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HUMAN FACTOR IN INDUSTRY 4.0: ABOUT SKILLS OF OPERATORS IN STEELWORKS 4.0

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Purpose: The article presents the issues of metallurgist skills in the conditions of implementing the key technologies of Industry 4.0. The purpose of the paper was to propose a skills framework for a metallurgist in the context of Industry 4.0.
Design/methodology/approach: The paper consists of an introduction and two substantive parts. The first part deals with the role of the human factor in Industry 4.0. The second part is about the skills of a metallurgist (the general framework of skills 4.0) in the transformation of metallurgical enterprises to Industry 4.0. The paper is part of the current research on skills of operators in Industry 4.0. The study uses a qualitative descriptive method referring to a critical analysis of literature about skills of the future. The article briefly reviews selected theoretical approaches to the operator-technology skills in the reality of Industry 4.0.
Findings: The main result of the analysis was to bring closer the current, yet poorly scientifically recognised research about the place of human factor in the Industry 4.0 together with the structure of skills for the restructured employment in the steel industry.
Research limitations/implications: In the conditions of the fourth industrial revolution and strong popularisation of the concept of Industry 4.0, enterprises must be able to reorganize human resources (HR). A new package of knowledge, new skills of employees are needed to perform tasks efficiently and to cooperate with new technological solutions of production and control and monitoring systems of manufacturing and service processes. The topic about human factor (HF) in Industry 4.0 is very actual and it will be developed according to wider and wider implementation of new (smarter) technologies in enterprises.
Practical implications: Presented framework of human skills can be used to improve the skills profile of a metallurgist 4.0 (a worker in smarter steel mill).
Social implications: In developing of new skills of employees in smart steelworks, besides steel mills, is needed an educational ecosystem, that joins different educational and science organizations.
Originality/value: Reorganization of employment in Industry 4.0 is a new research field but very actual in the realized transformation process of enterprises. The paper is a form of introduction to discussion about new skills of operators in smart production.

Keywords: Industry 4.0, Operator 4.0, Metallurgist 4.0.

Category of the paper: Conceptual paper.

Introduction

In the conditions of the fourth industrial revolution and strong popularisation of the concept of Industry 4.0, companies must be able to quickly change capabilities, technologies, resources to be more innovative. The pillars of Industry 4.0 are intelligent machines equipped with artificial intelligence and augmented reality algorithms, autonomous robots, integrated information-computing systems and Big Data. Industry 4.0 does not exist without the Industrial Internet of Things (IIoT), which facilitates the transfer of information from device (machine) sensors to a decision-making centre, as well as improving machine-to-machine (M2M) and machine-to-product (M2P) communication. Data transfer is also supported by cloud services, visualisation of industrial processes and autonomous computer-based control systems and real-time process control. Autonomous robots and collaborative machines are bridging the gap between traditional worker-operated technologies and creating new areas for full automation and robotization of production (Kumar, and Kumar, 2020). Robots perform work in a similar way to humans with the ability to monitor and transmit data during operations (Wiesmüller, 2014; Wang et al., 2016).

Industry 4.0 is not only about new technologies, but also about the human factor, which has to cooperate with new technologies. In Industry 4.0, a new package of knowledge, new skills and new abilities of the company's employees are needed to perform tasks efficiently and to cooperate with new technological solutions of production and control and monitoring systems of manufacturing and service processes. The human factor in smart factories can be considered in the level of managers and in the level of other employees. As technologies advance, the boundaries between managers and operational employees, disappear (Neumann et al., 2021). Operations at many workstations are autonomously performed by technologies. In Industry 4.0, the number of automated jobs is even greater than it used to be. Technological operators get strong support from information and computer systems and artificial intelligence algorithms of machines in augmented reality. Human work is strongly intellectual. Employees in Industry 4.0 learn to cooperate with new technologies, co-creating the new value of smart production. The human being in cyber-physical production systems (H-CPS) is a dynamic operator, strongly connected to the processes and management methods of new technologies.

In the revolution taking place, scientists are looking for the place of workers in cyber-physical production systems. Participating in the discussion, the author presented the requirements for the profession of a metallurgist in the concept of Industry 4.0. In accordance with the accepted numerology, the skills of a metallurgist in the fourth industrial revolution was called: Metallurgist 4.0 or Operator 4.0. The paper focuses on the framework of skills of operators in the metallurgical processes.

