, the procedure of formation of the plane is described by the following equitation:

$$Ax + By + Cz + D = 0$$

and it begins with the formation of a normal vector

$$\vec{n} = \overrightarrow{T_1T_2} \times \overrightarrow{T_1T_3} = A\vec{i} + B\vec{j} + C\vec{k}$$

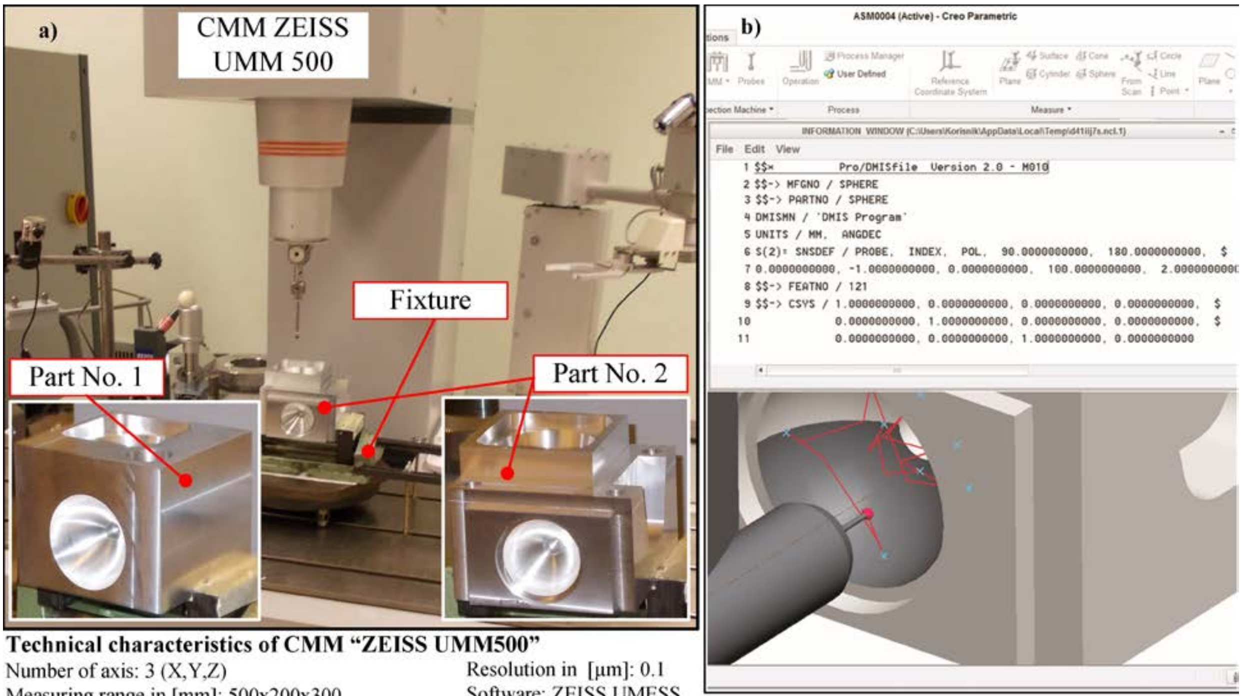
wherefrom the constants A, B and C could be identified. The constant D is calculated using the scalar multiplication $D = -\vec{n}\cdot\vec{r_1}$ where $\vec{r_1} = \overrightarrow{OT_1}$. The next step is the formation of line equitation through two points $P_{(N_{F1})1}$ and, $P_{(N_{F2})1}$, based on the vector form of line equitation:

$$\overrightarrow{M} = \vec{P} + t\cdot\vec{p}$$

where $\vec{p} = \overrightarrow{P_1P_2}$, $\vec{P} = \overrightarrow{OP_1}$.

The principle is iterative and consists from moving line *p* for distance $\delta$ until line became collision free (line segment p’’’).

The planning of an inspection of PP on CMM is performed with regard to three orthogonal directions. This fact is used for the definition of direction of a measuring probe access to PP.




**Technical characteristics of CMM "ZEISS UMM500"**

Number of axis: 3 (X,Y,Z)
Measuring range in [mm]: 500x200x300
Automatic change of measurement sensor: yes
Maximum weight of workpiece in [kg]: 150
Resolution in [µm]: 0.1
Software: ZEISS UMESS
MPE in [µm]: 0.4+L/600
Assurance in [µm]: 0,2

***Creo Parametric* simulation**

**Fig.7** *The principle collision avoidance*

Experiment involves measurement of two PPs that are produced for this research. In comparison to the simpler workpiece PP1 and more complex workpiece PP2 contains new types of tolerances that should be tested. Experimental setups for the measurement of PP1 and PP2 are shown in Figure 7. The measurement of both parts is performed in a single clamp, and the measuring probe configurations are shown at the figures. Experiment is performed on the coordinated measuring machine ZEISS UMM 500.

## 4. Conclusion

In the above presented of SPMSs for quality as a CAI model, it is important to consider the newly developed AP242 that is designed to improve the interoperability in STEP, support model-based GD&T and allows for CMM programming based on the inspection features. AP242 enables 3D product manufacturing information (PMI) with semantic representation and 3D model-based design and data sharing on service-oriented architecture (SOA).

Future research of virtual optimization of CAI process parameters for the sculptured surface inspection could include the usage of higher order splines and comparison of their performances with a cubic spline, for the observed problem. As a general outcome, RSM indicated quite promising results when applied to a CAM environment and more experiments will be conducted for multi axis surface machining in the near future.

The complex geometry of the PP by IMIP changes to the set of points whose sequence defines the measuring path of sensors without collision with work piece. Presenting measuring path by set of points with a defined order is optimizing by solving TSP with ants colony. Finding the shortest measuring path, the main criteria for optimization, influence to the reduction of the total measurement time, which is one of the goals of this research. The ISIP is especially suitable for use in case of measuring path planning for geometrically complex PPs with large numbers of tolerances. The simulation provides a visual check of the measuring path.

$CPM^3$ will integrated in CPMSs model in our future researches.

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# INDUSTRY 4.0 PLATFORM ACTIVITIES IN HUNGARY, PAST – PRESENT - PLANS

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***Abstract:*** *The digitalization efforts of the industry has initialised several scenarios at the industrial company level. It had started at the beginning of the 3rd Industrial Revolution, and by now we may remember some good or best practices, while also can remember experienced pitfalls and bottlenecks. Since the past 3 years has demonstrated the world-wide push for the 4th Industrial Revolution driven technology adoption, new questions ought to be answered by politicians, national economy decision-makers, scientists and ecosystem partners from all areas and sectors. Hungary had experienced both success stories and drawbacks from the past of industrial automation efforts. The present status of the Hungarian National INDUSTRY4.0 Technology Platform is summarized with the agenda of the freshly formed working groups. Some comments and messages have been selected regarding the robotics topics, as seen from the international opinions. The future plans are strategic in their nature, they ought to raise the innovation and profitability of the Hungarian national ecosystem. With national and international project partners, actions are taken to escort, to coach, to push and to drive more industrial SME-s to become winners in the course of the 4th Industrial Revolution. The paper introduces the main aspects of the platform, and their description parts were prepared by the experts in MTA SZTAKI, who planned, constructed and defined the details.*

**Keywords**: TECHNOLOGY PLATFORMS, ETP-s, ENGINEERING ASSOCIATIONS, GOVERNMENT POLICIES

## *1. Introduction*

INDUSTRY4.0 is a buzzword since the last 3-4 years, when the potential breakthrough of an emerging new technology-set had reached the open-minded top decision-making political level(s). Looking back, nothing has happened from one day to another, but numerous technologies have evolved continuously in a great number of co-related sectors (like processing technologies, micro- and Nano-electronics, intelligent data-processing technologies, IoT (Internet-of-Things), IIoT (Industry-related Internet-of-Things), sensor technologies, cloud-computing, e.t.c.), and their integrated effects within industrial application area, (like flexible production technologies, robotics, energy- and material savings and resource-optimization, predictive maintenance, minimization of logistic costs, processing of new materials, additive manufacturing AM, like LOM - Laminated Object modelling- or 3D Printing, implementation of SMART, digital or virtual enterprises, multimodal logistic networks within the value chains, with new business models, with new man-machine-robot interaction models,…) had reached a revolutionary overall potential change. This amount of change is so huge, that not a single company can jump to implement it alone, and immediately. Yet, the estimated and optimistic benefits that could evolve from those implementations, could deliver 20 to 30 % rise in GDP, and profitability of the related industrial segments. No wonder, that government high-rank officials are so keen to strengthen their commitment in the view of enabling such high outcome of this transition, namely the large-scale implementation of Cyber-Physical Production Systems (CPPS).

## *2. Hungarian economic relevance for activities in INDUSTRY4.0*

Regions along the globe, each have its own term, definition and scale for the technology-transfer related to the implementation of the digital economy. The transatlantic countries prefer to care for networked companies, networked manufacturing, and even European large countries have their own word. Germans are punctually referring to INDUSTRIE 4.0, and also define the limits and boundaries of their target-area: limiting the application sectors only to industrial production with the IIOT. It is clearly seen, that Japan, South-Korea, and China have already set up their national nodes, to harmonize the scientific and technical activities, define the national priorities and vocabulary for the national key players.

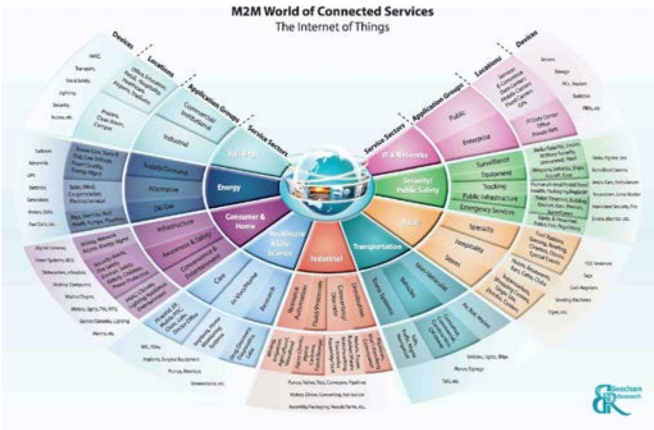


Fig.1. Industry 4.0 is a Sector in the Internet of Things (IoT), as demonstrated by KUKA-Robotics Heinrich.Munz Strategic Technical Consultant [1]

Hungarian experts-based support team for a National I4.0 Platform has also declared to select the industrial production sector, as the primary focus area. Other sectors, like digital governance, or digital well-being has separate means to prepare working papers for the decision-making bodies.

## *3. Launching the Industry 4.0 National Technology Platform*

After almost 20 month of preparation, the idea became implemented: a National Technology Platform needs to support the government decision-making process at a very high political level. In spring 2016, The Ministry of National Economy organized the event, invited 30+ CEO-s from reputed industrial firms, both from large and from small enterprises, from universities and other academic circles, and appointed MTA SZTAKI to be the first-term leader of the Platform. Within 3 month time another 25 firms had submitted their wishes to join the Platform. [4]

Fig.2. Founding CEO- members of the Hungarian National INDUSTRY4.0 Technology Platform

A group of experts had set up the Platform, and each member had to sign the joint understanding document, to accept the rules and terms. Thanks for their hard work, the platform is up and running. The very first draft suggestions and strategic orientation papers were prepared and forwarded to the ministerial-level decision-makers.

In October 2016, the most urgent topics forced the establishment of the following seven working groups. MTA SZTAKI has also prepared an intelligent application that can run on several mobile platforms as well, as shown in figure 3.

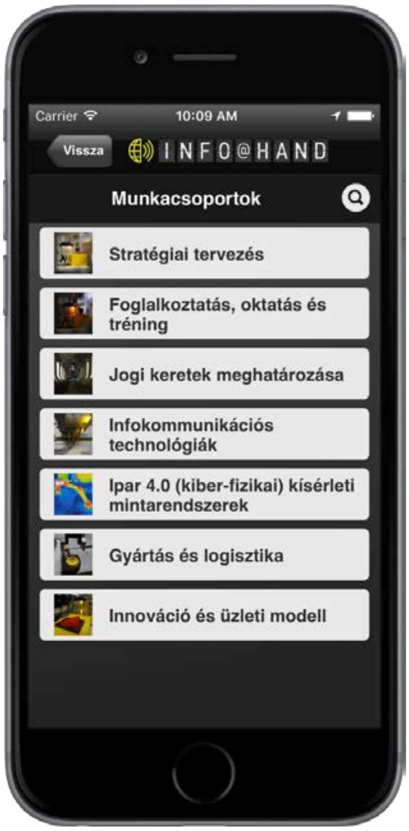


Fig.3. App to support the Working groups of the National Industry4.0 Technology Platform

**The Work Groups of the Hungarian I4.0 NTP (by T. Várgedő)**

The Hungarian Industry 4.0 National Technological Platform operates several Work Groups in order to fulfil its mission defined in its Organizational and Operational Regulations. Their activities focus on specific issues related to I4.0 and they formulate answers and recommendations to the challenges presented by the practice.

The participants of the Work Groups are delegated by their own organizations, members of the Platform and they represent special expertise in the given area. They work closely together with the corresponding governmental forums and bodies thus contributing directly to the formation and implementation of the Government's strategic goals.

Currently the Platform has 7 Work Groups:

- Strategic Planning
- Employment, education and training
- Production and Logistics
- ICT technologies (safety, ref.-architectures, standards)
- Industry 4.0 Cyber-physical Pilot systems
- Innovation and Business Model
- Legal Framework.

**Strategic Planning Work Group**

The Strategic Planning Work Group addresses mainly the issue what answers are required to the challenges raised by the Industry 4.0 towards Hungary, in order to adopt best practice solutions and thus the results attained so far in global competitiveness of our industry sector could be preserved and even further reinforced.

**Employment, Education and Training Work Group**

The Employment, Education and Training Work Group has as its main task to cover all educational aspects of I4.0 which determine the highest priority HR preconditions and implications for its implementation in practice. There is a fundamental impact to be expected on the employment and labour market that I4.0 is certainly to bring with in all areas: the technical environment of physical work, the organisation and control of production, the dominant concepts of corporate business economics, all these demanding more sensitive reactions to the turn in demography, workforce mobility and approach to the related social issues. These changes need a completely new strategic thinking and tools to be applied from all actors of the triple helix scene.

**Production and Logistics Work Group**

Cyber-Physical Systems (CPS) are computational structures that are strongly linked with the surrounding physical world and the physical processes therein while providing and, making an intensive use of, the internet based services for data access and data processing. The Cyber-Physical Production Systems (CPPS) can be expected to pave the way to the 4th Industrial Revolution, often referred to as Industry 4.0.

Accordingly, the Production and Logistics Work Group focusses on such key goals as the digitisation of the Hungarian manufacturing industry as defined in the Irinyi Plan (see Chapter 4) which will certainly play an over-important role in shaping the future of sectors in Hungary.

**ICT Technologies (safety, reference architectures, standards) Working Group**

The evolution processes of modern information and communication technologies closely tied with those of production and logistics systems create not only new opportunities but also generate new challenges. The ICT Work Group deals with those aspects of I4.0 that are connected to the implementation of the national strategy aiming to facilitate the digitisation of the Hungarian industry.

The main topics comprise the horizontal integration of the value creation chain, the vertical intra-factory integration of the entire product life-cycle, their technological assumptions to be considered and obstacles to be overcome.

### Industry 4.0 Cyber-Physical Pilot Systems Work Group

The Cyber-Physical Pilot Systems Work Group concentrate on the implementation perspective of one of the Platform's key topics, i.e. how can the required progress in culture, the existing paradigms of thinking as well as the related technologies be facilitated in the most efficient way. To complete this task it is crucial to create I4.0 pilot systems for research, development, demonstration and education / further training purposes.

### Innovation and Business Model Work Group

The main focus of the Innovation and Business Model Work Group is to determine the major directions of R&D work at the research institutions and companies - based on their direct needs and the international trends - in the way that the innovation requirements of the national economy could be met. A key goal is to strengthen the research potential of the institutes and enhance their innovation capabilities and through these to facilitate the general technological development and expand the scope of the impact of innovation in Hungary. An additional benefit of these efforts is expected in speeding up the process of transforming research results into marketable industrial products.

SMEs and start-ups may directly benefit from the technology transfer and the working group will formulate recommendations as for developing and applying new business models as well. Dissemination of innovation is high priority.

### Legal Framework Work Group

The Legal Framework Work Group's first task is to define the final legal and organisation form of the Platform which is operating now as a free association without any organised legal form. Also, it is required to finalise the current temporary Organisational and Operational Regulations complying with the new legal form.

Furthermore, it addresses any issues which have a legal implication, those which are beyond the primarily technical approaches and action plans. These are e.g. related to the risks and threats in the society of the digitisation and the mandatory harmonisation with the EU directive Digital Single Market Strategy for Europe.

## *4. Supporting SME-s to launch Industry4.0 implementation projects*

The Hungarian Government has prepared the S3, the Strategy for SMART Specialization in 2015, and expressed the interest and will, to increase the innovation within SMEs, and in the production sector of the economy. Also, the National Bureau for Research, Technology and Innovation has supported the plan, and funds were opened in the form of grants, and loans, and for exceptional actions. Among these actions, the national co-financing of EU grants enabled the opening of two Teaming EU projects, while small-scale support of individual bilateral, academic-industry cooperation projects were launched, like the INTRO4.0 EUREKA [5] project, supporting a German-Hungarian technology sharing/transfer action. The Ministry of National Economy has preannounced to open CALLs, named after a Hungarian, but internationally highly reputed, scientist-engineer: József Irinyi, and industrial companies are invited to submit their proposals for Cyber-Physical products, productions, services and business-models.

### Launching the EPIC Teaming project from 2017

The scientific objective of the proposal and project [6] is to further strengthen/upgrade the institute research potential, especially in the field of Cyber-Physical Systems, with special emphasis on Cyber-Physical Production Systems Design, control and management of robust, cooperative systems in the cyber-physical world. Industrial and scientific partners are welcomed to establish win-win partnerships and business cooperation.

Hungary wants to increase its strength in innovation, and to raise the productivity indicators. Though the automotive sector plays a number 1 position in the GDP, the aim is to broaden those industrial sectors that could strengthen Hungary's economic independence e.g. from the German automotive parts export ratio.

## *5. Robotics, as a fundamental topic in the 4th Industrial Revolution*

The cyber-physical products and production is closely related to the new type of robotic products and also as mechatronics-based production technologies. As seen and experienced from the World Robotics Forum, or from the Munich AUTOMATICA-ROBOTICA Fair, there is a significant rise in the production and industrial application of robots. There is a miss-belief, that by the increase of robots in the firms, the human workers have to lose their jobs. As pointed out by a world-survey, this is not the case, the number of required employees is increasing by each installed robot equipment in Europe, in USA, or in Japan. It is important to realize, that the application-area of new robotic sites are being forced out by human needs, namely by the 3D application zones. The 3D is now referencing the human working environments, where robots must replace humans: as DANGEROUS, as DIRTY and as DULL physical work-environment that prohibit humans –and soon European employee-law will give stronger force to it.

## *6. The Hungarian Scientific Society for Mechanical Engineers (GTE)*

The GTE has been a key player in the establishment of the relevant Platform-building started almost a decade ago. GTE was officially the responsible host to run the Hungarian National ManuFuture Technology Platform, and this post enabled GTE to interconnect the ManuFuture European Technology Platform with the Hungarian activities. This action integrated around 90 Hungarian engineering and manufacturing enterprises, supplied them with the European documents, generated the translated docs, and the experts prepared the relevant Vision, Strategic Research Agenda and Roadmap related to Hungary.

The GTE, as the most relevant scientific society with country-wide reach out, has decided to carry on with the preparation of the 2017 INDUSTRY4.0 conference, as the successor of the $22^{nd}$ biannual Manufacturing Conference, with an extended title: INDUSTRY4.0 In Practice-2017. The Conference is scheduled for the end-of September/early October [7] in Budapest.

## *7. Some closing remarks*

The driving force behind the Industry 4.0 efforts is clearly the deep need for the access of tested, standardized integrability of all process- and business-activities related to material and information flow in the production sector. Both manufacturing and also assembly, all servicing and total life-cycle based activities are in need of reliable data-, message-, knowledge sharing using a common facility and service background. Its high value had been pointed out already several years back [8]. The MAP (Manufacturing Automation Protocol, IEEE 802.3 and 802.4 standards had defined alternative media along the 7-layer ISO Open Systems Interconnection. There were very optimistic, good and reliable solution with the internationally developed standard stack, but business issues avoided to reach a maturity level. Real-time and deterministic solutions were too clumsy and expensive, thus non-deterministic, cheap, and easily available CSMA/CD based Ethernet networking covered the 85% of all implementations regarding industrial networking solutions. Today the need is the same, some more sophisticated and modern Software solutions are offered, like the OPC Unified Architecture model. Let us hope, that the same mistakes are not repeated again, by altering from sound, tested technologically correct solutions.

Another topic, where history could, but should not repeat itself, is the operation of Technology Platforms – in some respects. When the economy needs harmonized solutions, the relevant government bodies have the responsibility to enable a platform's useful activities.

The last message from the authors is the importance of security and safety. The higher the software ratio within the Cyber-Physical products and production processes, the higher is the risk. New, safe and sound solutions are still needed to be invented. [9]

## *8. Acknowledgement*

The work carried out had been supported by the EUREKA international cooperation, INTRO4.0 [5] team, including the 25-year old Hungarian industrial partner HEPENIX, while the EPIC consortium [6] of the EU TEAMING project helped to understand the ecosystem, the international R&D&I-environment to match Hungary with the neighbouring and other EU countries.

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## *10. Appendix*

Introduction of MTA SZTAKI, [2] the host of the National I40 Platform. www.sztaki.hu

The Institute for Computer Science and Control, Hungarian Academy of Sciences (MTA SZTAKI), the former Computer and Automation Research Institute, now with nearly 300 full-time employees including about 140 with scientific degrees, was founded in 1964 as a research and development institution of the Hungarian Academy of Sciences. The Institute gained worldwide reputation in computer graphics, computer-aided design and manufacturing, process control, robotics, operations research, numerical methods, advanced information systems and networking. ERCIM (European Research Consortium of Informatics and Mathematics) granted full membership to SZTAKI in 1994. The institute was awarded the title "Centre of Excellence" in "Information technology, computer science and control" by the EU in 2001.

Researchers at the Institute take part in the management bodies and working groups of the most significant international scientific organizations (CIRP, IEEE, IFAC, IFIP, etc.). Many of their colleagues are members of the Editorial Boards of leading international journals.

At the Institute, information science based developments exploitable both in Hungary and abroad, together with high-level advisory activity, are built upon the results, outstanding by international standards, in focused basic research. As a Centre of Excellence, this provides themes of interest and attracting conditions for talented young people in PhD study, for starting their creative scientific work.

The adequate infrastructure is an indispensable requirement of high-quality research activity. The Institute has realized in due time that its main research focus and the scopes of new laboratories (3D-internet, control of robotic devices and UAVs, SmartFactory, cloud-computing) should be determined by taking the most important directions of information and communication technology into account, joining this way the worldwide research arena of Cyber-Physical Systems.

The Institute is a stable, independent partner in R&D&I and in the fields of contract-based applied work, such as system planning, system integration, consulting and turn-key information systems. Quality is an important issue at the Institute: they have an EN ISO 9001:2000 certification.

Focused basic research:
- Computer Science
- Systems- and control theory
- Engineering and business intelligence
- Machine perception and human-computer interaction

Development and innovation
- Vehicles and transportation systems
- Production informatics and logistics
- Energy and sustainable development
- Security and surveillance
- Networks, networking systems and services, distributed computing

*International relations*

MTA SZTAKI in the past decade was intensively engaged in international scientific cooperation, the institute was involved in 44 projects within the EU FP7 Programme, in 8 cases acting as the head of consortium. This series of success seems to continue also in the Horizon 2020 Programme.

With respect to the research in avionics, the relationships with the University of Minnesota, the US Office of Naval Research (ONR), University of Bordeaux, as well as the German Aerospace Centre (DLR) and the European Space Agency (ESA) should be mentioned. Of special importance is the long standing R&D cooperation between SZTAKI and HITACHI that, going back to nearly a decade, has already resulted in a number of joint patent applications. Most of the Institute's activities pertaining to applied R&D in production informatics and logistics as well as to the industrial deployment thereof are carried out in the framework of the Fraunhofer-SZTAKI Project Centre for Production Management and Informatics established in 2010.

*Industrial cooperation*

MTA SZTAKI cooperates with significant major enterprises such as GE, Audi, Hungarian Telekom, MOL, Knorr-Bremse, Bosch, Opel. The technology transfer to small enterprises guarantees that the Institute's results keep on spreading in the widest possible spheres. The Hungarian National Technology Platform on Industry 4.0 is led by the Institute.

*Participation in higher education*

The Institute regards teaching activities as an important ingredient of its research work and also as an indispensable part of building the future. Many researchers at the Institute also fulfil teaching mandates at various Hungarian universities. On average, around 20 PhD students conduct research work at the Institute under the tutorship of the senior researchers.

# PREDICTION OF NATURAL FREQUENCIES OF THE TOOL CONTROLLED MODE USING SOFT COMPUTING TECHNIQUES

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***Abstract:*** *The dynamic characteristics of spindle-holder-tool assembly is one of the most important factors that have considerable influence on cutting process stability, quality of machined surface, tool life, material removal rate, etc. In order to determine the stable cutting conditions it is essential knowledge of the tool point frequency response function (FRF). The objective of this study is development of a two different artificial intelligence methods, namely, artificial neural networks (ANN) and adaptive neuro-fuzzy inference system (ANFIS) as a potential modelling techniques for prediction of natural frequencies of tool controlled mode. First of all, the natural frequencies of the tool controlled mode for limited combinations of tool overhang length and tool diameter were identified experimentally. The results were used to train an ANN and ANFIS models and both models were compared for their prediction capability with the experimentally determined data. Regarding the results, ANN and ANFIS models were found to be capable of very accurate predictions of natural frequencies of the tool controlled mode.*

**Keywords**: ARTIFICIAL INTELLIGENCE, TOOL POINT, NATURAL FREQUENCIES

## *1. Introduction*

The main objective of high performance machining is to produce the high quality parts in the shortest time possible, while respecting the other significant issues such are quality of machined surface, tool life, power requirements, etc. Regenerative chatter developed due to dynamic interactions between the cutting tool and workpiece is one of the major machining problem that could result in inconsistent product quality, process instability, increased tool wear, poor surface finish, excessive noise, etc. In order to determine chatter free machining conditions stability lobe diagrams have been used for decades [1-8]. Forming stability lobe diagrams implies knowing the tool point frequency response function (FRF), which is typically obtained using experimental modal analysis by impact test. However, this approach is time consuming, because measurements must be performed for each spindle-holder-tool combination. In order to reduce modal testing, analytically and semi-analytically approaches [9-14] are used to predict tool point FRF.

In machining operations, it is often required to change the tool and/or holder for practical reasons. It is previously shown that tool overhang length itself is a practical parameter to change the dynamics of the spindle-holder-tool assembly [15, 16]. Moreover, it was concluded that the tool overhang length most strongly affects the natural frequency of the most flexible mode. Similar conclusions were drawn by Cica et al. [17] who deduced that change of the tool overhang length and/or tool diameter have significant impact on the tool point FRF. According to the numerical and experimental study, it is observed that the variations in the tool overhang length and tool diameter mainly alter the natural frequencies of the tool controlled mode and don't have considerable effect on the other modes of the spindle-holder-tool assembly.

In this study, two different artificial intelligence methods, namely, artificial neural networks (ANN) and adaptive neuro-fuzzy inference system (ANFIS) as a potential modeling techniques for prediction of natural frequencies of tool controlled mode were discussed and analyzed.

## *2. Experimental design and setup*

In this section, an experimental study is carried out to provide sufficient data for developing ANN and ANFIS models. The FRF of spindle-holder-tool assembly is obtained by experimental modal analysis. A free-free boundary condition for performing an impact tests was simulated by suspend spindle-holder-tool assembly as is shown in Fig. 1. An impact hammer Endevco type 2302-10 was used for excitation of the spindle-holder-tool assembly, while the response was captured by accelerometer B&K type 4507, mounted on the tip of tool. Tool point FRF of the assembly were collected using the multichannel data acquisition unit Portable Pulse type 3560 C by Bruel&Kjaer, and analyzed in the Pulse LabShop 9.0 software, in the frequency range of 0-3200 Hz. Measurement frequency resolution was chosen to be 1 Hz.

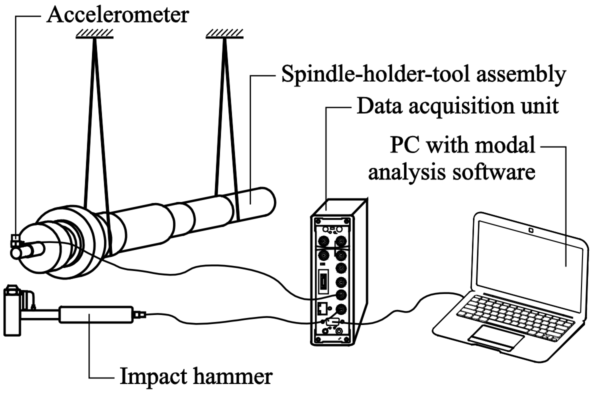


***Fig. 1*** *Schematic layout of experimental setup.*

Since natural frequencies of tool controlled mode depend on the geometry of the cutting tool, experiments were performed with different combination of tool diameters ($D$ = 10-30 mm) and different tool overhang lengths ($L$ = 19-83 mm). The criteria for selection of a tool diameter in the specified range was based on facts that tools of a diameter less than 10 mm don't provide accurate results due to problems of mounting accelerometer, while tools with a diameter larger than 30 mm are not suitable for the holder ISO 40 which was used during the experimental testing, since the size of this cone define the maximum diameter of tools. Tool overhang lengths are in direct correlation with the used tools, tools with smaller diameters have smaller overhang length, and vice versa. The geometry of the holder is not varied from the simple reason that only collet clamping were analyzed. Therefore, only one configuration of the holder is considered to be sufficiently representative. In this way, 174 measurements of different spindle-holder-tool assembly were performed. The measurements were repeated five times to obtain the average values and to decrease the disturbance of experimental noise. Natural frequencies of tool controlled mode were determined using rational fraction polynomial method.

Fig. 2 shows the result of estimated natural frequencies of the tool mode for different combination of tool diameters and overhang lengths. From these figure it can be concluded that with increasing tool diameter and/or overhang length results in the variations of the same mode, the tool mode. Increasing any of these two parameters reduces the frequencies of tool mode. Therefore, by changing one of these two parameters, the frequency of the tool mode can easily be altered in practical applications for a desired variation in the resulting tool point FRF of the spindle-holder-tool assembly.

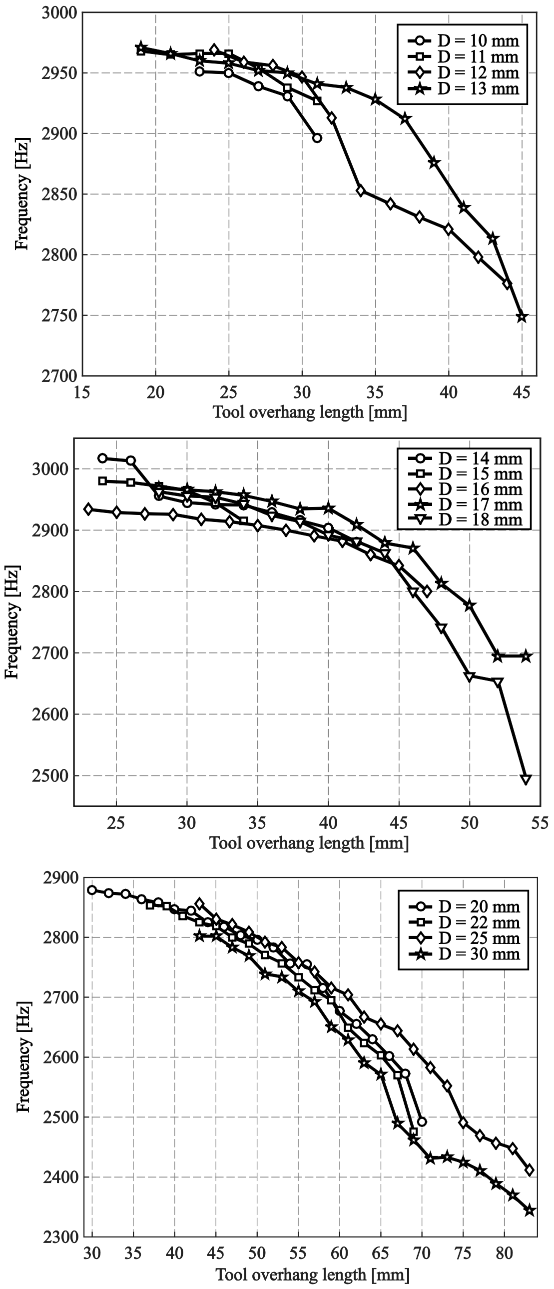


***Fig. 2*** *Estimated natural frequencies of the tool mode for different combination of tool diameters and overhang lengths.*

The obtained experimental results were used to train ANN and ANFIS models for prediction of natural frequencies of tool controlled mode of spindle–holder–tool assembly for different cases.

### *3. ANN based modeling*

In last few decades ANN have been verified as an effective tool for providing solutions to a wide range of engineering problems that cannot be solved using conventional methods, including function approximation, optimization, pattern recognition, classification, control, time series modeling, etc. ANN have been designed with the aim of achieving human-like performance and duplicate human brain intelligence by utilizing adaptive models that can learn from the existing data and then generalize what it has learnt.

In this study, a multilayer feed-forward ANN architecture, trained using an error backpropagation algorithm, was employed to develop predictive model for natural frequencies of tool controlled mode of spindle–holder–tool assembly. As shown in Fig. 3, an ANN is made of three types of layers: input, hidden, and output layers. There are two neurons in the input layer (corresponding to two inputs: tool overhang length and tool diameter) and one neuron in the output layer (corresponding to natural frequencies of tool controlled mode).

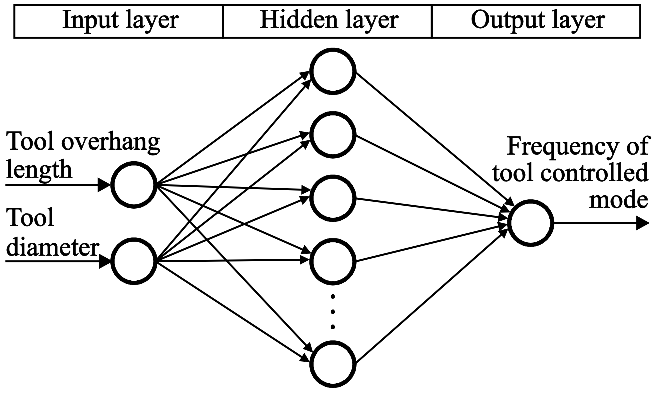


***Fig. 3*** *Artificial neural networks architecture.*

The first step in developing ANN model is normalization of all the inputs and the desired outputs within the range of ±1. Then, the estimated data, relating to natural frequencies of tool controlled mode for different combinations of tools, were by the random method divided into three datasets: training dataset, validation dataset, and test dataset. The training, validation and test datasets consist of 116, 29, and 29 data, respectively. In order to test how well how well the ANN based on the given input values provides output parameters, in all three datasets errors were analyzed using the following parameters: absolute fraction of variance ($R^2$), mean absolute percent error (MAPE) and normalized root mean square error (NRMSE). The higher value of $R^2$ indicate better prediction model (1 denotes perfect), while the smaller values of NRMSE and MAPE means better prediction model (0 denotes perfect).

The performance of supervised training of ANN depends on several factors, such as the number of hidden layers and neurons, activation functions and selection of initial connection weights. Network optimization is usually performed over the optimal number of hidden layers and the number of neurons in the hidden layer. In this study ANN architecture with one hidden layer is selected, and the most favorable number of neurons in the hidden layer was determined by monitoring of errors in the validation dataset and the test dataset. Since there is no exact procedure to determine the optimal number of the neurons on hidden layer, we intentionally chose to start with one neuron and neurons were added to the hidden layer incrementally until there is no further improvement in network performance. According to the evaluation results of various network architectures, an ANN with 9 neurons in the hidden layer provides an optimal values for absolute fraction of variance, mean absolute percent error and normalized root mean square error.

The activation functions are also important factor influencing the network performance. For the developed optimal ANN architecture, tangent of sigmoid activation function has been used in the hidden layer, while linear activation function has been used in the output layer. The weights and biases of the network are initialized with the help of Nguyen-Widrow algorithm. The ANN model was trained with various training variations of back propagation methods and among them the Levenberg- Marquardt method provided the best performance for the adjustment of weighting coefficients. Initial value of the Marquardts parameter was 0.001, reduction factor of the Marquardts parameter was 0.1 and increase factor of the Marquardts parameter was 10. ANN training was stopped when the value of the Marquardts parameter rises above the threshold that is set to $10^{10}$.

