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Key Challenges and Opportunities of Industry 4.0 in Metallurgical Industry in Slovakia

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Abstract

The main objective of the paper was to identify and explain the terms related to Industry 4.0 based on a review of foreign literature and then to interpret the results of the quantitative research. In the construction of the theoretical framework, the analysis, synthesis, comparison of scientific terminology from foreign scientific sources from recent years. Interpretation of the studied issues from the practical aspect was realised on the basis of the evaluation of the questionnaire survey. The object of the research were 29 enterprises participating in the metallurgical industry in Slovakia. The research results indicate that the respondents have partial information about Industry 4.0. Data evaluation also indicated that most of the respondents are applying Industry 4.0 in production. Industry 4.0 in metallurgical enterprises mainly optimise business processes. The use of smart sensors from Industry 4.0 technologies as well as advanced simulation is dominant in metallurgical enterprises in Slovakia.

Keywords

Digitalisation, Fourth Industrial Revolution, Industry 4.0, Industry 4.0 Technologies, Metallurgical Industry

I. Introduction

Industry 4.0 is a concept that has been around for a decade, but its rationale continues to gain global traction. Industry 4.0 is used to improve business processes by integrating systems, connecting physical and cyber capabilities, and leveraging information, including the application of big data development. The implementation of Industry 4.0 is finding applications in all industries. Industry 4.0 represents a modern industrial revolution as it declares increased flexibility in manufacturing along with mass customisation, better quality and increased productivity. Industry 4.0 enables enterprises to cope with the new challenges of production, where the focus is on increasingly individualised products with short lead times and higher quality. In the first part of this paper we compared foreign

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authors' views on the issue of the Fourth Industrial Revolution and Industry 4.0. Subsequently, in the next part of the paper we analysed Industry 4.0 in 29 enterprises participating in the metallurgical industry in Slovakia.

II. Theoretical Framework

In recent decades, technological advances along with rapid and major technological changes have been a chance to improve human life. New breakthroughs in the form of new technologies such as robots and artificial intelligence are a key element of the Fourth Industrial Revolution (K. Zervoudi, 2020). The First Industrial Revolution (around 1800) was primarily focused on the production of goods. The Second Industrial Revolution (circa 1900) was primarily focused on the mass production of goods. The Third Industrial Revolution (circa 2000) was primarily focused on mass customization of goods, services, or merchandise (Tien, 2020). In the present twenty-first century, society has entered a dramatic transformation called the Fourth Industrial Revolution. It is characterised by the proliferation of increasingly complex technologies that link the physical, digital and biological worlds (Rotatori et al., 2020). The Fourth Industrial Revolution is different from previous industrial revolutions. Technology plays a much greater role in it. The key challenge is to develop a technology policy that will play an active role in promoting and concentrating efforts to create an innovation ecosystem (Schäfer, 2018). Digitalisation and intelligence of the production process is a necessity in today's industry. Currently, the trend is to change manufacturing industries from mass production to customised production. Rapid advancements in manufacturing technologies and applications in industries are helping to increase productivity. These changes are a result of the ongoing Fourth Industrial Revolution. This industrial revolution is defined as a new level of organisation and control of the entire product life-cycle value chain; it is focused on increasingly individualised customer requirements (Vaidya et al., 2018). The Fourth Industrial Revolution represents the emergence of digital technologies and communication systems that are embedded in all industries. The Fourth Industrial Revolution is a new way of organising the means of production, processes and all the organisational structures of the manufacturing and service industries (Reyes Fabela et al., 2018). The Fourth Industrial Revolution represents a fundamental digital transformation. This revolution is known around the world as Industry 4.0, and it is advancing exponentially. The Fourth Industrial Revolution is transforming the way individuals live and work (Ghobakhloo, 2020). The Fourth Industrial Revolution is characterised by the advanced digitisation and integration of industrial production and logistics processes. Linked to this industrial revolution is the use of the Internet and 'smart' objects (machines and products) and the merging of the physical and virtual worlds through the deployment of information and communication technologies (Fonseca, 2018). The Fourth Industrial Revolution determines changes especially in the field of production, where there is a shift from mass production to personalised production, which leads to greater flexibility in production processes and provides the means to meet the individual needs of different customers more efficiently (Nosalska and Mazurek, 2019). Artificial intelligence and 5G connectivity are identified as the driving forces behind the ongoing Fourth Industrial Revolution. Artificial intelligence and 5G