The human factor in the concept of Industry 4.0

Industry 4.0 is a new idea of improving production in the fourth industrial revolution through high technologies and new tasks of its operators. In the fourth industrial revolution, the technological changes have radically accelerated and innovation has created common cyber space. In factories, Industry 4.0 is a change of production systems into Cyber-Physical Systems (CPSs), in which not only machines and IT systems or full real-time data analysis are important, but also the preparation of appropriate human resources. Each machine must be designed, programmed, serviced, and for this an operator is needed, who, according to the nomenclature of the idea of Industry 4.0, should be an "Engineer 4.0" or "Operator 4.0" (Romero et al., 2016a). The technological development forces changes in human labour. The digital transformation of businesses and organisations will increase the demand for all data analytics and digital occupations. Any change that involves the human factor often results in resistance and strong fears among employees about losing their jobs. Technological modifications in Industry 4.0 may entail the replacement of people employed in companies to build a new team of fourth-generation technology operators. Reports from global organisations including: World Economic Forum (2018) estimate that 75 million jobs could disappear when human labour is replaced by automated systems based on intelligent algorithms and smart machines, but at the same time nearly twice as many – 133 million – jobs will be created.

In Industry 4.0, the demand for workers will increase, especially where new directions for the production need to be set, where decisions are made by machines with learning algorithms. At the current stage of manufacturing automation, machines perform repetitive tasks and still require tools towards performance prediction and process simulation.

In Industry 4.0, humans must learn to adapt to new situations and function in dynamic manufacturing systems. Increasingly, operators' tasks will be hybrid in nature – a combination of human and machine skills. On the one hand, workers interact strongly with Industry 4.0 technologies, and Industry 4.0 operators support machines at the stage of training them (teaching them to work intelligently) and participate in explaining and interpreting the effects of their work and their maintenance. On the other hand, machines in Industry 4.0 amplify people's potential and enhance their cognitive, communication and physical skills (Daugherty et al., 2018).

Industry 4.0 needs more human responsibility for technologies and development of human skills in continuing education (Kopp, 2014 based on the platform: Industrie 4.0). Preparing employees for Industry 4.0 is a key challenge for companies implementing new technologies of the fourth industrial revolution. The concept of a systems approach to learning organisations created by Peter M. Senge is also current in Industry 4.0 (1990). This concept assumes that education is a core value and that companies are organisations that can continuously train and develop themselves. It is important that all employees do this. Learning organisations need to create good conditions for knowledge enhancement and motivate employees appropriately for professional development (Report: Manual 4.0, online:www.inspire-consulting.pl).

Figure 1 provides an illustrative diagram of the key challenges for the human factor in Industry 4.0. The scheme was inspired by G. Hamel's model – challenges for companies of the 21st century, which the author adapted to the requirements of the Industry 4.0 concept. The choice of three determinants of building Industry 4.0 was dictated by the adopted topic of the paper, in which the author focused on the development of the human factor in Industry 4.0.

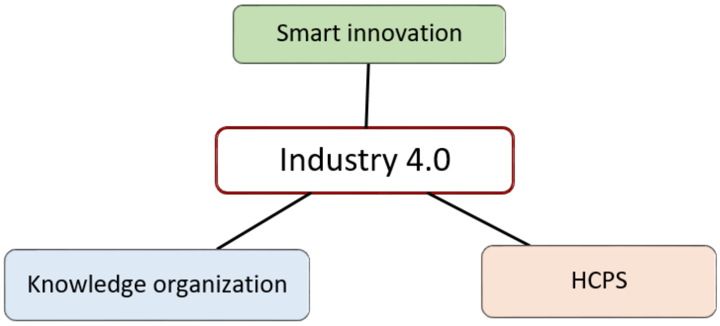

Figure 1. Complex Diagram of the dependence of human factor changes in the era of Industry 4.0. Source: own elaboration.

Human Cyber-Physical Systems (H-CPS) are collaborative relationships between humans and technologies of the fourth industrial revolution in a system of strong links between physical processes and digitalisation (Romero, et al., 2016a).