The developed ANN model was tested by comparing the predicted results with the experimental data and results for test dataset are summarized in Fig. 5. In predicting natural frequencies of tool controlled mode, absolute fraction of variance, mean absolute percent error and normalized root mean square error were 0.9914, 0.57 and 0.1299, respectively, while maximum mean absolute percentage error (MaxAPE) was 1.9%. Hence, it is evident that there is very good agreement between estimated and experimental values of natural frequencies of tool controlled mode.

### *4. AFIS based modeling*

The acronym ANFIS derives its name from adaptive neuro-fuzzy inference system. Utilizing the Sugeno fuzzy inference system (FIS), Jang [18] presented a neuro-fuzzy system that combines the explicit knowledge representation of fuzzy inference systems with the learning capabilities of ANN in a complementary hybrid system called ANFIS. ANFIS is perhaps the most popular hybrid artificial intelligence technique because it has potential to capture the benefits of neural networks and fuzzy logic into a single framework. The integration of excellent learning capability of ANN with FIS overcomes the limitations of a traditional FIS, such as the dependency on the expert for fuzzy rule generation and design of the non-adaptive fuzzy set.

Working principles of ANFIS is based on its architecture which is typical multilayer feed-forward network where each node performs a particular function on incoming signals as well as providing a set of parameters pertaining to this node. However, unlike multilayer feed-forward ANN, in ANFIS no weights are associated with the links which only indicate the flow direction of signals between nodes.

Basically, ANFIS architecture contains a five network layers (input layer, output layer and three hidden layers) which are characterized by the operations that they perform (Figure 4). These layers are used by inference system to perform the following fuzzy inference steps: (i) input fuzzification, (ii) fuzzy set database construction, (iii) fuzzy rule base construction, (iv) decision making, and (v) output defuzzification. Each layer consists of several nodes described by nodes function, which can be in the form of adaptive nodes (denoted by squares) and fixed nodes (denoted by circles).

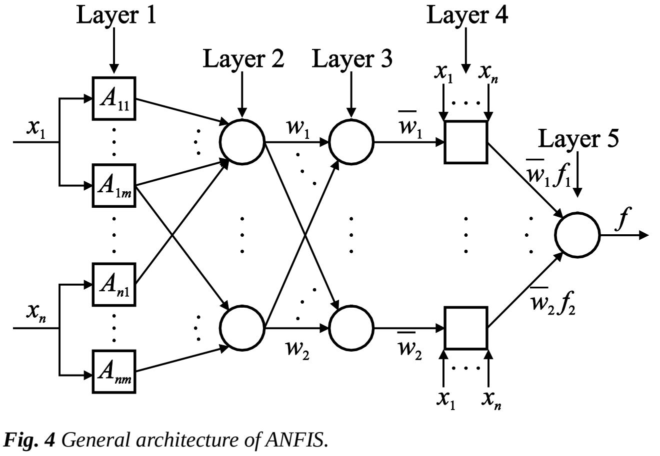


***Fig. 4*** *General architecture of ANFIS.*

Similar to ANN, first step in developing ANFIS model is partitioning the whole data into training and testing dataset. In this study, the ANFIS model was tested using same test dataset as in ANN to predict an output response. The size of training and test dataset of ANFIS model were 145 and 29 of the total number of experimental data, respectively.

In order to achieve maximum prediction accuracy of ANFIS, the model was tested in terms of the number of membership functions (MFs), their type and the most suitable training options. Each input variable was represented using different numbers and shapes of MFs type in the constructed ANFIS model. Optimal number of MFs which offers best performance of ANFIS and is computationally quite fast, were seven and five for tool overhang length and tool diameter, respectively. The model was developed using different shapes of input MFs type which were triangular, trapezoidal, Gaussian, and bell shapes, while the constant and linear output MFs type were employed to produce the natural frequencies of tool controlled mode value. The best responding models of ANFIS system were those which have Gaussian curve built-in membership functions (gaussMF) for each inputs and a linear output function. Furthermore, a hybrid of the least-squares method and the back propagation gradient descent method was used to emulate a given training data set. A first-order Sugeno FIS was used in this study with the hybrid learning rules used in the training.

The same variables as in ANN, namely, absolute fraction of variance, mean absolute percent error and normalized root mean square error, were used as a criterion for selecting the best ANFIS model.

The predicted values of response by developed ANFIS model were compared with the experimental data and results for testdata set are summarized in Fig. 5. In predicting natural frequencies of tool controlled mode, absolute fraction of variance, mean absolute percent error and normalized root mean square error were 0.99325, 0.48 and 0.1158, respectively, while maximum mean absolute percentage error (MaxAPE) were 1.8%. The predicted values of response from ANFIS model and experimental data are fairly close which indicates that ANFIS can be used effectively to predict natural frequencies of tool controlled mode.

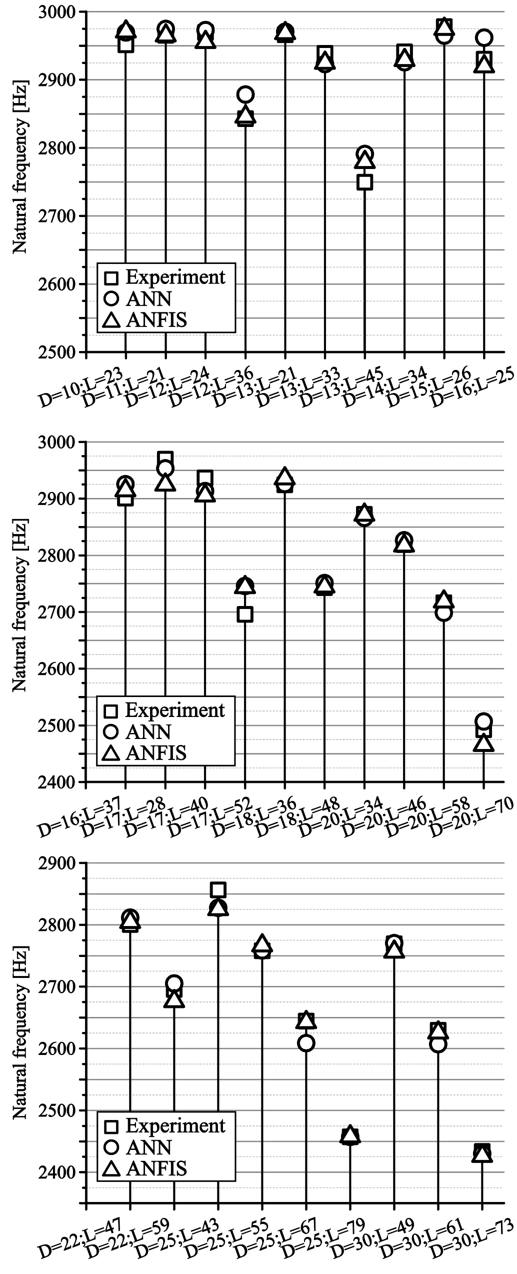


***Fig. 5*** *Comparison of ANN and ANFIS models with experimental results.*

## 5. Conclusions

Spindle-holder-tool assembly is one of the most important machine tool elements because its static and dynamic behavior, strength, speed, etc., have a significant impact on machine tools overall performance. Determination of the stable and unstable cutting zone in the machining process implies knowing stability lobe diagrams of spindle-holder-tool assemblies. For generation of these diagrams FRF of the spindle-holder-tool assembly should be achieved firstly using experimental modal analysis. However, tool point FRF is strongly depend on the individual components of the spindle-holder-tool assembly as well as their interactions. Tool geometry is very practical operational parameter which can be controlled by the user to alter the dynamics of the spindle-holder-tool assembly, by primarily altering the natural frequencies of the tool controlled mode.

The present work aims at estimating natural frequencies of the tool controlled mode of the spindle-holder-tool assembly using two different artificial intelligence methods, namely, ANN and ANFIS, as a tools for the prediction. Tool overhang length and tool diameter were considered to be the design variables. The natural frequencies of the tool controlled mode for limited combinations of tool overhang length and tool diameter were firstly identified experimentally. The obtained experimental results were used to develop ANN and ANFIS models for prediction of natural frequencies of tool controlled mode. Both models were compared for their prediction capability with the experimentally determined data. Regarding the results, ANN and ANFIS models were found to be capable of very accurate predictions of natural frequencies of the tool controlled mode, although ANFIS models give somewhat better predictions. Therefore, it can be concluded that ANN and ANFIS models can be used in the determination of the tool point FRF, and thus can be used for the generation of stability lobe diagrams.

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# MODELING OF CYBER-PHYSICAL SYSTEMS USING UML PROFILES

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***Abstract:*** *Cyber-Physical Systems integrate computation, networking, and physical dynamics. Systems and computer science has provided a solid foundation for spectacular progress in modeling of engineering software application for real-time and embedded systems. This paper discusses and analyses the possibilities of using UML and its profiles to model cyber-physical systems. Two approaches for modeling of cyber-physical components based on the UML profile for system engineering – SysML and on the MARTE profile for analysis and modeling of real-time systems are respectively described. The presented approaches are illustrated with a simple example for modeling of feedback level control system. Finally some conclusions are made.*

***Keywords****:* CYBER-PHYSICAL SYSTEM, INDUSTRY-4.0, MODELING, UML, SYSML, MARTE, MODEL DRIVEN DEVELOPMENT

## *1. Introduction*

Advances in information and communications technologies and embedded systems in recent years give a strong impetus in increasing the degree of integration between physical systems and virtual reality and are associated with the emergence of so-called Cyber-Physical Systems (CPS). CPS are physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core [1]. They are unique in that the components can be distributed both spatially and temporally, and include complex networks of feedback controllers and real time communication. The effective control, associated with achievement of a high degree of adaptability, autonomy, functionality, reliability, security and usability is the core of cyber-physical systems. The synergy between cyber and physical systems can be both at the nano-level and also at the level of "system of systems". Research and development in the domain of CPS is of great importance for 5 key areas in Europe - transport, energy, well-being, industry, and infrastructures.

Industry 4.0 or the Fourth industrial revolution means to put the manufacturing on the foundation of cyber physical systems. Industry is the dominant sector of the European economy, since each job in industry is linked to two additional jobs in high quality services [2]. The EU Commission's stated aim of increasing the industrial sector's share of gross value added in the European Union to 20% in 2020 is extremely ambitious and cannot be achieved in the foreseeable future [3]. The only way in which the manufacturing sector's share of the economy can ultimately be increased is if it achieves faster sustainable growth than the other sectors (especially services) [4]. This may advantageously be achieved by the introduction of CPS.

CPS integrate computing, networking and physical dynamics, as distinguished by a high degree of heterogeneity and parallelism. As a result, the software design techniques are insufficient. New approaches, methods, algorithms and techniques are needed, which will support the process of analysis and design of CPS. Some of the most successful approaches for CPS design use model base or model driven development where models play an important role in the design process. They form the systems specifications and reflect the evolution in the design of the system. These approaches allow for the simulation and analysis, which may lead to early error identification. They are based on automated or semi-automated processes and under certain circumstances may lead to implementations of models. The main problem in the application of these approaches comes from the inherent heterogeneity and complexity of CPS, which stressed existing languages and modeling frameworks.

The main aim of the paper is to summarize the fundamental requirements and research challenges to the future CPS and to present and analyze the capability of using UML and UML profiles for System Engineering SysML [5] and for Modeling and Analysis of Real Time and Embedded systems MARTE [6] to model of CPS.

The paper is organized in 4 parts. After the introduction, in part 2 a short analysis of basic requirements and research challenges to the future CPS is proposed. Part 3 discusses the main challenges of using UML to model of CPS. In the next two parts the UML profiles for System Engineering SysML and for Modeling and Analysis of Real Time and Embedded systems MARTE are respectively presented in short and the corresponding approaches discussed and illustrated. Finally some conclusions are made.

## *2. Fundamental requirements and research challenges to the future CPS*

The fundamental requirements for introducing CPS in industry are specified by [8] as follows:

- Adaptable to heterogeneous environments: integration with cutting-edge information systems, smart-devices and the existing environment (from old PLCs to smart object embedded in computing power).
- Capable of working in distributed networks: they should gather, transfer and store in a reliable manner all the information provided by smart sensors and actuators through the use of the IoT.
- Based on a modular open architecture: the interoperability has to be ensured across different platforms provided by several vendors along the value chain.
- Incorporate human interfaces (HW & SW based): integration of user-friendly and reliable service to make decision makers aware about the real time situation of the factory.
- Fault tolerant: given by the encapsulation of models to activate prediction control loop and correctness of automation systems.

The design of the CPS requires knowledge on the dynamics of computers, software, networks, and physical processes. The main challenges in the development of cyber-physical systems have different nature and may be grouped in different categories, such as technical, organizational and social. To organizational challenges belong the standardization and issues connected with regulations and legislation. Till now, there is no a reference framework for development of CPS. Different reference models and Standards for interoperability of different systems are needed. The most important social challenges are connected to the Computer – human interactions and interface design. The technical challenges in the design and analysis of CPS stem from the need to build a bridge between sequential semantics and parallel physical world and are connected with the following engineering domains:

- Modeling, development and realization of CPS components and systems;
- Validation, verification and testing of the models at different levels of abstraction;

• Maintenance and evolution of the introduced CPS components and systems.

## 3. Modeling of CPS using UML and its profiles

Unified Modeling Language (UML) is widely used in the field of software development and is connected with a reduction of software complexity and supporting the requirements to the software applications, such as modularity, portability, interoperability and reusability, as well as opportunities for modifications and extensions. Its 2.4.1 version has been formally published by ISO as the 2012 edition standard: ISO/IEC 19505-1 and 19505-2 [5].

Although UML is designed specifically for the development of software systems, it is considered as a visual general purpose modeling language based on unified notations and object-oriented meta-model. The main challenges using UML for modeling CPS may be summarized as follows:

- Creation of different mechanisms to handle real-time features such as: models of physical time, timing specifications, timing facilities, modeling and management of physical resources and concurrency;
- Means for early verification and validation of the designed systems in respect not only to their functionality, but also in respect to the non-functionality requirements;
- Ability to model physical systems;
- Development of framework for model-driven development of CPS applications.

There are many different proposals for extending UML to support the design and analysis of different aspects of CPS. Short overview and analysis of the frequently used is made in [9]. One of the most popular approaches for this purpose is based on the development of different profiles UML. A profile is a restricted form of a meta-model that must always extend some reference meta-model created from MOF, such as UML. The creation of UML profiles (standard and specific) is based on stereotypes, constraints and tagged values, which can be used separately or together. The objective of UML profiles is to package specific terminology and substructures for a particular application domain. One of the first attempt to provide RT capabilities of UML in this direction is the OMG initiative for creating of the profile for Schedulability, Performance, and Time Specification (SPT-profile) that is proposing a framework to model quality of service, resource, time and concurrency concepts in order to support predictive quantitative analysis of the UML1.4 models. This profile supports two well-established forms of time based model analysis: schedulability analysis based on schedulability theory and performance analysis based on queuing theory or Stochastic Petri Nets. The SPT profile is used as a basis for some other UML1.4 based profiles such as RT-UML, MAST-RT, embedded UML, HDOORS UML profile, Graf-Ober profile etc., as shown in Fig.1. With the advent of the new UML2.x, started the development and use of some new UML profiles for real-time, among them with the highest prevalence is MARTE profile that aims to completely replace the SPT profile. Among the most successfully applied and discussed profiles are UML profile for System Engineering – SysML [6], UML Profile for Modeling and Analysis of Real Time and Embedded Systems – MARTE [7], which will be shortly discussed, analyzed and illustrated in the next parts of the paper.

## 4. Modeling of CPS using SysML

### 4.1. Short overview of SysML

The UML profile of for Systems Engineering SysML supports the modeling of wide range of systems including hardware, software, data, personnel, procedures and equipment. It is the first UML profile in the field of systems engineering, built on OMG RFP (Object Management Group, Request For Proposals) and is a unified language for analysis, specification, design and verification of complex systems, directed at improving the system quality and the exchange of information between heterogeneous systems, and help to bridge the semantic gap between systems, software and various engineering disciplines [6].

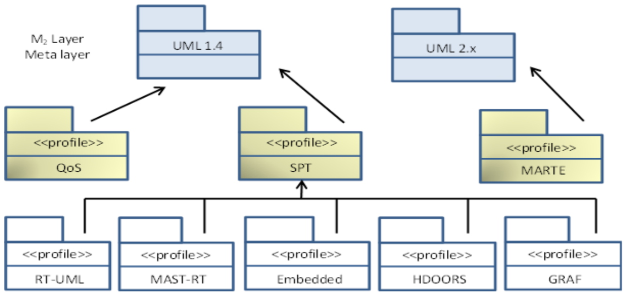


***Fig.1:*** *UML profiles for real time*

SysML is a general-purpose modeling language for system engineering that reuses a subset of the last UML2.x versions and provides additional extensions through stereotypes, diagram extensions and model library in order to model a wide range of system engineering problems as for example specifying requirements, structure, behaviour, allocations and constraints on system properties to support engineering analysis. The reusable subset of UML, known as UML4SysML includes Interactions, State machines, Use Cases and Profiles. In Fig.2 the set of SysML diagrams in respect to their modeling aspects is summarized. The system structure design is supported by four types of diagrams: Block Definition Diagram, Internal Block Diagram reinforced by Parametric Diagram, and Packages Diagrams. The behaviour diagrams incorporate four diagrams too, namely: Activity Diagram, Sequence Diagram, State Machine Diagram, and Use Case Diagram. The Requirements Diagrams, which can be presented in graphical, tabular or tree structure format, are used to specify different constructs for system requirements and to cover the relationships between them. In SysML two kinds of requirements are used – functional and performance, as they specify the capabilities or the conditions which must be performed or satisfied by the system.

Other modeling capabilities of SysML not shown in Fig.2 are the cross-cutting constructs, such as allocations for connecting of different views, and Profiles & Model libraries allowing further customizing and extending of SysML to specific applications. SysML also includes extensions supporting the causal analysis, the verification and testing processes and the decision tree development.

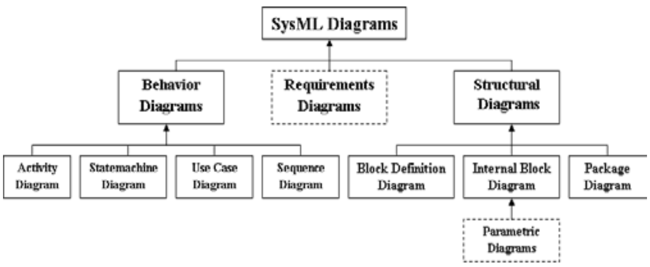


***Fig.2.*** *SysML Diagrams [6]*

SysML adds new features that are potentially useful for modeling of CPS. The internal block diagram of SysML, which is built on the composite UML2.0 diagram, added the use of flow ports and has a great potential for modeling of complex physical systems. The main obstacle of using SysML for modeling of CPS is the lack of defined semantics therefore the same SysML diagram can be interpreted in many different ways by different observers.

### 4.2. Modelling of CPPS component based on SysML

In this section, an application for water level feedback control system using PID controller as case study is presented. The physical system is shown in Fig.3 and consists of a cylindrical tank, filled with water until specified level that is registered with a level sensor and is controlled by changing the input valve position. The core of control system is a feedback controller, which controls the level in the tank according the PID principle. The discussed example is divided in two parts – modeling of physical system, named "Physical SubSystem" and modeling of control system called "ControlSubSystem".

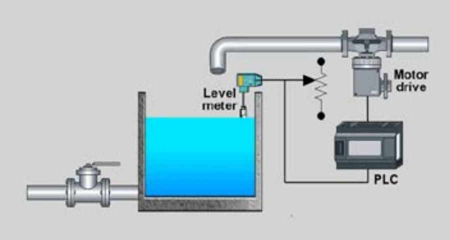


***Fig.3:*** *Physical system*

The model of level control system, based on the UML/SysML profile is realized by Rhapsody tool of IBM. System functional requirements are defined based on requirements diagram (Fig.4-1) and are defined as follows: The level set point in the tank should be 200 mm, the period of update - 0.01 seconds. With the use case diagram on Fig.4-2 the relationships between HMI and control in different mode (manual, automatic and reset) are modeled. A major advantage of the approach based on UML/SysML is the capabilities for modeling of parametric constraints to physical part of the system, represented by different types of equations supporting the analysis phase, using parametric diagram. The static composite structure of the system is represented by the Block Definition Diagram on Fig.4.3.

The human-machine interface, controller, the tank and communication bus are represented through the diagram main elements - blocks. Communications between blocks are modeled through different types of ports. The messages exchanged between the system blocks are represented by the sequence diagram of the type "white box", which is shown on Fig.4-4. The internal structure of the control system, including physical subsystem and control subsystem is modeled using internal block diagram. The controller model that implements the PID algorithm is presented as internal block diagram (Fig.4-5) and consists of three parts representing the proportional, integral and derivative part of controller. The links between them are presented with "flow ports". The behavior of the controller is modeled by state diagrams and activity diagrams representing the control algorithms. The tool used for modeling allows the automatic generation of Java, C ++ or other code that serve to configure the controller (Fig.4-7).

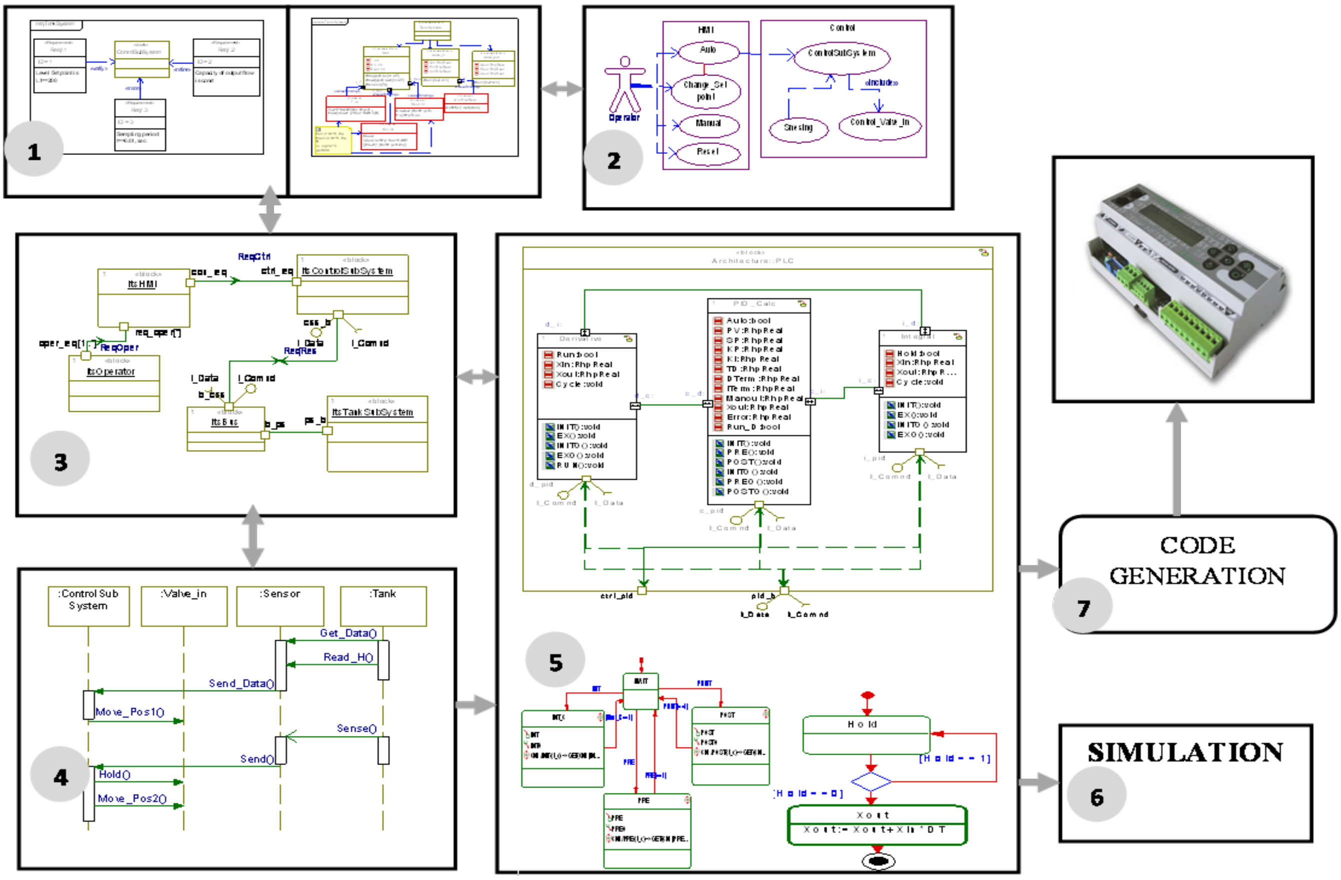


***Fig.4:*** *Modeling CPS components using UML/SysML of Telelogic (IBM)*

## *5. Modeling of CPS using MARTE*

### *5.1. Short overview of MARTE profile*

MARTE is a specification of OMG and is based on the SPT (Schedulability, Performance and Time) profile using the standard notations and semantics of UML [7, 10]. This UML profile is an independent framework, offering a compatible set of standard notations and semantics to design custom hardware and software applications. MARTE profile consists of three packages named "MARTE Foundation", "MARTE Design Model" and "MARTE Analysis Model", shown in Fig.5. "MARTE Foundation" package defines all basic foundational concepts required for design and analysis of real-time and embedded system. It provides model developers with constructs for modelling of non-functional properties, time modelling, generic resource modelling, generic component model and allocation modelling. "MARTE Design Model" package addresses model-based design, starting from requirement capture to specification, design and implementation. It provides high level concepts for modelling both, quantitative and qualitative features of real-time systems/protocols. Further, it also provides means for detailed description of software and hardware resources used for execution of an application. The package "MARTE Analysis Model" offers specific abstractions and relevant annotations that could be read by analysis tools. MARTE analysis is intended to provide trustworthy and accurate evaluations using formal quantitative analysis based on sound mathematical models. This package is sub-divided into three other packages, namely "Generic Quantitative Analysis Modeling", "Schedulability Analysis Modeling" and "Performance Analysis Modeling".

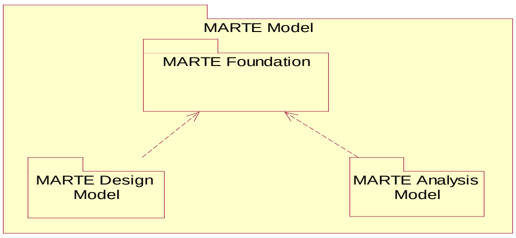


***Fig.5:*** *MARTE profile*

By defining new stereotypes for elements in structural diagrams, activity diagrams and statechart diagrams UML MARTE profile ensures concepts for modelling and analysis of time characteristics and constraints such as clocks, time and delay. Additional stereotypes used to model the time are <<Clocks>> and its instances as: <<ClockType>>, <<ClockConstraint>>, <<TimedEvent>> and <<TimedProcessing>>. The properties of the types of clocks used, the timer functions as a resolution, maximum value and act are defined by stereotype <<ClockType>>. <<ClockConstraint>> stereotype is used to present the constraints of the clock by determining the dependence on the time structure in a time domain [11]. The specification of time constraints is presented declaratively using OCL language [12]. By stereotype <<TimedEvent>> a particular clock is specified. In cases of repeated event, the frequency and period of repetition are defined. Stereotype <<TimedProcessing>> expand meta-classes of elements representing behaviour, messages, and actions [13]. MARTE profile extensions are implemented by adding new model library stereotypes. The elements from library models can be used to model different levels of meta-models, profiles and applications.

Like SysML, the concept "allocation" is introduced. The allocation in MARTE profile means the choice of platform on which the developed application will be realized. The allocation covers both the spatial distributions and temporal aspects of time scheduling in order to map different executable algorithms to existing computing and communication resources and services. The time scheduling is necessary in cases in which multiple applications are distributed on the same platform, or when synchronization is required between the various elements.

### 5.2. *Modelling of CPPS component based on MARTE*

The suggested methodology for development of software control system based on the combined use of the both UML profiles SysML and MARTE is suitable for development of open, interoperable, re-configurable, and distributed CPS. This methodology allows describing the whole live-cycle of the control system. One of the most essential features of this approach is that control engineers are able to model the closed loop control system and to apply the different type of analysis techniques in order to determine whether these models meet their performance and schedulability requirements, without requiring a deep understanding of the inner working of those techniques. Another main advantage of the suggested approach is the possibility for analysis of the designed system and detailed deployment on the hardware and software platforms of the modelled application, provided by using of allocations.

For the development of the same case study from Fig.4 for feedback level control, Modelio tool [14] is used. The Modelio is a development of Softeam group and provides an open source tool for development and maintenance of Model Driven Architecture through the profile technique. Modelio supports several UML diagrams, as well as additional diagrams such as Business Process, Requirement, SysML or Enterprise Architecture diagrams. The Requirements Analysis and System Functional Analysis are developed according the methodology and diagrams, described in part 4.2 of the paper. Different MARTE stereotypes are used in the Block Definition Diagrams of "ControlSystem", "ControlSubSystem" and "TankSubSystem". For "ControlSubSystem" part the <<ComputingResource>> is assigned, while "TankSubSystem" part is defined by <<ProcessingResource>>. The communication bus presented by part "BUS" is defined through stereotype <<CommunicationMedia>>.

## *6. Conclusions*

The presented approaches for modeling of cyber-physical components and systems based on the use of UML profiles SysML and MARTE support the modeling of open, interoperable, re-configurable, and distributed systems. They support the modeling of the whole system live-cycle. One of the most essential features of these approaches is that control engineers are able to model the closed loop control system and to apply the different type of analysis techniques in order to determine whether these models meet their performance and schedulability requirements, without requiring a deep understanding of the inner working of those techniques. Another main advantage of suggested approach is the possibility for analysis of the designed system and detailed design of the hardware and software platform of the modeled application, provided by using of UML/SysML/MARTE profiles. The standardized notation is not sufficient to achieve effective methods of analysis and unequivocal communication between designers. Without semantics framework for modeling fails to provide a platform for design. However, the high degree of flexibility of these notations for modeling leads to a partial success because designers can achieve "interoperability standards", without leading to change their existing practices.

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# MANUFACTURING OPERATIONS MANAGEMENT - THE SMART BACKBONE OF INDUSTRY 4.0

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***Abstract:*** *Industry 4.0 offers an unprecedented opportunity for transformational success, but companies must have plant floor software that is ready for that journey. The fact that Industry 4.0 is already predicted means companies can prepare themselves now. This paper helped companies understand what they need to drive manufacturing in an IIoT world and the new role of manufacturing operations in the enterprise. It also discussed what Smart Manufacturing means and why companies should start the journey now, actions executives should take to address the convergence of IT and automation, and key criteria for selecting a MOM partner to support next-generation business solutions.*

**KEYWORDS**: INDUSTRY 4.0, IIOT, OPC UA, MOM, MES, FCS, SCHEDULING, CMMS, ISA 95, IEC 62264

## *1. Introduction*

The Industry 4.0 vision of decentralized, autonomous networks of smart products and automated equipment collaborating in smart supply chains is the direction manufacturing industries must move to achieve intelligent, high-performance, resource efficient and fully predictive manufacturing. The subject of this paper is the transformation of Manufacturing IT in order to handle thus new complex environment successfully. Industry 4.0 shapes a future of agile, affordable manufacturing fueled by technology enablers such as the Internet of Things (IoT), Additive Manufacturing (3D printing), Augmented Reality, Cloud Computing, Mobile Devices, Autonomous Robots and Big Data Analytics (Figure 1)[9]. That future reality actually does have the potential to change the process of manufacturing. It's a disruptive change of how companies and supply chains work, what people and software applications do, and what customers can expect and when. That does not mean all the processes, equipment, IT systems, and procedures a company uses today will disappear. They need to prepare for the following transformations:

- Distributed Manufacturing - from centralized to decentralized decisions and control
- Autonomous Machines (robots) - from people directing or even doing much of the operations work to automated intelligent mechanisms capable of acting independently
- Vertical Integration - from isolated systems at each level (work centers, production lines and units, plants, enterprises) to vertically integrated information flows that enable full business processes. That includes IT/automation convergence of information technology (IT) systems used for data-centric computing with automation technology systems traditionally associated with industrial control systems (ICS) such as supervisory control and data acquisition (SCADA).
- Horizontal Integration - from separate systems in each department and organization in the supply chain to horizontally integrated information flows among everyone in the organization and extended supply chain
- Simulation – from somehow organized to fully predictive processes, which could be readily tuned to the best performance with the respect to specific but fast-changing requirements faced by complex manufacturing businesses
- Augmented Reality - from drawings, instructions and manuals to context-sensitive interaction between people and technology.
- Reliability Centered Maintenance - from reactive maintenance of the assets and tools to smart predictive, condition-based one in the environment of big data.
- Mobile - from large companies and particular types of processes being connected to the widespread democratization of connectivity, mobility and location-sensitive technologies
- Cloud Computing - from on-premises to cloud-based, service oriented computing
- Big Data Analytics - from limited and localized analytics to advanced plant-wide analytics, both real-time and offline

For most manufacturing companies, a disruptive approach to implementing new and thus unknown technologies is rather risky. Industry 4.0 technologies are at the heart of most manufacturing processes and influence critical steps within the value chain. The cost of production downtime per day is high, and thus manufacturing companies will carefully weigh the benefits of introducing new technologies against possible risks to process reliability. In addition, many companies had some concerns around having the right skills to capitalize on Industry 4.0. Digitalization skills are critical. The younger people coming through are digital natives but there are generations of existing workers who will need to rapidly reskill and retool. As a result, companies approach fundamental disruptions with caution, so that change will be rather incremental.

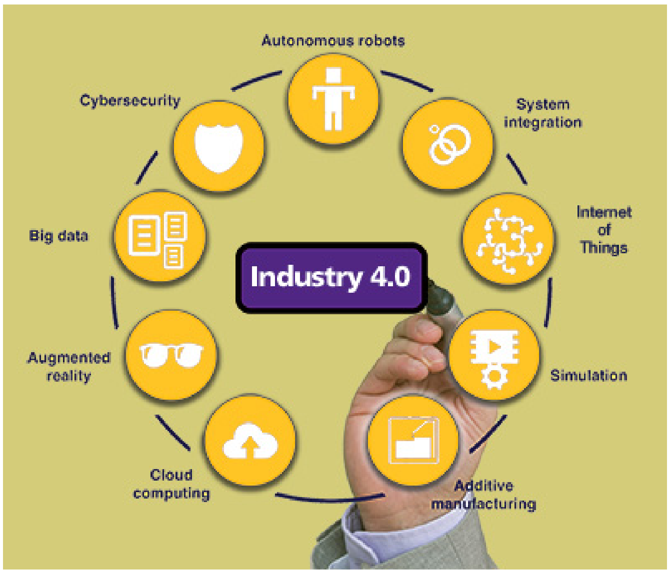


*Figure 1. Industry 4.0 enablers [4]*

All these transformations could be challenging to fully understand Industry 4.0 and what it will mean to a company and to its manufacturing IT systems. The convergence of all of them is truly disruptive, and opens up entirely new opportunities and challenges.

Our goal with this paper is to go beyond the vision and the technology hype and propose an approach for the gradual migration to Industry 4.0. Our approach envisions a seamless, connected factory where Cyber-Physical Systems (CPS) communicate and collaborate with each other, but also, at a new level, with customers and employees. The backbone of such complex software and hardware integration will be provided through a Manufacturing Operations Management (MOM) systems. [4]

## *2. Basic concepts of MOM/MES for Industry 4.0*

Successful manufacturing, particularly as it has gone global, has relied heavily on Manufacturing Execution Systems (MES) – also sometimes called Manufacturing Operations Management (MOM) [8]. This multi-faceted software for production plants has been a pivotal enabler for the performance, quality and agility manufacturing leaders have achieved.

There is an ongoing discussions about the use of the term manufacturing execution system (MES) vs. manufacturing operations management (MOM) to describe the type of software solutions used in production operations. We would like to clarify our position in this dispute. For us, MES stands for computerized systems used in manufacturing, to guide, track and document the transformation of a consumed to produced materials at one work place (process line/unit) including data exchange with automation layer (SCADA, DCS, PLC, CNC). MOM systems, extend the functionality of a MES to cover the whole manufacturing process in an area, including Final Capacity Scheduling (FCS), Workflow Management (digitalize manual work), Maintenance Management (CMMS, EAM), Quality Management (QMS, LIMS) and Warehouse Operations (WMS), etc..

We expect MOM will continue to play an essential role in the manufacturing enterprise's IT landscape because it sits at the critical point where revenue-generating products come into being. MOM already handles rapidly flowing streams of disparate unstructured and structured data and turns it into useful, targeted information in a near real-time fashion. The upcoming Cyber-Physical Systems (CPS) and Cyber-Physical Production Systems (CPPS) data will require this and more.

Cyber-physical Systems (CPS) are simply physical objects with embedded software and computing power. In Industry 4.0, more manufactured products will be smart products, CPS. Based on connectivity and computing power, the main idea behind smart products is that they will incorporate self-management capabilities.