connectivity, along with other new technologies such as blockchain, gene editing, IoT sensors, nanotechnology, 3D printing, are accelerating the blurring of the boundaries between the digital, biological and physical realms (Krafft et al., 2020). The Fourth Industrial Revolution, also known as Industry 4.0, has begun with new and disruptive smart and information technologies. These new technologies are enabling ever higher levels of production efficiency. The technologies also have the potential to have a significant impact on social and environmental sustainability (Bai et al., 2020).

The German Federal Government has introduced Industry 4.0 as an emerging structure in which production and logistics systems in the form of a cyber-physical production system use a globally accessible information and communication network for the purpose of large-scale automated information exchange in which production and business processes are harmonised (Kamarul Bahrin et al., 2016). Industry 4.0 was created as a new concept by a group of German mechanical engineers in 2011. The aim of this concept was the extensive integration and adaptation of information and communication technologies in the manufacturing sector (Schuh et al., 2017). Industry 4.0 originated in Germany and its nature is based on the use of automatisation and digitalisation processes in industry. This transforms today's factories into self-managed and self-adapting social and technical systems (smart factories) that enable the creation of intelligent value chains (Kagermann, 2014; Lasi et al., 2014). Industry 4.0 is seen as a new paradigm for smart and autonomous manufacturing. Industry 4.0 intensively integrates manufacturing operations systems with communication, information and intelligence technologies (Jeschke et al., 2016). Industry 4.0 and its effect on processes and people becomes reality with all organizational and technological complex implications for the future (Fidlerová et al., 2021). Industry 4.0 is the result of technological innovation and changing customer demands. This transformational change will fundamentally affect operating models and management strategies to adapt and integrate with new challenges (Barreto et al., 2017). Fidlerová et al. (2022) connect the implementation of Industry 4.0 with the introduction of innovations in order to increase the competitiveness of sustainable entrepreneurship. Industry 4.0 is the intelligent, horizontal and vertical interconnection of people, machines, objects and information and communication systems in real time (Müller et al., 2018; Stock et al., 2018). Industry 4.0 represents a new industrial revolution that focuses on cyber-physical systems. This revolution envisages that the real-time interconnection of physical and digital systems, together with new enabling technologies, will change the way work is done and managed. Industry 4.0 has the potential to disrupt or at least change the traditional way organisations operate, including cost, flexibility, speed and quality (Lennon Olsen and Tomlin, 2019). Industry 4.0 is part of the integrated and connected world that has evolved thanks to the revolution in information and communication technologies. This technological change in Industry 4.0 is taking place through the Internet of Things and the Internet of Services. This makes the industry "intelligent", and all this is supported by cyber-physical systems (Liao et al., 2017). Industry 4.0 represents a technological revolution that embraces big data, industrial automation, simulation, integration systems, the Internet of Things, cybersecurity, cloud computing, additive manufacturing and augmented reality as the main complex drivers of technological work