Innovation in Industry 4.0 can be described by: smart, efficiency, effectiveness, optimisation, dynamism, personalisation and customisation at reasonable (acceptable) cost (Kumar, and Kumar 2020). Innovations in Industry 4.0 arise in Cyber-Physical Production Systems (CPPS).Quoting from Flores et al. (2020, based on: Monostori et al., 2016) cyber-physical systems are engineered systems used to monitor, control and integrate operations in systems (structures) of physical and computer (digital) requirements. Considering different technological forms, cyber-physical systems can be more or less complex. Cyber-physical systems evolve at different stages of technological change and successive levels of implementation of Industry 4.0 technologies in enterprises. Companies start the changes with simple and single projects, and over time the number of projects increases (Gajdzik, 2020b). J. Lee et al. (2015) identified five levels of CPS architecture within the collaboration of physical processes and digital space. The different levels of CPS correspond to the functions of technology in smart factories. The first, lowest level includes data collection and interpretation – the level: Connection. The second level is the application of modern technology for analysing process performance – analyticcs capability – the level: Conversion. The next level includes monitoring of work (processes) in real time – real-time acquisition, and comparing monitoring – the level: Cyber. The fourth level is called cognition, annoyance or presentation – the Cognition level. At this level, technologies strongly support humans in optimising processes. The fifth (highest) level is services, processes, and network configurations – the level: Configuration. At this level, machines have cooperative learning and adaptive and executing algorithms. The different levels of cyber-physical systems are discussed in publications such as: Flores et al. (2020), Wiesner et al. (2017), Liu et al. (2017), Oztemel, and Gursey, 2020). To the key CPS architecture proposed by the team led by J. Lee, another team of researchers led by E. Flores (2020) adds human factors requirements. At level one of cyber-physical systems, operator primarily involves the cognitive senses. At levels two and three, thinking skills (memory, intellect) are needed. At level four, operator acquires experience in cooperating with technology and becomes its machine teacher (engages his consciousness and emotional intelligence). At level five of cyber-physical systems, the operator takes concrete action through his technical and digital skills (bodily action). The links between Operator 4.0 and CPS levels are in line with the proposal of the scientific team led by Romero (2016a), who introduced the term: Human Cyber-Physical Systems (H-CPS or HCPS) – Figure 2.

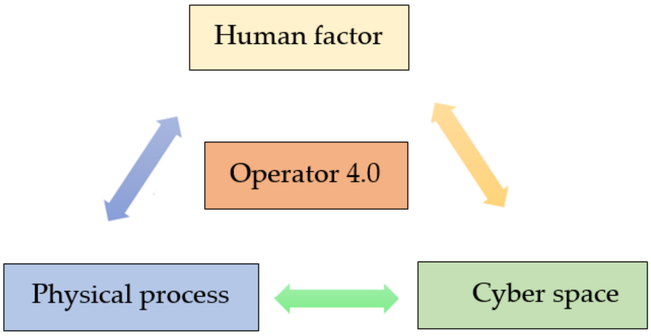

Figure 2. Key components of H-CPS. Source: own elaboration based on Flores et al. 2020.

Employees in Industry 4.0 are operators of increasingly intelligent technologies. The name "Operator 4.0" has been applied to describe the role of humans in cyber-physical systems. The established new arrangement of cyber-physical systems with human factors, abbreviated H-CPS, is a new concept of human-machine collaboration in increasingly intelligent production (Sun et al., 2020: based on Ruppert et al., 2018; Lorenz et al., 2015). The team: Rupper et al. (2018) classified operators according to the extent of their collaboration with machines and the type of activities performed, starting from the lowest level or Operator 1.0, where manual activities dominate, to the highest level of Operator 4.0, which represents a new philosophy of collaboration between the operator and increasingly intelligent machines, at the level of their adaptation to each new situation in a dynamic production process. As part of cooperation with new solutions (machines) in cyber-physical production systems, the operator can take on various roles, such as: VR/AR (virtual operator), (Sun et al., 2020; Romero et al., 2016b; Rupper et al., 2018), smarter operator, being a personal assistant of this technology, operator cooperating with robots (collaborative operator), analytical operator and many others. In addition to these functions, operators can also perform the functions of social operator and even personal data operator in the context of the impact of technology on humans and the efficiency of using technology (healthy operator).

In the conditions of digital transformation, knowledge becomes a key resource in transforming enterprises, and the key directions– the ways and speed of knowledge building in an enterprise. The wide use of new technologies in Industry 4.0 increase the demand for new skills, which are defined as human-skill perspectives. The skills of the future are "a set of many skills enabling taking on and carrying out tasks in a new work environment that is increasingly flexible, geographically dispersed, susceptible to frequent and rapid changes, and in which it assumes the need to operate digital technologies and cooperate with automated systems and machines using artificial intelligence" (Report: Manual 4.0, p. 17).