On the other hand, manufacturing equipment will turn into CPPS, Cyber-Physical Production Systems - software enhanced machinery, also with their own computing power, leveraging a wide range of embedded sensors and actuators, beyond connectivity and computing power. CPPS know their state, their capacity and their different configuration options and will be able to take decisions autonomously.

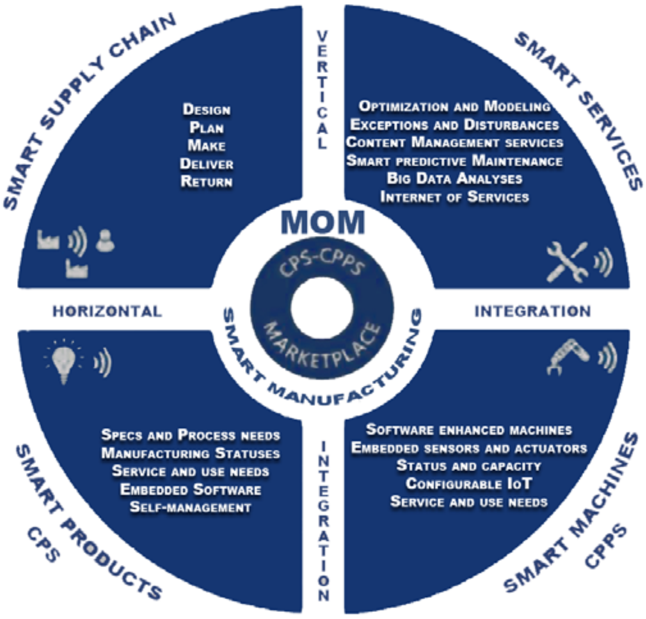


***Figure 2.*** *MOM/MES plays a central role in Industry 4.0*

The primary functions of MOM are a critical foundation around which manufacturers can build the Industry 4.0 application structure. Today, MOM provides critical information both within the production environment and to the supply chain, customer service, product development and management teams. Industry 4.0 will not be fully implemented overnight, so there will be a transition period.

Over the longer term in Industry 4.0 situations, MOM will play several roles. Figure 2 shows a simplified concept of this:

- Sit at the center of the smart supply chain
- Sit at the center of the product lifecycle - an end-to-end information flow, a "digital thread" that runs through the entire product lifecycle as its digital representation.
- Be the essential coordinator for both the horizontal and vertical integration of Industry 4.0
- Prepare online Final Capacity Schedules based on real-time capacity reported by the CPPS and the actual statuses from CPS. Implement advance optimization algorithms and supporting emergency re-planning in case of incidents
- Supervise and coordinate the manufacturing workflow
- Monitor, and as needed, coordinate the CPS-CPPS marketplace and incorporate CPS and CPPS data into off-line compliance and quality activities
- Act as the stand-in for any products, materials, or equipment that are not CPS enabled
- Be the place to collect and store Big Data related to the manufacturing process
- Provide operational KPIs and enable complex statistical analyses (SPC)
- Manage operations related to smart predictive and condition-based maintenance
- Deliver aggregated information for customer service and other ecosystem activities
- Serve as an Intranet Content Management System (CMS) for facilitate true collaboration inside a plant

## *3. Main characteristics of MOM for Industry 4.0*

MOM is a critical element in the manufacturing IT landscape and therefore it requires a completely new generation of MOM systems to cope with the new challenges created by Industry 4.0 (see Figure 2). The following are the main characteristics MOM needs to support Industry 4.0 effectively.

**Decentralization**

Industry 4.0 is inherently a decentralized system, with intelligence in independent entities. Smart materials and products (CPS) are service consumers and smart equipment and plants (CPPS) are service providers. CPS and CPPS are not physically coupled; rather, a dispatching operation delivers logical binding between a material to be processed and a resource to process the material.

Since each product in the Industry 4.0 vision may be unique, it will be very difficult to centralize or optimize shop floor operations in the traditional way. Managing the end-to-end information flow will facilitate information sharing with suppliers and distributors, enabling further operational effectiveness through approaches such as real-time supply chain optimization and data-driven demand prediction, which will reduce inventory costs and improve service levels due to a better match between supply and demand. In asset-heavy manufacturing businesses (such as those in the automotive industry), remote monitoring and predictive maintenance will play an important role to improve asset utilization by decreasing unscheduled downtime. It facilitates maintenance scheduling, work execution, and material availability processes. In energy intensive manufacturing, the real-time scheduling and optimization of machine times will decrease the energy costs. The future MOM systems will extend the production planning and control area to include energy-oriented order planning which, in conjunction with smart grids, will continue to permit flexible energy and cost efficient planning even in the face of rising energy costs.

All of the above will increase the demand for a near real-time fast optimisation algorithms for Final Capacity Scheduling and Re-Scheduling of the production sequences. The extension of classical control principles to include autonomous goal redefinition makes it possible to establish artificial intelligence in technical systems. In conjunction with the availability of real time information, this paves the way for the creation of robust and at the same time flexible production systems even in highly dynamic Industry 4.0 environments.

The dynamic marketplace of CPS and CPPS means that rather than hold a single unifying model, the MOM needs context resolution possibilities. This allows a product that requires a certain service at a certain step to combine the flow of its product category to be adapted, or unique to its specific context. Going one step further, the smart product may hold the recipe (set points) needed at a given processing step. When negotiating with the smart resource, it will transfer the recipe to the resource so that it can perform its unique transformation process. So the CPS and CPPS have their own intelligence. As an example, a smart product CPS knows its state, its position, its history, its target product and its flow alternatives. Likewise, a smart resource or CPPS will hold information about its state, its history, its maintenance plan, its capacity, its range of possible configurations and setups, etc. What this means is that a smart product or CPS has the capability to identify itself, providing its position and state to a physically centralized system. MOM decentralization needs to be mainly logical. With cloud computing, it's such a system could not be considered physically centralized. What is critical is that the logical decentralization must exist. So the MOM may be a loosely connect applications (apps) that acts decentralized with agents or objects representing the shop floor entities and are connected through web services.

A good starting point for defining the objects and the logical separation is the existing standard IEC/ISO 62264 (ANSI/ISA 95) "Enterprise-Control System Integration".

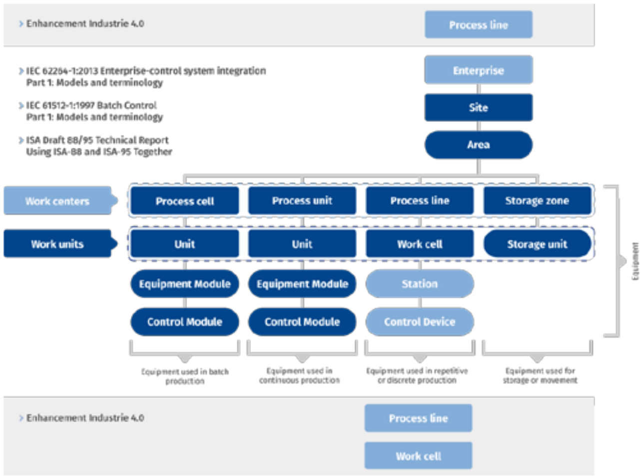


***Figure 3.*** *Industry 4.0 CPPS Equipment Hierarchy*

**Vertical integration**

MOM has traditionally resides in the space between administrative IT systems (ERP, SCM, CRM, etc.) and the automation layer (SCADA, PLC, DCS, CNC, etc.). This vertical integration is an enabler for the orchestration of everyday business processes that may be simple or complex but nearly always require multiple layers and groups to be involved. Business processes for compliance, quality, maintenance, logistics, engineering, sales or operations all have components inside the plant as well as others that reside beyond the factory that are crucial to a business process being executed effectively.

In Industry 4.0, CPS and CPPS communications create new data flows to integrate. For example, a CPS or smart product may know that it needs to stop a lot or only part of it (sub-lot) and collect a measurement process parameters or other related information such as downtimes, quality checks, etc. The layer above then specifies and checks whether the outcome is correct. This is where statistical process control (SPC) rules reside, and if it's not within limits, it might open a corrective and preventive action (CAPA). All of that activity will be in a layer above the CPS in controls of MOM.

Within the plant, the MOM will need to aggregate and put these additional data flows into context. Vertical integration of these autonomous entities is critical as they could otherwise make decisions independent of the rules and best practices for the factory or company. MOM providers must continue to expand the product capabilities to ensure that all plant activities are visible, coordinated, managed and accurately measured. Only then can the enterprise systems respond effectively. Thus optimum parameters, process conditions and process strategies for increasing the efficiency of manufacturing and product quality can ultimately be derived from neural networks, decision trees or correlation analyses and feedback into the system. The technology database and the subsequent analysis operation permit end-to-end data acquisition, analysis of production data throughout the process chain and the derivation of optimum process settings.

**Horizontal integration**

In the Industry 4.0 final report, horizontal integration focuses on supply chain status communication among facilities and trading partners. Horizontal integration enables the smart supply chain or network to be transparent so status is always visible. What horizontal integration requires is service oriented ways of alerting the rest of the information system to the information available.

However, that is not likely to all come from the CPS and CPPS directly. In Industry 4.0, the MOM must be truly modular and interoperable so that all functions or services can be consumed by CPS smart materials, CPPS smart equipment or any other shop floor entity. As an example, a typical maintenance management process, often centralized, could consist of a series of services that each piece of equipment might use. Horizontal integration may extend from the internal maintenance team to the external subcontractors. With extensive outsourcing and supplier base, this is a vision these industries could benefit from greatly.

**Connectivity, sensing and mobile**

Advanced manufacturing environments have had highly integrated connectivity for a long time. As an example, some of the more sophisticated semiconductor facilities have RFID transponders in the material containers and the equipment has bidirectional communication through interfaces, exposing readings from sensors, alarms or reports or allowing recipes to be externally selected or downloaded.

Industry 4.0 is creating a true democratization of such connectivity, allowing it to be widespread in manufacturing facilities of different sophistication levels. Three elements contribute:

- The IoT, in the industrial world called IIoT (Industrial Internet of Things) translates into very low cost hardware (RFID, etc.) and lean OS (such as Windows 10 IoT running on a Raspberry Pi), allowing true connectivity with equipment not requiring heavy systems and interfaces.
- Increasingly affordable passive identification and location tags allow all shop floor resources (CPS and CPPS) to hold their positioning coordinates. The MOM needs logically autonomous entities to store this location data and show it in real-time in interactive maps.
- The traditional automation pyramid with central PLC or SCADA will be replaced by an OPC UA based CPS network.

Quickly changing products and services resulting from a shift in customer expectations require agile software development methods with daily or weekly release cycles. As these short release cycles are not only often a challenge for established IT processes, but also for existing IT and data infrastructure, companies should make the following preparations:

Introduce a parallel fast-speed IT and data infrastructure. Since not all processes require quick release cycles, a parallel fast-speed architecture should be introduced alongside the transactional architecture. The fast-speed architecture requires manifold interfaces with the transactional architecture, the connected devices on the shop floor and with customers, supplier systems, and others. Companies should make use of emerging data and interface standards to minimize the effort required for the continuous integration of new data sources.

On the operational side of MOM software, connectivity and mobile combined will allow more adaptable interfaces. MOM will consist of different apps, making a reality the vision of getting to a piece of equipment, downloading and later using an app specifically built to operate that equipment. An intelligent web-based portal accommodating this apps and seamlessly connects users, teams and knowledge so that people can take advantage of relevant information across business processes will help them to work more efficiently. The transition to configurable Enterprise Content Management Systems (eCMS) is the obvious path ahead for a MOM systems of the future.

The same combination of mobile devices with the increase in reliable and inexpensive positioning systems will also allow the representation of real time positioning in 3D maps, opening the door to augmented reality scenarios. A person with augmented reality can walk around and get immediate identification of items, and be pointed to their location. Maintenance operations can benefit particularly.

On one side, equipment integration, typically done with well-defined and complex interfaces, will need to be complemented with connectivity. Sensors, actuators or other equipment come into play not requiring heavy systems and interfaces. On the other hand, on the operational front, combined connectivity and mobile will enable more adaptable interfaces. This mean that MOM will consist of different apps, allowing you to get the equipment, downloading, and using an app specifically built to operate that equipment.

**Cloud computing and advanced analysis**

The Smart Factory vision of Industry 4.0 requires achieving a holistic view of manufacturing operations. Clearly this can only happen by integrating data from several different sources rapidly and flexibly. This suggests the MOM of the future must also leverage cloud computing and advanced analytics.

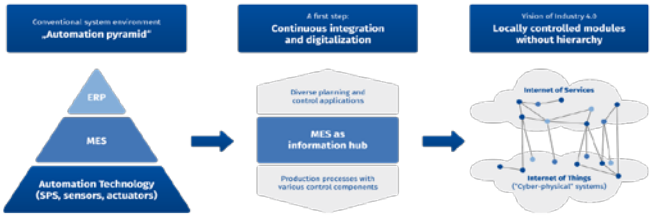


***Figure 4.*** *Transformation vision by Simestic*

Considering a hybrid cloud strategy of integrating private and public cloud services is the smart choice for a MOM solution. A private cloud is the best option of providing security to sensitive data while satisfying regulatory requirements on data storage, and a public cloud is the preferred way of cutting down the costs of scaling operations of non-sensitive big data. One hybrid strategy is to sign up with a single cloud provider that provides both private and public cloud services. An alternative is to sign up separately with a private cloud service provider and a public cloud service provider. The third option is to set up a private cloud service in-house, on-premises and then sign up with a public cloud service provider.

While many MOM have manufacturing intelligence components today, this must expand to better accommodate the diversity and volume of big data. Both CPS and CPPS will generate huge amounts of data, which needs to be stored and processed. Advanced analytics are then needed to fully understand the performance of the manufacturing processes, quality of products and supply chain optimization. Analytics will also help by identifying inefficiencies based on historical data and pointing staff to corrective or preventive actions for those areas.

Future MOM must accommodate both:

- Advanced offline analysis using very sophisticated statistical process models. These will need to be both in structured data, generally residing in a relational database or in data warehouse cubes, and in unstructured data, which is very difficult to analyse with traditional tools.
- "Real-time" analysis to trigger actions in the plant as quickly as possible, even before data is stored. This needs techniques such as "in-memory" and complex event processing. Cloud computing is the obvious infrastructure for the speed and agility suggested by Industry 4.0.

Manufacturing data analysis is an area where some leading manufacturers are already starting to leverage the cloud.

The Industry 4.0 approach is to combine intelligent manufacturing solutions that will target fully predictive processes, which could be readily tuned to the best performance with respect to specific but fast-changing requirements faced by complex manufacturing businesses. [6, 7]

## *4. Standards*

Industry 4.0 and related initiatives recognize that efficiently building self-managing production processes requires open software and communications standards that allow sensors, controllers, people, machines, equipment, logistics systems, and products to communicate and cooperate with each other directly. Future automation systems must adopt open source multivendor interoperability software application and communication standards similar to those that exist for computers, the Internet, and cell phones. Industry 4.0 demonstrations acknowledge this by leveraging existing standards, including the ISA-88 (IEC/ISO 61512) batch standards, ISA-95 (IEC/ISO 62264) enterprise-control systems integration standards, OPC UA, IEC 6-1131-3, and PLCopen.

The harmonization of standards worldwide recently took another step forward when representatives of the German alliance Platform Industrie 4.0 and the U.S.-based Industrial Internet Consortium met in Zurich, Switzerland, in March 2016 to explore the potential alignment of their two architecture efforts—respectively, the Reference Architecture Model for Industrie 4.0 (RAMI4.0) and the Industrial Internet Reference Architecture (IIRA).

On 6 April 2016, the OPC Foundation and Object Management Group (OMG) announced a collaborative strategy for technical interoperability that encompasses the OPC Unified Architecture (OPC UA) and the OMG Data Distribution Service (DDS) standard.

These are significant cooperative efforts that illustrate maturity in the industrial automation industry. They recognize that manufacturing has worldwide interdependencies requiring common standards and interoperability.

## *5. MOM4 implementation*

Based on the above findings, NearSoft had developed MOM4 solution as a culmination of leveraged technology: distributed application design, object-oriented programming methodologies and multi-tiered Service Oriented Architecture (SOA) and a broad understanding of manufacturing process, applied to the business and integration needs. The MOM4® is based on the international standard IEC 62264 (ANSI/ISA-95) [1,2,3] and is therefore also investment and future proof under the RAMI 4.0 Reference Architecture.

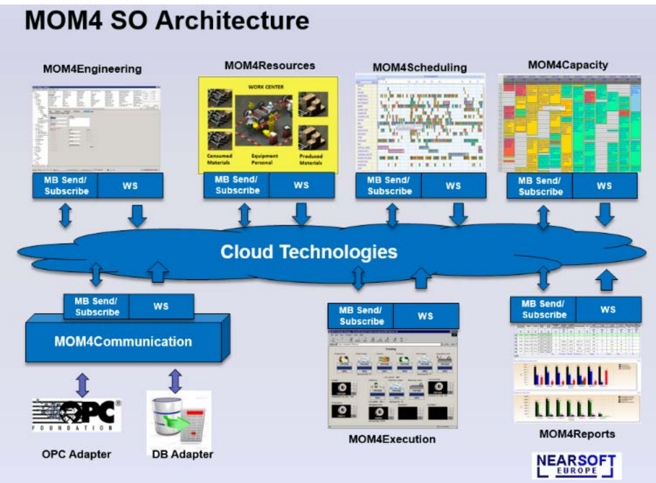


***Figure 6.*** *MOM4 SOA*

The technology and architecture of the MOM4® products was designed around objects and services as defined per IEC 62264 standards and adapted to the environment of configurable Enterprise Content Management System with web based Portal and communication adapters to the shop floor automation.

MOM4® is an open Manufacturing Operation Management solution that incorporate apps for Advance Planning and Scheduling (MOM4Scheduling), Finite Capacity Scheduling (MOM4Capacity), Manufacturing Execution Systems (MOM4Execution), Data Warehousing and Analyses (MOM4Reports) and real-time performance management (MOM4Production), quality (MOM4Quality), maintenance (MOM4Maintenance) and inventory (MOM4Inventory) processes. MOM4® combines all these powerful

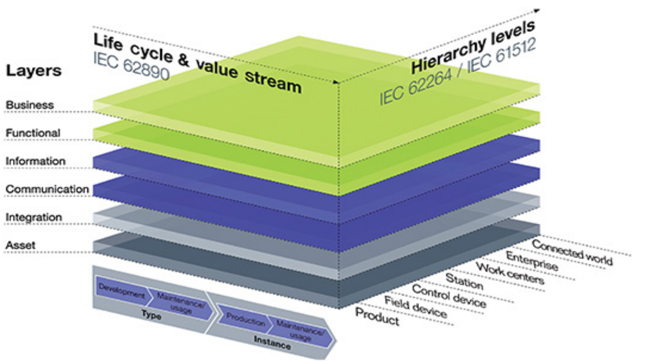


***Figure 5.*** *Reference architecture model for Industry 4.0 (RAMI4.0)[4,5]*

configurable software products through a full collaboration based on functional integration and web service interfaces based on Business To Manufacturing Markup Language (B2MML), an XML/XSD implementation from the ISO/IEC 62264 standard family. They provide a flexible approach to collecting, organizing and distributing of production, maintenance and quality information throughout a manufacturing plant via and web based eCMS user experience.

The Manufacturing Model as defined per IEC 62264 is described in details inside the dedicated app called MOM4Resources. It extends the functionality of traditional Product Definition Management (PDM) and Product Lifecycle Management (PLM) systems with respect to Manufacturing Operation's needs. MOM4Resources hold information for Materials, Equipment, People, Segments and Product Production Rules. The app could exchange B2MML data with other systems such as ERP, CAD/CAM, etc.

The MOM4® platform implementation is made to allow any combination of hybrid cloud strategy. The hardware components (Fig. 7) can be configured in different ways depending on size of the system and the specific needs.

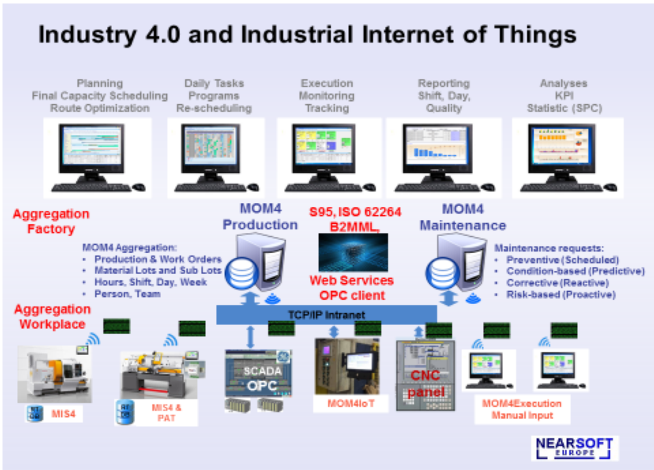


***Figure 7.*** *MOM4 and IIoT*

The MOM4® enables an up-to-date content through configuration based on ever-changing customer's requirements using standard products that provides horizontal and vertical integration trough web services, to each other or to the external systems in order to cover the whole process of manufacturing execution. The horizontal integration is implemented as web services based on B2MML standard, and the vertical one supports in addition OPC UA interfaces. The different apps are operated using configurable displays for presenting the information in the dedicated process area. That means that the user could get a complete overview of the plant and of its control system functions, using a state-of-the-art and uniform Human-System Interface throughout web based eCMS from any device (incl. mobile) with browsers such as Internet Explorer, Google Chrome, Firefox, etc.

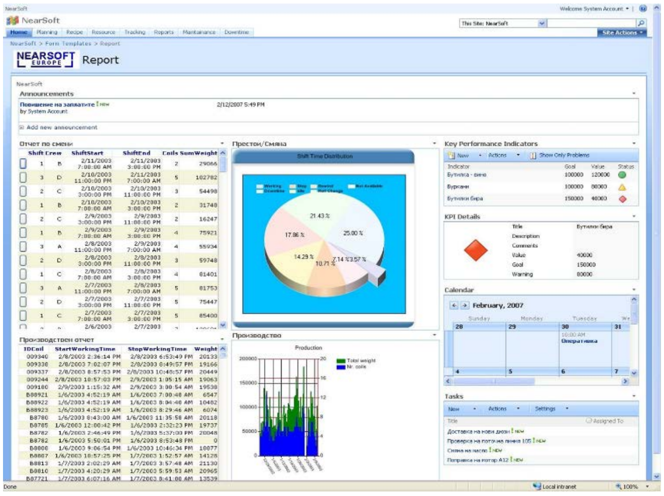

***Figure 8.*** *MOM4 interoperability with MS SharePoint*

NearSoft MOM4® solution is prepared and ready solution that comprises Industry 4.0 enablers in the following manner:

- Uses service oriented web based technology and it is ready for cloud distribution on a hybrid cloud;
- Achieve interoperability through user friendly configuration of the web service interfaces for communication with external systems, thus building an entire Industry 4.0 ecosystem (B2MML, OPC UA, Barcode printers, RFID, etc.).
- MOM4® is entirely built based on the standard IEC 62264 (ANSI/ISA S95) that provides unified approach (objects and models) for integration with other information systems;
- Provides data collection from different sources and realizes following aggregation functions Min (MIN), Max (MAX), Average value (AVG), Counters (CTR), Cumulative value (CUM), Running Hours value (RHR), Limit Check (LMC), etc.
- Provides powerful SPC instruments (Standard Deviation, Normal Distribution, Pareto Charts, Histograms, etc.) for analysing production information and ISO 22400 KPI calculation; (Fig. 9)

*Figure 9. MOM4 SPC Instruments*

## 6. Conclusions

Industry 4.0 transforms the entire business and changes the rules of the game for manufacturing. Connecting real machines with information technologies and the Internet increases productivity. The immense scope of change it brings, and the level of investment required means that it belongs on the CEO's agenda. It encompasses not only digitising both horizontal and vertical value chains, but also revolutionising corporate product and service offerings, with the final goal being to better satisfy customer requirements.

The paper try to propose an approach for the gradual migration to Industry 4.0, starting with implementation of existing apps in the MOM layer, and in this way minimizing the risk of adopting new strategies. The required technologies (including mobility, MES, Cloud, Industrial Internet, and Connectivity) are available today and we can leverage the potential by being smart, addressing specific use cases towards an evolving Industry 4.0 IT architecture.

An innovative solution for integrated manufacturing operation management has been presented. MOM4® fulfils customized customer requirements with state-of-the-art industry software that links all stages of the value chain through standardized interfaces. It consists of interoperable products that could be deployed on any hybrid cloud environment. MOM4® is developed for agile smart manufacturing supported by the right information to the right person or system at the right moment with fit-for-purpose instructions. Technology-wise it is a melting pot that combines Big Data technologies; new generations of human-machine interfaces and reliable layers of ubiquitous connectivity, to manage the flood of information from smart machines, connected workers and the products themselves. MOM4® solutions, utilizing Product Control Flow concepts, connect the physical machines, products and people with the IT-systems and applications to form a manufacturing execution layer (MOM/MES). With the MOM4® now able to represent actual demand and capacity, production schedules and plant configurations can be optimized and replenishment of materials triggered in real time for the next order arriving.

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# MATHEMATICAL MODELING AS A KEY TO SYSTEM ANALYSIS METHODOLOGY

## МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ КАК КЛЮЧ К МЕТОДОЛОГИИ СИСТЕМНОГО АНАЛИЗА

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**Abstract:** *this paper attempts to provide a transparent and, if possible, a formal hierarchy of the main types of mathematical models used in the description of dynamic processes inside, at first glance, different systems. It is emphasized that the mathematical modeling is a natural and universal environment for effective analysis of system processes of different nature. From our point of view, the term "system analysis" means the methodology for classification of real systems (physical, biological, economic, social, etc.), which is based on the classification of mathematical models that are used to describe these systems.*
***KEYWORDS****: SYSTEMS, SYSTEM ANALYSIS, MATHEMATICAL MODELS, MATHEMATICAL MODELING, CLASSIFICATION*

### 1. Introduction

*To read the Great Book of Nature,*
*you need to know the language in which it is written.*
*And it is written in the language of mathematics.*
*Galileo Galilei*

We define a system as a collection (set) of objects[1] of a particular nature, interacting with each other and the external environment. Since every interaction presupposes the possibility of state changes as the objects themselves that make up the system, and the system as a whole, the first task of the researcher is to establish the patterns of these changes in order to predict the latter. The second task is the task of forming effects on the system as a whole (through changes in environmental conditions) or of its component objects to implement the required changes to the characteristics of the system and/or its objects. In other words, we have to talk about the study and management of the processes occurring in the system.

For definiteness, formulations, point to a sense that we put here in the term "characteristics". Under the characteristics of the system, we understand the qualitative or functional description important for the purposes of the study of the properties of the system as a whole and its constituent objects. A set of important characteristics are not cast in stone, and can vary in research depending on the results obtained, change the purposes of the study, further information (experiments, calculations, discoveries, etc.). Here are a few examples. In classical mechanics the important characteristics of the free material point are its coordinates (more precisely, the radius vector) and momentum. For holonomic system of material points – a set of generalized coordinates and velocities (momenta) of the system and the Lagrangian function[2], the latter, as you know, is a function of generalized coordinates and generalized speeds of the system and, possibly, time. In quantum mechanics, the important characteristics for the particles are, for example, the wave function, the energy (operator) and spin (number). In gas dynamics, the important characteristics are functions of the spatial coordinates and time (density, velocity, pressure, temperature, etc.). In classical molecular-kinetic theory of gases basic properties of a system of molecules are the distribution function and the law of interaction of molecules between themselves, representing the operator.

### 2. On the modeling of systems

In practice, the learning processes in any real system, is reduced to their modeling i.e. to approximate description by creating their simplified models. Traditionally, models of systems and processes are dividing into two main classes: physical and mathematical models, although this division is largely arbitrary, since, as we shall see below, the physical model without its mathematical counterpart loses much of its effectiveness and practical significance. These models should go "hand in hand" in serious research.

Under a *physical model*, we usually mean a product, device or imaginary system, which simplified the likeness of the object or system, and allows you to recreate the monitoring process or phenomenon with the required degree of accuracy. At the same time, elements of the system are associated with the physical equivalents, reproducing the structure, basic properties and relations of the studied object or process. Typically, the physical model of the object or system should have the same qualitative nature as the simulated object (system). The basis of constructing an adequate physical model are placed, as a rule, the idea of the theory of similarity and dimension.

Under a *mathematical model*, we usually mean an approximate description of a class of phenomena of the external world, expressed by mathematical symbols. Most often, the mathematical model is a set of equations and/or inequalities (algebraic, differential, integral, operator, functional). Arsenal research methods of mathematical models is extremely wide - from the logic of algebra to functional analysis[3]. In this case, since the mathematical model of the object is "mathematical world", it should be investigated on the received in this "world" level of rigor. Finally, it is important to understand that a mathematical model cannot "be proved". It is always a hypothesis, whose validity is checked only by its practical application.

### 3. Stages and features of mathematical modeling

The process of mathematical modeling, i.e. studying phenomena of any nature with the help of a mathematical model, can be divided into four stages [1].

The first phase - the formulation of laws connecting the main objects of the model. This stage requires a broad knowledge of the facts relating to the phenomenon, and deep penetration into their relationship. This stage is completed in mathematical terms formulated qualitative ideas about the links between model objects.

The second stage - the study of mathematical problems, which leads to a mathematical model. The main issue here is the solution of the direct problem, i.e., obtaining as a result of the analysis of model output (theoretical consequences) for further comparison with the results of observations of the phenomena studied. At this stage, the mathematical apparatus acquires the main role that is necessary for the analysis of mathematical models and computer engineering - a powerful tool for obtaining quantitative output data as a result of solving complex mathematical problems.

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[1] The objects that make up the system, often referred to as its elements.

[2] On the other hand, the total energy of the system.

[3] Including, of course, numerical methods. However, the method of their application and interpretation of the results must be mathematically strictly justified.

The third stage - clarification as to whether the adopted (hypothetical) model is the criterion of practice, i.e., asking the question of whether the results are consistent with the observations of the theoretical consequences of the model within the observational accuracy. If deviations are outside the limits of accuracy of the observations, the model cannot be accepted. It often happens in the construction of the model that some of its characteristics remain uncertain. Tasks, which define the characteristics of the model (parametric and functional) so that the output information was comparable within the accuracy of the observations with observations of the phenomena studied, called inverse problems. If such compatibility cannot be achieved for any choice of the characteristics, the model is not suitable for the study of the phenomena under consideration. The use of practical criterion to appraise a mathematical model allows to conclude that the validity of the assumptions underlying the study of the subject (hypothetical) model.

The fourth stage - the subsequent analysis of the model due to the accumulation of data on the phenomenon, and the model of modernization. In the development of science and technology, phenomenological data are more and more refined, and there comes a point of time when the conclusions derived on the basis of an adopted mathematical model do not correspond to our knowledge of the phenomenon. Thus, there is a need to build a new, more sophisticated mathematical model.

A good illustration of the above can be an example of the development of the theory of gravitation. The classical theory of gravitation Newton's mathematical point of view was based on Euclidean space-time model that eventually led to the description of the dynamics of the system of material bodies based on the Lagrange equations. Experience has shown that the Newton-Lagrange theory adequately describes the mechanical processes that we face on Earth and in space within the solar system. A brilliant example of this - the discovery of the planet Neptune, which was made in 1846 by German astronomer Johann Galle based on calculations, made by Urbain Le Verrier (France) and John Adams (England), is based on Newton's theory of gravitation. However, the development of cosmological studies in the early twentieth century led to the discovery of phenomena that could not be explained in the framework of the classical theory of gravitation. The search for answers to your questions led Einstein (in 1916) to construct a new mathematical model of space-time, which was the basis for the hypothesis of space-time as a Riemann space, in which the curvature tensor depends on the distribution and magnitude of the masses of space objects. In this space, in particular, light (more precisely, the photons) extends not straight (as is the Euclidean model), and on geodesic lines corresponding Riemann space. Einstein's theory was confirmed experimentally in 1919, when there was a ray of light deviation from the star as it passes close to the sun that qualitatively and quantitatively consistent with the predictions of the theory. On the other hand, in the absence of the objects near the large (on space standards) gravitating mass, corrections (with respect to the classical theory of gravitation), given by Einstein's theory, are, from a practical point of view, negligible. This allows you to successfully continue to use the relevant conditions of Newton's theory of gravitation.

A.N. Tikhonov in the article in «Mathematical encyclopedia» cited above gives another example illustrating the steps of mathematical modeling.

Concluding the topic of physical and mathematical models point to stand somewhat apart the analog model. This type of model clearly demonstrates the organic link between methods of physical and mathematical modeling. The essence of the analog simulation is as follows. Consider two systems of different physical nature (e.g., mechanical and electrical). Processes in these systems proceed according to qualitatively different physical laws. If, however, the mathematical models of both systems have the same form, i.e., from a mathematical point of view, these systems are the same, based on the study of the behavior of a system can be inferred about the behavior of another system[4].

As an example, consider the following mechanical and electrical systems [2]. Let the mechanical system with one degree of freedom is a mass m, moving under the action of which the exciting force $p$, elastic restoring force (e.g., spring), characterized by stiffness $c$, and the damping force of viscous friction with coefficient $r$. Let $h$ - coordinate of the mass m, which determines its deviation from its equilibrium position. The equation of motion of a mechanical system has the form

$$m\ddot{h} + r\dot{h} + ch = p. \qquad (1)$$

Suppose further that the electrical system is an electrical circuit consisting of series-connected source voltage ($e$), the inductance of $L$, resistance $R$, and the inverted container $S$ ($S = 1 / C$). Let $q$ - the electric charge transferred by a current $i$ through the conductor cross-section:

$$q = q_0 + \int_0^t i dt.$$

The second Kirchhoff's law leads to the following equation:

$$L\ddot{q} + R\dot{q} + Sq = e. \qquad (2)$$

If the values of $p$ and $e$ are changed as a function of one and the same law, the equations (1) and (2) are substantially identical and, therefore, to study the behavior of the mechanical system can be replaced by studying the electrical behavior of the system and vice versa. Thus, these two systems in terms of their mathematical models are similar to each other, although they are different systems of physical nature.

The above examples touch simulation "material and physical" systems, but all of the above applies equally to problems of mathematical modeling of systems of different nature - social, economic, etc. In other words, the behavior of systems "made of different test" can be investigated effectively by using models built in one of them - mathematical. It is only necessary to select the appropriate mathematical apparatus. For example, for the construction and study of adequate mathematical models of social and economic processes have to resort to such seemingly quite abstract, analytical areas of mathematics as catastrophe theory and algebraic topology (see., e.g., [3, 4]).

## 4. *System analysis and adequacy of mathematical models*

The foregoing gives grounds to propose to classify the system (regardless of their actual nature) according to the classes of mathematical models used to describe these systems.

Thus, it seems reasonable to take as a basis the following definitions.

*System* is a collection of objects highlighted by a researcher, which are interacting with each other and the environment.

*Systems analysis* is a methodology for classification of real (physical, technical, biological, economic, social, etc.) systems, based on the classification of mathematical models used for formalized description of these systems.

That is, we unite into the same class those real systems, formalized description of which requires the use of the same class of mathematical models (e.g., ordinary differential equations, partial differential equations, operator equations in function spaces, probability theory, mathematical logic, graph theory, etc.).

Speaking about the importance of mathematical modeling in the analysis of processes in different systems, it is necessary to say a few words about the features of this simulation. If we want to use mathematical methods for solving problems related to any technical, economic, biological or any other system, we must, as mentioned above, to start with the construction of a mathematical

[4] It is necessary to distinguish between analogue and similar models studied in the theory of similarity and dimension. In the latter case, we are dealing with models of the same nature, while the analogue model is a model of a different nature.

model of the relevant system. Build a model - which means indicate what mathematical objects under study is characterized by the system and how these mathematical concepts reflect the laws that describe the functioning of the system.

Since the mathematical model cannot display the studied reality in all its concreteness and fullness, when its construction is necessary to choose such factors and the relationships that are most important in this problem. In many cases, the right to choose the model - means to solve the problem by more than half. The main difficulty in this case lies in the fact that the construction of the model requires special connection (for the study of the qualitative features of the simulated process) and mathematical knowledge.

When constructing a mathematical model can meet and insurmountable (at the moment) the difficulty, for example,

– Insufficient knowledge of laws that describe the system (for example, biology, economics, sociology);

– We do not know some significant characteristics of the system (for example, the density distribution of matter in the interior of the Earth, the pressure in the blood vessels of a living organism).

In such cases, the construction of the model is necessary to make additional assumptions that have the character of hypotheses. Consequently, the conclusions drawn from the study of this model are conditional. But even if the laws are known and measured characteristics of the system, the model can get so complicated that it would be available for the study of well-known (for now) with mathematical methods.

Therefore, we often have to make some simplifications in the simulation of the real process, idealized model.

Thus, the construction of a mathematical model must meet two important criteria:

1) the model must be adequate, i.e. to the extent necessary correspond to reality.

2) The model must be simple enough to allow finding an effective solution within a reasonable time and with reasonable accuracy.

