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Transformation from Steelworks 3.0 to Steelworks 4.0: Key Technologies of Industry 4.0 and their Usefulness for Polish Steelworks in Direct Research

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Bożena Gajdzik[1]

Abstract:

Purpose: *Based on the knowledge of steel producers in Poland (results of field research), this publication presents the degree of knowledge of respondents about key technologies of Industry 4.0 and their usefulness for the steel sector in Poland.*
Design/Methodology/Approach: *In field research was used a questionnaire. The research subjects (fields) were keys enabling technologies (KETs): Internet of Things (IoT) with other solutions, Big Data with analytics, advanced simulation, cloud computing and cognitive computing, cyber physical systems (CPS), autonomous systems, universal integration and connected enterprises, , additive manufacture with printing 3D, augmented reality and real-time deliveries. Steel producers have knowledge of Industry 4.0 technologies. Information and communications technology (ICT) are well known by them. The technologies help them to achieve the integration with co-operators in the supply chain (end to end engineering). Of the key technologies of Industry 4.0, they also well know cloud computing and additive manufacturing with 3D printing. On the basis of the analysis performed, a statistically significant monotonic positive correlation (i.e. increasing dependence) between the level of awareness of individual pillars of the Industry 4.0 concept and the level of awareness of the Industry 4.0 concept was found in the producers group.*
Findings: *In the research field of technology usefulness in metallurgy, additive manufacturing received the highest marks (rank 1), followed by integrative systems/ ICT (rank 2), and real-time deliveries (rank 3).*
Practical Implications: *The present results suggest that steelworks in Poland are in the transformation process from steelwork 3.0 to steelworks 4.0.*
Originality/Value: *The presented research is part of a larger own study of the degree of transformation of steelworks 3.0 to steelworks 4.0.*

Keywords: *Industry 4.0, steelworks 3.0, steelworks 4.0.*

JEL classification: *D25, L61, O33.*

Paper Type: *Research study.*

[1]*Silesian University of Technology, Faculty of Materials Engineering, Gliwice, Poland, ORCID: 0000-0002-0408-1691, bozena.gajdzik@polsl.pl*

1. Introduction

Initiated by the German government in 2011, Industry 4.0 is not a fully homogeneous and integrated technological concept, so the selectivity (segmentation) of technologies implemented in different industries around the world. It is difficult to indicate a common set of technologies for all enterprises. Each enterprise chooses its own path to Industry 4.0 (Gajdzik, 2021). In steel mills, changes are directed towards 'full' automation and digitisation of processes. Currently, steel mills are "halfway" between steel mill 3.0 and steel mill 4.0 (Zeman, 2017). The different areas of technological innovation of the fourth industrial revolution are more and more popular in steel mills. The steel industry has started to implement the key enabling technologies (KETs) into steel mills (Peters, 2017). Industry 4.0 has started the transformation of steelworks3.0 to steelworks 4.0. The transformation will be realised in the long term. Although the changes have started but it will take time to achieve all the necessary conditions of Industry 4.0.

New technologies are also being implemented in steel mills on the Polish steel market. Strong foreign capital groups that own the largest steel producers in Poland invest in Industry 4.0, e.g. ArcelorMittal (Gajdzik and Wolniak, 2021). For many years (after the economic transformation), strong foreign capital groups in the Polish steel market have determined the competitiveness in Polish sector (Gajdzik and Sroka, 2012). Apart from steel producers, Industry 4.0 technologies are also implemented by steel customers, e.g. the automotive sector. Full automation is in the big steel warehouses (Gajdzik, 2019). Key technologies of Industry 4.0 are used in sustainable logistic system (Walaszczyk *et al.*, 2019). For many years now, steel producers have been improving production and maintenance systems on the levels of autonomous and professional (Gajdzik, 2014). The technologies used in metallurgy are subordinated to the sustainability strategy. Environmental aspects and waste logistics are determinants of business (Gajdzik, 2009). Sustainability is strongly linked to industrial development.

In the new concept - Industry 4.0 - still industrial development must be sustainable also (Gajdzik *et al*., 2020). In the production of steel, sustainability was and is a basic condition for the activity. With the popularisation of the Industry 4.0 concept (a decade ago) the transformation process from steelworks 3.0 to steelworks 4.0 started in the steel mills. Steel manufacturing in the 3.0 steelworks are automated and computer systems support production. Steelworks 4.0 strives for smart production in cyber- physical systems (CPS). In order to establish the extent of the changes I carried out direct research. The research topic: Industry 4.0 in Polish steel mills is multi-segmental. In this publication I present the first area of research. This area concerns steelmakers' knowledge of key Industry 4.0 technologies and their usefulness to the steel sector. A questionnaire was used for the study. The research was conducted in the first quarter of 2020 (before COVID-19 pandemic).