The summary of this part of the publication and the presented conceptual issues of the location of man in Industry 4.0 is the comparison of the levels of cyber-physical systems with the human factor and the functions of operators (Table 1).

Table 1.
Humans in the cyber-physical systems of Industry 4.0

Levels of CPSs according to J. Lee (original nomenclature)		**Functions of the technology**	**Human skills**	**Operator types according to Rupper et al.**
1.	Connection level	Collection of data from the devices and their transfer to the system.	Using the human senses and human skills, such as: perceptiveness, concentration, field of vision, agility, etc.	Activity operator
2.	Conversion level	Process analysis using modern technologies (data transferred to decision-making centres in real time).	Human cognitive skills, such as: memorization, intellectuality.	Data Analyst Operator
3.	Cyber level	Process monitoring using modern technologies, including computer simulation, forecasting, intelligent algorithms, machine learning models, etc. – increasing human-robot collaboration.	Cognitive human skills: creativity, logical reasoning, complex problem solving, etc.	Cooperating operator, VR and AR operator
4.	Cognition level	Computer programs, graphics, interfaces, data penetration, etc., process optimization prioritization, autonomous process optimization, IC systems modularity, IC systems integration.	Operators' experience in working with machines and technological intelligence, emotional intelligence.	Operator of integrated systems, smarter operator
5.	Configuration level	Adaptation of machines to new situations, machine learning, smart technology, networking of devices.	Hard skills in the field of IT.	Co-operator of smart technologies.

Source: own elaboration based on: Flores et al., 2020; Lee et al., 2015; Romero et al., 2016b; Rupper et al., 2018.

When using measurement abbreviations, there should be space between the number and unit of measurement.

The framework for the skills of a metallurgical technology operator – Metallurgist 4.0

With the popularisation of the Industry 4.0 concept, work in the steel industry is changing. Manual activities and typical physical labour are being reduced to a minimum and replaced by the work of technological installations with an increasingly high degree of automation in steel production. Steel companies are strongly committed to digital transformation in the industrial revolution that is happening (Gajdzik, and Wolniak, 2021). The level of digitisation of the steel industry varies from company to company, but throughout the steel sector, the change towards Industry 4.0 is well underway. The sector is moving from level 3.0 to level 4.0. Companies are implementing solutions typical of Industry 4.0 to develop smarter steel production (Gajdzik, 2021a; 2022). And although the changes taking place are start-ups, they are developmental for the metallurgy of Industry 4.0 (Gajdzik, 2022). The main reason for steel mills to engage in digital transformation is the strong need to secure the future development of the industry.

At the current level of maturity for Industry 4.0, steel mills use information and computer systems for operational production management and control (MES), apply electronic document flow (EDI) systems and customer management databases (CRM), as well as mobile technologies and social media. Digital technologies typical of Industry 4.0, such as big data solutions, cloud computing, sensors and sensors that monitor machine operations, 3D printing and other incremental manufacturing technologies are also being used. The automation and computerisation of the steel sector is laying the foundation for investments in increasingly smart technologies.

Technological changes result in personnel changes. The importance of personnel reorganisation in the steel industry in Poland is important because the steel sector is part of five industries that together provide more than 50% of the gross value added in Poland. These sectors are: production of food products, metal products, motor vehicles, rubber and plastic products and furniture) (Owerczuk, 2016). These five industries in Poland, employ 51% of the industrial production workforce (Gőnt, and Gracel, 2017).

The steel sector in Poland employs over 24.5 thousand people (Gajdzik, 2020a). The situation of human resources in the domestic steel sector in Poland is unfavourable to the extent that there has been a generation gap in steel mills for many years, which is a century of radical downsizing in the 1990s (Gajdzik, and Szymszal, 2015). The opportunity for the sector's development are young, well-educated and creative people but they need to be attracted and encouraged to work in metallurgical enterprises. Steel mills need to build a new image of a metallurgist working with digital technologies and overseeing steel smelting and the production of steel products.

The work of a metallurgist in Poland has changed a lot over the last two decades. The metallurgist is surrounded by IT systems, process visualisation systems, equipment monitored by computers, autonomous robots and artificial intelligence algorithms. In these new technological areas used in the steel production system, workers must reorganise their existing skills, adapting them to the requirements of Industry 4.0.