It is easy to note that these criteria are contradictory. On the one hand, to build adequate models requires consideration of more complete and varied number of factors, which inevitably complicates the model. This complexity leads to that the posed problem cannot be solved at all or for practical time. On the other hand, over-simple model, which does not take into account a number of important factors, is clearly inadequate, and therefore does not meet its intended purpose. Art researcher is to find a harmonious matching of these two mutually exclusive requirements. We should seek to ensure that the model is consistent with reality, other things being equal. However, the degree of compliance must be determined by the terms of the problem, i.e., the model should provide enough (within the required accuracy) true reflection of reality.

In connection with the above, you can specify the steps of the solution of applied problem using mathematical methods:

1. Correct application wording task is to extract the essential properties and relationships of the studied object or process.

2. Construction of mathematical model - display of quantitative (functional) relationships allocated for the first stage of the properties with the help of mathematical concepts and relationships. As noted above, this is the most difficult part of the study. Firstly, for the same phenomena of a variety of mathematical models can be built. Secondly, it is necessary to satisfy the requirements of the constructed model adequacy and simplicity.

3. Logical-mathematical analysis of the model: model checking for consistency, and the solution of a mathematical problem. Sometimes the implementation of this phase requires the development of new methods or even creating a new mathematical discipline. The solution of the mathematical problem cannot always be found for a particular formula, even if it exists. Therefore may require numerical solution methods, - i.e., methods which give no exact and approximate (with reasonable accuracy) response. This phase includes the theoretical study of mathematical problem and its practical solution (including baseline data collection, programming).

4. Interpretation of results from a known empirical data (the results of observations or experiments specially designed), i.e. translating mathematical answer to the specific language of science.

## *5. Concluding remarks*

In conclusion, I would like to note the following. Due to the increasing amount of scientific information and the deepening of the process of differentiation of sciences one researcher has become almost impossible to work in several branches of knowledge. Therefore, to build the model and effectively solve the mathematical problem (especially when it comes to major scientific problems) requires the cooperation of scientists from different specialties and, of course, the attraction of modern computer technology. It follows that a real expert in systems analysis - a kind of "knowledge synthesizer", it has a good understanding of where and what lies in science. Only such a person can intelligently choose the appropriate research team and direct it to work in the right direction. Training and education of the experts - not easy, but a very important task facing the higher education system.

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# NITROGEN ION IMPLANTATION OF CHROMIUM CONTAINING MARTENSITE STEELS: PRELIMINARY SURFACE PROCESSING AND DOSE RATE INFLUENCE

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***Abstract:*** *X-ray diffraction, optical and electron microscopy were used to analyze microstructural variations in the surface layers of martensite chromium containing steels after low-energy, high-current-density ion implantation. These data show that nitrogen implantation produces solid solutions and precipitates of new phases in surface layers that are several micrometers thick. Phases formed are controlled by the virgin microstructure of blocks, the temperature of implantation and the ion fluence. The influence of processing length and ion beam current density are also considered.*

## Introduction

A unique, promising technique of low-energy ion implantation at ion current densities as high as several milliamperes per square centimeter has been successfully developed over the past few years [1-5]

High-current-density treatment induces significant heating of the surface which facilitates effective diffusive redistribution of implanted atoms thereby combining the benefits of traditional thermo-chemical and ion-beam technologies. The increased concentration of radiation-induced defects (e.g. vacancies) during ion implantation in a surface layer with a thickness around 20-30 nm, favors prompt growth and saturation of a deeper surface layer. The interaction of chemically active alloying elements with implanted atoms can also promote the effective redistribution of impurities.

It was demonstrated elsewhere that low-energy elevated-temperature ion implantation of nitrogen improves dramatically tribological properties of ferrous materials and modifies comparatively deep surface layer. Data have been presented that demonstrate solid solutions, precipitates of new phases and sometimes amorphization of surface layers with thicknesses up to several μm and more are induced by elevated-temperature low-energy ion implantation. The phases formed are controlled by the implantation parameters, which can be maintained easily and precisely to ensure optimum properties of the surface (Fig. 1). Most of the microstructures, produced by ion implantation are metastable and characterized by increased level of stored energy. This excessive energy can be used for transformation of surface microstructure during friction to optimize tribological properties of the surface.

However, the mechanisms that yield these benefits during high-current-density implantation, the influence of ion beam current density (dose rate) and the virgin structural state of the surface layer on the microstructures and mechanical properties of various implanted metals and alloys are still not well understood.

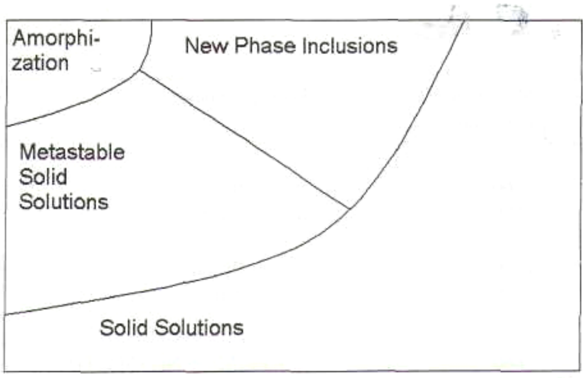



***Fig. 1.*** *Schematic for phase transformations induced by low-energy elevated-temperature ion implantation.*

**Materials and experimental techniques**

40X and 40X13 martensite steels were used in the research. Table 1 shows the chemical composition of the surface of steels determined using a scanning electron microscope (Nanolab 7), equipped with an X-ray microanalyzer. The values given are the average of concentrations measured at three different points on a block. Heat treatment prior to implantation involved quenching in oil or annealing (1270 K, 30 min) of blocks. After heat treatment all blocks were ground to $R_\alpha$ = 0.4 μm so the influence of the surface finish and microstructure on the parameters of the implanted layer could be determined. Nitrogen ions from the gaseous implanter were molecular (approximately 70%) and atomic (approximately 30%). Blocks were implanted with 3 keV nitrogen ions at an ion current density (dose rate) of 1 - 2 mA/cm$^2$. These conditions correspond to integrated fluence of $1\times10^{20}$ ions/cm$^2$. Blocks were held at 670 K during implantation. The temperature was selected on the basis of preliminary research on low-energy, high-current-density ion implantation which demonstrated that 670 K was sufficient to yield a modified surface layer that was several tenths of micrometers thick. The temperatures of the blocks were monitored during implantation using a thermocouple located 2 mm from the surface being treated.

Table 1

| Element⇒ / Steel⇓ | C | Cr | Ni | Mn | Fe |
|---|---|---|---|---|---|
| 40X | 0.39 | 0.95 | 0.20 | | Balance |
| 40X13 | 0,45 | 13,5 | 0,5 | 0,1 | Balance |

Microhardness was measured at a 25 gf load with a 10 s dwell time. Ten indentations were made on each block so statistically significant mean values could be obtained.

Optical microscopy was used for metallographic study of blocks that were sectioned so the etched edges of the implanted layers could be observed. Samples were etched in an acid mixture of $HNO_3$ and HCl. X-ray diffraction analysis was carried out to study microstructural changes induced by the ion treatment. Bregg-Brentanno focusing and scanning in 0.1$^o$ steps with a fixed counting time (40" per step) were used in the analysis. Standard ASTM data were used for phase identification.

## Results and discussion

Cross-sectional views showing the microstructures near the surface of nitrogen-implanted 40X steel are presented in Fig. 2. The microphotographs show the depth of modified surface layer exceeded several micrometers for both annealed and quenched steel.

After hardening 40X steel had a martensite structure with the lattice parameter a = 0.2872 nm and surface microhardness $H_\mu$= 6700 MPa. Low-energy nitrogen ion implantation at 1 mA/cm$^2$ influences 40-50 µm surface layer (Table 2, Fig. 2,) and increases its microhardness up to H = 9900 MPa. Bulk microhardness.of ion implanted steel falls down to H = 3700 MPa. Analysis of X-ray data revealed ε-$Fe_{2\ 3}N$, γ'-$Fe_4N$ and martensite phases (Fig. 3). Ion implantation at dose rate 1.5 mA/cm$^2$ results in significantly thinner nitride surface layer (30 - 40 µm). The microhardness of the surface falls down to $H_\mu$ = 9500 MPa.

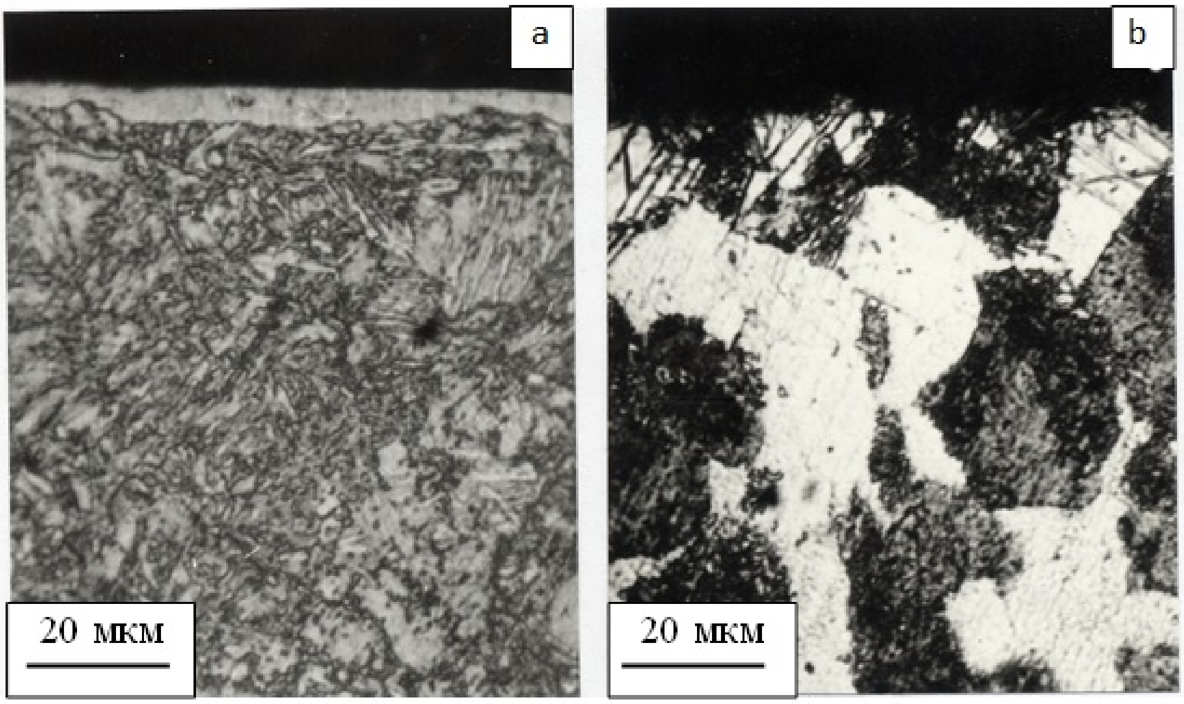
After annealing 40X steel had a ferrite-perlite structure consisting of α-Fe and $Fe_3C$ with the lattice parameter a = 0.2866 nm and surface microhardness $H_\mu$ = 2300 MPa. Nitrogen ion implantation results in continuous 2 µm thick surface layer of nitrides containing large lamellar nitrides. The doped layer thickness did not exceed 20 µm. X-ray data revealed α-Fe; ε-$Fe_{2\text{-}3}N$; γ'-$Fe_4N$, and $Fe_3C$ phases. Dose rate did not influence phase composition of doped layer, but dense ion fluxes resulted in low intensities of nitride lines. Surface microhardness fell down up to 6200 and 5800 MPa for dose rates 1.5 and 2 mA/cm$^2$ correspondingly.

After hardening the unimplanted 40X13 block had a martensite structure with the lattice parameter a = 0.2876 nm and microhardness H = 6000 MPa. Nitrogen ion implantation at 1 mA/cm$^2$ influenced 18-20 µm surface layer (Fig. 4) and increased its surface microhardness up to $H_\mu$ = 12000 MPa. Bulk microhardness of ion implanted block fell down to $H_\mu$ = 5000 MPa. X-ray diffraction of blocks revealed a near-surface layer containing $\alpha_N$, ε-$(Fe,Cr)_{2,3}N$, γ'-$(Fe,Cr)_4N$, and α''-$(Fe, Cr)_8N$ phases.

***Table 2*** *Surface layer parameters for steels ion implanted at different ion beam current densities*

| Alloy | Ion current density, mA/cm$^2$ | Depth of modified layer, µm | Surface microhardness, MPa | Bulk microhardness, MPa | Main phases |
|---|---|---|---|---|---|
| 40X quenching | Virgin | – | 6700 | 6700 | α–Fe |
| | 1 | 40* | 9900 | 3700 | ε–$Fe_{2–3}N$; γ′–$Fe_4N$; α–Fe |
| | 1,5 | 30* | 9500 | 4000 | Same |
| | 2 | 20* | 9500 | 4200 | Same |
| 40X13 quenching | Virgin | – | 6000 | 6000 | α–Fe |
| | 1 | 18 – 20 | 12000 | 5000 | ε–$(Fe, Cr)_{2–3}N$; γ′–$Fe_4N$; α′′–$Fe_8N$; $\alpha_N$ |
| | 1,5 | 18 – 20 | 13000 | 5000 | Same |
| | 2 | 15 – 20 | 12500 | 5200 | Same |

***Fig. 2*** *– Microstructure of the surface layer for nitrogen ion implanted 40X steel: (a) – quenched steel; (b) – annealed steel*



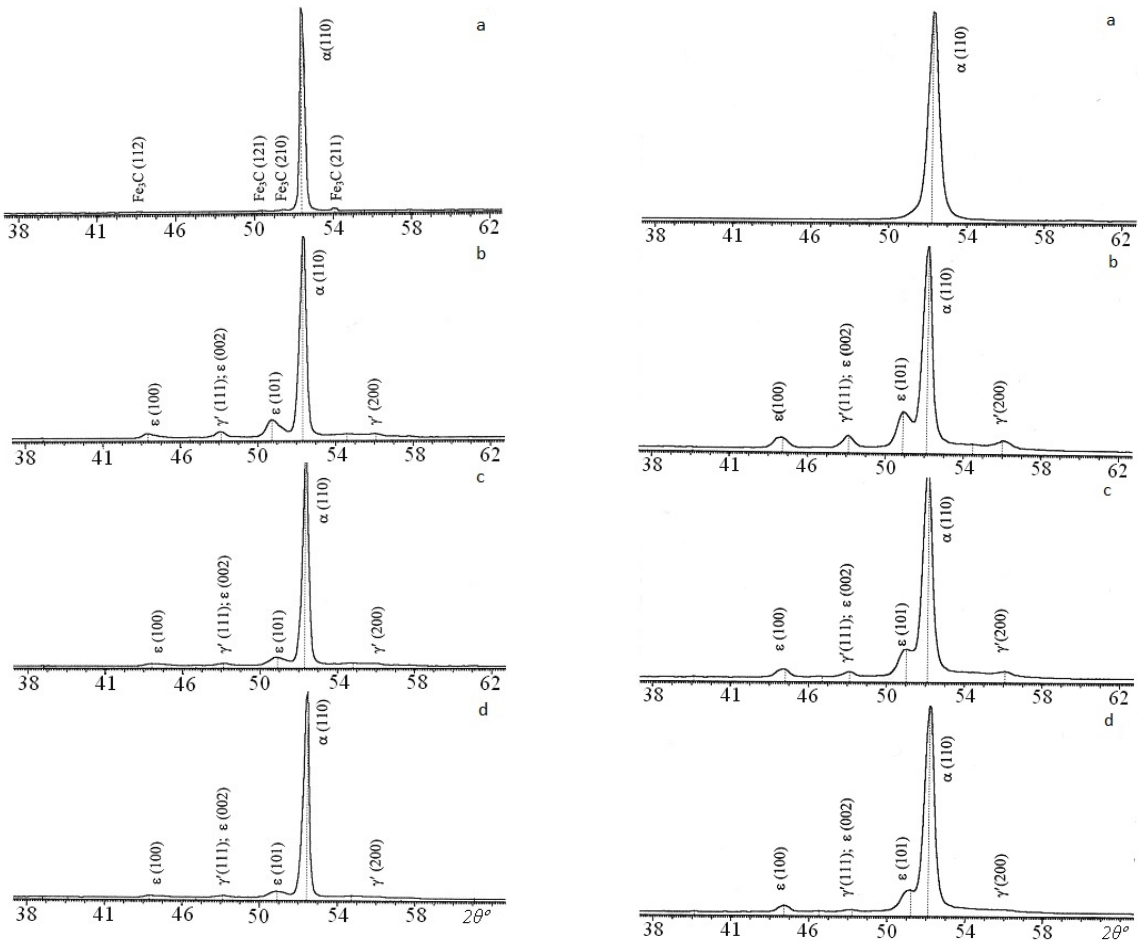



***Fig. 3.*** *Segments of X-ray diffraction spectra (CoK$_\alpha$) from surface layers of 40X steel (left column – preliminary annealed steel; right column – preliminary quenched steel): a – virgin bocks; b – ion implantation at dose rate j=1 mA/cm$^2$; c – j=1,5 mA/cm$^2$; d – j=2 mA/cm$^2$*

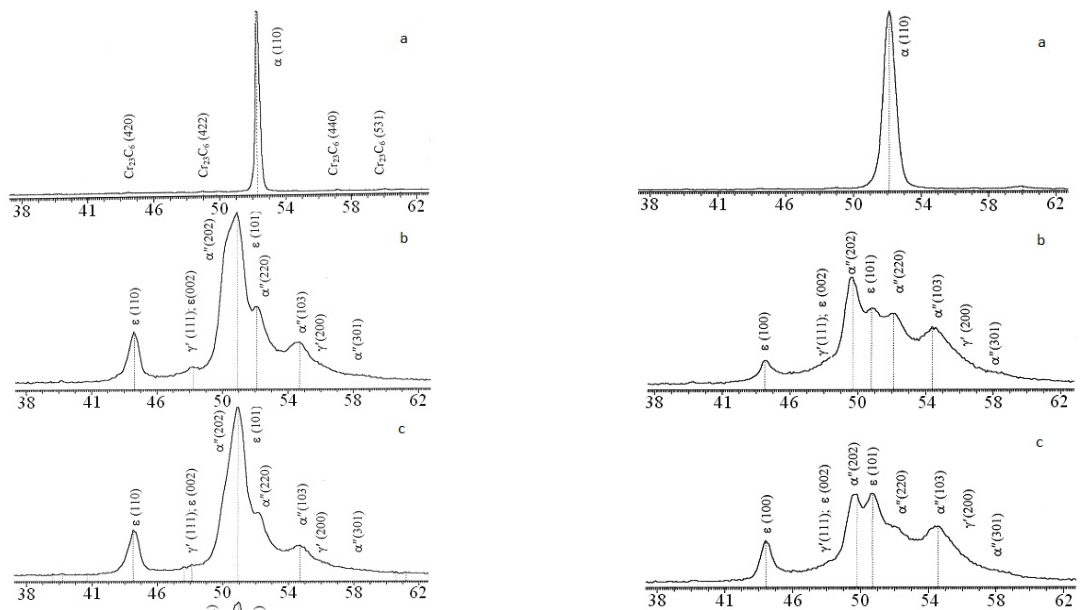
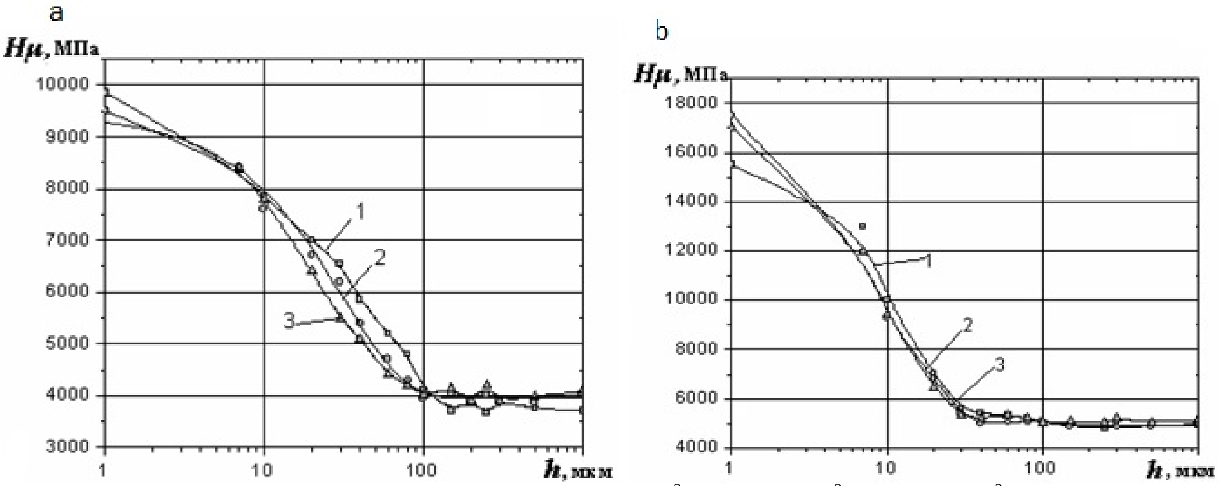



***Fig. 4.*** *Segments of X-ray diffraction spectra (CoK$_\alpha$) from surface layers of 40X13 steel (left column – preliminary annealed steel; right column – preliminary quenched steel): a – virgin bocks; b – ion implantation at j=1 mA/cm$^2$; c – j=1,5 mA/cm$^2$; d – j=2 mA/cm$^2$*

Alter annealing 40X13 steei had a bainite structure, containing α-phase, $Cr_{23}C_6$, $Cr_7C_3$ carbides (traces). The lattice parameter of α-phase was 0.2870 nm and surface microhardness of the steel $H_\mu$ = 2400 MPa. Ion implantation at a low dose rate (1 mA/cm$^2$) influenced 14-16 nm surface layer and increased its surface microhardness up to $H_\mu$ = 12000 MPa. Bulk microhardness of ion implanted block fell down to $H_\mu$ = 5000. MPa. X-ray diffraction of blocks revealed a near-surface layer containing α''-$Fe_8N$; ε-(Fe, Cr)$_{2\ 3}$ N; γ'-$Fe_4N$ and $\alpha_N$ phases. The concentration of α''-phase was lower and concentration of ε-phase higher, than in the case of quenched steel. Dose rate increase up to 1.5 and 2 mA/cm$^2$ resulted in a doped layer with 8-10 μm thickness (Fig. 4d). Surface microhardness increased up to $H_\mu$ = 12500-14000 MPa. X-ray diffraction of annealed blocks ion implanted at high dose rates revealed a near-surface layer containing nitrogen rich E-(Fe, Cr)$_{2\ 3}$N phase. Concentrations of nitrogen poor α''- and γ'-phases were dramatically lower than in the case of quenched steel.

Date for surface microhardness versus distance from the implanted surface of blocks are presented in Fig. 5




*1 – ion beam current density equals 1.0 mA/cm$^2$; 2 – 1.5 mA/cm$^2$; 3 – 2.0 mA/cm$^2$*

***Fig 5 –*** *Surface microhardness of quenched 40X (a) and 40X13 (b) steels implanted with nitrogen versus depth from the surface*

The depth of modified layer in quenched 40X13 steel is determined mainly by the ion fluence and does not depend significantly on the processing time. Comparatively low defect concentration in annealed steel results in a comparatively low diffusivity of nitrogen. Radiation-induced defects do not compensate the lack of high defect concentration typical for martensite structure. As a consequence the depth of modified layer falls down, and nitrogen-rich e-phase inclusions dominate in the surface layer. The depth of nodified layer increases with the time of treatment.

Data obtained show that dose rate is an important ion beam treatment parameter. As the role of diffusion during elevated-temperature, low-energy implantation exceeds that of simple, ballistic ion delivery, virgin microstructure and chemical composition of the surface layer were extremely important.

Chromium concentration dramatically influences parameters of the implanted layer. The thickness of modified layer on the surface of 40X13 steel was significantly smaller than on the surface of 40X steel. The microstructure of ion implanted layers was also significantly different with high-strength non-brittle tetragonal a''-(Fe, Cr)$_8$N phase observed only for nitrogen implanted chromium-rich 40X13 steel.

Processing of 40X steel with low nitrogen solubility in martensite, results in a prompt formation of surface nitrided layer. This layer consists of nitrides and slows down further saturation of the bulk material because of slow nitrogen diffusivity. Diffusivities of nitrogen in γ'- and ε-phases were correspondingly 25 and 6 times smaller than those for martensite). Nitrogen diffusion in the bulk material takes place mainly along grain, twin, low-angle boundaries, and dislocations. The depth of doped layer for both quenched and annealed steels was controlled by nitrogen diffusivity and increased for a long processing time (low dose rates). Low dose rates also insured higher concentration of nitrides with dominating of the hard wear-resistant nitrogen poor γ'-$Fe_4N$ phase. On the contrary high dose rates' result in thin modified layers and low concentrations of nitrides, essentially of nitrogen poor γ'-$Fe_4N$ inclusions. Steel hardening led to a dramatic increase of defect concentration and intensified nitrogen diffusivity with consequent variation of nitride morphology.

In the case of chromium-rich 40X13 blocks the kinetics of ion-implanted layer formation looks dramatically different. High concentration of chromium results in a thinner doped layer with a different phase composition. High concentration of crystal defects favors solubility and diffusivity of nitrogen during ion implantation and results in the development of inner nitriding zone, containing nitrogen-doped martensite with inclusions of nitrides. Concentrations of nitrides and nitrogen-rich phases increase towards the surface. Precipitates of tetragonal α''-phase ($Fe_8N$), with the regular arrangement of nitrogen atoms in a-phase lattice, were observed in the surface layer. Low dose rate favors formation of nitrogen poor γ'-$Fe_4N$ and α''-$Fe_8N$ phases in quenched 40X13 steel. Schematic to illustrate dose rate influence on on parameters and properties of modified surface layer is presented in Fig. 6.

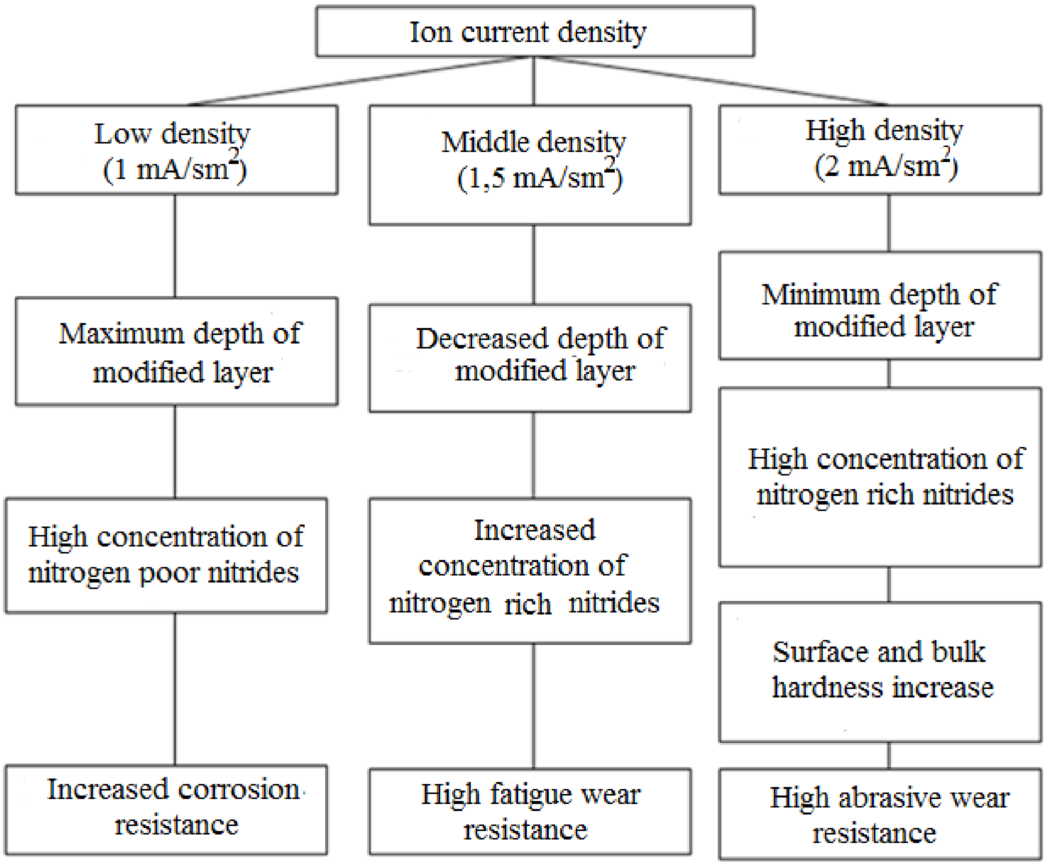



***Fig. 4*** *– Schematic to illustrate influence of ion beam current density on parameters and properties of steel surface layers*

## Conclusions

The data presented demonstrate that dose rate, chemical composition and initialsurface microstructure are extremely important for low-energy, elevated-temperature ion implantation, when the role of diffusion exceeds that of ballistic penetration and the thickness of nitrided layer extends far beyond the ballistic implantation range.

Microstructure and kinetics of the surface modification dramatically differ for steels with low and high concentration of chromium atoms. The implanted layer on the surface of 40X steel consists of ε- and γ′-phases and its thickness scales with the processing time. Nitrogen diffusion along grain, twin, low-angle boundaries, and dislocations takes place during ion-beam processing of both quenched and annealed 40X steel.

In the case of 40X13 blocks dose rate does not influence the thickness of implanted layer. Fast diffusivity of nitrogen in quenched chromium-rich steel 40X13 as well as radiation-stimulated diffusion explain formation of comparatively deep modified layers at dose rates 1.5 mA/cm$^2$ and 2.0 mA/cm$^2$. Tetragonal phase with low concentration of nitrogen was detected in the surface layer of ion implanted 40X13 blocks.

Preceding block hardening increased the density of crystal defects, increased nitrogen diffusivity, and led to homogeneous nitrogen distribution in the surface layer. As a consequence high-strength nitrogen poor inclusions dominated in the doped layer of implanted steels. Low inherent crystal defect concentration after annealing results in low diffusivity of implanted species, thin modified layers, and formation of comparatively brittle nitrogen-rich e-phase.

## Acknowledgment

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# ADDITIVE MANUFACTURING OF MEDICAL IMPLANTS WITH BIOCOMPATIBLE MATERIALS, A CHALLENGING APPROACH IN INDIVIDUALIZED PRODUCTION IN MEDICAL ENGINEERING

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***Abstract:*** *In this paper, the capacity of additive manufacturing in the medical engineering will be considered in order the fourth industrial revolution, industry 4.0. The benefits of additive manufacturing, particularly individualization and sustainability, will be discussed and the particular demands of medical engineering are mentioned in relating to the manufacturing technology. Also, the challenges and technical lacks of the technology, mechanical properties, will be analyzed due to the scientific experiments and technical reports. The solutions for the problems are considered briefly and the alternative systems or processes will be obtained regarding the medical application. This research presenting the starting steps of the new project which is planned for next years, in the Institute of Materials and Processes, IMP, at Karlsruhe University of Applied Sciences.*

**Keywords:** ADDITIVE MANUFACTURING, MEDICAL IMPLANTS, BIOCOMPATIBLE MATERIALS, NUMERICAL SIMULATION

## *1. Introduction*

Nowadays, Additive manufacturing, A.M, is rapidly developed for production of complex shapes and forms. One benefit of A.M. is the possibility of production of the entire form of a product without using different technologies of conventional or unconventional manufacturing processes [1]. Also, A.M. is highly sustainable technology, which has the close-to-zero waste materials, due to less usage of subtractive manufacturing technologies [2]. In other hand, customization of products is the new trend in production engineering which is one of potential of cyber-physical system and cloud computation in the fourth industrial revolution, Industry 4.0 [3, 4]. Combination of these three concepts lead us to the individualized production system, which can produce wide range of products according to the customers' order. Additive manufacturing, which is known as 3D printing, is the unique manufacturing process which has the potential of individualized production in fast procedure of soft tissue and artificial organs for body, medical implants, and biomedical ergonomic devices. [5] Regarding the research, 3D printing is a valuable technique for production of medical implants, [6, 7] which has to be prepared based on patients requirement, in a particular dimension and in few numbers, mostly it is requested to make an implant in desired dimensions once [8].

Particularly, the novel 3D computer models of the structure and shape combined with simulations, e.g. of the mechanical characteristics, support the future design of optimized individual implants. The mechanical properties of the material and the structure will be improved toward the implant development with accepted performance. Thus, additive manufacturing is the fascinating technology that increase the effectiveness of medical companies in the modern market. Briefly, additive manufacturing of the live tissue, similar characteristics as cells, skin, and bone, is the leading edge of the science to improve the medical treatments of patients [7, 9, 10, and 11] and societies' health level.

## *2. Individualization processes*

In the modern trend of manufacturing systems, Industry 4.0 utilizes cyber-physical systems to develop the traditional systems to smart factories. This involves cloud systems to collect the data from different manufacturing units [12, 13], and to make the production system adopted to the market's demand. Development of manufacturing systems in the recent decades was aimed to make it more adoptive and responsive to the market demand. Flexible Manufacturing System FMS and Reconfigurable Manufacturing System RMS are two examples to adjust the manufacturing systems for variable products production as requested by clients [14, 15]. The next level was customized production which is using the cloud systems to collect the desired options for a product from clients. Thus, industry 4.0 prepares the platform for collecting the customers' orders, analyzing them to obtain the new product. In this direction, additive manufacturing will be the unique technology, to use the analyzed data to produce the customized product. In this category, the product can be produce exactly regarding the customer's order [12, 15]. This is the concept of individualized production utilizing 3D printing.

In the smart factories production processes are running under the cyber-physical network which the data are storing in it continuously. The data is transferred within the cloud system, for processing and real-time decision making actions [3]. Thus, smart factory prepares the interactive field for dynamic response to demands, toward manufacturing the individualized products. Although, the response time of the factory depends on the facilities and flexibility of the production system [4, 13].

## *3. 3D printing of biocompatible materials*

Biocompatibility is a characteristic of materials, which are non-toxic, and has not harmful progress on body. Also, the biocompatible materials are corrosion resistant [16]. Generally, National Institute of Health determines biomaterials as "any substance (other than a drug) or combination of substances synthetic or natural in origin, which can be used for any period of time, as a whole or part of a system which treats, augments, or replaces tissue, organ, or function of the body." Biocompatibility is the key parameter of the implanted materials which is defined as surface properties. This covers how the body reacts in the interaction with the implant on the surface [17]. Chemical reaction on the implant's surface means instability of the material and unpredicted effects during the time. The physical diffusion of the soft tissue in the porous structure of the implant is accepted if there is not any chemical reaction or mechanical instability.

There are known categories of biocompatible materials, which are used in medical implants and some medical devices. Titanium is widely used for bone and dental implants and their accessories for example screws or bolts. Titanium alloy grade 5 (ASTM F136) is an alloy with 6% Aluminum and 4% Vanadium [12], and titanium grades 4, 3, 2, and 1 [ASTM F67] are unalloyed. Titanium grade 1 has the highest purity and lowest mechanical strength, and respectively, Titanium grade 5 has less purity and highest mechanical strength [16]. On the other hand, there are biocompatible ceramics and polymers, which are used for production of medical implants, artificial vessels and skins, artificial heart and heart valves, biocompatible coating and drug delivery [17]. The leading research on synthesis of the new biocompatible materials is concentrated on polymer- or ceramic-based materials [18, 19], which are adjusted for different mechanical characteristics, for wide variety of applications with different properties and characteristics. Ultra-high-molecular-weight polyethylene (UHMWPE), Polyether ether ketone (PEEK), and photopolymer are three groups of the polymers, additionally Alumina, bio-ceramics and bio-glasses are the biocompatible ceramics, which are used for medical implants [17]. Referring the goal of the research, the mechanical characteristics of the biocompatible materials are investigated and developed. The numerical simulation of the implant's structure will guide the mechanical characteristics as required criteria for the aimed application.

## *4. Microstructure modeling*

The medical implants are mechanical structures which are involved with cells and organs of an alive body. The implant is used in a patient's body, which is named "host". The implant is installed on the body, which has to have the mechanical and biological behavior as the normal organ or tissue. However, the mechanical behavior of the bone implants will be developed in the 3D numerical simulation. The numerical modeling will be performed in PACE3D, which is developed during years for microstructure simulation. Due to the goal of the research, the porous structure and network of microscale strings of the implants is simulated mechanically, to realize the optimum design for the structure and to improve the material properties and characteristics.