aimed at continuous improvement. Industry 4.0 connects information and communication technologies with manufacturing and production processes (Lopes de Sousa Jabbour et al., 2018). Industry 4.0 comprises five key elements – digitalisation, optimisation and customisation of production, automation and adaptation, human-machine interaction, value-added services and commerce, and automated data exchange and communication (Roblek et al., 2016). Industry 4.0 includes additive manufacturing, advance robotics and cobots, artificial intelligence, augmented reality, human-machine interfaces, machine-to-machine communication, blockchain, internet of things, cloud stored data, internet of services, digital transformation, autonomous vehicles, drones (Markov and Vitliemov, 2020). Industry 4.0 provides the use of various technologies in the form of drones, autonomous vehicles, and other technological options is an opportunity for innovation, of course, with due respect for the demands of security and the necessary level of digital skills in collaboration with IT professionals (Porubčinová et al., 2020). Industry 4.0 technologies and the Industrial Internet of Things are rapidly driving data and software for digitalisation solutions in many areas, especially in industrial automatisation and production systems. Among the multiple advantages these technologies offer is the infrastructure to leverage big data, machine learning, and cloud computing software tools, for example, in the design of advanced data analytics platforms (Kabugo et al., 2020). Key Industry 4.0 technologies include: big data analytics, autonomous robots, cloud technologies, simulation, industrial IoT, additive manufacturing, augmented reality, business intelligence, cybersecurity (Ghadge et al., 2020).

III. Methodology

The main objective of the paper was to identify and explain the terms related to Industry 4.0 based on a review of foreign literature and then to interpret the results of the quantitative research. The intention of the paper was to provide an overview of the key challenges and opportunities of Industry 4.0 in the metallurgical industry in Slovakia. In the construction of the theoretical framework, the analysis, synthesis, comparison of scientific terminology from foreign scientific sources from recent years, which are in the international databases Web of Science, Scopus and EBSCO, was used. Interpretation of the studied issues from the practical aspect was realised on the basis of the evaluation of the questionnaire survey. The data collection was conducted between July 2021 and December 2021 through an electronic standardised questionnaire. The questionnaire was distributed among the managers of the metallurgical industry through email addresses. The questionnaire was structured into several areas. The first area concentrated on the identification of the respondents and then other parts of the questionnaire dealt with Industry 4.0 and its key challenges and opportunities. The construction of the questions in the questionnaire made use of identification questions and closed questions where the respondent had a choice of options or a choice through a numerical scale. Descriptive and inferential statistical analysis was used in the analysis. Visual analysis of data under descriptive statistics was done through pie charts, group bar charts and spider chart. The results of the quantitative research were evaluated using IBM SPSS Statistics 20.0 statistical software. Non-parametric tests in the form of the non-parametric Spearman's rank correlation test

and Pearson chi-square test were used for inferential statistics, in which the strength of association was performed through Phi and Cramer's V coefficient. The homogeneity of variance was also used in the data analysis and tested through Levene's test. After its evaluation, we concluded that the homogeneity of variance was violated. Based on this fact, the non-parametric Kruskal-Wallis test, which is a one-way ANOVA, was used in further testing. When the tests were applied, the significance level was $\alpha = 5\%$ (confidence interval 95%).

Yanzhao et al. (2020) deal with current issues of digital transformation of metallurgical enterprises in the conditions of sustainable development of Industry 4.0. The authors systematise the tools of digitalisation of enterprises in the metallurgical industry in Russia. Romanova and Sirotin (2019) analysed new technological and institutional trends in the development of metallurgy in the context of Industry 4.0 in the Central Urals Region. As part of the study, they developed a plan that includes a balanced modernisation of traditional production and the development of new high-tech technologies. The priorities list includes the production of high-tech metal products, the share of which in the structure of finished products will be 70% by 2050. By 2024, the metallurgy industry in the Central Urals region will be comparable in its readiness for digitalisation to more technologically advanced industries. Yasynska et al. (2022) determine the level of development of the metallurgical industry of Ukraine in accordance with the global trends of its transformation from the concept of Industry 4.0. The study analyses the dynamics of crude steel production for 2011–2020. After comparing and analysing the indicators of export-oriented industries in Ukraine, it is found that the metallurgical industry has relative stability. In the study, Glukhov et al. (2022) showed that the active implementation of modern logistics systems developed using the Industry 4.0 concept has enabled metallurgical enterprises in Russia to achieve higher business efficiency. The digitalisation of Russian metallurgical enterprises lies in the active development of the Industry 4.0 concept. Biały et al. (2019) developed a profile of employees for Industry 4.0 who must demonstrate a variety of skills, including IT knowledge, analytical skills, creativity and visionary thinking, the ability to initiate and change, the ability to adapt to new solutions, and an enthusiasm for learning new things within the cyber-physical business space. The study defined a new term – Engineer 4.0 in a metallurgical enterprise in Poland. Shi (2022) says the metallurgical industry is among the pillars in China and plays a very important role in the national industrial economy. The author's study promotes 5G technology in the metallurgical industry as an opportunity to accelerate digital transformation and modernize movement control. Martins et al. (2021) examined Industry 4.0 in terms of technological dynamics, market structure and intrasectoral heterogeneity in the Brazilian metallurgical industry. Based on their research, they found that Industry 4.0 technologies tend to incrementally improve the operational efficiency and productivity of the activity in question, rather than revolutionising it, while the minimum optimal scale of both plants and specific equipment remains unchanged. In the study, Komakech et al. (2021) concentrate on examining the impacts of Industry 4.0 on the activities and strategies of metallurgical enterprises in Uganda. The results of the study show statistical evidence to explain the impact of Industry 4.0 on activities and strategies such as the effects of