The framework of the new metallurgist's skills profile is determined by hard and technical competences connected with operating steel production technology supported by metallurgical knowledge and many soft skills, including social skills, which are necessary in the work environment and in contacts with other people and in teamwork of equipment operators. Basic metallurgical and metallurgical knowledge, which employees acquire at the stage of education (vocational and secondary schools with technical profile, studies at technical universities) and during their professional work (work experience), under the conditions of Industry 4.0 must be supported by digital knowledge and digital skills.

Education and science centres in cooperation with industry must take care of the development of employees' competences and skills. The solution is cooperation of universities with industry and other organisations supporting employees in their professional development. The cooperating entities should create an educational ecosystem and join in the process of creating content and didactic forms for the development of personnel needed in Industry 4.0. In the popularised fourth industrial revolution, employees expect fast and effective acquisition of new competences and skills.

Reviewing the courses of education at several technical universities in the country, the author has determined the scope of education, useful for the profession of metallurgist, details in Table 2. In the prepared list, three categories of competencies and skills were combined, that is, metallurgical, engineering and digital.

Table 2.
Key fields of study to build up hard skills of metallurgist 4.0

Areas of education (study)	Examples of engineering typologies
Industrial engineering	production engineering, manufacturing engineering, materials engineering, process engineering: metallurgy engineering, welding engineering, foundry engineering, rolling engineering, etc.
Process support engineering	production quality engineering (quality control and quality assurance), environmental and recycling engineering, mechanics - machine operation, mechatronics, industrial chemical analysis, electrical engineering of industrial machines, electronics micro- and nanoelectronics, nanotechnologies, industrial biotechnology, photonics, sensorics, industrial mechatronic machines and systems, machine design, mechanical engineering and machine construction technology, maintenance engineering (PM), electrical engineering, robotics engineering.
Industrial informatics	computer programming and design, including: 3D design, computer simulation, computer modelling, data analysis, programming, process visualisation, industrial data platformisation, neural networks, industrial network administration, machine learning, AI support, AI environments, autonomous decision-making systems, sensorics, robotics engineering, cybersecurity.

Source: own elaboration.

Digital competences and skills are not limited to handling information and computer technology (process support systems) or computer programming and data analysis, but cover a wide range of skills from digital problem solving to knowledge of data privacy or cyber security. In addition to technical and digital skills, a steelworker must have soft skills, including: cognitive (thinking skills, creativity, logical reasoning, inquiry, recognition, compilation of knowledge, solving complex problems) and social skills (communication, teamwork, leadership and management of employees, effective group collaboration, emotional intelligence, entrepreneurship and others) (Gajdzik, 2021b).

In the category of soft skills, World Economic Forum experts (2018, p. 29) point to the usefulness, first of all, of skills such as: human resource management, negotiation skills, emotional intelligence regarding social and customer needs (product personalisation), alignment of one's actions with those of other team members (team of operators within a given process), cognitive flexibility (ability to flexibly switch thinking between different problems or sets of rules) complex problem solving (developed ability to solve non-obvious problems in complex real-world contexts, in the case of a metallurgist in controlled processes and operated technological ranges), critical thinking based on logic, reasoning, inference, and creativity as the ability to come up with unusual or non-obvious ideas on a given topic or in response to a given situation, or to develop creative ways to solve a problem).

Particular emphasis in operating next-generation technologies is on problem discovery, especially at the lower levels of the cyber-physical manufacturing systems architecture. The metallurgical operator must be a good researcher and observer of the technologies used in metallurgy. The metallurgical operator learns about the technology being operated and discovers its problems. Innovation and design thinking in operators is all about finding problems, not just solving them. It is important for the metallurgical technology operator to acquire the skills to deal with complex process problems. Metallurgists with many years of experience have learnt to look at process plants from different perspectives – practice makes perfect – and over time, this knowledge must be passed on to new employees so that it becomes a source of new possibilities for controlling processes and optimising operations.

These three categories of qualifications and skills are represented by the letter 'T' (Figure 3). In the European Commission's blueprint entitled: European vision on steel-related skills (...), May 2020, technical skills, digital skills and soft skills are the components of the letter "T", to which the author added basic cognitive, technical and social skills.