Also, the mechanical structure has to have the adoptive interaction with host's organs, which means the healthy application of the implant. There are two factors effective on healthy application of an implant, the biocompatibility which is described before, and the ergonomic bio-design, due to interaction of host's cells and the surface of implant microstructure. The medical implants cause two different responses during the time which is used in host's body. The initial response, due to mechanical forces, protein adsorption or cell adhesion [18], will be damped with medicaments and post-threating. Although, the determinative parameter is referred to the progression of the host response. Negative factors, e.g. calcification or inflammation [18] are followed and the interaction of the implant is simulated to find out the reasons. The feedback will lead researchers to develop the implants as similar as the body elements, with the adoptive healthy performance. The numerical modeling in the porous is a developed numerical simulation of vector-valued multiphase-field model [20, 21], to simulate the mechanical characteristics and surface interaction of the medical implant. Also, the mechanical strain will be analyzed regarding the elasto-plastic behavior of the structure, with using the multiphase-field model [22]. The evaluated strain in 3D model will improve the initial design of the structure for production.

## *5. Conclusion*

In this research, the capacity of additive manufacturing technology in medical engineering is reviewed and examined, also the challenges in the manufacturing techniques and the material production are analyzed as it will be simulated in 3D novel model. The numerical model will be developed particularly for the medical application, based on the PACE3D code on Linux machines. Finally, the benefits of product individualization in medical field is presented, as a comparative advantage of cyber-physical systems in Industry 4.0. The manufacturing process of the product, considering the above factors, is the next step of the project, which will be conducted beside the research.

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# GENERALIZED ALGORITHM FOR NUMERICAL ANALYSIS AND MULTICRITERIA OPTIMIZATION OF MULTIPARAMETRIC REGRESSION MODELS

# ОБОБЩЕН АЛГОРИТЪМ ЗА ЧИСЛЕН АНАЛИЗ И МНОГОКРИТЕРИАЛНА ОПТИМИЗАЦИЯ НА МНОГО ПАРАМЕТРИЧНИ РЕГРЕСИОННИ МОДЕЛИ

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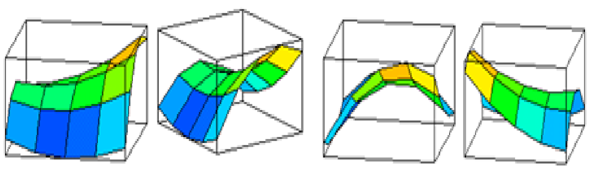
***Abstract:*** *An algorithm for numerical analysis of multi-parametric regression models is introduced. It is intended for software realization mainly to offer an user-friendly environment for analysis, appropriate to/related to future multi-criteria optimization. The analysis is performed via visualizing various fragments from the domain supported by different tools and editors. The definition of the algorithm is followed by a test sample for analysis in the distribution of hardness of ion nitriding instrumentation, class heat resistant steel.*

**KEYWORDS**: MODELING, OPTIMIZATION, MCDM, ION NITRIDIG, INSTRUMENTATION STEELS

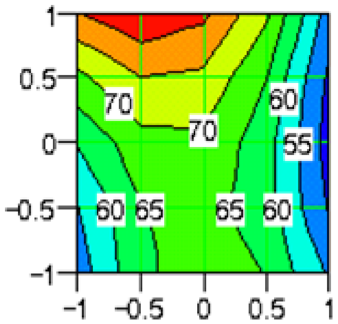
## *1. Staging and Purpose of the Task*

The design of various equipment and processes requires research and analysis of different quality indicators depending generally on a significant number of parameters [1]. The representation and the analysis of multi-parametric functions is limited for wider use by the existing software on the market [2]. The decision maker (DM) is significantly hampered by the existing products if he/she wishes to analyze a multi-parametric model.

The purpose of the present research is to present an algorithm for analysis of multi-parametric regression models that must be realized in the specialized software MCDA’10 and also to make a test sample to check the operation of the algorithm. The idea of the algorithm is to create a way to represent multi-parametric models as a possibility for an “ad hoc” procedure for decision making. The final goal of the presented research is to reduce the feasible set to reach compromise solutions in various criteria [3]. Since the experimental approach does not use information about the mechanism of the ongoing events, so the idea about a system like MCDA’10 proves [to be] very universal. It is possible to apply the same method for processing experimentally obtained values to many various by their nature processes: chemical, metallurgical, ecological, biotechnological, etc.



a)




б)

***Fig.1.*** *Ways to visualize the same response surface: a) via space images from different views; b) via a contour diagram with equal-level lines*

During the research of innovative technological processes or processes of dedicated designation, the software makes it possible in the early calculations to code the limits of changes of separate parameters by the concerned researcher to protect the secret of effective solutions.

The specialized calculation software (MATLAB, MCAD, EXCEL, etc.) offers possibilities to visualize the research quantity for analysis of two parametric factors; their changes are located along the ordinate axis and the values of both factors change in the plane of the base. An example of such presentation of the same response surface from different views is made with MCAD; they are presented in Fig.1a. It is possible to obtain from such presentation just a qualitative information; it is not possible exactly to define the address of the input parameters in which the explored quantity obtains a specific value in the research interval.

It is possible to be more useful to the DM the image from the contour diagram during the analysis of the respective response surface with equilevel lines (Fig.1.b); now the value of the research quantity is coded by a certain color in a defined interval. The disadvantage of the specialized software in this case is in the precise fixing of the bounds of the research quantity; thus it is impossible to analyze parts of the diagram for new specific arrangements of the values of the research quantity; also it is impossible to define strictly the address (the combination) of the controlling factors for these values.

One can point out as an another disadvantage of the specialized calculation software the hardness to visualize models with more than two parameters via combinations from 2D contour diagrams for a suitable space arrangement using global and local separations of the variables.

For example the DM orientates himself/herself for the selected discretization on four parameters (X1, X2, X3 and X4) and a single research quantity with nodes [-1, -0.5, 0, 0.5, 1] examining 25 contour diagrams varying globally with X1 and X2 in the defined nodes.

The resulting graphics with the specialized software are built not coordinated relative to one another and therefore the graphics are not normalized to each other. This makes not possible using them for the analysis of decision maker.

## *2. Tools and Editors in the Execution of the Algorithm*

Magnifiers are a basic tool in the intended for development software. They are directed at exactly defined compass parameters. They enclose the endmost (and all) addresses of the variables. Certain definite initial values of the input parameters of the model are fixed hitting a key or [directly] clicking with the mouse. Magnifiers differ by size. They are gradually directed covering the final position of the cooler in a certain way value of the explored quantity.

The research quantity has two values: normed and the real one. The normed value changes in the range of [0-100%]. It is the basic one in the analysis. Using the percentage editor these values are colored in a suitable color depending on their size. The possible coloring interval are six.

The compass determines the range and the step of the research in the domain. The first iterations may be executed via templates by default. These iterations direct the analysis in a certain direction that can be refined afterwards with the step-by-step editor. The step-by-step editor can set uniform or varying steps of discretization during visualization of the explored quantity. When determining the search direction of satisfactory values of the explored quantity, during the analysis it is possible to fix two or four parameters; the rest of them may be explored more in detail. In such cases the explored interval may include more calculation nodes with a constant or varying step.

The template for the first analysis of all up to ten parameters in the range [-1, +] is with a step of 0.5. In analyses of models with up to four parameters in the interval [-1, +1] the template may be set for analysis with a step of 0.25.

Fig.2 presents a graphical interpretation of the parametrical changes in the magnifier movement till its final state.

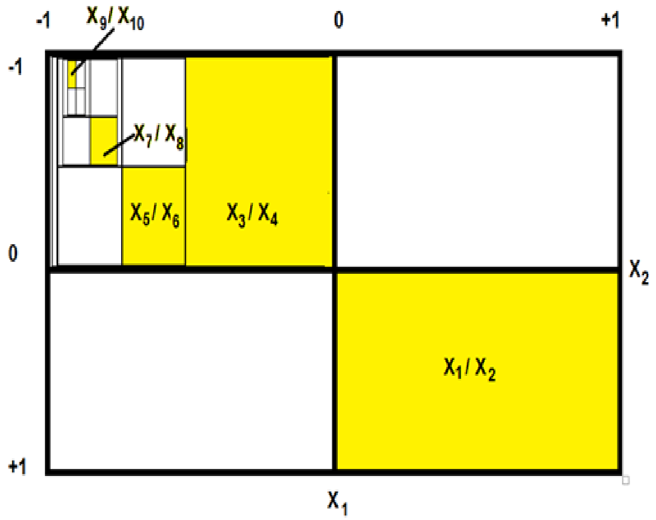



***Fig.2.*** *Ways to display the location of the basic input parameters in analysis with discretization of ten factors in two nodes of change*

The function of the algorithm provides the usage of the following editors during the work with the software:

- Input-Data Editor. The data necessary to realize the analysis and the optimization are input with this editor. The input data are the regression coefficients of the model and the maximal and minimal values for each of the models. The definition of a multi-criteria optimization problem includes the definition of the requirements for various criteria tending to maximum, minimum or in a predefined interval. Besides the editor, the software will provide the input of the required information also from a file.

- Step-by-step editor. This editor makes it possible to define the step of discretization for all explored parameters. Also this editor allows the fixation of certain parameters in the analysis of the model. So the whole domain is digitized with a steady or varying step.

- Percentage editor. This is the basic editor for analysis during ratings of the research value quantities and also for localizing the compromise solution of the defined multicriteria problem. The interval [0, 100%] or parts of it in constantly limited iterations are colored with this editor under freely shifting restrictions with definite colors. The number of the colors may vary from 1 up to 6.

- Editor to set real values. Used to set the minimal and the maximal real values of all factors in the cases when calculations are performed in coded units.

- Editor for analysis at the same base. Used to allow changes of the extreme values in an analysis that is performed for at least two models.

### *3. Description of the Algorithm*

The proposed numerical approach is designed to solve single-criteria and multi-criteria problems with many parametric variables. It is applied after derived regression models and for defined extreme (maximal and minimal) values for them. The algorithm is designed to create software to automate calculations to enhance the definition of effective solutions for formulated multi-criteria problems. First a discretization is determined of the variables with a certain step. The algorithm can construct a generalized function from the normed values of several criteria. So it is possible to determine the values of the control factors and their respective values of the individual goal parameters. For the implementation of the multi-criteria optimization the analysis of the research quantity is made in a normed form according to formula –

$$Ns = \frac{100*(x-a)}{b-a}$$

Where:

Ns - Normed value of the research quantity;
x - Real value of the research quantity;
a - Minimal value of the research quantity;
b - Maximal value of the research quantity;

So it is possible in the future to fulfill requirements for the criteria matching mini-max, average arithmetic or geometric average effective points.

The proposal to the user (DM) to work not in the criteria plane but in the variables' plane instead and the use of various up to five-six color delimiting intervals proves to be rather untraditional. These two prerequisites, however, are capable to realize some very useful analysis for various processes.

### *4. Test Example from the Field of Material Science.*

The approbated approach is realized at the methodical level.

The purpose of the cited authors' works is to cover the following problem :

- Creation of nonlinear analytical models for control of the properties of steels, depending on the ion nitriding treated condition. For this purpose there has been developed a procedure and software for analysis of the research parameters.

The research methodology includes the following stages:

1. Conducting planned experimental research with the chosen object for exploration aiming at establishing the relationship between the input and output parameters.
2. The research may be directed at a priori preparative unplanned sufficient in number data about the research object.
3. Regression models are output and a test for the model adequacy is performed.

The object of this study – the chemical composition of tested steels – is shown in the table.

4. An experimental check for the adequacy of the models is also performed with exceptional and different from the plan of the experiment investigations.
5. Each model defines a relevant respective criterion of the multicriteria problem. Various multicriteria problems are defined that must be solved from which there are defined the values of all combinations of input parameters which in turn suggest a priori requirements of the output parameters related to maximal and minimal values or of values in a defined interval.

Below is described an example of a study of microhardness of ion nitriding heat–resistant alloys of the same class.

The object of this study with the specific chemical composition and mechanical propretes of the tested steels is shown in the table 1 and table 2.

The data from the experimental plan are taken from the thesis of Zyumbilev, A. (1992), Effect of low temperature plasma nitriding on the properties of tool steels for hot working.

In order to ensure the management of the object, there must be control parameters (degrees of freedom) that are being modified independently from each other. Table 3 indicated the range of variation of the ruling parameters for the mode of thermal and chemicothermal processing. With the variation of the technological factors on the process a planned experiment is run which resulted in the output models checked for adequacy. Zyumbilev's dissertation has defined the relationship between the goal parameters and the technological factors of the modes for processing.

Based on bibliography data and preliminary experiments, the following input (control) factors are defined in Zyumbilev A. (1992): the nitriding temperature, the pressure, the duration of the process, and the temperature of tempering. The following requirements are satisfied during the selection of these factors: independence from each other, compatibility between them and the ability to drive them.

To determine the nitriding modes there have been used mathematical and statistical methods of the planned experiment. A characteristic of this approach is that a compulsory change of input factors is performed within certain limits. Minimum number of trials and simultaneous adjusting of all factors is used. The main problem is reduced to determining the mathematical form of the research, which can be expressed in the given process.

Based on the influence of various factors on the nitriding and the objectives pursued, the following parameters were selected for optimization (matching factors): maximal micro-hardness of the layer HV, relative degree of wear Kv and toughness of destruction K1c (Kq).

Selected in this way, the factors and intervals are used to design experiments also on the basis of a plan of the various combinations of processing-mode parameters with which the experiments were conducted. In order to reduce the errors it is recommended that every attempt is done twice and the combinations of zero-level factors five times. All samples were ion nitrided in an installation of type ION-20. The impregnation gas during nitriding in glow discharge was gaseous ammonia. After nitriding the samples were cooled in air

***Table 1.*** *Chemical composition of steel from the class of scope, [%]* (GOST, Tool steel, 2010)

| Steel | C | Si | Mn | Cr | Mo | W | V |
|---|---|---|---|---|---|---|---|
| 4H5MFS | 0.32 - 0.4 | 0.9 - 1.2 | 0.2 - 0.5 | 4.5 - 5.5 | 1.2 - 1.5 | – | 0.3 - 0.5 |
| 3H3M3F | 0.27 - 0.34 | 0.1 - 0.4 | 0.2 - 0.5 | 2.8 - 3.5 | 2.5 - 3.0 | – | 0.4 - 0.6 |
| 3H2V8F | 0.3 - 0.4 | 0.15 - 0.4 | 0.15 - 0.4 | 2.2 - 2.7 | Up to 0.5 | 7.5- 8.5 | 0.2 - 0.5 |

***Table 2.*** *Characteristics of the steels in scope* (GOST, 2007-2013)

| Steel | Yield strength **Rm**, [MPa] | Tensile strength **Re,**[MPa] | Elongation, **A**[%] | Reduction of area **Z** , [%] | Impact strength **KCU**, [kJ/m$^2$] |
|---|---|---|---|---|---|
| 4H5MFS | 1750 | 1480 | – | – | 570 |
| 3H3M3F | 1670 | 1470 | – | 50 | 220 |
| 3H2V8F | 1530 | 1390 | 12 | 36 | 200 |

***Table 3 Variation range of the input parameters***

| Factors | $T_{nit}$ [°C] | P [Pa] | τ [h] | $T_{tem}$ [°C] |
|---|---|---|---|---|
| Levels X | $X_1$ | $X_2$ | $X_3$ | $X_4$ |
| Zero level (0) | 530 | 300 | 7 | 650 |
| Interval of variation | 20 | 150 | 3 | 50 |
| Upper level (+I) | 550 | 450 | 10 | 700 |
| Lower level (-I) | 510 | 150 | 4 | 600 |

***Table 4. Connection between input outputs parameters***

| No | $X_1$ | $X_2$ | $X_3$ | $X_4$ | 4Х5МФС | 3Х3М3Ф | 3Х2В8Ф |
|---|---|---|---|---|---|---|---|
| | | | | | $HV_{0,1}$ MPa | $HV_{0,1}$ MPa | $HV_{0,1}$ MPa |
| 1 | - 1 | - 1 | - 1 | - 1 | 10970 | 11140 | 11310 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2 | +1 | -1 | -1 | -1 | 10800 | 10800 | 11310 |
| 3 | -1 | +1 | -1 | -1 | 10200 | 10970 | 12060 |
| 4 | +1 | +1 | -1 | -1 | 12060 | 11860 | 11080 |
| 5 | -1 | -1 | +1 | -1 | 11490 | 11490 | 12660 |
| 6 | +1 | -1 | +1 | -1 | 12250 | 11300 | 11680 |
| 7 | -1 | +1 | +1 | -1 | 10170 | 12060 | 11680 |
| 8 | +1 | +1 | +1 | -1 | 11490 | 11300 | 10970 |
| 9 | -1 | -1 | -1 | +1 | 9980 | 10970 | 10480 |
| 10 | +1 | -1 | -1 | +1 | 10480 | 10480 | 10170 |
| 11 | -1 | +1 | -1' | +1 | 10170 | 11000 | 10640 |
| 12 | +1 | +1 | -1 | +1 | 11310 | 10640 | 11000 |
| 13 | -1 | -1 | +1 | +1 | 11240 | 11000 | 10000 |
| 14 | +1 | -1 | +1 | +1 | 10970 | 10480 | 10970 |
| 15 | -1 | +1 | +1 | +1 | 10170 | 10320 | 9320 |
| 16 | +1 | +1 | +1 | +1 | 10500 | 10480 | 10480 |
| 17 | +1,414 | 0 | 0 | 0 | 12060 | 11680 | 11310 |
| 18 | -1,414 | 0 | 0 | 0 | 11680 | 11000 | 11140 |
| 19 | 0 | +1,414 | 0 | 0 | 10970 | 10640 | 10970 |
| 20 | 0 | -1,414 | 0 | 0 | 10480 | 12060 | 10640 |
| 21 | 0 | 0 | +1,414 | 0 | 11490 | 11310 | 10170 |
| 22 | 0 | 0 | -1,414 | 0 | 11680 | 10640 | 11680 |
| 23 | 0 | 0 | 0 | +1,414 | 12060 | 11140 | 11000 |
| 24 | 0 | 0 | 0 | -1,414 | 11310 | 10970 | 10640 |
| 25 | 0 | 0 | 0 | 0 | 11680 | 11860 | 11410 |
| 26 | 0 | 0 | 0 | 0 | 11000 | 11680 | 11140 |
| 27 | 0 | 0 | 0 | 0 | 11490 | 11860 | 11310 |
| 28 | 0 | 0 | 0 | 0 | 12060 | 11680 | 11310 |
| 29 | 0 | 0 | 0 | 0 | 11490 | 11680 | 11410 |
| 30 | 0 | 0 | 0 | 0 | 11680 | 11860 | 11410 |

The levels of the input parameters of the research are shown in the tab. 5.

***Table 5.*** *Variation range of the input parameters*

| **Factors** | $T_{nit}$ [°C] | **P** [Pa] | **τ** [h] | $T_{tem}$ [°C] |
|---|---|---|---|---|
| Levels X | $X_1$ | $X_2$ | $X_3$ | $X_4$ |
| Zero level (0) | 530 | 300 | 7 | 650 |
| Interval of variation | 20 | 150 | 3 | 50 |
| Upper level (+I) | 550 | 450 | 10 | 700 |
| Lower level (-I) | 510 | 150 | 4 | 600 |

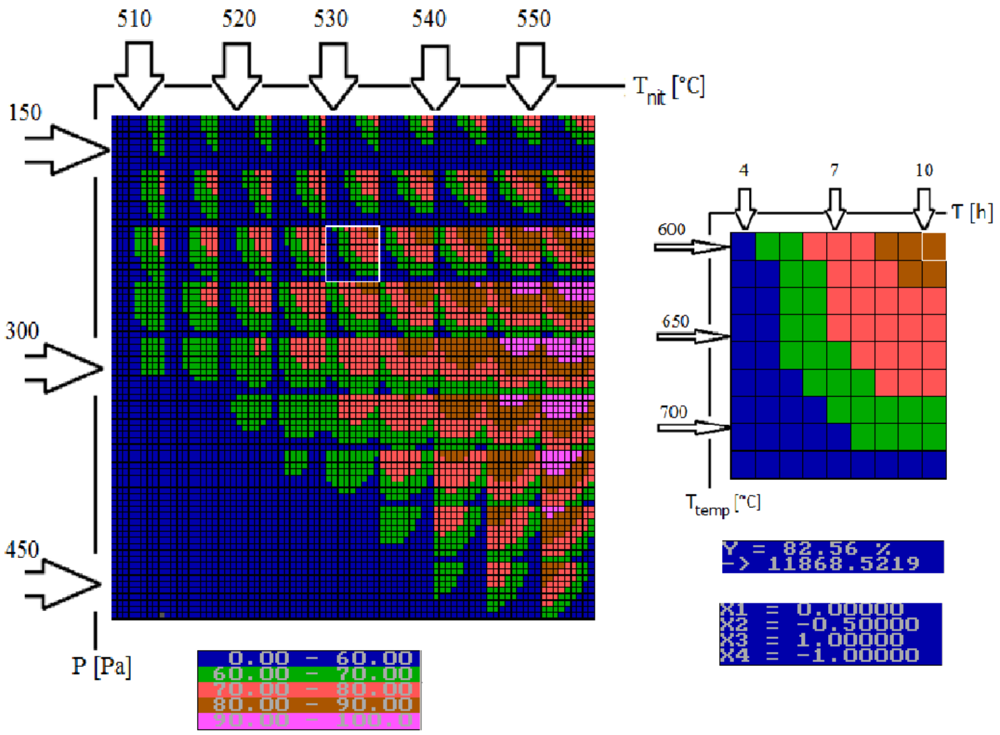
The output parameter is of the explored steels and the multi-criteria problem which we set ourselves to solve is the definition of the input parameters for which the whole class of steels has a relative maximal hardness.

The regression models are micro-hardness as it follows:

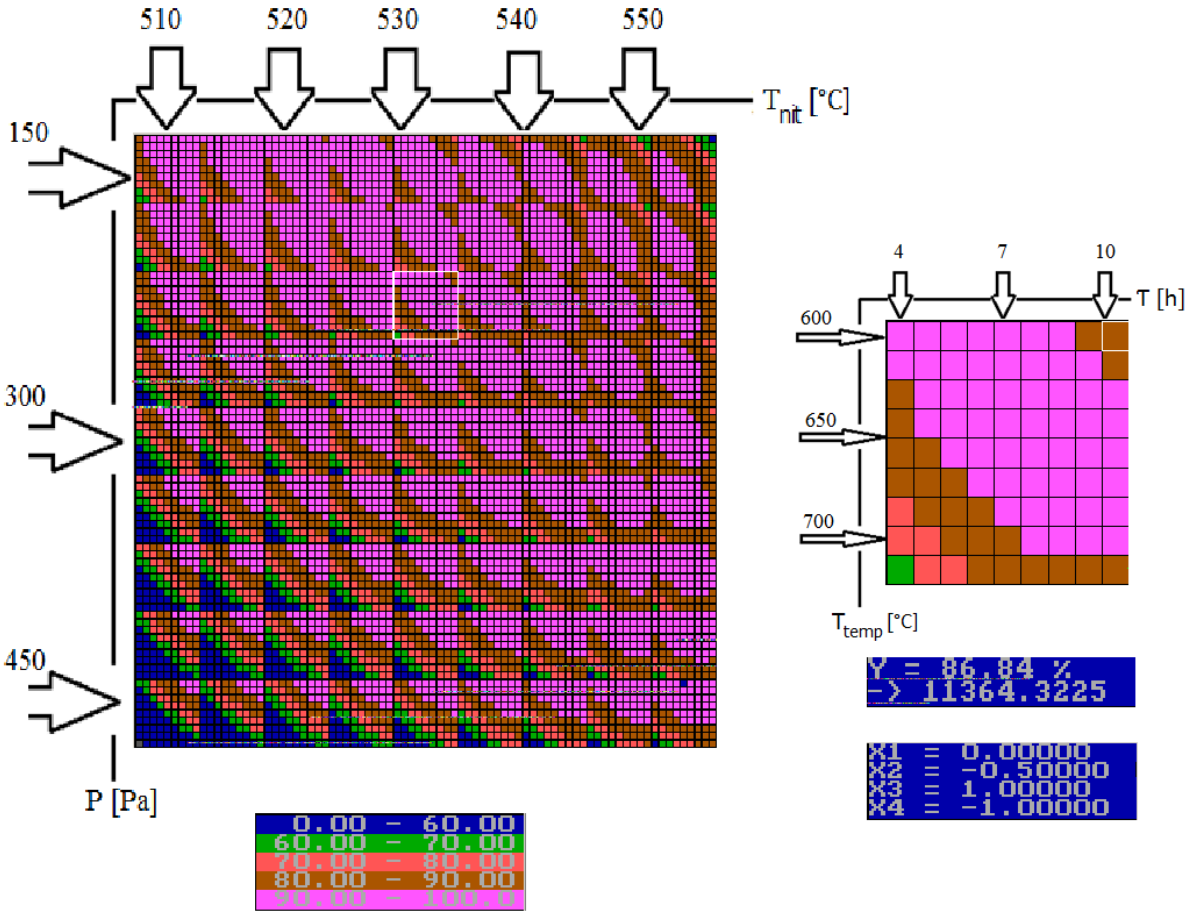
| **parameters** | $H_{\mu V}$ $(HV_{0,1})$ **for steel** | | |
|---|---|---|---|
| | 4H5MFS | 3H3M3F | 3H2V8F |
| Free | 11675.26 | 11813.49 | 11232.81 |
| $x_1$ | 300.3842 | 462.604 | -12.78176 |

| | | | |
|---|---|---|---|
| $x_2$ | -70.86131 | -546.9271 | -44.17166 |
| $x_3$ | 102.0732 | 570.9035 | -121.2643 |
| $x_4$ | -177.4857 | -760.527 | -459.0758 |
| $x_1.x_2$ | 239.375 | 710.625 | 9.375 |
| $x_1.x_3$ | -74.375 | -681.875 | 85.625 |
| $x_1.x_4$ | -129.375 | 568.125 | 303.125 |
| $x_2.x_3$ | -320.625 | 544.375 | -273.125 |
| $x_2.x_4$ | 66.875 | -740.625 | 61.875 |
| $x_3.x_4$ | -26.875 | 481.875 | -171.875 |
| $x_1^2$ | 15.95109 | -269.4298 | 70.23389 |
| $x_2^2$ | -556.7208 | -264.4267 | -139.8285 |
| $x_3^2$ | -126.592 | -451.9834 | -79.80983 |
| $x_4^2$ | -76.57547 | -411.9729 | -132.3259 |
| $R^2$ = | 0.85549 | 0.819219 | 0.8211649 |
| Fcalc > Ftabl | 2.92458 > 2.4244 | 2.18637 > 2.4244 | 2.2183 > 2.4244 |

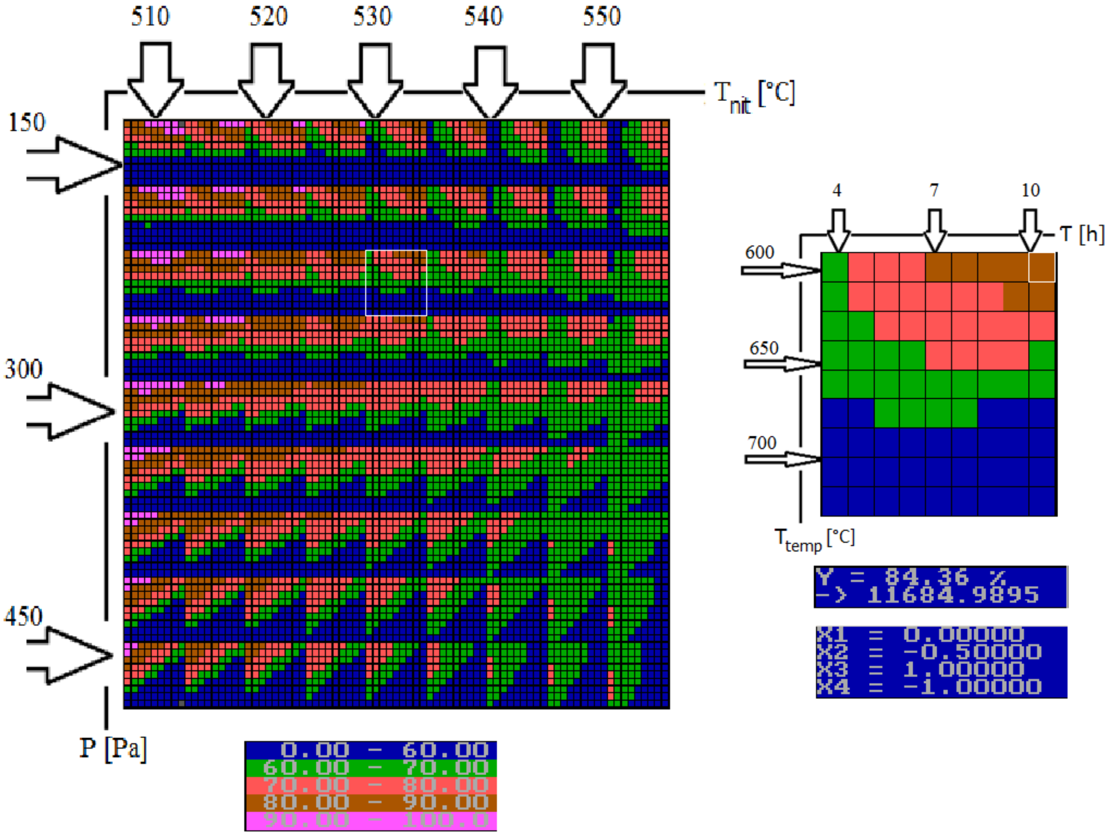
It is possible to make analysis via the graphical interpretation of the results. This analysis determines the influence of the input parameters for the explored steels 4H5MFS, 3H3M3F, 3H2V8F. The percentage interval of the explored micro-hardness parameter is colored in the relevant due way along the chosen scale /right below in the image/.




a)




b)

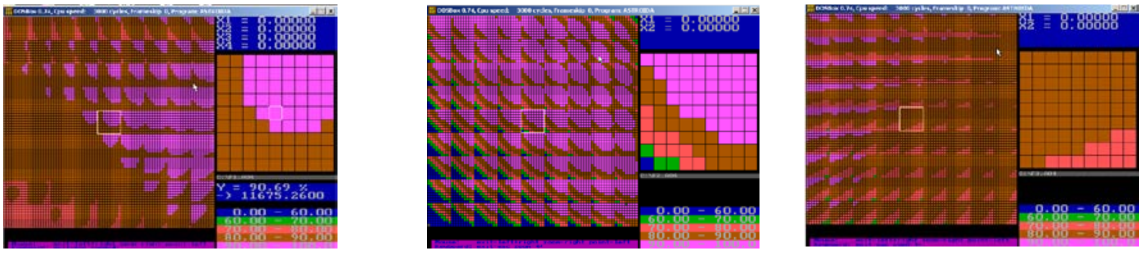



c)

***Fig. 3.*** *Distribution of microhardness in the test domain of input parameters - a) - 4H5MFS, b) - 3H3M3F, c) - 3H2V8F.*

In the presented in Fig.3 images the parameters change horizontally or vertically as it follows: in the horizontal direction and globally $X_1$, locally $X_3$; in the vertical direction and globally $X_2$, locally $X_4$.

It is possible to determine a common basis comparing minima and maxima of the three models so that the images from Fig.3 change in the way shown in Fig.4.



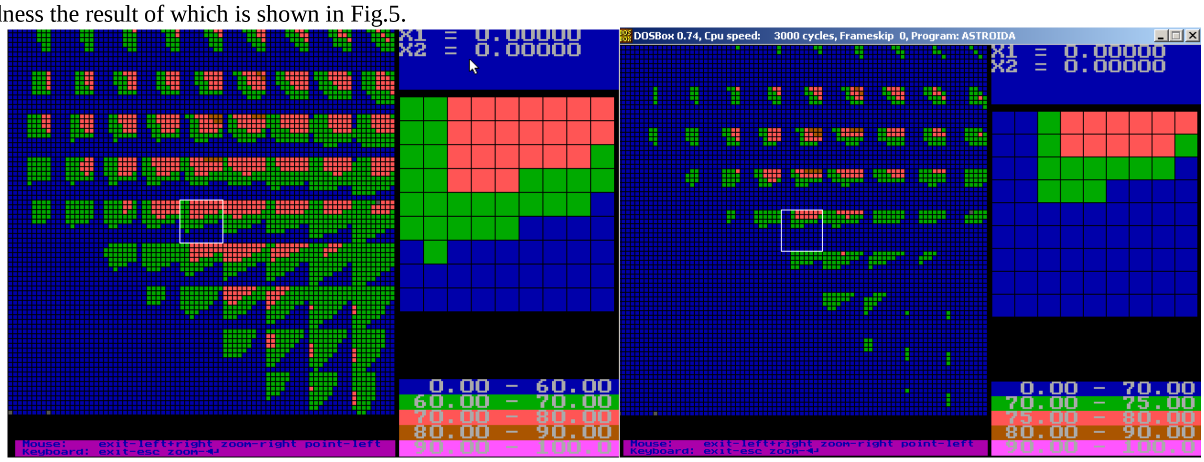
a) b) c)

***Fig. 4.*** *Distribution of microhardness against common basis, in the test domain of input parameters - a) - 4H5MFS, b) - 3H3M3F, at) - 3H2V8F.*

From the analysis of FIG. 2 one can draw the following conclusions:

1. The widest range of variation in hardness in the test domain of input parameters occurs in steel 4H5MFS and 3H3M3F;
2. The most sustainable is the behavior of the hardness of steel 4H5MFS in the research domain of the input parameters. There is a coincidence of the maximal values of microhardness in the same modes of the input parameters for steels 4H5MFS and 3H3M3F
3. There is a sustainable change of hardness of steel 3H2V8F in the research domain of the input parameters but there are no signs for coincidence of the maximal values of microhardness in the same modes for the input parameters of steels 4H5MFS and 3H3M3F.

After this analysis the next task is define the input parameters for which the whole class of the three steels possesses the maximal hardness the result of which is shown in Fig.5.




a) b)

***Fig. 5.*** *Distribution of simultaneous high values of micro-hardness of steels from the whole class in the test domain of input parameters - a) - iteration starting coloration from 60% b) - iteration beginning coloring from 70%.*

From the analysis of Fig.5 it is clear that the processing mode for the maximal values of all three steels is concentrated in the "brown" interval of 80 – 90%. This may be visualized via defining the percentage editor of values shown in Fig.4 where the final decisions are shown, too.

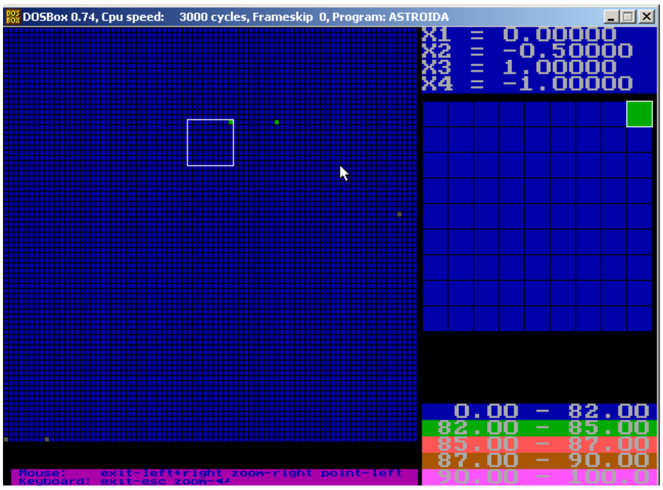



***Fig. 6.*** *Location of the decision of simultaneous high values of micro-hardness of steels from the whole class in the test domain of input parameters.*

The relatively maximal values of hardness for the investigated class of steels for the chosen processing is with the mode of $X_1$ = 0.0, $X_2$ =-0.5, $X_3$ =1.0, $X_4$ = - 1.0.

## *4. Conclusion.*

This research is an algorithm for numerical analysis of multi-parametric regression models is introduced. It is intended for software realization mainly to offer user-friendly environment for analysis, appropriate to/related to future multi-criteria optimization. The analysis is performed via visualizing various fragments from the domain supported by different tools and editors. The definition of the algorithm is followed by a test sample for analysis in the distribution of hardness of ion nitriding instrumentation, class heat resistant steels. This design concept was tested using experimental data. Thus it was shown that the approach has the potential to identify new technological parameters with significantly improved defined properties.

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# INFORMATION AS A STRATEGIC RESOURCE FOR PROTECTION OF TECHNOLOGICAL SECURITY

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**Abstract:** *Two approaches to a new factor of production – information – are defined. The modern system of factors of production and income, in which information is the only resource that can have unlimited number of participants of the global economy, is represented. It is proved that information activity has a number of features which distinguish it from other activities due to specific of new kind of social division of labor. The essence of the phenomenon of asymmetric information and information situations that arise during negotiations and making bargains is analyzed. Classification of information asymmetry on different criteria is proposed. Actions to prevent threats to information are proposed. It is determined that the availability of the information resources deficit can not be regarded as a question of it's "non-participation" in global development. The statement of the problem under the new ideology of the current stage of globalization is the presence of fixing the problem, whose solution is the key element of forms, rates of entering the country in the new world structure.*
**KEYWORDS**: INFORMATION, TECHNOLOGICAL SECURITY, INFORMATION RESOURCE, ASYMMETRY, GLOBALIZATION.