rapidly evolving technological capabilities, product quality, quantity and raw materials, increased supply chain and channel strategy, value addition, organizational realignment to integrate physical and digital technologies, market positioning, pipeline management, illicit business practices, skills shortages, research and innovation and other tools.
The summarisation of the above scientific issues was the background for the formulation of research questions and hypotheses:

RQ_1: What is the role of Industry 4.0 in metallurgical enterprises according to the size categorisation of enterprises?

H_{0A}: We assume that there is no significant relationship between leveraging of Industry 4.0 in the metallurgical industry in Slovakia and the selected business size.

H_{1A}: We assume that there is a significant relationship between leveraging of Industry 4.0 in the metallurgical industry in Slovakia and the selected business size.

RQ_2: What is the relationship between the implementation of Industry 4.0 in business areas in the metallurgical industry?

H_{0B}: We assume that there is no significant relationship between the implementation of Industry 4.0 in metallurgical enterprises in Slovakia and the business area – production.

H_{1B}: We assume that there is a significant relationship between the implementation of Industry 4.0 in metallurgical enterprises in Slovakia and the business area – production.

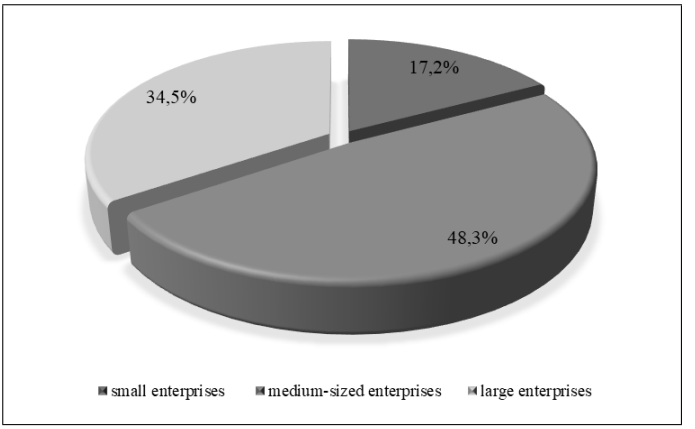
RQ_3: How do the business areas of metallurgical enterprises perceive Industry 4.0 technologies?

H_{0C}: We assume that there is no significant relationship between the use of Industry 4.0 technologies and the business area – production.

H_{1C}: We assume that there is a significant relationship between the use of Industry 4.0 technologies and the business area – production.

The object of the research were enterprises participating in the metallurgical industry in the Slovak Republic. The number of relevant respondents whose answers were included in the analysis was 29. In the data analysis, the structure of respondents by size of the enterprise was determined. Commission Regulation (EU) No. 651/2014 differentiates between micro, small, medium-sized and large enterprises. Figure 1 illustrates the percentage distribution of respondents located in the metallurgical industry in Slovakia. Medium-sized enterprises from the metallurgical industry participated in the research with the largest percentage (48.3%). Large enterprises participated in the research with a share of 34.5%. Small enterprises were the least represented in the research. Their percentage share obtained 17.2%.