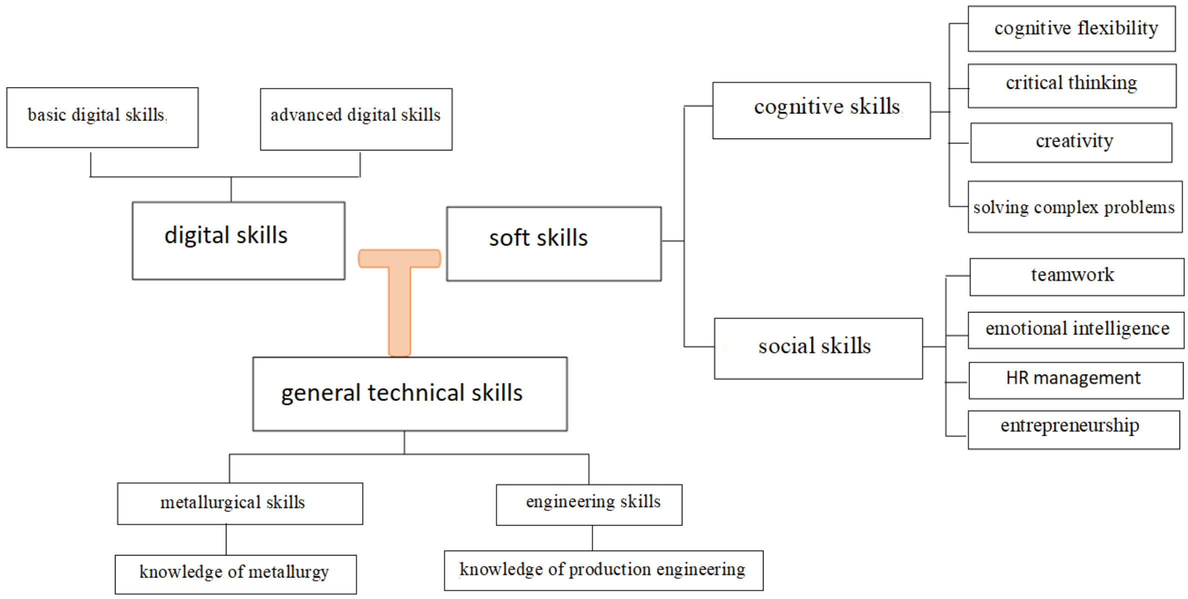

Figure 3. T-shaped diagram of a metallurgist's basic skills. Source: own elaboration based on report of EC, Blueprint, European vision on steel-related skills (...), May 2020.

In the OECD report The Future of Education and Skills: Education 2030, three additional categories of future skills were identified, called "transformative" skills. Transformative skills are: knowledge of creating new values (useful qualities of an employee: adaptability, creativity, curiosity, open-mindedness), skills of reconciling tensions and solving problems (useful qualities: empathy, emotional intelligence, cooperation in a team) and responsibility of an employee (key qualities: intellectual and moral, professional and technological maturity).

The metallurgical operator must be able to work both independently and in a team. Specific process technologies are operated by several teams of operators. Working in teams, often dispersed at work, requires the ability to efficiently manage the work of people and technologies, coordination and decision-making. It is in the employer's interest that team skills are transferable skills (Yate, 2019). Teams in steel mills should be multi-tasked and metallurgists in technology teams should be strongly supported by IT staff, especially at the stage of learning the technology to be supported. Over time, the ability to do basic computer programming of technology gradually becomes as basic as the ability to operate computer office programs. From basic digital skills, the metallurgist moves over time to advanced digital skills. The key skills of the metallurgical operator are continuously adapted to the technological maturity of the enterprise to Industry 4.0.

Each enterprise is at a different stage of transformation to Industry 4.0. There is no universal path for enterprises on their journey to Industry 4.0 (Gajdzik et al., 2021). The set of key competences of a metallurgical operator may differ from one enterprise to another. In general, it can be assumed that the key skills of a metallurgical operator refer to what is not yet written in the algorithms of the machines and are necessary to perform process operations in the transformation of a steel mill to Industry 4.0

Summing up the considerations, the author would like to point out that the profession of a metallurgist evolves with technological progress, in successive industrial revolutions, the workers of steel mills acquire new process skills and physical labour is replaced by machine work. In the fourth industrial revolution, in addition to the process typology of the metallurgical profession (blast furnace worker, steel worker, rolling mill worker, etc.), the typology of industrial digital technologies is used, e.g. metallurgical analyst, metallurgical programmer, metallurgical technology transformation specialist, metallurgical process optimisation specialist. The operator metallurgist as part of the teamwork collaborates with specialists in AI (artificial intelligence), ML (machine learning), process automation and robotics and multiple data analysts (data analyst, software analyst, data security analyst, etc.). Figure 4 shows a new overview layout of the operator metallurgist skill map – Metallurgist 4.0.