The remainder of the paper is organized as follows: a short review of the literature is presented in section 2; section 3 presents the research methodology; section 4 the results, and the 5th section summarizes the paper.

2. Literature Review

The development of the iron and steel industry followed the industrial revolutions (of which there were four), but it was only after the second industrial revolution, marked by the invention of the production line and the improvement of transport technology and the electrification of industrial processes, that it became possible to produce more steel. Innovations were realised in the ironworks, for the first time, by H. Bessmer. In 1856 H. Bessmer invented the first converter for the production of steel. In 1864 Pierre-Émil Martin, developed the process of melting steel in a regenerative furnace. The development of metallurgy took place in conjunction with successive industrial revolutions. The first and second industrial revolutions are now history and the third revolution is still ongoing.

Many steelworks are still at the level of 3.0. This level is a combination of the technologies of the third industrial revolution and the fourth industrial revolution. Important features of steelworks 3.0 include (Santos *et al.*, 2017), autonomous processes without learning function, process optimization but without self-optimization, digitalisation of physical processes, virtualisation, statistics and quality control systems, process monitoring, strong cooperation people and machine (P2M) with Total Productive Maintenance (machine learning has been started), IT systems – especially ERP system, industrial Internet is used to communication and cooperation in supply chain but Big Data, Big Data Analytics, cloud computing, IoT have been started in steelworks, classic automatization (maybe with single of robots) and other solutions such as, FMS, JiT, Lean, TQM, pull systems, embedded systems. In highly developed countries, the third revolution has been superseded by a fourth called the era of Industrie 4.0 (Industry 4.0) or digital transformation.

The characteristics of the fourth industrial revolution are, digitalisation, virtual simulations, real-time data processing, machine communication and artificial intelligence. The key technologies of Industry 4.0 are, Internet of Things (IoT), Internet of Services (IoS), Big Data with Big Data Analitics, advanced simulation, cloud computing, augmented reality, learning machines, cognitive computing, additive manufacture, printing 3D, autonomous robots/cobots, digital twins, smart manufacturing, autonomous production systems, Cyber Physical Systems (CPS) and universal integration in value chains and cyber security. These technologies are classified as the nine pillars of Industry 4.0, IoT, systems integration, simulation, augmented reality, big data, additive manufacture, autonomous system, cloud computing, cyber security (Senn, 2020; Erboz, 2019; Burrel, 2019). The fourth industrial revolution needs smart IT networks to facilitate process execution and machine communication. The result of the changes is to be a smart steelworks operating in cyber-physical systems. Features of smart steelworks are, automation, standardisation, modularisation, networking, virtualisation, flexibility, integration, autonomy, cyber-physicality, self-optimisation and self-improvement. Smart steel mills are included in the level of industrial development called, Industry 4.0.

In 2011, at the Hanover event, Germany introduced Industry 4.0 or ‘‘Industrie 4.0’’ for 2020 (Zhou *et al.*, 2015). Steelworks which are part of Industry 4.0 are called steelworks 4.0. Steelworks operating on the Polish steel market implement key technologies of Industry 4.0, the transformation from steelworks 3.0 to steelworks 4.0 has begun. Referring to the EU nomenclature, technologies forming the framework of Industry 4.0 are referred to as KETs - Key Enabling Technologies. KETs are generic technologies that, alone or more often in combination with other Industry 4.0 technologies, form the basis of a range of new products and processes used in manufacturing. KETs have been central in Horizon 2020, the Framework Programme for Research and Innovation 2014-2020.

These enablers (KETs) are the Internet, IIoT, blockchain, big data, edge and cloud computing, robotics, human-machine interaction, artificial intelligence, and open source software. The automation of the industrial systems is going to be achieved through interconnected cyber-physical systems (CPS) in Industry 4.0, thus, allowing the industrial infrastructure and production processes to transform into an autonomous and dynamic system (Davies, 2015). Industry 4.0 is not a homogenous development concept in steelworks. Each steel plant determines its own path to Industry 4.0. The choice of the way steelworks develop depends on their resource capabilities. Core technologies: analytics, big data, cloud computing, advanced automation of machines, advanced scheduling, robotized palletizing, smart robots and machines, intelligent sensors, autonomous vehicles, additive manufacturing (e.g., 3D printing), full automation, robots, cobots etc. are essential to create steelworks 4.0 (Santos and Piechnicki *et al*., 2017; Gracel and Łebkowski, 2018, Di Nardo, 2020). We can say about three scenarios of changes according to level of investment of steelworks in new technologies (Gajdzik, Grabowska *at al*., 2021):

- Traditional production is a priority in relation to intelligent (smart) production,
- Both production: traditional production and intelligent (smart) production are almost equally important,
- Intelligent (smart) production is more important and more developed than traditional production.