## *1. Introduction*

The phenomenon of information picture of the world as a scientific and methodological means of study of information reality reflects an important aspect of social life. Various areas of modern science in some way take into account information factor. The hour of information reign, the hour of its study and systematization of knowledge about this phenomenon in the socio-economic world has come.

Problems of providing technological security of regions and state as a whole, and information as strategic resource for technological security, in particular, were investigated in publications of the following leading scientists: G. Akerlof, Yu. Bajal, V. Geyets, A. Gritsenko, I. Maliy, W. Nayser, R. Nuryeyev, S.Nekrasov, R. Sternberg, G. Styhler, L. Fedulova, A. Chukhno and many others.

At the same time, it is necessary to admit that now the scope of human activity is based on the power of information and knowledge, the rate of appearance of which increases daily, and the spread of information and communication technologies is uneven across countries and sectors of society. Therefore, issues related to information as a strategic resource for technical security is extremely important and requiring further deeper investigation.

One of the forms of systematization of knowledge about the information reality is informational world picture, which is characterized by a number features [1].

First, the current socio-economic world is experiencing technical and information stage of development, it exists in the form of information civilization. Modern technologies in ever increasing degree concentrate new forms and methods of collection, production, storage and dissemination of information around them.

Second, world picture is transforming due to changes in the information environment of a person, on the basis of information and increasing globalization of the world.

Third, intensive research of information has created the preconditions for determining information first as discipline and than in interdisciplinary research area.

Fourth, the development of information sphere actualized the problem of the relationship of goals and objectives, tools, values and rules of scientific research.

Thus, the information picture of the world can be interpreted as the World Bank of Information that allows a person to perceive adequately the surrounding world. By providing specific information resources, classifying them accordingly, organizing access to them, the information picture provides a choice of particular system of values. The formation of an information society and changes in information world picture are prerequisites for the evolution to the next stage of human development, the civilization and technological foundation of which is the information industry, production of intellectual innovations, and continued modernization of the economy and the formation of cultural standards on the basis of intellectual innovations [2].

## *2. Information in the system of the factors of production*

A small article of the future Nobel Prize winner George Joseph Stigler [3], the one of the founders of "The economics of information" contained an attempt to answer the question: how long will the problem of search of information about the seller of a particular product that offers the best price be ignored? Later he said in his Nobel lecture: "The proposal to explore the economics of information were adopted quickly and widely and even without any decent minimum objections."

So, regarding the new factor of production – information – Ukrainian economists use two approaches. The first, which is embodied in the government's modernization program, focuses on intelligence and innovation, which means intellectualization and innovatization of economy, the widespread use of information and communication technologies as an important condition of solution of problems of economic modernization. Second, as academician A. Chukhno considered, – it is a confusion, denial of information and knowledge as an independent factor of production, limitation of its action with the sphere of material production [4]. Figure 1 represents a modern system of the factors of production and incomes, proposed by I. Maliy [5]. Therefore, the information is the only resource that can be simultaneously owned by unlimited number of agents of the global economy.

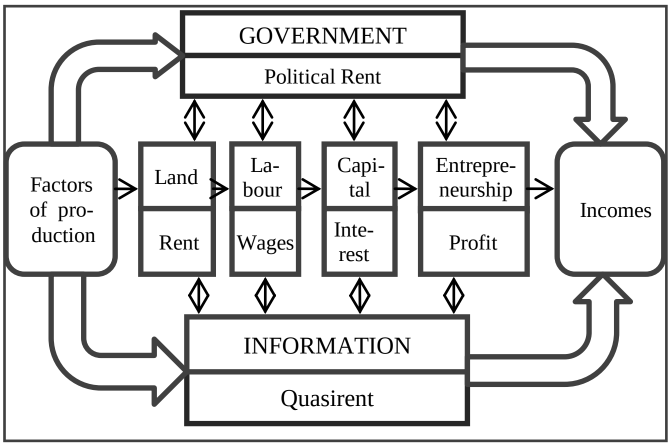


***Figure 1.*** The information in the modern system of the factors of production

It is clear that the laws of reproduction of information significantly differ from the laws that regulate of reproduction of material things. But modern society tries to regulate economic relations, arising in the production, distribution, exchange and use of information, and on the basis of ideas and system of categories, which have formed on the basis of industrial-market economy. Such regulation may not be adequate to the new economic structure that is formed. The uncertainty of the legal framework and conflicts in intellectual property are associated with that. It is also a factor, contributing to the property stratification of members of society and updates the validity of the distribution of the national product and income.

However, today the strategy of development of information and knowledge society is considered as the central system core of the of social and economic policy in developed countries, allowing them to take advantage of the most dominant informational technological and economic structure of the evolution of human civilization.

The benefits of new information technologies have caused the existing economic and technological gap between rich and poor countries. Rejection of dynamic development of information and knowledge society lead to the strengthening of the accumulated crisis potential in any country, as well as contemporary issues of their economic development are related primarily to intellectualization of work, giving the highest priority to processes of producing new knowledge in the information economy that can provide socio-economic progress of society [6].

The result of comparative analysis of industrial production and knowledge industry, conducted by D. Busygin and N. Antipenko [7] and improved by the authors is shown in Table 1.

**Table 1**

*Comparative analysis of industrial production and the industry of knowledge in the information economy*

| Economic category | Industrial production | Industry of knowledge |
|---|---|---|
| Marketing | The study of market conditions, competitors, prices, prospects and results of the use of goods | The research of the subject area of science, identifying areas of research and development, prospects of their implementation |
| Planning | Business plan of production of a good or development of an innovative project | Development of research program taking into account the availability of intellectual resources |
| Investments | Calculation of equipment needed for the project, attracting investors | Public financing and investors searching |
| Buildings | Production areas, required for the production | Intelligent workplace |
| Raw materials | Material resources | Information |
| Energy | Electricity, gas, fuel | Intelligence and experience |
| Labour force | Human resources and personnel | Intelligent personnel |
| Means of production | Equipment and tools | Information and computer equipment and communication |
| Logistics | Transport facilities | Computer networks |
| Technolo-gies | Organization of the production process technology | Organization of scientific inquiry, freedom of creativity |
| Compensa-tion of employees | Wages depending on the quantity and quality of manufactured goods | High wages and dividends on intellectual capital |
| Manage-ment | Production management | Knowledge management, information management |
| Effective-ness | Profit, profitability, return on investment | Intellectual property, the number of citations, bonuses for implementation |

A number of features due to specific new type of social division of labor distinguishes information activity from other activities. The main difference is the use of information as a resource, as a result this activity is the information ie it is regarded as a productive resource and as a commodity. On the one hand, information resource has a number of features that are common to all resources, and, on the other hand, those features, that are inherent to this type of resource and increase its value (Table 2).

**Table 2**

*Features of Information Resources*

| The same with other resources | Inherent only for information resources |
|---|---|
| Increase the value of products and services | Repeated use without additional costs |
| Allow to collect, store and transfer, improve own consumer qualities for users | Synergism the use of information – combining information with other types of resources, as well as other information enables a greater effect than the conventional combining of certain beneficial effects caused by each resource |
| Can utilize used information as a archiving with the ability to restore your data as secondary information resources | Operate in various forms of electromagnetic fields as communications and data display in memory of the entity (person, vehicle), as well as a variable structure of different physical media |
| Are created in a process of specific – higher human activity – intellectual work | Are transmitted by various channels on almost any distance and for 24 hours a day |
| Create only information products and services | A new form of knowledge provided in the alienated from the direct producer form |

Robert Sternberg [8] identified three types of intelligence components that are responsible for processing information:

I. *Metacomponents - management processes* that regulate the processing of specific information. They include:

1) recognition of the problem;
2) awareness of the problem and selection of processes suitable for its solution;
3) selection of strategy;
4) selection of mental presentations;
5) distribution of "intellectual resources";
6) control over the solution of the problem;
7) assessment of effectiveness of the decision.

II. *Executive components* – processes of lower hierarchy level. According to R. Sternberg they include coding, identifying relationships, attitude, which calls to actions, use of comparison, justification of answers.

However, W. Nayser [9], criticizing the R. Sternberg position argues that the number of executive components can be infinite, and their specificity is determined by the characteristics of tasks. Scientist believes that at least this part of the concept of researcher less detailed and justified.

III. *Components of acquiring the knowledge* necessary to the subject to learn to do what the megacomponents and executive components do. According to R. Sternberg they include:

1) selective coding;
2) selective combination;
3) selective comparison.

## *3. Classification of information asymmetry in the market*

Prices and conditions for granting information is very important. The significance of this question is obvious. However, due to its complexity, that is: necessity of determination of precise classification of products, measurement units of volume, certain standards or standard units, analysis of variations in prices for some information products and services on the basis of quality, terms and conditions for granting, guarantees and price comparison of "shadow" and "official" markets, – all of which requires a separate study. Managerial decision making is preceded the agreement on the sale of information. Such transactions in the market of information services are very often aimed at reducing of asymmetric information at the conclusion of commercial agreements in the future [10]. The essence of the phenomenon of information asymmetry was investigated by G. Akerlof. It consists in the fact that subjects of business that operate in a particular market and act as potential or actual business partners, have unequal or asymmetric information on: the subject of the transaction – counterparty of the agreement; object of the transaction; possible or quite likely future events, that may cause business risks to subjects who do not have such information [11]. Analysis of information situations that arise during negotiations and agreements, makes it possible to classify types of asymmetric information on different criteria.

The phenomenon of unilateral asymmetric information occurs when one of the two partners of the agreement is better informed about the subject of the transaction, the unfavorable factors of external environment and so on. If the partner can get additional information, which his/her counterparty do not have, then such information situation is transformed into a phenomenon of bilateral asymmetry information. If the agreement for the period of its implementation brings together three or more participants, each of whom is informed about the subject of the agreement or terms of cooperation in differing degrees, informational situation at the moment of signing the agreement or contract can be characterized as a phenomenon of multilateral asymmetric information.

Typically, partial information asymmetry occurs when concluding agreements, since the subjects of business avoid transacting business under conditions of complete uncertainty. Full information asymmetry occurs when concluding transactions in the market with asymmetric information, also called market with imperfect competition. The level of acceptability shows: acceptable or unacceptable asymmetry information according to the law, terms of the contract and so on.

In particular, systematic information asymmetry arises at completing transaction on the emerging market of information. Specific information asymmetry is caused by the financial possibilities of business agent on collecting (buying) of the necessary information, and his/her experience, competence, degree of specialization, etc. The potential information asymmetry becomes available simultaneously with the emergence of real events that make up the content of asymmetric information.

The phenomenon of information asymmetry is typical at completing transaction in the market of information services. Because the presence of asymmetric information between the buyer and seller leads to the need for agreements of such type.

According to the proposed classification, a situation, typical for agreements on sale information, can be considered as a phenomenon of unilateral, intentional and systematic asymmetry. Such information could meet the situation of complete or partial, acceptable or unacceptable asymmetry, depending on the certain circumstances.

Therefore, the information asymmetry reduces the efficiency of the economy as a whole and the effectiveness of the entities in particular. Such information situation is caused by several reasons [12]:

1) macroeconomic cause of information asymmetry is the immaturity of the market of information services;

2) collecting and acquiring information involves additional previous costs of partners and, in addition, collected information may be irrelevant;

3) better awareness of a single business partner enables him/her to control the situation and dictate the terms of the transaction;

4) information capacity of each partner depends directly on his/her experience, competence, level of specialization and other objective factors that influence the situation;

5) doubts about the reliability of the information.

The advantages in information support of a party of economic relations create conditions for receiving additional incomes, so-called information rent. In this case the information is a resource that has economic value. Also it is a source of competitive advantage and a means of reduction in uncertainty and risk.

In the conditions when there are no methods of evaluation of information or it is not enough fulfilled, the negative impact of asymmetry will increase: buyers try to artificially understate prices for information, and sellers refuse from the providing of information services through their unprofitability. Must admit that some information products, or their fragments, in some cases, can be provided free. Sometimes certain set prices "per unit" of the product are an indicator, table, company, analytical development. Often the price is contractual, and the buyer is difficult to understand how it has been compiled. In general, the prices set by different vendors on similar information products (such, which can be conditionally comparable on the subject, scope and structure) fluctuate widely.

## *4. Information component of technological security*

As the objects of information of technological security are considered: information resources that contain information classified as commercial secrets and confidential confidential information, represented in the form of documented information files and data; information systems (tools and system of informatization) – means of computer and office equipment, computer networks and systems, system-wide and application software, communication systems and data communication, technical means of collection, recording, transmission, processing and displaying information, and their informative physical media.

The deterioration of these parameters information (information resource) as confidentiality, integrity, availability, reliability, etc. can lead to significant negative effects, such as:

- disruptions in the operation of technological process control systems and other systems;
- disclosure of data constituting commercial and other secrets;
- reduction in the reliability of financial documentation;
- unauthorized access to personal data of individuals and others.

The result of these actions may be:

- rupture of business relationships with partners;

- the failure of negotiations, the loss of beneficial contracts;

- failure to fulfill of contractual obligations;

- the need for additional market research;

- rejection of the decisions that have become ineffective because of publicity of information and ultimately financial losses associated with new developments;

- loss of opportunities to patent the results of scientific and technical activity or sell license;

- price reductions or sales of products;

- loss of reputation;

- more strict conditions for obtaining loans; difficulties in the supply and purchase of equipment and so on.

As already mentioned, in certain situations, the neglect of the protection of information can lead to complete loss of business.

Thus, it is important to detect and prevent threats to information. These threats can be divided into four groups: software, technical, and physical and regime.

To counter this threats, such measures should be implemented:

firstly, to develop a technique of analysis and assessment of threats of information security of entity and corporate standards of system of its provision;

secondly, to organize and carry out specific activities on the protection of information;

thirdly, to organize the operation of technical means of information protection;

fourthly, to implement technological audit and control of the system of information security [13].

As business information has received form of a good in Ukraine's information space, and comprehensive government regulation in this area absent, the industry quickly commercializes.

The question of ownership on the database are partly protected by the Law of Ukraine "On Copyright and Related Rights". The issues of access to information on pricing, determination of the reliability of information are decided by each party independently and arbitrarily. Some of these issues are reflected in the Law "On information", Law "On protection of information in automated systems." However, article 5 of the Law "On Protection of Rights on Inventions and Utility Models" does not provide legal protection informational technologies, computer programs and integrated circuits.

## *5. Conclusions*

Thus, the entire sphere of human activity is based on the power of information and knowledge, the rate of appearance of which increases daily. Development of software has created conditions in order to personnel can improve knowledge and develop skills much faster than at any time in previous years.

Internet is a universal communication space, in which very different interests and values coexist. Of course, the spread of information and communication technologies is uneven across countries and sectors of society. It should be mentioned prospect of transition to the information age depends primarily on the availability of education for all segments of the population, as well as the opportunities of operative learning and processing information.

However, establishing leadership and division of markets in the new global community are based on a new common cultural criterion, namely the degree of country ownership on scientific knowledge and forms of this ownership. The attitude to scientific knowledge guides the development of the world community and opportunities of each country to occupy a special place in it. It is important, that the availability of the deficit of information resources in a country cannot be regarded as a question of "non-participation" of it in the global development. On the contrary, ascertaining of availability of the problem of their shortage in the country according to the new ideology of the current stage of globalization is the fixing of the existing problem. Lack of knowledge is seen as the problem of shortage of knowledge whose solution is the key point of forms, rates of entering the country in the new world structure. Lack of information is identified as a threat to information security.

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# THE ISSUE OF MANAGEMENT OF PRODUCTION PROCESSES IN MODERN ENTERPRISES IN ACCORDANCE WITH THE STANDARD OF INDUSTRY 4.0

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***Abstract:*** *The present is an age of technical progress, the rapid development of new technologies and digital transformation in the industry. In the professional experience is often mentioned as the fourth industrial revolution and there is generally used the term "Industry 4.0". The article describes the current state of the problem in area of management and trends and perspectives of management of complex structures using Business Intelligence (BI). At the end of the article is given a summary of requirements that must be implemented for the possibility of establishing a compatible management system that link all elements of the marketing chain.*

**Keywords**: INDUSTRY 4.0, PROCESS, MANUFACTURE, STANDARDS, CONTROL, ROBOTS, BUSINESS INTELLIGENCE

## *1. Introduction*

New, advanced computer systems and their application into our life alters the social life and change our life style in all levels of society. New trends in customer behavior in the world together with the improvement of technology and increasing availability of computers represent new approaches to the implementation of production.

Modern industries are undergoing a transformation in accordance with the standards of Industry 4.0. This is a modern standard used mainly in the Germany and it is an approach to implementing new technology into production [15]. In otherwise, in other countries, the process is known as Smart Factory (SF) [12]. Individual enterprises made in accordance with the standard of 4.0 Industry can be integrated into larger units, thus creating virtual enterprises known as Cyber Physical Systems (CPS) [14]. Due to the complexity of such systems, it is clear that the part of the production management needs to be appropriate Enterprise Resource Planning system (ERP) associated with the appropriate Customer Relationship Management (CRM) system. In addition it is necessary to create a direct connection with CRM systems on side of suppliers and customers.

The combination of these advanced software tools along with other production technologies together with BI and new methods of design and analysis is a really big challenge. The potential of such a solution is enormous but also presents a number of problems when applied in practice and in a dynamic environment of modern automated robotic manufacturing systems.

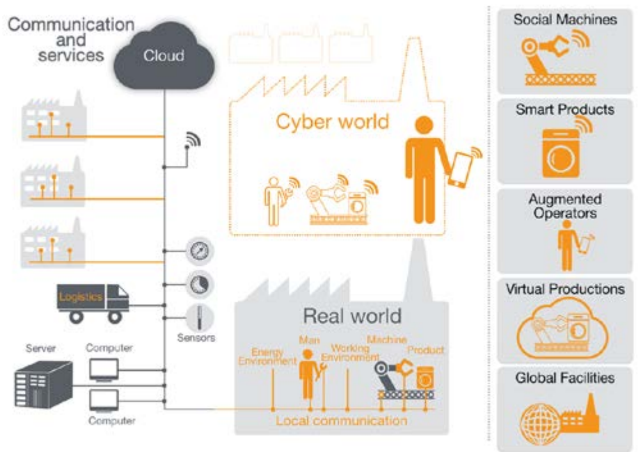


***Fig. 1*** *Communication in real world and CPS [8].*

The public is familiar with term Internet of Things (IoT) [17], which represents the next generation of products and communication between them. The implementation of this technology in practice (IoT) is directly linked with the standard Industry 4.0. The existence of smart products [2] and communication between products is one of the main prerequisites for the realization of intelligent manufacturing. Due to the complexity of the whole process it is necessary to include Customer Relationship Management (CRM) systems and supply systems into communication process.

The implementation of new standards in the realization of manufacturing enterprises will place increased demand on industrial communication. Communication occurs at various stages of the production process. In CPS regards communication between departments of production, on lower levels is a communication between products and machines, machine and man, alternatively product (smart product). Communication paths yet represent most vulnerable points especially in the use of wireless technology and connecting to a network.

## *2. The current state of implementation Industry 4.0 in practice*

Scientific and Technical Development can be divided into several revolutions. The first three were the result of the technical revolution and revolution in electronics and mechanics. The current stage of development of the industry can be described as a revolution of informatics and communications. This results in a high degree of globalization and the creation of enterprises, whose existence is based on communication. Solutions realized in accordance with the standards of Industry 4.0. respectively Smart Factory, are slowly beginning to appear in all industry sectors. The overwhelming majority of solutions, however, exist only in the form of models or theories, exceptionally in test operation in a specialized case. According to the authors [18], the problem is the cause of the lack of implementation of the following functions in the production process:

- horizontal integration through value networks
- end-to-end digital integration of engineering across the
- entire value chain
- vertical integration and networked manufacturing systems

Moreover, the authors in their work set 8 different targets to be met in the future for the successful implementation of Smart Factory in practice. Similar conclusions are contained in the work of the author Defang Li [5]. He clearly defines the estimated plan of implementation of necessary functions in practice in specialized production. However, it is everything in the stage of preconditions without any real deployment.

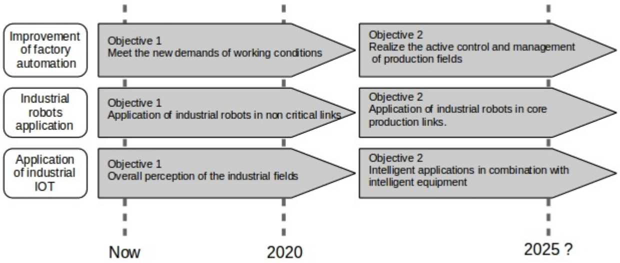


***Fig2.*** *Prediction of application of Industry 4.0 standards in production [5]*

There are many articles as implement Smart Factory. The authors of the source [14] believe that it is mainly the implementation of universal cells and working model of production as a dynamic process. Authors of sources [29, 12] elaborated a design of implementation of the flexible production line in accordance with the standards elaborated Industry 4.0. Part of their work is simulation and they are also present diagrams and calculations with respect to optimizing the quality, availability of resources and energy consumption of factory. The real model of production unit is a work of team of authors [19] and similar solutions are implemented in the aerospace industry [25] and in the petrochemical industry [5]. The implementation of virtual enterprises is described in other sources.

The authors [3] describe CPS (Cyber Physical Systems) which represent the next stage of industry innovation.

A very interesting approach to the proposal of CPS production unit with optimization to localization of sources of raw materials and territorial conditions is outlined in [19] in the food industry. In [16], the team deals with predictive maintenance and data management using BigData and neural networks. Similarly, authors of work [26] describe the realization of factory for production of hybrid electric drive in accordance with the standard of Industry 4.0.

Authors of the article [4] and [7] define a framework for Industry 4.0 that meets the requirements for the implementation of the CPS. They define the system for connection of the real and the virtual world by creating virtual objects within the Smart Factory. Because the processes in these objects are considerably complicated, to deal with them is necessary to use methods such progressive methods as BMMN [1] and MDCN (Multicriteria Decision Making) [6].

The highest level of implementation of Industry 4.0 is in practice creation of virtual enterprises with almost universal possibilities of production. A detailed description of the implementation of these factories is the content of the work of authors [13] and [11]. They defines the term Ubiquitous Manufacturing (UM), which represents the Smart Factory implementation of such a high degree that is almost unimportant the type of manufactured products, production technology and factory location. The mentioned literary sources are largely only theoretical or experimental laboratory solutions. However, there are working models of Smart Factory implemented in real practice. For example Zhang et al. [6] established a real-time management system for a small flexible manufacturing system (FMS) by using smart objects such as RFIDs and auto IDs and Web services. The FMS was composed of three workstations, one trolley, and one shelf. RFID tags were used to identify operators, components, pallets, and locations on the shelf. RFID readers were integrated with a smart gateway and wrapped with Web services to be easily invoked. Thus, the material flows in the FMS could be automatically traced; the WIP level could be monitored, and, based on the monitoring results, proper shop floor control actions could be taken. Bose and Pal [30] installed auto-ID readers at point-of-sale, storage, and receiving locations to automate data collection. During their investigation, several concerns were raised regarding whether an auto-ID application could be successful, including the acceptable initial investment, item-level or pallet-level tagging, data storage, analysis, privacy, big-band or phased adoption, and integration with existing management information systems (MISs).

The application of Industry 4.0 standards is the aim of research of many world leaders in automation and they have testing facilities for testing of deployment and development of new technologies for Industry 4.0.

## *3. Problem identification*

The common element of all the work is only partial implementation of standards, which is of course due to the lack of standardization of processes, devices and applications. The team of authors in [11] identify the causes of this condition. According to them, this is because of the great variety of materials, products and procedures. They offers solution through the creation of industrial clusters, where are created groups of facilities with similar orientation to the production units and taken together form a Virtual Enterprise (VE). A similar approach asserts authors of the work [15, 20]. Similarly standardization is needed for a communication tools and software interfaces. In addition the communication is often wireless and it is also necessary to originate a unified encryption and security system.

Standardization issues in the implementation of Industry 4.0 process are clearly due to the insufficient level of flexibility of automation in general. Devices at the lowest level are highly specialized for a particular function and are focused on maximum efficiency. This results in a low variability and small level of compatibility.

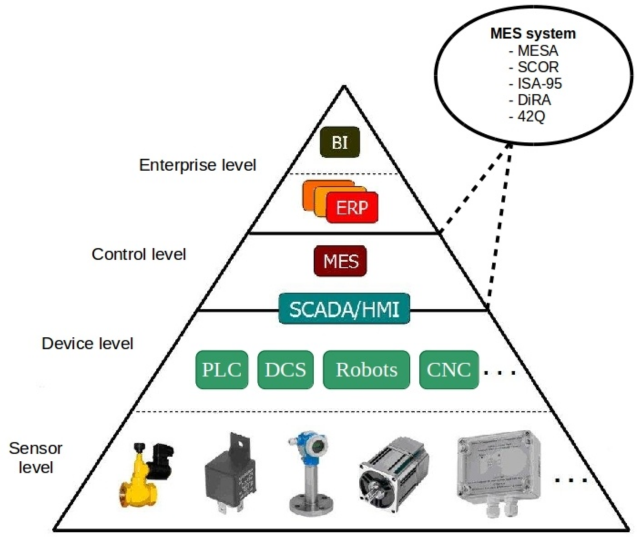


***Fig. 3*** *MES in standard automation model.*

For the realization of enterprises in accordance with the Industry 4.0 standard it is necessary to solve the above conditions. This involves hardware and software interference with the essential elements of the current automation. It requires a comprehensive approach and solution from the highest level to the lowest level of automation model. The current situation is opposite. For example, on control level, to existing standards for MES systems (MESA, SCOR, ISA-95) has been added new MES standard – DiRA. Behind the acronym is hiding activity of companies Hewlett Packard and Microsoft (Reference Architecture Framework for Discrete Manufacturers) and according to source [32] it represents their "enterprise approach" to MES and "fits nicely within the Microsoft framework to help companies meet today's manufacturing challenges more effectively." The expansion of family of MES systems however does not end. We have to add to them latest MES system 42Q [33].

## 3. Problem solution proposal

It is clear, that the key to solve a really large set of problems is probably deeper standardization for hardware and software basis. We consider that it is important to specify framework regions, in which it is necessary to make changes to the system.

For successful implementation of Industry 4.0 standards and creating SF is necessary to satisfy the following conditions in the production and planning process:

- need for standardization of communication protocols
- need for standardization of connectors and physical interfaces
- need for standardization of data exchange (standardization of applications)
- the necessity of the existence of a standardized management system (there is missing a unified ERP or MES system)

The process of real deployment of Industry 4.0 standards in practice itself implies significant progress in the development of key technologies, such as:

- artificial intelligence, neural networks (Intelligent Robotics)
- processing and analyzing "big data"
- automatic knowledge discovery, i.e. self-learning, self-adapting and subsequently self-optimization in a dynamic environment
- possibility of full automation of all processes
- possibility of virtualization and simulation of processes in all stages of the production cycle of a product (processing of raw materials - suppliers - production - sales - waste/recycling)
- improve interaction in the relationship man - machine ( better perception of the environment by machine, better perception of human behavior and simplified communication of human and devices/computers)

The communication between all devices is an essential element on which it stands enterprise infrastructure in an Industry 4.0 standard. However, no existing standardized communication or network infrastructure has been used to widely accepted standard in automation. Most of protocols are based on TCP/IP communication; also the TCP/IP is part of many automation protocols. Difference between TCP/IP internet communication and automation networks is timing. Therefore one of top needs in Industry 4.0 is to create a possibility of communication and data transfer between networks of IoT, automation devices network, customers and suppliers systems.

## 4. Conclusion

The presented text makes it clear that the implementation of enterprises in accordance with Industry 4.0 standards in practice is a very complex process. The key to achieving a satisfactory state is mainly standardization. It means not only standardization of basic structural elements, but also standardization on higher levels, i.e. software, control systems and communication interfaces. Moreover, the current state of industrial automation in principle does not allow such flexibility as needed. We believe that it is possible with the gradual application of Industry 4.0 principles into practice over time to achieve high degree of flexibility in production companies but really universal production and virtual smart factories are currently dreams of the future. Success deployment of Industry 4.0 standards depends on the development of appropriate new standards as an application, as well as communication.

## Acknowledgement

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# KNOWLEDGE TRANSFER INDUSTRY 4

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***Abstract:*** *In this article we consider the need to work with all knowledge. For Industry 4.0, in particular for micro-companies (family) is compulsory transfer of the knowledge to them. This revolutionary change will free many works places. Create new jobs for mathematicians and physicists Mathematical Physics i.e. digitalization of business by "smart factories" and we introduced these ideas to micro-foundry.*

**Keywords**: INDUSTRY 4, DIGITALIZATION OF BUSINESS, MATHEMATICIANS AND PHYSITIANS, ECONOMY

## *1. Introduction – Horizon 2020: European, global thinking and openness to the world [1, 2, 3, 4].*

The knowledge is open system: 1. The results of all sciences complete knowledge continuously throughout the history of mankind; 2. Fundamental scientific results are the basis for innovation technologies and products; 3. The full history of knowledge to the modern point of time limits of knowledge. Development of knowledge through, because research done at its borders, often called - border.

## *2.1 Three pillars developing of the Knowledge – History: philosophy, mathematics and physics [12].*

Greek: *φιλοσοφια*, from *φιλεῖν* — I love and *σοφία* — wisdom) it is the study of general and fundamental questions concerning man and the world. **History of Philosophy:** Main areas and object of study: ***Metaphysics*** – Nature and Origin of the existing and the world; ***Ontology*** – Being; ***Epistemology*** – Knowledge of nature and the possibility of a cognitive process; ***Ethics*** – Morality - how to act human, correct behavior and "good life"; ***Political philosophy*** – Governance and respect for human and communities to the state; ***Aesthetics*** – beautiful, sublime, art, pleasure; ***Logic*** (mathematical and philosophical) – Forms and laws of thinking; valid forms of argumentation; ***Philosophy of Language*** – Beginning, development, use and attitudes towards thinking; ***Scientific methodology*** (academic disciplines) - Grounds and subject: science; history; mathematics; physics; psychology; anthropology, etc. **History of Mathematics Before Christ:** to ~ 2500y. necessary: count + measurement and verbally counting; ~2500y. Mesopotamia was introduced and developed decimal-sixty positional notation; ~2000y. Mesopotamia – solving algebraic equations of second degree (square equations); mathematics developed in Ancient Egypt; ~ 550y. Pythagoras – theorem for countries in right triangle (known before in China, Mesopotamia and ancient Egypt); ~450y. Ancient Greece Hipas (Hipazos) – some numbers are irrational; ~300y. Euclid - the laws of geometry taught today; ~230 magnetism y. Eratosthenes – finding all primes (sieve of Eratosthenes); ~190y. China – use rates of 10 to express values; ~100y. China – began using negative numbers; **After Christ (Anno Domini)** ~210y. Diophantus – first treatise on algebra; ~600y. India – began to use the decimal positional system; 829y. Persia Mohammad ibn Musa al Khoresm – use decimal notation, which get to know later and liaison with European scientists; ~876y. India – symbol for zero. ***1000-1599*y.:** 1202 Italy Leonardo Fibonacci – numerical series: 1, 1, 2, 3, 5, 8, 13, 21, … , $n_i = n_{i-1} + n_{i-2}$; 1550 Germany G. von Lauhen – a seven trigonometric tables (for 1st time + sekansi); ***1600-1699*y.:** 1614 John Napier – logarithms; 1623 Germany W. Schickard – mechanical computer with (+, −, ×, :); 1637 R. Descartes – analytical geometry; 1654 Blaise Pascal and Pierre de Fermat began construction of probability theory; 1666 England I. Newton – differential calculus as a method for calculating the instantaneous speed; 1675 G. Leibniz – differential and integral calculus + mathematical signs and symbols used today; 1679 G. Leibniz – binary arithmetic; 1684 G. Leibniz – essay on differential calculus; ***1700-1799*г.:** 1713 J. Bernoulli – 1-st law of large numbers of probability theory; 1718 J. Bernoulli – common definition of functionм 1744 Switzerland L. Euler – variational calculus; 1747 J. d'Alembert – partial differential equations in the problems of physics; 1798 Denmark C. Wessel – vector representation of complex numbers; 1799 C. F. Gauss – the base algebra theorem: the number of solutions to algebraic equation is the degree equation; ***1800-1899*г.:** 1810 J. Fourier – presentation of functions by trigonometric lines; 1812 P. Laplace – First complete and detailed statement of probability theory; 1822 United Kingdom Ch. Babbage – began construction of the 1st mechanical computer Difference machine to calculate logarithms and trigonometric functions, introduced (1834) and recording mechanical The apparatus and punch card tabulator; 1827 C. F. Gauss – beginning of differential geometry of surfaces; new geometric system of N.I. Lobachevski – non-Euclidean geometry hyperbolic, with the validity of the axioms of Euclid without parallel lines; E. Galois created the theory of groups with basic terms used today; 1844 France J. 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Cantor continuum of other axioms of set theory; 1975 USA M. Feigenbaum – new constant (≈ 4, 6692016…) with an important role in chaos theory; 1976 USA K. Appel and B. Haken – decision, a 4-colors are sufficient to color any planar map; 1980 Ends 35-year labor of hundreds of mathematicians from around the world – classification of all final and simple groups results hold over 14 000 pages; 1989 Group of mathematicians Amdal Corporation, California, is the largest known prime number so far (containing 65 087 digits); 1994 United Kingdom A. Uaylz – evidence (about 150 pages) of Fermat's Last Theorem, one of the biggest challenges of pure mathematics; 1996 The proof of A. Uaylz (in revised form) is recognized. History of physics Before Christ: ~450г. Leucippus – ancient atomistic; ~400–450г. Democritus – develops of atomistic Leucippus; ~250–450г. Archimedes – Law hydrostatic pressure; **After Christ:** 9-15 century Arab scientists – Alhazen optics; mechanics, static and dynamics; ***Physics – independent science*** 1600y. W. Gilbert – magnetism and many и electrical phenomena; ~1610y. G. Galilei – law on free fall of bodies; 1642y. B. Pascal – principles of hydraulics; 1643г. E. Torricelli – mercury barometer; 1657y. K. Huygens – clock with pendulum; 1662y. R. Boyle – ideal gas law (relationship between volume and pressure at a constant temperature (Boyle-Marriott); 1687y. I. Newton – "Mathematical principles of Natural Philosophy", foundations of classical mechanics; 1690г. K. Huygens – wave theory of light; ***Physics – intensive development*** 1704y. I. Newton – corpuscular theory of light; 1714y. D. Fahrenheit invented the mercury thermometer; 1771y. L. Galvani – experimental electrophysiology; 1787y. J. Charles formulate the ideal gas law – the relationship between pressure and temperature constant; 1801y. Thomas Young – principle of interference of light; 1811y. A. Avogadro – ideal gas law (relationship between volume and amount of molecules in it); 1818y. O. Fresnel – theory of diffraction of light; 1820y. H. Oersted – magnetic effect of electric. current; A. Ampere – laws of electromagnetism; 1826y. G. Ohm – law of electrical resistance; 1827y. R. Brown observed Brownian motion explained later by Albert Einstein between molecular interactions; 1831-34y. M. Faraday – electromagnetic induction, inductance and the laws of electrolysis; 1842 y. J. Meyer – low of conservation energy; A. Fizo measured the speed of light in earthly conditions; 1851y. G. Foucault demonstrates around-founded rotation of the Earth through the experience with the Foucault pendulum; 1854-59y. R. Bunsen and G. Kirchhoff – spectral analysis; 1873y. J. Maxwell – electromagnetic field theory, classical electrodynamics; 1880y. P. Curie – piezoelectric effect; 1886-89y. H. Hertz experiment – There are electromagnetic waves; 1892y. A. M. Lyapunov – theory sustainability of balance and movement of a mechanical system with a finite number of parameters; 1895y. W. Röntgen – X-rays (Röntgen rays); 1896y. A. Becquerel discovered natural radioactivity; 1897y. J. Thomson discovered the electron; 1899y. A. Rutherford – nature of α- and β-rays; ***Modern physics*** 1900y. M. Plank – explanation of the law on radiation blackbody by hypothesis: energy exchange of small packets (quanta) i.e. quantum mechanics, in large part is based on the quantization of matter and Energy + wave-particle duality (de Broglie hypothesis). Quantum theory was developed by Planck, Einstein, Bohr, Schrodinger, Heisenberg, Ehrenfest, Bourne and others. It proved fundamental to the progress of physics and technology in the 20th century. Without it, it would be unthinkable learning and understanding the atomic nucleus (with applications in energy, medicine, and of course, fundamental science), semiconductors, lasers, interstellar medium, compact stars (white dwarfs and neutron stars) and the early universe. 30% of US GDP comes from industry applications of quantum mechanics. 1903 y. — A. Rutherford and F. Soddy – theory of radioactive decay; 1905y. A. Einstein – special theory of relativity; 1911y. A. Rutherford – planetary model of the atom; 1913y. N. Bohr developed the quantum theory of the atom; 1915-16г. A. Einstein – general theory of relativity; 1919-21y. A. Rutherford – proton, predicts the existence of neutron; 1926y. E. Schrödinger – wave interpretation of quantum mechanics; 1927y. W. Heisenberg – uncertainty principle in quantum theory; 1932y. J. Chadwick – the neutron; K. Anderson – the positron; 1933-34y. I. and F. Joliot-Curie – artificial radioactivity; 1937y. P. L. Kapitsa – superfluidity of liquid helium; 1938y. O. Hahn and F. Strassmann – division of atomic nucleus; 1942y. E. Fermi – the first controlled nuclear chain reaction; 1947-48y. D. Gabor – method of recording, conversion and reproduction of wave fields (holography); 1954y. Ch. Townes (US), N. G. Basov and A. M. Prokhorov (USSR) – the first laser; 1956y. K. Cowan and F. Rayns – neutrino; 1958y. R. Mössbauer – elastic nuclear resonance absorption of γ-raise; 1964y. M. Gell-Mann and J. Zweig – quark theory; J. Cronin and V. Fitch – theory of breaking the law of symmetry in the combined inversion; 1983y. K. Rubin – gauge boson $W^{\pm}$ and $Z^0$ –carriers of the electroweak interaction; 1986y. K. Muller and J. Bednorts – superconductivity in ceramic materials at T = 35 K (high-temperature superconductivity); 1989y. Comes into play large electron-positron collider (LEP) at CERN (European Organization for Nuclear Research); 1995y. At CERN – the first atom of antimatter (antihydrogen); K. Viman and E. Cornell – condensate Bose-Einstein; 2009y. Comes into play Large Hadron Collider (LHC) at CERN.