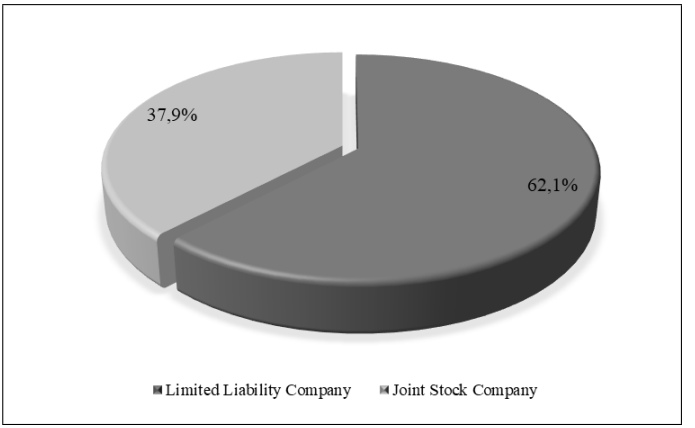
Figure 1: Structure of respondents by size of enterprise



Source: Author's own research

The analysis by legal form of business was also used to categorise the surveyed enterprises. On the basis of the collected data, the largest percentage (62.1%) of limited liability companies from the metallurgical industry participated in the research. The surveyed enterprises that indicated the legal form of joint stock company achieved a share of 37.9%.

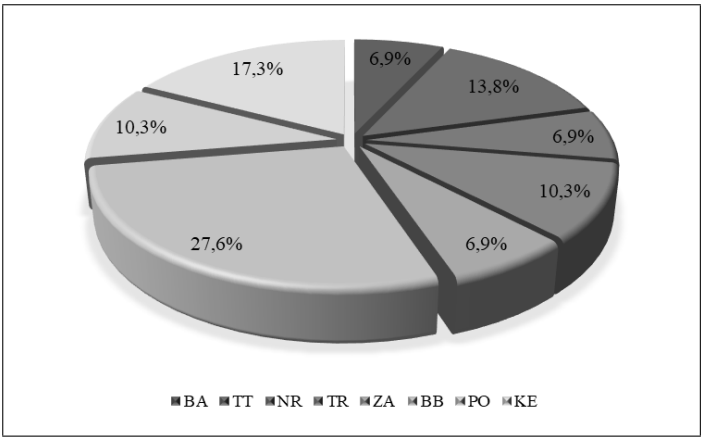
Figure 2: Structure of respondents by legal form of business



Source: Author's own research

The Slovak Republic is divided into 8 regions. According to the regions of Slovakia, enterprises from the metallurgical industry participated in the research with the largest percentage (27.6%) from the Banská Bystrica Region. The larger percentage share (17.3%) was also achieved by enterprises from the metallurgical industry located in the Košice Region. The least participating were respondents from the metallurgical industry from the Bratislava, Nitra and Žilina Regions. These three regions achieved the same percentage representation with a share of 6.9%.