On the way of transformation of steelworks 3.0 to steelworks 4.0 there are four levels of technological changes in the market:

- the technology of the third industrial revolution is dominant (there are more steelworks 3.0 than steelworks 4.0 in the market),
- both technologies are cooperate with themselves and steelworks 3.0 transform to steelworks 4.0,

- new technologies of Industry 4.0 displace old technologies and the first cyber-physical steel production systems (CPSPS) are created,
- CPSPS cooperate with technologies of companies in the supply chain.

The process of transforming steelworks 3.0 to steelworks 4.0 starts inside the steelworks and expands to include other participants in the supply chain (moves to other plants) until a cyber-physical value-added chain is created. Peters (2017) lists several stages in the development of Industry 4.0 in steel mills: 1) a single plant as a Cyber Physical Production System (CPPS and vertical integration), 2) full traceability of intermediate and final products into the value chain, 3) an "intelligent" product with knowledge of its own quality and production history (one aspect of end-to-end engineering), 4) intensive communication of plants (integration within the company), 5) intensive communication along the supply chain (integration outside the steel mill), 6) appropriate handling and use of all data, 7) decentralisation of decisions (De-central) instead of central solutions, 8) self-organisation.

Industry 4.0 investments are implemented in enterprises gradually (in stages) over a long period of time and there is no universal instruction for implementing changes. The implemented changes begin from the implementation of individual machines and ends with entire production lines. In the future, these modern production lines will create smart steelworks. A lot of economic, financial, organisational, legal, social and other factors influence the level of change in the transformation of steelworks 3.0 to steelworks 4.0. The initiators of innovation are leaders (managers) in steel plants. Their knowledge about Industry 4.0 determines their willingness to implement of the technologies. Therefore, I realized research about steelmakers' knowledge of key technologies and fixed the usefulness of the technologies (KETs) for the transformation process from steelworks 3.0 to steelworks 4.0.

3. Research Methodology

The research was conducted in Poland. In field research the questionnaire was used. In the questionnaire, a five-point scale (Likert scale)was used to assess the degree of research topic, where: 1 was extremely negative ocean (lowest ocean) and 5 was extremely positive ocean (highest ocean). Spearman rank correlation was used to determine the relationship between the studied characteristics.

The nine pillars of Industry 4.0 (key enabling technologies – KETs) were used. The pillars were numbered, where:

1 – big data and data analytics,
2 – autonomous robots,
3 – advanced simulation,
4 – horizontal and vertical system integration by IC systems (simply: ICT),
5 – Internet of Things (IoT) or Industrial Internet of Things (IIoT),

6 – CPS/CPPS/ cyber security (the field research was identified by cyber security by respondents),
7 – cloud computing,
8 – additive manufacturing, 3D printing,
9 – Real-time deliveries/virtual and augmented reality.

62 respondents (producers) were participants in the study. By using the filtering questions respondents who did not know the concept of Industry 4.0 was rejected. In the paper, there field research were presented:

- General knowledge about Industry 4.0; Question 1 (Q_1): Is the concept of Industry 4.0 known?
- Detailed knowledge about the pillars of Industry 4.0; Question 2 (Q_2): Are the individual pillars of the Industry 4.0 concept known?
- Usefulness of the KETs in steel sector at the current stage of transformation from steelworks 3.0 to steelworks 4.0; Question 3 (Q_3): What technologies (pillars of Industry 4.0) are particular useful in the steel industry ?

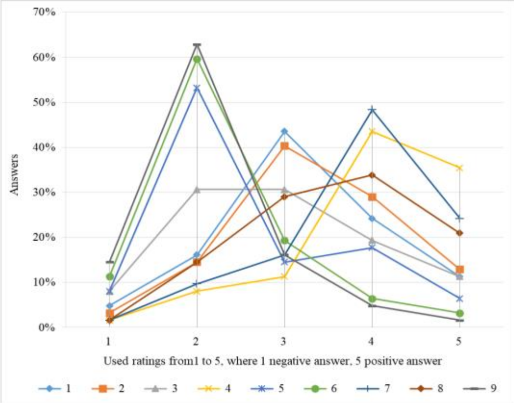
4. Research Results

Questions about familiarity with the Industry 4.0 concept were answered satisfactorily (negative ratings were only from 12.4% of respondents). The sources of knowledge about Industry 4.0 were various, e.g. training in the workplace, work meetings, conferences. In my own research (Gajdzik, 37-th IBIMA, 2021) this topic has already been described by me. In this publication I would like to present the results of the level of knowledge of the pillars of Industry 4.0 in connection with their usefulness (in the opinion of respondents) for the development of the steel sector. Based on the responses received, it was found that the IC technologies and systems used to achieve the integration of processes within the company and in the supply chain (end to end engineering), cloud computing and additive manufacturing with 3D printing were well or very well known to steel producers. Ratings from 1 to 5 were used, where:

1 – I have never heard of this pillar;
2 – Yes, I have heard about this pillar, but I don't know what it is characterized by;
3 – I am familiar with this pillar, I can describe it briefly;
4 – I am familiar with this pillar, it is planned to be introduced in our company;
5 – I am familiar with this pillar, it is already used in our company.

Results of the research were presented in Figure 1 and in Table 1. In order to compare answers to question: Is the concept of Industry 4.0 known? with answers to question: Are the individual pillars of the Industry 4.0 concept known?, a correlation assessment based on the Spearman rank correlation test was used. Table 2 and Figure 2 present the results of statistical evaluation. For all correlations, p was <0.001. Results in Table 2 and in Figure 2 were presented from low to high.

***Figure 1**. Producers' knowledge about technologies/pillars of Industry 4.0*



***Source:** Own study.*

***Table 1.** Producers' knowledge about technologies/ pillars of Industry 4.0*

KETs/pillars of Industry 4.0		Used scale:				
		1	2	3	4	5
1.	Big data and data analytics	5%	16%	44%	24%	11%
2.	Autonomous robots	3%	15%	40%	29%	13%
3.	Advanced simulation	8%	31%	31%	19%	11%
4.	Horizontal and vertical system integration/IC systems/ **ICT**	2%	8%	11%	44%	35%
5.	IoT/IIoT	8%	53%	15%	18%	6%
6.	CPS/CPPS/ **cyber security**	11%	60%	19%	6%	3%
7.	Cloud computing	2%	10%	16%	48%	24%
8.	Additive manufacturing, 3D printing	2%	15%	29%	34%	21%
9.	Virtual and augmented reality/ **Real-time deliveries**	15%	63%	16%	5%	2%

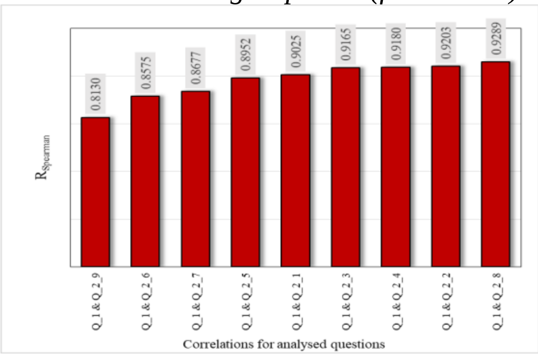
***Source:** Own study.*

***Table 2**. Results of statistical evaluation between question 1 (Q_1) and question 2 (Q_2) for individual technologies/pillars (from 1 to 9)*

Correlation between:	*N*	$R_{Spearman}$	*t* (*N*-2)	level *p*
Q_1 & Q_2_9	62	0.8130	10.8145	0.0000
Q_1 & Q_2_6	62	0.8575	12.9083	0.0000
Q_1 & Q_2_7	62	0.8677	13.5197	0.0000
Q_1 & Q_2_5	62	0.8952	15.5619	0.0000
Q_1 & Q_2_1	62	0.9025	16.2325	0.0000
Q_1 & Q_2_3	62	0.9165	17.7497	0.0000
Q_1 & Q_2_4	62	0.9180	17.9314	0.0000
Q_1 & Q_2_2	62	0.9203	18.2256	0.0000
Q_1 & Q_2_8	62	0.9289	19.4311	0.0000

***Source:** Own study.*

Figure 2. *Results of statistical evaluation between question 1 (Q_1) and question 2 (Q_2) for individual technologies/pillars (from 1 to 9)*