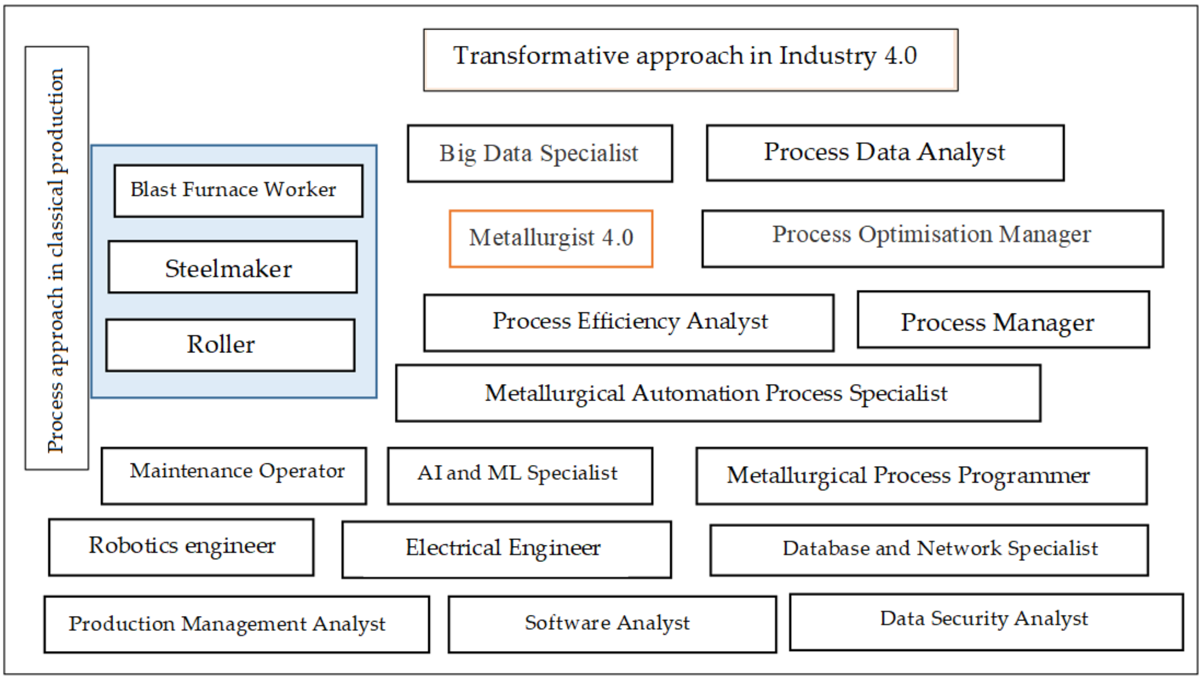

Figure 4. Map of operator skills in steelworks 4.0 – Metallurgist 4.0. Source: own elaboration.

Conclusion

In the conditions of digital transformation, knowledge becomes the key resource, and the key competence of people and organizations - the way and speed of acquiring and using it. In the labour market shaped by automation processes based on artificial intelligence and platformisation, there is a need for employees who, relying on advanced cognitive, social and technical (including digital) competences, can cooperate with fourth generation technologies and participate in the creation of cyber-physical manufacturing systems. The use of new technologies affects the form and nature of work in many industries, including the steel industry under analysis. With the transformation of metallurgical enterprises to Industry 4.0, many tasks performed by people will be increasingly replaced by the work of machines (the replacement concerns repetitive and routine activities, both physical and mental). At the current stage of metallurgical transformation, the metallurgical profession is subject to the enrichment of digital (initially basic, with time advanced) and cognitive and social skills.

The arrangement of the triad of skills (hard, soft and digital) of metallurgy facilitates employees to work with technology and understand complex operational (process) tasks. A contemporary metallurgist is a member of a team of operators and IT specialists, with whose participation he gradually acquires knowledge and learns the possibilities of high technology. The acquired experience should be enriched by education in the organisations offering training, courses and other forms of education.

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