Figure 3: Structure of respondents by regions of Slovakia

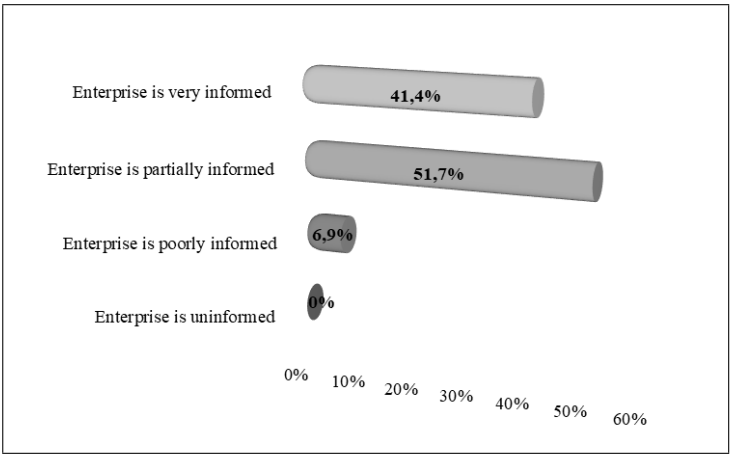


Source: Author's own research

IV. Results and Discussion

The summarised data within the selected responses have been interpreted in the following paragraphs of the paper. In Figure 4, we can see the percentage distribution of the enterprises that were asked about their awareness of Industry 4.0. From the responses we obtained that 41.4% of the respondents are very aware of Industry 4.0. 51.7% of enterprises from the metallurgical industry in Slovakia have partial information about Industry 4.0. Respondents with a share of 6.9% said that they do not have enough information about Industry 4.0. None of the enterprises interviewed confirmed that they did not have any information regarding the ongoing Fourth Industrial Revolution.

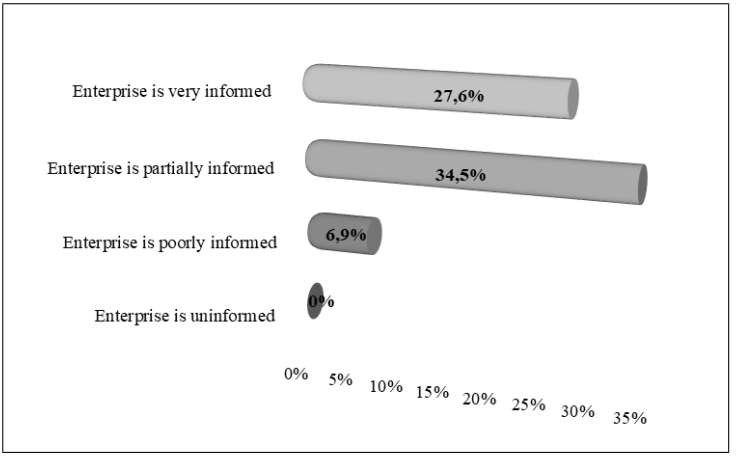
Figure 4: Awareness of Industry 4.0 in metallurgical industry in Slovakia



Source: Author's own research

Industry 4.0 is changing the way the enterprise operates through the Internet of Things, smart devices that communicate with each other through cyber-physical systems. The state of implementation of Industry 4.0 was investigated in the enterprises of the metallurgical industry in Slovakia. Based on the answers of the respondents, it was identified that 27.6% of the enterprises surveyed had implemented Industry 4.0 established in the enterprise. Currently, 34.5% of the surveyed enterprises are introducing Industry 4.0. In the metallurgical enterprises in Slovakia, 37.9% of the respondents are emerging Industry 4.0 at the enterprise level. None of the enterprises surveyed said that they were not involved in the application of Industry 4.0.

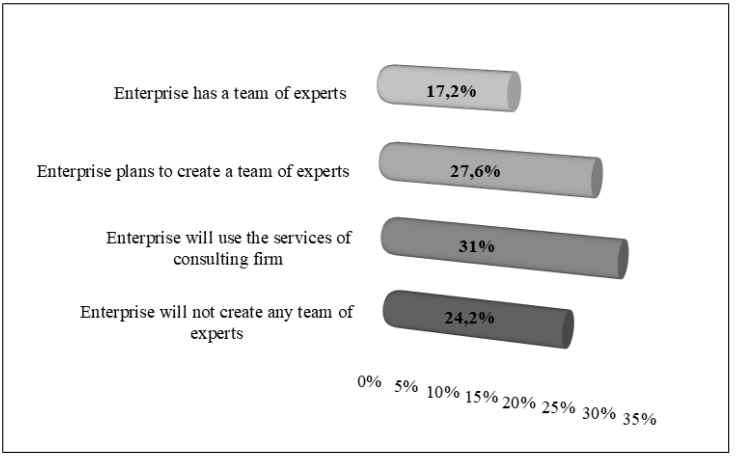
Figure 5: State of implementation of Industry 4.0 in metallurgical industry in Slovakia