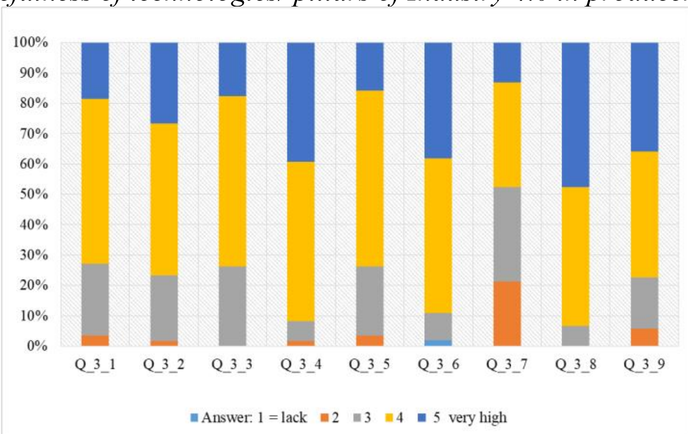


Source: *Own study.*

On the basis of the performed analysis, a statistically significant monotonic positive correlation (i.e., increasing dependence) between the level of familiarity with particular pillars of the Industry 4.0 concept and the level of familiarity with the Industry 4.0 concept was found in the group of steel manufacturers, which translates into high reliability of answers in the surveyed questionnaire. The highest level of correlation was obtained for pillar 8: additive manufacturing with and 3D printing.

In order to assess the usefulness of technology, respondents were rejected who, when asked about their knowledge of the pillars, indicated an answer of 1 = I have never heard of this pillar. Table 3 does not include these respondents (there are fewer respondents than at the beginning of the survey, where there were N=62). Among the usability, additive manufacturing received the highest ratings (rank 1), followed by: integrating systems (rank 2), cyber security (rank 3) and real-time delivery, (rank 4). Table 3 and Figure 3 show the structure of the responses obtained . Used scale: 1: none/lack, 2: small, 3: medium, 4: large, 5: very large/ very high usefulness.

Figure 3. *Usefulness of technologies/ pillars of Industry 4.0 in producers' opinions*



Source: *Own study.*

***Table 3**. Usefulness of technologies/ pillars of Industry 4.0 in producers' opinions*

KETs/pillars of Industry 4.0		Used scale:					Total
		1	2	3	4	5	*N*
1.	Big data and data analytics	0.0%	3.4%	23.7%	54.2%	18.6%	59
2.	Autonomous robots	0.0%	1.7%	21.7%	50.0%	26.7%	60
3.	Advanced simulation	0.0%	0.0%	26.3%	56.1%	17.5%	57
4.	Horizontal and vertical system integration, IC systems/ **ICT**	0.0%	1.6%	6.6%	52.5%	30.3%	61
5.	IoT/IIoT	0.0%	3.5%	22.8%	57.9%	15.8%	57
6.	CPS or CPPS/ **cyber security**	1.8%	0.0%	9.1%	50.9%	38.2%	55
7.	Cloud computing	0.0%	21.3%	31.2%	34.4%	13.1%	61
8.	Additive manufacturing/**3D printing**	0.0%	0.0%	6.6%	45.9%	47.5%	61
9.	Virtual and augmented reality/ **Real-time deliveries**	0.0%	5.7%	17.0%	41.5%	35.9%	53

***Source:** Own study.*

The final result of the research was a comparison of knowledge of the pillars by steel producers in Poland with the usefulness (in their opinion) of particular technologies and solutions for the steel sector. A comparison of the results from table 2 with the results from table 2 resulted in a common set of analysed research results. Two technologies/pillars of Industry 4.0 received high R Spearman indices and high scores for their usefulness for the development of the steel sector:

1 Additive manufacturing/ 3D printing: *R*Spearman 0.9289; estimation: 4 (45.9%), estimation (rank) 5: 47.5%,
2 ICT, IC systems: *R*Spearman: 0.918, estimation (rank) 4: 52.5%, estimation (rank 5) 5: 30.3%,
3 High usefulness was assigned to real time deliveries but *R*Spearman was 0.8130.

5. Conclusions

The progressive fourth industrial revolution involves steel producers and their co-operators in chain supply. This article is a part of own field research realized in the Polish steel sector. The topic of own research was transformation of steelworks 3.0 to steelworks 4.0 in Poland. Popularised for a decade, Industry 4.0 is changing industries. The framework of Industry 4.0 is a symbiosis of operational and information technologies. The integration of information, operational and network technologies is called cyber-physical systems (CPS). The concept of Industry 4.0 is a technological and organisational challenge for many industrial sectors. Among the sectors is the steel industry. Steel producers see opportunities for development of steelworks in the Industry 4.0.

On the basis of this research it can be confirmed that the steel sector in Poland is changing under the influence of the Industry 4.0 technology. Steel mills in Poland are in the process of transformation from steel mills 3.0 to 4.0, but at this stage the usefulness of IC (digitalisation of steel Industry) and additive manufacturing with 3D printing technology is visible.

The research I have conducted is a pilot study. The participating manufacturers were randomly selected and the scope of the research presented in this article (Questions from 1 to 3) is part of a wider study.

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