### *1.2 Ecology in the Knowledge [12].*

Greek philosophers Hippocrates and Aristotle laid the foundations of ecology in their study of natural history. The concept of ecology (ecology) (Ökologie) t was introduced by the German scientist Ernst Haeckle in 1866y. From Greek: οἶκος, "house", or "environment"; -λογία, "study of". Modern ecology becomes science in the late 19th century. Environmental thought is derived from the established currents in philosophy, especially ethics and politics. ***Ecology** is the scientific analysis and study of interactions among organisms and their environment. It is an interdisciplinary field*: **Hierarchy of life:** Biosphere > Ecosystem > Community (Biocoenosis) >Population > Organism > Organ system > Organ > Tissue > Cell > Organelle > Biomolecular complex > Molecular (Macromolecule, Biomolecule) > Atom; **Foundations:** Cell theory, Ecology, Energy Transformation, Evolution, Genetics, Homeostasis Synthetic biology Taxonomy; **Principles**: Evolution, Adaptation, Genetic drift, Gene flow, Macroevolution, Microevolution, Mutation, Natural selection, Speciation; **Ecology**: Biodiversity, Biological interaction, Community, Ecosystem, Habitat, Niche, Population dynamics, Resources; **Molecular biology**: Cell signaling, Development, Epigenetics, Gene regulation, Meiosis, Mitosis, Post-transcriptional modification; **Biochemistry**: Carbohydrates, Lipids, Metabolism, Nucleic acids, Photosynthesis, Proteins.

### *1.3 History of XIX and XX century and it influence on developing of the Knowledge [12].*

Politics influence on the developed of the knowledge by interaction knowledge-technology: 1. Knowledge-technologies and standard of living; 2. Knowledge-technology and problems of security. Challenge – sustainable society, the world and nature.

Introduction is a short picture of **KNOWLEDGE** to transfer.

### *2. Digitalization of Business by Smart factory [2-4]*

The subject of Industry 4 is Smart factory – based on: integration of cyber-physical systems that create virtual copies of the physical world in the design, monitoring physical processes in the production and take your-self decentralized solutions.

### *2.1 Knowledge Transfer – Industry 4*

The innovations are product of the fundamental results, which show on Fig. 1 – transfer of the full knowledge (see Introduction)

| K N O W L E D G E | | ⇨ TRANSFER |
|---|---|---|
| **PHYLOSOPHY** - Methodology of Science | | ↓ |
| Mathematics and Foundation of Mathematics | Fundamental Experiments and Mathematical Physics | INNOVATION ↓ TECHNOLOGY |
| Ecology | History and XXI Century | |

***Fig. 1*** *Subject of Knowledge Transfer → Innovation → Technology*

*Knowledge: Philosophy – Methodology of Science; Mathematics and Foundation of Mathematics; Fundamental Experiments and Mathematical Physics; Ecology; History and XXI Century.*

On Fig.2 is shown scheme Office of knowledge transfer

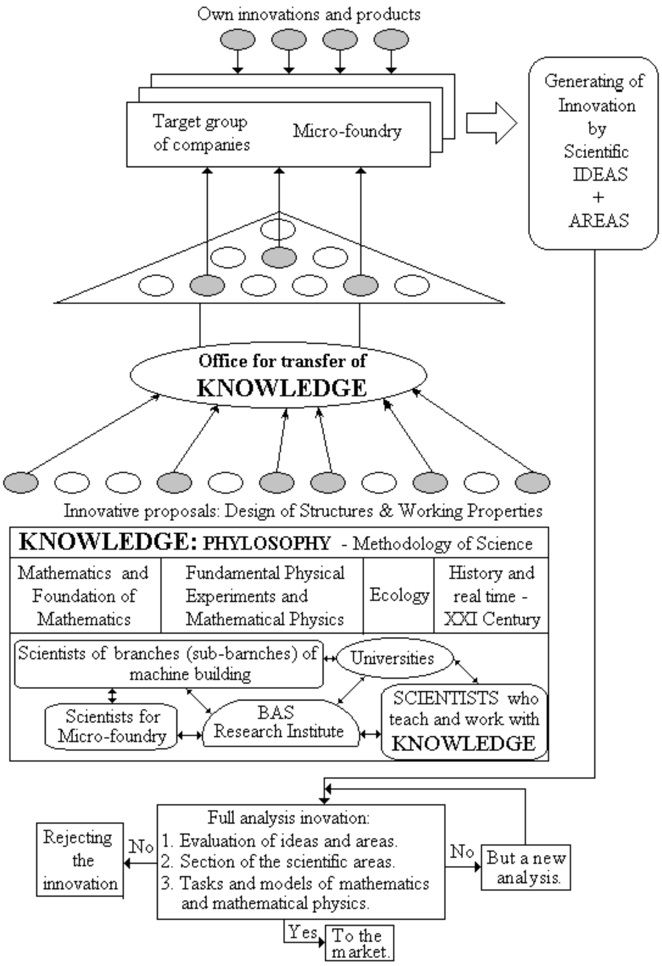


***Fig. 2*** *Principle scheme of office of knowledge transfer to innovation the subject of cast technology – Design of structures & Working properties*

*Knowledge: philosophy – methodology of science of: Mathematics and Foundation of mathematics; Fundamental experiments and Mathematical Physics; Ecology; History and real time of XXI century; Scientists, who teach and work with knowledge; Institutions - Universities and thoroughly Researches Institutes of the Bulgarian academy of sciences; Business branches; Office for transfer of knowledge; full knowledge are whites ⬭ and ⬬ innovations ideas + areas of our transfer are the grays; Target group of companies; Full analysis of generated innovation – micro-foundry.*

Sustainable development of the world is necessary to ensure homogenization of standard of living and security, but modern technology cannot provide “renewables” as there is in nature.

## *2.2 Knowledge Transfer – micro-foundry [7, 8, 9]*

Development of knowledge is strongly influenced by ecology and politics, and further hinders research to create new technologies. **Ecology complexity**: everything is connected and its multidisciplinary field of research between model and process in natural systems. **Politics**: History of the World in the 19th and 20th century is very instructive about the impact of policy on the development of knowledge. The achieved standard of living is the biggest confirmation interaction knowledge technologies. Security issues are another impetus to the development of knowledge. Interaction knowledge technologies in the economy provide a reduction of costs of labor, energy, materials and resources.

The structures are obtained in phase transitions of first and second order and winner of working properties of cast materials and products. On Fig.3 is shown: Knowledge transfer for micro-foundry according to Design of structures & Working properties

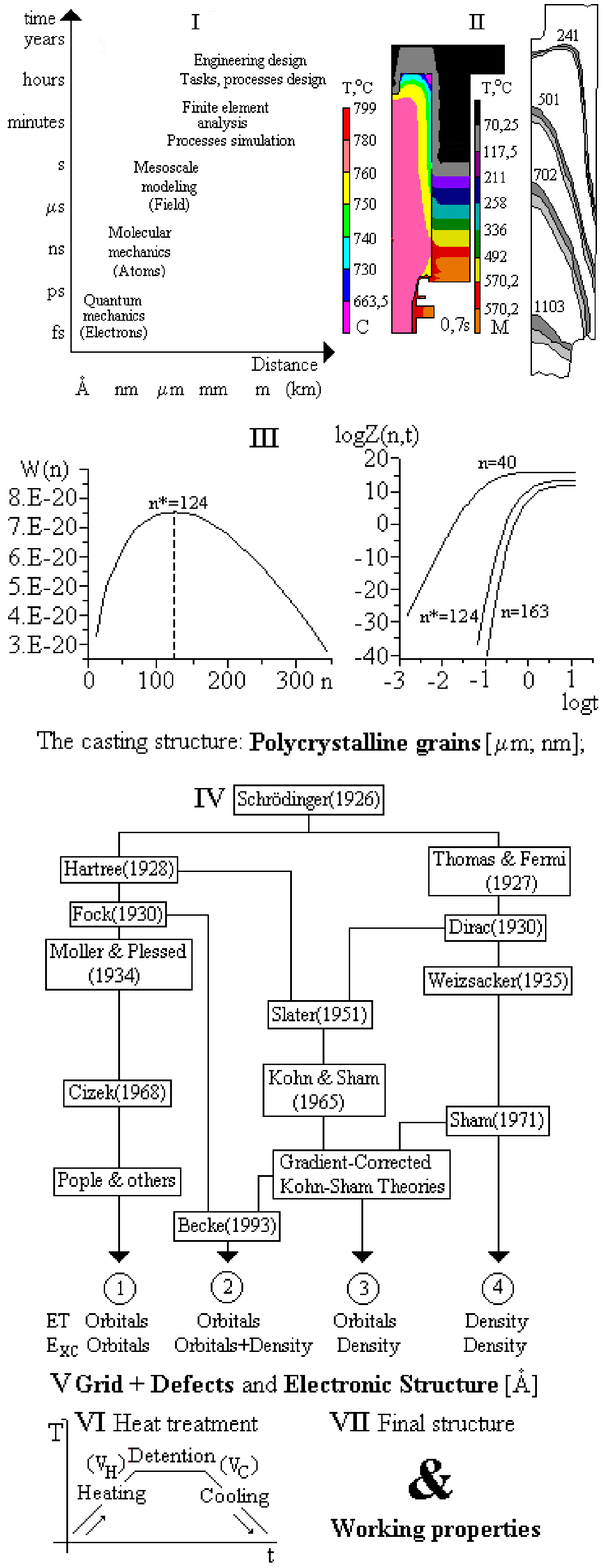


***Fig.3*** *Knowledge Transfer for micro-foundry – Design of structure & Working properties*

*I – Multiscales modeling and structure design; II technological move (regime) of solidification zone – , where develop phase transition of first order; III – crystallization, nucleation work W of nuclei with n particles(atoms), number of nuclei of n particles (n* – critical nucleus) and the end Polycrystalline grains with size [μm; nm]; IV – quantum chemistry methods, $E_T$ – the kinetic energy of electrons; $E_{EX}$ – exchange functional [5];*

*V – meso-level structure of grains, Grid+Defects and electronic structure [Å]; VI –heat treatment, phase transition of second order; Heating and Cooling with velocities $V_H$ and $V_C$; VII – Final structure with Working Properties.*

### *2.3 Economy – little market, micro-foundry and sustainable future*

World economy creates ample opportunity for the development of small (local) geography markets. For small domestic market – the main reason as a source of development is the preservation and development of the standard of living. Sustainable future of our economy is transfer Sustainable future of our economy is the inclusion in the fourth revolution Industry 4. For example in the US historically taken [2]: The 1st industrial revolution was driven by the advent of steam engines being used to power production facilities; The 2nd industrial revolution was driven by the assembly line, exemplified by Henry Ford a century ago; The 3rd industrial revolution, which occurred in the 1970s, was driven by the use of computers in production.

### *2.4 Base principles – smart factories*

**Interoperability:** the ability of cyber-physical systems (delivery of parts, assembly plants and products), people and "smart" factories to connect and communicate with each other through the "Internet of Things" and "Internet Services"; **Virtualization:** virtual copies of the smart factory created by connecting the sensor data to monitor the physical production process with the virtual model of the factory and models for simulation of production; **Decentralization:** the possibility of cyber-physical systems in a smart factory to make decisions for yourself; **Ability to work in real time:** the ability to collect and analyze data in real time for immediate decision-making; **Orientation services:** supply of services (cyber-physical systems, people or smart factories) by "Internet Services"; **Modularity:** flexible adaptation to smart factories to changing requirements through replacement or extension of individual modules; 3D Printer **Security:** the biggest challenge is limiting risks related to security.

### *2.5 Market "Smart Factory" – micro-foundry.*

On Fig. 4 is shown “Smart Micro-foundry” for Industry 4

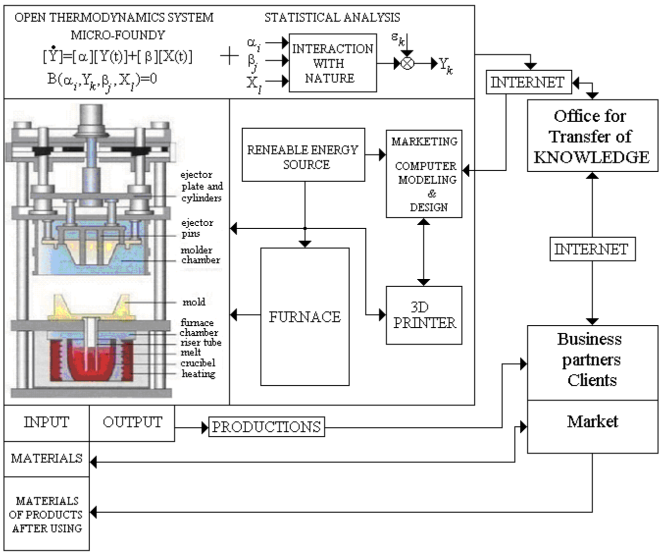


***Fig.4*** *Ecology–economics complex of “Smart Micro-foundry” on the base of Gas counter pressure casting method – Industry 4*

*Micro-foundry is Open Thermodynamics System (OTS) is describe by stochastic differential equation in the subject of Ito – Stratonovich, which introduce transformation input materials and energies flows, where matrixes $\alpha_i$, $\beta_j$ – physical and constructive parameters, and i, j =1,…, m; matrixes column X(t), Y(t) – input, output parameters, and k, l = 1,…n; equation B is operator of controllability of OTS, which is support in zero by change of some parameters of control [10]; Statistical analysis $\varepsilon_k$ – ecological complexity interaction micro-foundry with nature [6], 3D Printer [11].*

For preservation and development of our standard of living is necessary in our opinion to buy and patents to quantum mechanics and economic reforms. The revolution Industry 4 is need of many scientists – mathematicians, physicists, IT specialists, engineering of electronics and computer hardware. Many work places will close. For that reason the workers need of skills of “sustainable job” or “sustainable future” on the base of education of all life.

Scientific Research Fund intensifies through mathematics but complete theory cannot do according to Gödel’s theorem. Development of knowledge is through research on its borders, which requires estimates with the greatest likelihood to prove theorems necessary. Development of knowledge is through research on its borders, which requires estimates with the greatest likelihood to prove theorems necessary. Person-year is a measure of infiltration of mathematics and mathematical physics in scientific experiments and micro-companies (family) needed job creation - for example is needed 3600 (person-years per year); BAS total of 35 000 (person-years per year); for the economy to about 100 000. This perspective we believe is aimed at the future with decades ahead, but a mass influx of scientists in the economy should start from many years ago.

## *X. Conclusions*

Knowledge transfer to economy is by Computational Mathematics and Mathematical Physics and patents of quantum mechanics.

Our economy will need for the next years from many mathematicians and mathematical physicians

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# COMPANIES OF FUEL-ENERGY COMPLEX IN THE CONTEXT OF REGIONAL DEVELOPMENT: SOCIAL INNOVATION

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***Abstract:*** *The main issues considered in this paper are: social innovation: the approach to increase financial participation of energy companies in the development of municipalities and regions; financial basis of social partnership between the enterprises of fuel and energy complex and regional authorities.*

**Keywords**: REGIONAL DEVELOPMENT, SOCIAL INNOVATION, COMPANIES OF FUEL-ENERGY COMPLEX, INFRASTRUCTURE, SOCIAL PARTNERSHIP

## *1. Introduction*

Due to the specific structure of the Russian economy, the fuel and energy complex (FEC) is having a multidirectional impact on regional socio-economic system because it is basic regional infrastructure, and even in a crisis it remains the most important source of formation of a profitable part of budgets. It largely determines the possibility of implementation of social programs of regions and municipalities. The restructuring of the Russian economy and the negative processes in the external environment necessitate the use of social innovations, taking into account the existing potential of energy companies. They can include a change in the tax relations, as well as the development of social partnership in regions.

Companies of FEC are part of infrastructure development corridors (the territory where major investment projects are realized), which include both physical and innovation-investment infrastructure. Fuel-energy infrastructure provides the possibility of life on the territory (statics); transport infrastructure provides the connectivity of the territory (dynamics). Companies of FEC, receiving income from the resources of the territory, form the production frame of a territory. The combination of infrastructure development corridors, passing through the territory of the municipality and region, creates a framework for their development. Thus, the corridors of development have used resources of the territory. In this regard, it is necessary to increase financial participation of energy companies in the development of municipalities and regions.

A new approach to the taxation of income of employees may become the mechanism of participation of the extractive energy companies in the funding of strategic programs and development projects. The changes affect those individuals who have gross income for the tax period exceeding eight times the average wage by region. An additional amount of tax is distributed between the municipal and regional budget. The mass of municipal tax is proposed to determine using the Gini index. Regional mass of tax depends on the status of the region in the corridors of development, firmly fixed fact of implementation of projects in the region.

Such distribution may become the financial basis of social partnership of the enterprises of fuel and energy complex and regional authorities.

The *objective* of the theoretical research is to analyze possible mechanisms for the participation of companies of the fuel-energy complex in the regional development.

## 2. *Prerequisites and means for solving the problem*

The activities of companies in fuel-energy complex are carried out in the framework of regional socio-economic system. Communications of companies in fuel-energy complex with other elements of regional socio-economic system, forms and conditions of such communications, which are depending on the competitiveness level of such enterprises, can be defined by theory of the market space, including the theory of spatial competition [1].

Actually, the reference points of this theory are:

- highlighting of complex factors of the productive forces localization in certain territories of the regional socio-economic system;
- possibility of obtaining the cumulative effect of the selected option territorial productive forces distribution.

Space (territory) localization of the activity of companies in fuel-energy complex is called the territory, where main production of the corporations and/or its subsidiaries, branches, divisions, provided the extraction, processing, transportation of fuel-energy resources, are located.

Companies in fuel-energy complex are important elements of sustainable development of regional socio-economic system, which have bipolar determinants of placement. They gravitate to the territories, possessing large reserves of natural resources; to urbanized territories, characterizing by a high level of transport, industrial, social, and financial infrastructures development [2,3,4].

Taking into account these determinants in the context of declining financing of the companies in fuel-energy complex the axis of regional development of economies and TRANS-regional interactions are formed.

Statistics demonstrate a high and growing over the last two years level of population poverty in the Russian Federation (table 1) during simultaneously increasing of Gini Index. This situation indicates the relative ineffectiveness of the current fiscal policy, which doesn't stimulate the development of small and medium enterprises and doesn't provide fulfillment of the social state obligations.

The unfavorable business environment and reducing real incomes are sufficient reason for review of fiscal policy in the direction of strengthening communication companies in extractive industry, in particular – in fuel-energy complex, with municipal and regional authorities in target to develop territories. This cause requires a review of the fiscal federalism mechanism, including fiscal relationships from the standpoint of increasing their own revenue part of local budgets.

Powerful industrial, economic and human potential of companies in fuel-energy complex plays a significant role in territorial development. However, it is worth attention to the social problems in the area. The reduction of budget financing of health, education and culture should be combined with an increase of corporate social responsibility for condition and development of social infrastructure in the areas of their localization [5,6].

Table 1 – Population with incomes below living wage and lack of cash income in Russia

| | Population with incomes below living wage | | Lack of cash income | |
|---|---|---|---|---|
| | million people | percentage of total population | billions of rubles (before 1998 г. – trillions of rubles) | percentage of total volume of money incomes |
| 1992 | 49.3 | 33.5 | 0.4 | 6.2 |
| 1993 | 46.1 | 31.3 | 4.3 | 5.4 |
| 1994 | 32.9 | 22.4 | 11.1 | 3.1 |
| 1995 | 36.5 | 24.8 | 34.9 | 3.9 |
| 1996 | 32.5 | 22.1 | 42.8 | 3.2 |
| 1997 | 30.5 | 20.8 | 46.2 | 2.8 |
| 1998 | 34.3 | 23.4 | 61.5 | 3.5 |
| 1999 | 41.6 | 28.4 | 141.3 | 4.9 |
| 2000 | 42.3 | 29.0 | 199.2 | 5.0 |
| 2001 | 40.0 | 27.5 | 238.6 | 4.5 |
| 2002 | 35.6 | 24.6 | 250.5 | 3.7 |
| 2003 | 29.3 | 20.3 | 235.3 | 2.6 |
| 2004 | 25.2 | 17.6 | 225.7 | 2.1 |
| 2005 | 25.4 | 17.8 | 288.7 | 2.1 |
| 2006 | 21.6 | 15.2 | 277.1 | 1.6 |
| 2007 | 18.8 | 13.3 | 272.1 | 1.3 |
| 2008 | 19.0 | 13.4 | 326.7 | 1.3 |
| 2009 | 18.4 | 13.0 | 354.8 | 1.2 |
| 2010 | 17.7 | 12.5 | 375.0 | 1.2 |
| 2011 | 17.9 | 12.7 | 424.1 | 1.2 |
| 2012 | 15.4 | 10.7 | 370.5 | 0.9 |
| 2013 | 15.5 | 10.8 | 417.9 | 0.9 |
| 2014 | 16.1 | 11.2 | 478.7 | 1.0 |

*Source: composed by http://www.gks.ru/* [7].

Corporate social responsibility is an effective tool for the participation of business organizations in the development of social infrastructure in the areas of their localization. This tool implies that public policies aimed at the motivation of firms, which are responsible of corporate social responsibility, should not be based on the effect of individual charity executives. The policy should base on scientifically idea that socially oriented corporations have the possibility of obtaining additional competitive advantages in the form of institutional annuities' various types. Such annuities allow corporations to effectively implement financial programs of social infrastructure in the areas of their localization [8,9].

We proceed from the fact that according to its economic nature corporate social responsibility is long-term investments in social infrastructure, which forms the institutional environment. In results of process investor has an opportunity to create new competitive advantages, which are the basis of institutional annuities' various types. In these conditions, the social infrastructure is becoming the main point of the institutional environment, the development of which directly influences on the competitive market development, the formation of business competitiveness and improve living standards.

## *3. Solution of the examined problem*

Companies in fuel-energy complex are part of infrastructure development corridors. The level of development of each infrastructure element in the corridor influences on the width of the corridor defined by the least developed element. There are the following infrastructure elements in the corridor: the level of development of fuel-energy infrastructure; the level of development of transport infrastructure; the level of development of social infrastructure; the level of development of regulations and rules of material resources movement; the level of the formation and development of human capital; the level of implementation of property functions; the level of development of the technology transfer order; the level of development of regulations and standards of innovation.

Territories entering in the development corridors, especially – located at their intersection or at the center of regional development have more favorable conditions for development due to project support of federal center. Companies in fuel-energy complex, which have access to non-regional resources and at the same time use the region resources, should invest part of their profits to the region (areas of their localization) development. Directions and targeted use of these funds are determined by the regional authorities within the framework of regional programs.

Personal income tax is a major source of increased revenue of the municipality budget. Companies in fuel-energy complex provide their employees remuneration that may significantly increase the average wage in the region. Differentiation of income, increasing in recent years, is a factor of instability growth in regions and municipalities.

Analysis of Gini Index results, which characterizes the population stratification by income at the regional level, has shown that almost all oil and gas producing regions are characterized by the maximum index value. At the same time the regions, providing the greatest contribution to the federal budget, are the least favorable according to the Gini Index. In such regions local budget are also deficient. Consequently, companies in fuel-energy complex are not the drivers of municipalities development in the areas of territory self-development.

Modification in tax relations consists in the rejection of the flat rate personal income tax. The mechanism of concept realization of the levying tax on windfall revenues of individuals – employees of companies in fuel-energy complex - may be the following:

The rate of the formation of the municipal tax mass (Rm) is supposed to take equal to the difference between the meaning of Gini Index in region (Gs) and the minimum meaning of Gini Index in regions of Russia (Gmin):

$$Rm = f(G) = Gs - Gmin \qquad (1).$$

The total tax mass of the windfall revenues of individuals - employees in central offices of companies in fuel-energy complex (regional mass tax on windfall revenues of individuals) is expected to transfer to the budgets of regions. The region share of transfer depends on the status of its territory in the development corridors and fixed by the fact of projects implementation in the region.

The task of the distribution of tax mass of the windfall revenues of individuals is solved in four stages by using dynamic programming. Model approbation (simulation) ensures the feasibility of mass distribution of the municipal tax using a supposed method.

The variability of economic effect presentation from the realization of municipal socio-economic processes is simply provided, for example, by standard sensitivity analysis of the business plan to changes in external factors.

Along with the improvement of fiscal federalism relations, focused on the formation of funds for the territories development, we can also offer the concept of corporate social responsibility.

In usual conditions business isn't directed to free society aid. It creates the conditions and opportunities to reduce its production and transaction costs in different types of rental relations. In this case financial and material investments in the social infrastructure development are the medium-term, and often long-term in comparison with the corporate life cycle. Therefore, only those organizations which at an economic point of view analyze the potential of its development in the medium and long term, have the opportunity to engage in activities called corporate social responsibility.

Moreover, if the investment benefits in the social infrastructure for the state and society is obvious (the society gets new features of its development, the state reduces the pressure on the budget, shifting payments of part of its social functions in the business), the business implementation of corporate social responsibility programs is a matter of alternative expectations and opportunities.

The basic implementation principle of the proposed concept of using the potential companies in fuel-energy complex for territories development is a principle of systematic dialogue based on mutual respect of interests, values, attitudes and differences of key participants. The corporate program of the territory development in its socio-economic content should be an instrument of cooperation companies in fuel-energy complex with local authorities and regional government.

The funds allocated for the program implementation should be output from the tax base in the calculation of the income tax. Program of activities should be formed in communication with the regional and local authorities and it should contribute to solving urgent problems in the macro- and meso-levels.

Business activities, based on its social responsibility, implies its participation in various social programs, aimed at reducing the environmental, technological and other problems, associated with its production in certain territory. Note that large corporations in the fuel-energy complex participate in environmental activities.

Socially responsible business, participating in scientific, economic and social researches, creates the mechanisms and programs of human capital development as the basis for the economic potential growth of the territories.

Territorial dominants of social activity of Russian fuel-energy corporations establish quite difficult due to incomplete data on directions and volumes of financing in the areas of their corporate social responsibility programs. In order to get an overall picture, it was made a content analysis of sites of the largest fuel-energy corporations - PJSC "Gazprom" and JSC "Lukoil" [10,11]. «Gazprom" in the framework of corporate social responsibility implements three basic programs:

- "Gazprom to children";
- support for cultural projects;
- support for the sport.

The program "Gazprom to children" has undoubted importance for the regions and municipalities, because it directly contributes to the formation and development of human capital - important resource of the regional economy. Social and charity programs are positioned by PJSC "Gazprom" as an essential element of cooperation with the state and business environment. Its strategic charity programs and social investments are considered in the aspect of harmonization of the strategic corporation objectives and urgent municipalities social and economic problems.

"Lukoil", using its subsidiaries, is involved in solving the problems of the indigenous population in the territories of its localization. Corporation developed the Social Code.

Also, analysis of companies programs and reports was carried out and the results are the following: "Gazprom" [11], Rosatom [12], "Transnefteprodukt" [13], "Yakutskenergo" [14], "Transneft Siberia" [15], "Inter RAO UES" [16], and some other.

The programs allow generalizing corporation's experiences and proposing the concept of the impact of socially responsible corporations' behavior in the fuel-energy complex on regions and municipalities development.

## 4. *Results and discussion*

Companies in fuel-energy complex are part of infrastructure development corridors, including both physical infrastructure elements and innovative-investment infrastructure.

Among the objects of physical infrastructure fuel-energy and transport infrastructure are highlighted. Fuel-energy infrastructure enables the ability of livelihoods in the territory, its static; transport infrastructure provides connectivity of territories, its dynamics. Corporate structures of fuel-energy complex, receiving income from the territory resources, creates production frame of territory. The set of infrastructure development corridors, crossing the municipality and region territories, creates development frame. Development Corridors created during the implementation of major investment and national projects, use territory resources.

Stimulating role of corporate structures in the sector consists in increasing of their financial presence in the municipalities and regions. This is possible due to the attachment of income to territorial development, including social infrastructure within the framework agreed with regional management programs.

The question of the producing companies' participation in the formation of revenues in municipal budgets to finance expenditures in excess of current needs (strategic development programs and investment projects) is also legitimate. It is supposed to direct part of the tax on personal income imposed on employees of companies in fuel-energy complex whose total income for the period prior to the tax payment exceeds the eightfold size of the average wage in the region to the municipal budget revenues. Such standard seems fair in relation to employees in industries profiting by the use of natural resource rents, and appropriate the national focus on the development of social policy.

In the regions and municipalities, where the corporate structures in the fuel-energy complex are based, great potential has the development of corporate social responsibility. Corporate social responsibility is institution aimed at the formation and realization of public goods in the development of social infrastructure. Institute, in which socially-oriented company in the medium and long term gains the possibility to reduce different types of transaction costs in the market and intra-firm relations, through the competitive advantages formation of using different types of institutional annuities resulting from the development of social infrastructure.

Companies in the fuel-energy complex have significant organizational and financial capacity and are able to direct it in the implementation of social development programs, corporations and territorial development programs. The potential for such development programs based on the fact that the interests of large corporations in the development of the municipality and / or the region connected with the use of the territory as a competitive business advantage. Today an effective corporate social strategy can be a major tool of competitive advantages creation of the company.

## 5. *Conclusion*

In the socio-economic region development corporate structures in fuel-energy complex play a special role as economic agents, whose decisions about the choice of their activity localization on the basis of bipolar placement determinants (resources and urbanization) in the conditions of financial support decrease, creates the axis of regions economic development and trans-regional interaction.

Economic federalism is based on the recognition of the economic viability of regions in the Russian Federation and factual equality of regions within their suitable competences. The unfavorable business environment and reducing real incomes are sufficient base for review of fiscal policy in the direction of strengthening communications corporate structures in fuel-energy complex with municipalities and regions for the territory development.

Companies in fuel-energy complex can be seen as part of infrastructure development corridors. Territories included in the development corridors, in the framework of project financing are supported by the federal government. Companies in fuel-energy complex, which have the project financing, at the same time using non-regional resources and capacities of the territory, therefore, should be involved in solving social and economic problems of the regions and municipalities.

A mechanism of producing companies participation in the formation of municipal budgets revenues to finance the strategic areas of development programs. It is proposed the concept of levying tax on windfall individuals – workers of companies in fuel-energy complex - based on the measurement of the difference between the meaning of Gini Index in region and the minimum meaning of Gini Index in regions of Russia.

Powerful industrial, economic and human resources potential of corporations in fuel-energy complex plays a significant role in territorial development, and should be used in the framework of corporate social responsibility for the availability, condition and development of social infrastructure in the areas of their localization.

Thus, the development of corporations in fuel-energy complex should be implemented as an integrated territorial and sectoral approach taking into account the interaction with the institutional environment of the regional socio-economic system, with the use of mechanisms to fairly redistribute the resulting FEC rents in order to improve the spatial uniformity of the socio-economic development of regions and municipalities.

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# CORRELATION BETWEEN EUROPEAN SMART CITIES AND REGIONAL COMPETITIVENESS

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***Abstract:*** *The Hannover Fair of 2011 opened a new era in the German industry: this is when Industrie 4.0, was first published. The series of innovations and developments in information and communication technology, which in turn affects the economic players, thus influencing regional competitiveness. Industrie 4.0 is an imagined future, which in my opinion if a direct or indirect was will have a fundamental influence on smart cities and their environments and regions, given that their primary goal is improving the competitiveness of a country. In the thesis I will provide an overview of the Global Competitiveness Index of the World Economic Forum and the Technisches Universität Wien's criteria for smart towns. I will establish a statistical correlation between the towns and their countries listed in the two rankings. I will point out how dominant the innovations affecting competitiveness are in these countries and how these may facilitate the implementability of Industrie 4.0. Finally, using cluster analysis I will take a look at the factors that contribute to the cities relative competitiveness.*

**Keywords**: SMART CITY, INDUSTRY 4.0, COMPETITIVENESS, RANKING

## 1. Introduction

The industry of 21st century Europe faces significant challenges. The ever-decreasing raw material supply, the rising energy prices and the demographic changes necessitate the modification of the existing model. The intensifying competition, which is mostly driven by the increasing productivity of the Asian industry and innovation makes it clear that the production industry needs solutions with which they can efficiently respond to challenges[1]. The following factors in my opinion post a challenge to the industry of the 21st century[2]:

- Global competition
- Market volatility
- Customized products
- Time-to-market and delivery performance (speed)
- The sustainability of the full life cycle of products
- Productivity (resource-efficiency, value orientation)
- Shortage of skilled labour

The manufacturing and production systems have been gradually complemented with information technology support tools in recent decades, as increasingly complex technological solutions, production in often multiple locations and the coordination of supporting logistics processes started to pose a more and more complex challenge. Accordingly, 90% of all production processes are now supported by IT tools. The increasingly dominant and pivotal role of IT in companies have changed lifestyles and working environments, the significance of which is unquestionable.

Miniaturization and the development of communication technologies enables the blending of the physical and virtual world and gives way to the so-called CPS – Cyber-Physical System. Industrial production becomes integratable into an intelligent environment that is referred to in reference literature as smart factory. Based on this technological evolution, Germany announced the arrival of Industrie 4.0, also called the fourth industrial revolution.

The year 2000 meant a paradigm shift insofar as half the world's population was living in cities by then. In our global world, cities have an intense role in shaping the economy, culture and society. Cities are structured into network systems and share functional roles[3]. The previously hierarchical relationship structure is replaced by horizontal integration. Earlier, urban concentration would have been justified by the codependent relationship between corporations and technologies, which by now have been replaced by economic benefits derived from a common milieu and common interest in innovation and the exploitation of shared knowledge. Sustainability and enhanced competitiveness has become a dominant priority of cities. They must, therefore, develop long-term strategies that provide for liveable, environmentally conscious spaces for regional economic players and local residents alike[1].

***Smart city ranking***

A leading scientific center in the research into smart cities is the technical University of Vienna (Technisches Universität Wien, TUW)[4] where the Smart City Ranking (SCR, TUW SCR), a kind of competitiveness, "smartness" index of European cities derived from a system of indicators chosen by the researchers is regularly published. Six basic characteristics are identified in their research (figure 1)[5]

- smart economy
- smart governance
- smart people
- smart mobility
- smart environment
- smart living,

which are weighted and represent the current and relative ranking among the cities involved, taking into account the criteria of smart cities.

Varying numbers of towns are chosen from different European countries, but they basically have to meet the following criteria in order to be considered for the annual assessment:

- The city's population must be between 100 and 500 thousand
- 80% of the data pertaining to the indicators must be available
- The city must be included in the Eurostat Urban Audit database

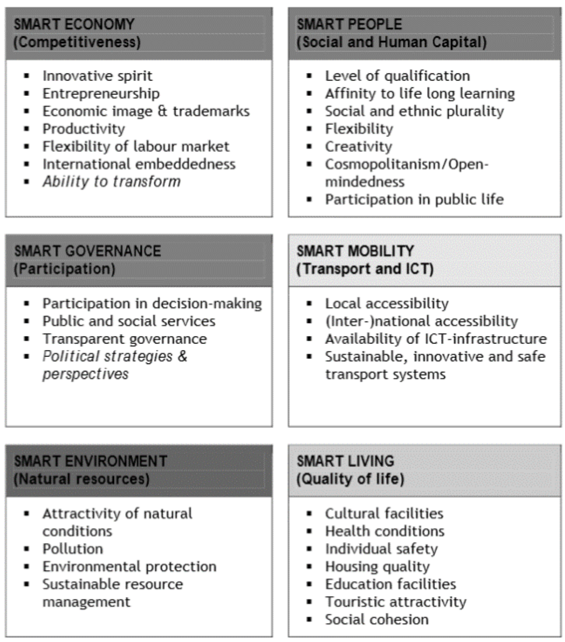

***Figure 1:*** *The characteristics of the smart city index*[5]

Factors are assigned to the characteristics, data for which is derived from indicators. For example, within the Smart economy characteristic (competitiveness), which is of interest to this paper, we can find the Innovative will factor, which comes from three NUTS2 indicators:

- R&D expenditure in % of GDP
- Employment rate in knowledge-intensive sectors
- Patent applications per inhabitant

### *1.2. Global competitiveness index*

The relevant annual publication of the World Economic Forum (WEF), The Global Competitiveness Report[6] is a macro level competitiveness index of great significance.

The document provides a detailed description of the structure, the calculation method, the input data and the resulting competitiveness ranking of the Global Competitiveness Index (WEF GCI). The competitiveness index defines 15 so-called pillars (figure 2)[7], which provide the final ranking of the countries derived from 300 indicators.

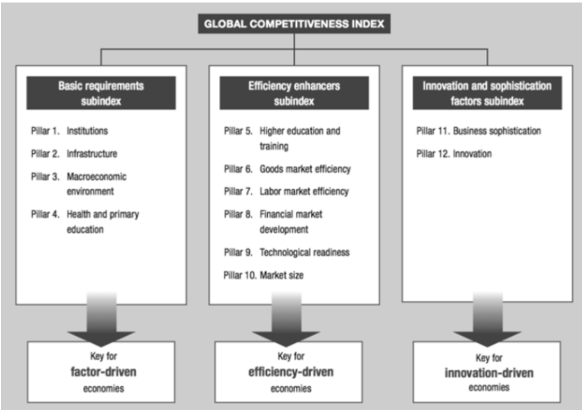


***Figure 2:*** *The pillars of the Global Competitiveness Index*[6]

## *2. Hypotheses*

Although the series of innovations, the developments in Information and Communication Technology (ICT) and Cyber-physical systems (CPS), i.e. Industrie 4.0 primary concern the industry, its effects can be felt, similarly to previous industrial revolutions, on cities, regions and their competitiveness, i.e. their competition. In order to measure competitiveness in a comparable way, it is important to use indicators. Given the numerous criteria, indicators and their weighted values, several existing best practices may be applied in the evaluation of a given territory. In my opinion, Pearson's correlation coefficient known from statistics can provide relevant information with respect to certain competitiveness ratings both in the comparison of factors influencing competitiveness ranking and the comparison of certain rankings, which is why I will apply it for proving the following hypothesis.

- Competitive countries and cities are the most conducive to introducing innovative solutions.
- There is a positive correlation between the rankings of smart cities and competitive countries.
- Innovative indicators have a fundamental influence on the rankings of smart cities and competitive countries. There is a high and positive correlation between ranking and innovation.

## *3. Analysing and interpreting findings*

My calculations were conducted with the help of IBM SPSS, the data for which were based on:

- the EUStat database
- the Smart City Ranking model of the Technical University of Vienna
- the Global Competitiveness Index of the World Economic Forum
- my own derivations.

My research was conducted on the basis of the 2013 World Economic Forum Report on cities and towns included in the Smart Cities ranking of the Technisches Universität Wien of the same year, i.e. 71 cities from 24 countries[5].

The most countries, 7 respectively, are from Germany and Italy, each country thus representing 9.9% of the total. Other dominant countries with 6-4 cities in the ranking include Poland, France, Austria, the Netherlands and the UK. Ireland, Latvia, Lithuania, Luxembourg and Portugal are each represented by 1 city.

The World Economic Forum established the following ranking among the countries included in my research. Based on the 2013 index, Finland is ranked third, Germany fourth and Sweden sixth (table 1).

***Table 1:*** *WEF GCI 2013*[6]

| Country | The ranking | Value |
|---|---|---|
| **Finland** | 3 | 5,54 |
| **Germany** | 4 | 5,51 |
| **Sweden** | 6 | 5,48 |
| **Netherlands** | 8 | 5,42 |
| **United Kingdom** | 10 | 5,37 |
| **Denmark** | 15 | 5,18 |
| **Austria** | 16 | 5,15 |
| **Belgium** | 17 | 5,13 |
| **Luxembourg** | 22 | 5,09 |
| **France** | 23 | 5,05 |
| **Ireland** | 28 | 4,92 |
| **Spain** | 35 | 4,57 |
| **Poland** | 42 | 4,46 |
| **Czech Republic** | 46 | 4,43 |
| **Lithuania** | 48 | 4,41 |
| **Italy** | 49 | 4,41 |
| **Portugal** | 51 | 4,40 |
| **Latvia** | 52 | 4,40 |
| **Bulgaria** | 57 | 4,31 |
| **Slovenia** | 62 | 4,25 |
| **Hungary** | 63 | 4,25 |
| **Romania** | 76 | 4,13 |
| **Slovakia** | 78 | 4,10 |
| **Greece** | 91 | 3,93 |

It can be established based on the competitiveness values of the individual countries (table 2) that the highest value is 5.538 (Finland), while the lowest is 3.928 (Greece), accounting for a median value of 4.515. Given the low value range of 1,61, the standard deviation of 0.518 and the 0.268 variance, the values are very close together.

***Table 2:*** *WEG GCI statistical analysis, own compilation*

| | | |
|---|---|---|
| Mean | | 4,7 |
| Std. Error of Mean | | 0,1 |
| Median | | 4,5 |
| Std. Deviation | | 0,5 |
| Variance | | 0,2 |
| Range | | 1,6 |
| Minimum | | 3,9 |
| Maximum | | 5,5 |
| Percentiles | 25 | 4,3 |
| | 50 | 4,5 |
| | 75 | 5,1 |

The competitiveness ranking is a cumulative value, which is derived from several pillars. Since the innovative value is the most of interest to this paper, I will look at what kind of correlation can be established from the model between the competitiveness ranking of the individual countries and the raking within the pillar 12, *Innovation*.

Competitiveness and Innovation ranking of countries: innovation ranking, global competitiveness ranking

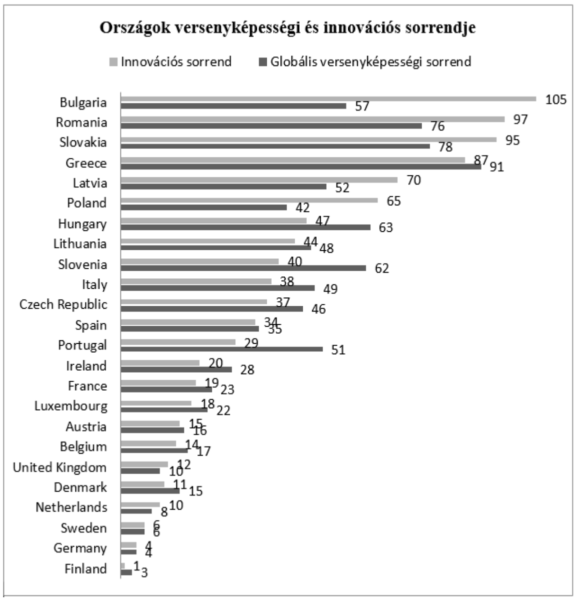


***Figure 3:*** *WEF GCI and Innovation 2013*[6]

As we can see from the graph (figure 3), *Innovation rankings* and total *Competitiveness rankings* (WEF GCI) correlate with each other and a high ranking in innovation is associated with a high ranking in competitiveness. Statistical analysis of the two rankings (table 3) establish a significant correlation. Their Pearson's coefficient is 0.894, which is high (given that it is between 0.7 and 1.0). They show a positive correlation, which means that if a country ranks among the top in innovation, its competitiveness is also high. For example, while Finland ranks first in the *Innovation pillar*, they come third in the total *Competitiveness index*. Hungary ranks 47th in innovation and 63rd in competitiveness. I.e., based on the innovation pillar of the competitiveness index, it can be established that Hungary shows stronger competitiveness traits in innovation than in total.

In order to further look into the influential role of innovation in the present model, let us take a look at how the ranking of different countries in the other pillars correlate with their total ranking.

In an effort to test my hypothesis, I explored the correlation between the total competitiveness ranking of each country and their ranking within the different pillars associated with the index, i.e. the connection, for example, between a country's ranking 10th in the WEF GCI and same country ranking 20th in the *Infrastructure* pillar.

Table 3 indicates that the most dominant element is *Institutions* (0.930), accounting for the highest correlation between the total WEC ranking and an individual indicator, while on the other end of the spectrum, *Macroeconomic environment* (0.381) and *Market size* (0.441) show a weak correlation**,** playing a less significant role in the index. The correlation coefficient for the pillar I wished to investigate and presented above, *Innovation,* is 0.894, which indicates a strong connection, meaning that the model also confirms the significant influence of innovation on a country's competitiveness.

***Table 3:*** *Pearson correlations between WEF GCI pillars and WEF GCI — own compilation*

| **Competitiveness Pillars** | | **Global Competitiveness Index** |
|---|---|---|
| **Institution** | Pearson correlation | ,930** |
| **Infrastructure** | Pearson correlation | ,740** |
| **Macroeconomic env.** | Pearson correlation | ,381** |
| **Health and prim. edu.** | Pearson correlation | ,696** |
| **Higher edu and training** | Pearson correlation | ,889** |
| **Goods and market efficiency** | Pearson correlation | ,907** |
| **Labor market efficiency** | Pearson correlation | ,733** |
| **Financial market dev.** | Pearson correlation | ,683** |
| **Technological readiness** | Pearson correlation | ,896** |
| **Market size** | Pearson correlation | ,441** |
| **Business sophistication** | Pearson correlation | ,886** |
| **Innovation** | Pearson correlation | ,894** |

**. Correlation is significant at the 0.01 level

If we illustrate the standardized values of the countries' competitiveness rankings (WEF GCI) and smart cities rankings (TUW SCR) in a coordinate system (figure 4), the correlation between the two values become visible. Statistically speaking, the significance of the correlation between the standardized rankings is 000., i.e. detectable, while the Pearson coefficient is 0.808, which indicates a positive relationship. The correlation is positive, i.e. the higher the competitiveness of a country, the better the chances that its cities will also rank higher among smart cities. The very smart cities of the highly competitive countries, such as Finland (FI), Germany (DE), Sweden (SE), can be found in the upper right quadrant of the figure. A striking finding is that the less competitive country of Slovenia (SI) also has a city listed among the very smart cities.

Standardized smart city ranking, standardized global competitiveness ranking

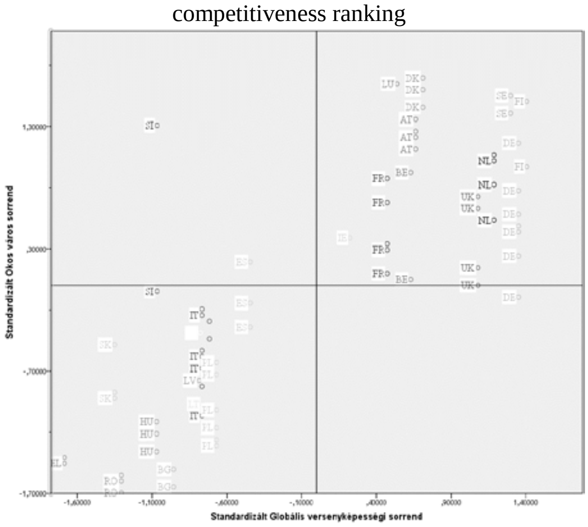


***Figure 4:*** *Standardized country-city rankings — own compilation*

Although the Global Competitiveness Index, the Smart City ranking and regional rankings assess competitiveness on different levels, it is important to investigate the connection among these rankings in order to confirm or refute my hypotheses.

A strong positive correlation can be established (table 4) both the Global Competitiveness Index and the Smart City ranking (0.794), the Global Competitiveness Index and the NUTS2 competitiveness ranking (0.842) as well as NUTS2 competitiveness and the Smart City rankings (0.829), which confirms my hypothesis that Smart Cities are located in a regional (mezzo) and a national (macro) competitive space.

*Table 4: Correlations between Competitiveness rankings — own compilation*

| | | Global Competitiveness Index | Smart City ranking | NUTS2 Competitiveness Index |
|---|---|---|---|---|
| **Global Competitiveness Index** | Pearson correlation | 1 | ,794** | ,842** |
| **Smart City ranking** | Pearson correlation | ,794** | 1 | ,829** |
| **NUTS2 Competitiveness Index** | Pearson correlation | ,842** | ,829** | 1 |

**. Correlation is significant at the 0.01 level

My mezzo level research established a positive, strong correlation between the NUTS2 level regional competitiveness ranking (NUTS2 RCI) and certain factors of smart cities (table 5).

*Table 5: Pearson correlation coefficients between TUW SCR and NUTS2 RCI rankings — own compilation*

| | | NUTS2 Competitiveness Index |
|---|---|---|
| **Economy** | Pearson correlation | ,860** |
| **People** | Pearson correlation | ,805** |
| **Governance** | Pearson correlation | ,566** |
| **Mobility** | Pearson correlation | ,774** |
| **Environment** | Pearson correlation | ,398** |
| **Living** | Pearson correlation | ,688** |

**. Correlation is significant at the 0.01 level

There is a significant, positive and strong correlation between the Smart City ranking (TUW SCR) and its internal factors (table 6). This connection is the strongest in the case of the *People* variable (0.938), while the weakest correlation (0.664) is accounted for by the *Environment* and *Life* variable. The *Economy* variable, which is important for my hypothesis, showed a strong correlation (0.845); it can thus be established that in the case of smart cities model, the indicator that also includes innovation has a strong influence on the ranking of the given town or city.

*Table 6: Pearson correlation coefficients between TWU SCR and its factors — own compilation*

| | | Smart City ranking |
|---|---|---|
| **Economy** | Pearson correlation | ,845** |
| **People** | Pearson correlation | ,938** |
| **Governance** | Pearson correlation | ,735** |
| **Mobility** | Pearson correlation | ,808** |
| **Environment** | Pearson correlation | ,664** |
| **Living** | Pearson correlation | ,664** |

**. Correlation is significant at the 0.01 level

When investigating the correlation among the six factors determining the final smart cities ranking (TUW SCR) (table 7), I noticed that the *People* and the *Economy* variables show a very strong connection (0.822), compared to a lower than average correlation between *Mobility and the Environment* (0,380).

If we take a look at the indicator components behind the factors presented earlier (figure 1), we can see that while *Training, Education and Creativity* as human capital show a strong correlation to competitiveness factors, such as *Innovation, Entrepreneurial spirit and Productivity*, the same cannot be said for *ICT development, International access and Attractive natural environment*.

The correlation between the other variable pairs is relatively strong, ranging between 0.749 and 0.437. Overall, all correlations are positive and significant.

*Table 7: Pearson correlation coefficients between TUW SCR factors — own compilation*

| | | Economy | People | Governance | Mobility | Environment | Living |
|---|---|---|---|---|---|---|---|
| **Economy** | Pearson correlation | 1 | ,822** | ,462** | ,749** | ,437** | ,665 |
| **People** | Pearson correlation | ,822** | 1 | ,703** | ,738** | ,665** | ,643** |
| **Governance** | Pearson correlation | ,462** | ,703** | 1 | ,485** | ,511** | ,549** |
| **Mobility** | Pearson correlation | ,749** | ,738** | ,485** | 1 | ,380** | ,622** |
| **Environment** | Pearson correlation | ,437** | ,665** | ,511** | ,380** | 1 | ,486 |
| **Living** | Pearson correlation | ,665** | ,643** | ,549** | ,622** | ,486 | 1 |

**. Correlation is significant at the 0.01 level

Using the characteristics ranking of smart cities and the Two-step clustering method, I created clusters from the cities that were part of my research. The advantage of the applied method is that it standardizes the entered — in this case 6 — variables (*Economy, People, Government, Mobility, Environment, Living*) and automatically offers an optimal cluster number. The cluster analysis resulted in 5 separate groups of cities based on the ranking among city characteristics. My goal was to understand as deeply as possible the correlations between the variables determining the rankings of cities and identify possible trends.

The different variables can be prioritized and they have varying degrees of significance in the establishment of clusters. The investigated variables in the order of significance in the cluster creation are the following: *People* and *Economy* are the two variables that play the most dominant role in cluster creation. These two are followed by *Governance, Mobility and Environment,* while *Living* played the least significant role in cluster creation.

The first and largest cluster in terms of multiplicity accounts for 39.4% of the total item number, the second 15,5%, the third 8.5%, the fourth 19.7% and the fifth 16.9%. Each cluster can be viewed (figure 5) in terms of where the individual variables are compared to the averages of all items. This way we can distinguish variable with above average, average and below average values within the cluster.

I named the clusters after their typical characteristics so I can assess, taken all variables into account, where the values of a given cluster are and which clusters have a higher or lower position compared to the other groups. For future reference I named the clusters after their typical characteristics.

The first, *Leading* includes cities that also ranked the highest in total in the TUW SCR ranking. The *Economy, People* and *Mobility* variables are dominant and above average. Due to the high standard deviation of the values, the cluster center of the *Governance* variable is close to the average, but never goes below. The values of the *Environment* and *Living* variables show a wide range.

After the overview of the list of cities (AARHUS, LUXEMBOURG, AALBORG, UMEAA, TAMPERE, ODENSE, JOENKOEPING SALZBURG, LJUBLJANA, LINZ, INNSBRUCK, REGENSBURG, GRAZ, EINDHOVEN, GRONINGEN, OULU, GENT, NIJMEGEN, GOETTINGEN, CARDIFF, ERFURT, ENSCHEDE, TRIER, KIEL, CORK, PORTSMOUTH, LEICESTER) it can be clearly seen that, with the exception of Ljubljana in Slovenia, this list consists of Western European and Scandinavian cities. Ljubljana ranks very high in *Economy* (4) and *Living* (3). The NUTS2 regions of the cluster have a high GDP the and employment rate of over 75%.

The cities in the second, *Pathfinder* cluster rank below average in every variable in terms of their cluster center. This is especially true for the collectively low *Governance* variable value, which means non-transparent governance, a lack of political strategy and future vision, as well as low quality social and public services. Looking at the *Environment* variable I can conclude that is also not in the center of focus. The cities in this cluster are: VENEZIA, VERONA, PLZEN, OVIEDO, USTI NAD LABEM, TRENTO, TRIESTE, PERUGIA, LIEPAJA, PADOVA, KAUNAS.

The third, *Natural* cluster typically includes Greek and Slovakian cities. This is the group with the fewest items, 6: BANSKA BYSTRICA, KOSICE, NITRA, ANCONA, LARISA, PATRAI. These cities rank very high in terms of the *Environment* variable, while the values of all other variables are below average. Employment rate in the region is 63%, accompanied by modest GDP production. Research and development spending is less than 60% of GDP.

The fourth, *Lagging* cluster includes all Hungarian cities of the survey and most of the towns of the Eastern-European region: RZESZOW, SZCZECIN, BYDGOSZCZ, GYOR, BIALYSTOK, PECS, KIELCE, SUWALKI, MISKOLC, RUSE, SIBIU, TIMISOARA, PLEVEN, CRAIOVA. All values are below average. It is interesting to note that the *Governance* variable produced that highest during the study. These cities are characterized by low GDP and about 60% employment rate.

The fifth, *Conservative* cluster includes Western cities that did not quality for the *Leading* cluster: MONTPELLIER, NANCY, CLERMONT-FERRAND, POITIERS, ROSTOCK, PAMPLONA, DIJON, BRUGGE, MARIBOR, MAGDEBURG, VALLADOLID, COIMBRA. This cluster also includes a Slovenian city, Maribor, which ranks in the prestigious 16th position in both *Environment* and People. A typical characteristic of the cluster is the high number of patent submissions.

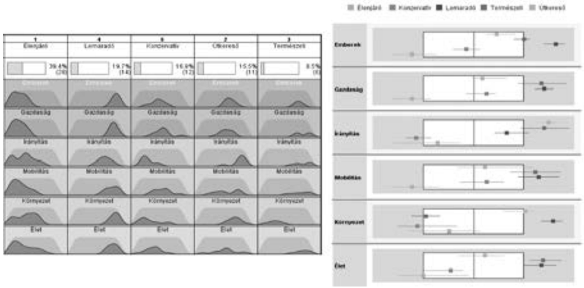

***Figure 5**: City clusters — own compilation*

The cluster analysis resulted in 5 separate clusters, but if we merge the *Leading* and the *Conservative* cluster on the one side and the *Pathfinder, Natural and Lagging clusters*, we can see a clearly divided Western and Eastern Europe.

Based on the competitiveness index illustrated on a map (figure 6) – in both cases a darker colour means a higher ranking – the thesis statement of the hypothesis is confirmed by the correlation analysis, i.e. smarter cities can be found in more competitive countries.

***Figure 6:** WEF GCI and TUW SCR EU on map* [5, 6]

## 4. Conclusion

The conducted correlation calculations proved my hypothesis that there is a positive correlation between the smart cities and competitive countries rankings.

I was also abele to establish innovation indicators have a fundamental influence on the rankings of smart cities and competitive countries. In addition, the correlation between ranking and innovation is positive and strong.

The cluster analysis made it possible to identify the criteria, such as economic performance, innovation, education level and flexibility of the inhabitants, which contribute to the competition between cities. It was interesting and surprising to see that the boundaries between the West and the East are still significant decades after the fall of communism. The investigation of the reasons behind this boundary might be the continuation of the research started with the present paper.

In the future I wish to interpret the relevance of the NUTS2 and NUTS3 statistical data in the ranking of smart cities.

In addition, it might be a good idea to include the competitiveness rankings of larger cities (with 500.000-1.000.000 inhabitants) in further research.

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# ETHNO-RELIGIOUS VARIETY AS A STRATEGIC STAKE OF MODERN DEVELOPMENT

## ЕТНОРЕЛИГИОЗНОТО МНОГООБРАЗИЕ КАТО СТРАТЕГИЧЕСКИ ЗАЛОГ НА СЪВРЕМЕННОТО РАЗВИТИЕ

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***Abstract:*** *The article discusses the relationship between ethnic and religious differences through the prism of power, hate speech and national identity. The author concludes that ethno-religious variety in Bulgaria continues to be perceived passively, as something given, and not actively, as a resource for nation building. The author outlines certain problems engendered by the predominantly Muslim immigration pressure on Europe.*

**kEYWORDS:** ETHNICITY, RELIGION, INEQUALITY, iSLAM, POVERTY, MARKET SOCIETY, IDENTITY, DIALOGUE

### *1. Inequalities and Poverty*

With time research is clearly confirming the hypothesis that the attitude towards ethnic and, even more so, religious difference is mediated and defined to a great degree by the problem of power. Concrete cases taken from the Bulgarian political environment prove the high degree of connection and mutual dependence between the forms and intensity of religious separation on one hand and access to power resources on the other. That is why every attempt at taking a partisan approach to the problem or using it for short-term political aims, essentially enhances the feeling of otherness in the Muslims, perceived by them as a situation of inequality, and hence strengthens the internal ties within the community and the search for new grounds of difference from the society at large [Bosakov 2010].

The topic of inequality has customarily been a prevalent one in public interest and is in fact an inevitable part of any economic debate due to its great social importance and also because the attitude towards inequality defines the frameworks of more general ideas on economic development. The existence of inequalities is to some extent understandable in view of the varying degrees of productivity of individuals. The misbalance in income and material status of the population should create incentives for more efforts at work, for striving to obtain a better education, and hence, for improvement of the general productivity of the population. Inequality of wealth and income is an issue that does not inherently involve injustice. The case of the developed economies has proven that the presence of inequality does not block sustainable growth. Some of the highlights:

- There is a very high share of people in risk of poverty or social exclusion: nearly half the population of the country is below the poverty threshold, suffers severe material privations or is incapable of finding a place on the labour market;
- The problem of income inequality occurs with various degrees of severity at regional level; in some regions of Northwest Bulgaria, inequality is far above the average levels for the country;
- The implementation of social policy in Bulgaria does not lead to the desired result with respect to reducing inequality;
- Social mobility in the country is relatively low. Factors such as education and social-economic status continue to be basic for determining the labour realization of people.
- There exists in Bulgaria a new kind of poverty that is not simply an element of the individual’s life cycle but is rather a kind of social-economic dependence which has a very strong impact particularly on the Roma, a numerous ethnic minority. A large proportion of these people are excluded from the labour market for long periods of time and gradually drop out of all social spheres, including the economy, education, healthcare services, the cultural and political life of Bulgarian society. Poverty is inherited among the Roma, and ethnic segregation cuts short their possibility for realization and gradual integration within the social structures. Due to the prolonged and all-encompassing social exclusion of this minority and the rigid borderlines established by the ethnic majority, it is not the specific cultural content within the ethnic boundary but the boundary itself that separates, consolidates and preserves this community.

### *2. Hostile Speech*

Can religions be held under the control of the secular state, and by what means? Is the European secular model threatened and where does the threat come from? What are the enemies of the secular state? Can fanaticism and passionate religiosity be restrained without oppressing religions as such? Does freedom of speech, including its particular form as freedom of hate speech, a threat to the community ties in society and to the health of society? Is a society in which hostile speech generates fear and distrust of others a sick society? These numerous questions are given a variety of sometimes contradictory answers. Still, it is necessary to reflect on the issues.

Many crimes are incited by hatred. In times of economic, social and other crises (including war), it is a frequent practice to manipulate the population into hating the others, those who are different. Hatred is aimed at people who are outsiders or belong to different groups from ours. This is xenophobia. The others, the different, the strangers, are the target of negative qualifications, perceptions and identifications [Dimitrov 2014].

According to the definition of the Council of Europe, hate speech includes all forms of expression which spread, incite, promote or justify racial hatred, xenophobia, anti-Semitism or other forms of hatred based on intolerance, including intolerance expressed by aggressive nationalism and ethnocentrism, discrimination and hostility towards minorities, migrants and people of immigrant origin [Wikipedia].

“Language is the house of Being”, said the German philosopher Martin Heidegger. Speech is a mechanism for production of meaning. In fact, speech produces the meaning of our lives. The world we live in is as meaningful as we make it through the language we use. That is why the media environment is so important. Public speech, which can have a strong influence on society and on the production of the social meaning of our world, carries great responsibility. Freedom of belief provides the freedom to speak publicly, but it is impermissible to offend the dignity of the people about whom one is talking. The opposite of hostile speech is integrating speech. The latter integrates differences into a common community. The opposite of hostile speech is not tolerant speech, which is simply a general norm. Since hostile speech is an active verbal strategy that intends to achieve something, it should be countered by a different active verbal strategy – integrating speech. Tolerance should become an internalized value. Instead, we resort to “hostility as therapy”. When you have a problem you cannot solve, you construct an enemy and lay the blame on him. But this does not solve your problem. This is a kind of therapy that makes the problem insolvable by only increasing it [Discussion, club Obektiv 2013].

Concerning the wave of refugees coming into the country, public statements were made in which the refugees from Syria were described as cannibals, criminals, mass murderers and/or Islamic fundamentalists fleeing justice. A survey conducted for the Association of European Journalists showed that in 8439 online publications, the keywords equated *refugee* with *threat, disease, danger*.

Bulgaria must investigate and prosecute hate crimes in order to put an end to the instigation of fear. The failure of the state to do this fosters fear, discrimination and ultimately violence. Even though legislation that permits legal indictment of hate crimes related to racism and xenophobia does exist in Bulgaria, in the majority of cases the authorities fail to investigate such violations, as pointed out in the Amnesty International Report presented at the BTA National Press Club (09.02.2015). The report also states that, in Bulgaria, victims of hate crimes are not provided access to justice due to the refusal of investigators and prosecutors to identify discriminatory motives in these cases. Usually, such crimes are classified as cases of hooliganism. People subjected to violence do not receive legal support. That is why in most cases the victims refrain from reporting to the police. [Novinite].

### *3. Ethnicity, Religion, National Identity*

The image that the Christian, and later on the West European rationalist, tradition had formed of Islam has been undergoing a many-sided transformation in the last decades. After the breakdown of the Soviet Union and the Socialist Bloc, the changes that took place at the geostrategic and political levels transformed in a dramatic way both the *visibility of difference* and the scale on which difference can be assessed and defined. The global scale of the changing visibility of, and attitude to, Islam, and the political dimensions of this change as yet remain insufficiently understood. Even now, the prevailing viewpoint on these facts is limited to declaring various standpoints regarding the strategic orientation of the globalization process. Perhaps that is why difference (which is increasingly becoming synonymous with Islam) is distinctly seeking to side with the opponents of globalism despite the endless variety of ideas, motives, and interests that go into, or are prepared to go into, this doctrine. The processes we designate as globalization tend to provoke resistance, which arises ever more often as an effort on the part of various ethno-cultural and religious traditions to preserve their own identity. In this context, ethnic and religious affiliations become centers of meaning in the striving towards a separate identity in the global debate regarding the quality of human development.

Achieving a national community and building new norms of coexistence under the conditions of ethno-religious variety are becoming a strategic goal of contemporary development. Contemporary civilization faces the need to respond to the critique and resistance of various forms of religious fundamentalism, and especially the critique formulated in the tradition of Islamic fundamentalism.

The problems related to national identity have been far more often described and discussed in the context of nationalist fears of difference than in terms of the effort to overcome the crisis of identity amidst the imposed similarities. Under Bulgarian conditions, ethnic and religious diversity continues to be perceived as an established fact that we must take into account, and not as a resource for nation building. Achieving a national identity should be the result of joint effort. The first and most difficult part of this effort is to recognize that this common meaning exists in a diversity of forms. The coming years will be marked by a search for new grounds of one's own identity, a search for the spaces that define parts of ourselves. The great challenge facing Bulgaria is to rediscover the values and meaning of the national community. Only thus will our genuine, full presence in Europe become a fact.

A culture that is different but shared, most often serves as a "marker" of the individual and group uniqueness that lies at the basis of ethnic identity. Of defining importance is the presence of a dynamic system of ethno-differentiating factors united into an integral whole by collective memory. These factors may acquire different significance and be restructured depending on the concrete social conditions determining the process of ethnic identification. The greater the number of these specific characteristics that the members of the community define as such, the more distinctly expressed and strong is the ethnic identity, and the greater are its chances of surviving and developing in the future.

The triple structuring of "production" of ethnic identity in terms of the coordinate system of space, functions and inequalities determines the similar structure (at the historical-logical level) of the knowledge of ethnicity, while the identicality, continuity and consistency, as basic qualitative characteristics of identity, are infringed under conditions of a social conflict that devalues the meaningful whole of the ethnic life world.

Security is a necessary condition for dialogue between cultures. Without this condition, cultures would have little chance of opening to each other and engaging in talks that may enrich them and enlarge the universal element in their coexistence. Past and present experience has shown that the ethnic concept of nation and its related ethnic nationalism may have disastrous consequences for a society; they may lead to intense conflict and opposition. That is why the concept of political nation should obviously be adopted, in which every citizen has equal rights and is not discriminated in any way in society [Bauman 2003].

### *4. Islam:The European Scale of the Problem Situation*

In most cases, the abstract representation of the dimensions of Muslim presence in the present-day multi-dimensional and complex modern societies remains inaccessible to public opinion, which orients and shapes its attitudes primarily with reference to concrete examples of incompatibility, or conflictive toleration, generated by concrete demands, which are justified on the basis of religious affiliation but, at the same time, represent a specific type of social expression that puts in doubt the secular character of institutions. Islam is a structural element of world identity. Just as a Muslim cannot profess some other religion concurrently with Islam, neither can he simultaneously be a Muslim and a nationalist. There is no place for national feeling in Islam. This is a matter of identity – Islamic identity rejects every other kind.

The immigration pressure that is exercised on Europe - the prevalent component of immigration being Islamic – generates problems in the social sphere, in education, interreligious relations and security. The trends related to the increasing numbers of immigrants are the following:

- Inability to integrate into Western societies and ghettoization of those who are "different";
- The formation of separate societies in parallel with the main ones and a growing number of so-called "sensitive zones";
- The decreasing attractiveness of the so-called multi-cultural model;
- Radicalization of Muslims;

One of the major problems related to research on Islam continues to be the degree of legitimacy of its representatives and the measure of shared meanings and symbols interpreted in a communication context. The question is: who is actually speaking on behalf of Islam – in Europe, throughout the world, and in our country? How valid is the exchange of thoughts and the mutual understanding in the space of public debate? Is there a double perspective, a specific communication strategy of the Muslim community, which may be sending out certain messages outside and different messages inwardly, to the brothers and sisters in the community? Could this double meaning be part of the reason for the lack of mutual understanding, or does the reason lie mostly in the various dimensions of the phenomenon that we traditionally define as a crisis of identity?

Part of the images of present-day Islam are formed not in the framework of the House of Islam, but in places where the religious community is forced to coexist with others. The transformation of the representations regarding the so-called European Islam can be identified in Bulgarian reality. The willingness to accept and obey certain rules of behaviour typical for fundamentalism grows according to the variety of the immediate social environment. In fact, the spaces of fundamental interpretation of the religious canon are formed not where the traditional Muslim community exists and develops, but at the borderline of its active contacts with other cultural and religious models.

In Europe, the Other is primarily the Muslim. The latter is most often an immigrant, whose social position is defined almost entirely by his/her limited access to resources. The Muslim is viewed as part of the risks involved in the modern European way of life and security. But the moral defect of the modern society is greed – a greed that allows market values to penetrate the lifeworld of people that has traditionally been guided by nonmarket norms. As a result of this expansion, social relationships come to be shaped in the image of the market. The trends dictated by our times are manifest in a great variety of areas: in consumption, technological standards, mass popular culture, youth subcultures and counter-cultures, the media and advertising, and even in elite forms of art, science and philosophy. But they all have one thing in common: directly or indirectly, these trends stem from the advance of the all-powerful global market. In recent decades the financial levers and formalized vocabulary of the market have been imposed as a kind of social algebra in widely different areas of life: the neo-liberal mantras such as efficiency, accountability, strategic planning, the project principle, optimized use of resources, maximized profit, etc., have colonized spheres of life that are quite remote from the economy, including education, healthcare, creativity, innovation, knowledge, the art market, and have oriented these spheres to results that are "immediately measurable" in an economic and managerial perspective. But is this neo-liberal religion not turning democracy, the liberal ideals, the freedom of the individual, the arts, the quality of life, etc., from values in themselves, into conditions, "dependent variables", that are important only insofar as they influence economic development?

The difference between market economy and market society is this: a market economy is a means – a valuable and important means – for organizing our productive capacity. The market society, to the contrary, is a way of life where market values permeate all aspects of human striving and effort. It is a place where social relations are molded in the image of the market. The only escape from this apocalyptic situation lies in the transformation of modern democracy by means of civic control, prevention and indictment, which might put a stop to the escalating loss of legitimacy of the procedures of representative democracy and of the figures of the politician, the scientist, the expert and the judge. In this precise aspect, the fourth wave of the European Values Study [Bosakov 2009] can serve to orient us to a deeper and more subtle understanding of the importance of religious morality and of the answers it provides in the face of the daily challenges of secular life. Of determining importance for the problems we are concerned with here is the general correspondence between shared moral principles and the degree to which religiousness and religious morality serve in structuring certain value attitudes among Muslims. The comparison between the results obtained for Eastern Orthodox Christians and for Muslims show different profiles for the two groups as regards the strict obedience to moral principles. The greatest share of Christians is that of respondents who indicated they have a relativistic perspective on morals, so that the qualification of good and evil entirely depends on the circumstances. This view is least supported by Muslim respondents. Among them, the largest percentage indicated they judged good and evil categorically. It is in the context of this general moral perspective that the respondents' attitude to the other religion and the correctness of their own religion can be inscribed. What serves as a basis for religious tolerance here is, to a far greater degree, the view that there are clear criteria of good and evil, combined with an understanding that specific circumstances can lead to deviations from these moral norms. In the context of the growing importance of Islamic religious morality and the relatively low degree of Muslims' civic participation, it may be presumed Muslims would give greater attention to the religious education of their children. The findings show that among the younger generations of the Muslim communities in Bulgaria there is now a more active and meaningful relation to religious practice and a clearer willingness to follow its rules. . The study of Islam and its active preaching are becoming the norm for a righteous life, a norm that must be shared with the others. Through knowledge of the principles of the faith and understanding the rules and restrictions imposed on the faithful, Muslims here begin to build a new Islamic culture that, as in other European countries, is based on active maintenance of differences and consolidation of the community's notions that Islam is the correct religion. The present-day forms of religious mobilization in the Muslim community are significantly different, especially as regards the willingness to strictly obey canonic requirements and preach the values of Islam through them. The achievement of a dynamic equilibrium between religious morality and social changes will continue to be a fundamental issue, with reference to which all other research perspectives can find a place [Bosakov 2015].

## *Instead of a conclusion*

The religious world of the Other provokes us to rethink the foundations of our own faith. In view of the fundamental difference of the unfamiliar faith with respect to our own, we cannot but problematize the justification of our own religiousness. Sociological studies of religious relationships in our country point to the significance of power as a decisive factor of the registered stereotypes and levels of tolerance in society. The capacity of preserving and transmitting values has become a basic argument in the multi-dimensional debate between the religious and the secular grounds for constructing a community identity.

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