Source: Author's own research

The implementation of Industry 4.0 requires having a team of experts that deals with the whole concept of its application within the enterprise. Opinions differ as to whether these competencies should not only be held by top management with individual department managers. There are enterprises where only the top management of the enterprise is in charge of the whole implementation, but there are also enterprises that create a team of experts to deal with the issue in depth. As part of the research, we asked respondents how enterprises in the metallurgical industry in Slovakia cover the implementation of Industry 4.0. Based on the evaluated data, it was identified that 17.2% of the respondents have a team of experts that deals with the implementation of Industry 4.0 in the enterprise. 27.6% of respondents plan to create a team of experts. Of the sample enterprises, 31% are using a consulting firm for implementation. Enterprises with a share of 24.2% do not plan to create any dedicated teams for Industry 4.0 application. We assume that for these respondents the implementation is covered by the top management of the enterprise.

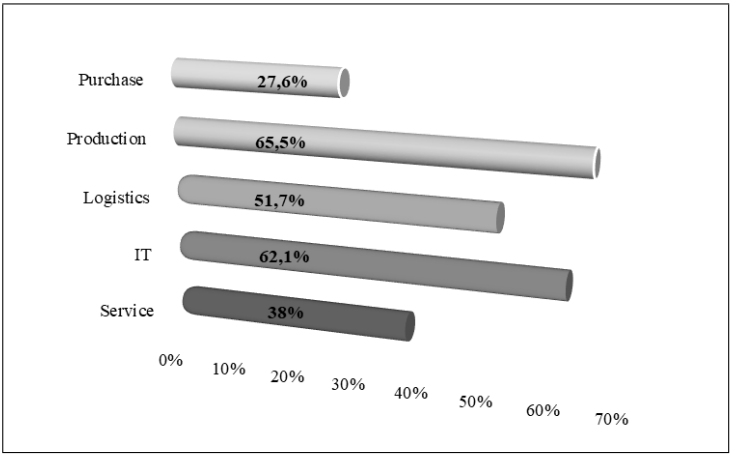
Figure 6: Staffing Industry 4.0 in metallurgical industry in Slovakia



Source: Author's own research

When implementing Industry 4.0 in an enterprise, it is necessary to digitalise various business area. From the responses, we obtained that 65.5% of the respondents are implementing Industry 4.0 in production. IT also recorded a high percentage, with 62.1% of enterprises in the metallurgical industry implementing Industry 4.0. The least percentage of enterprises surveyed are using Industry 4.0 in purchasing. This business area reached 27.6%.

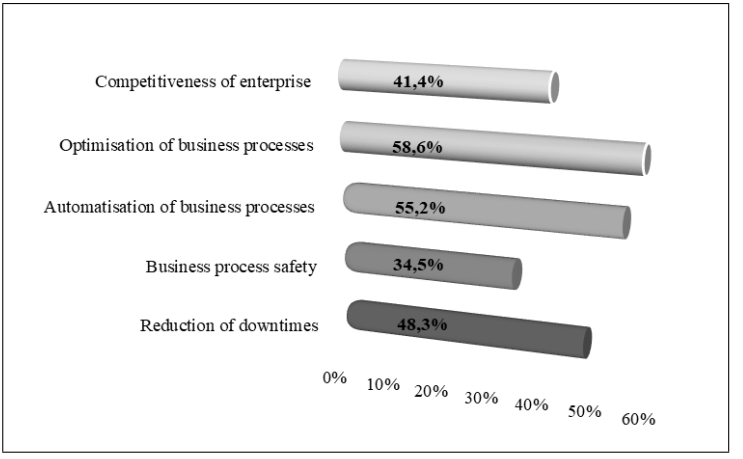
Figure 7: Implementing Industry 4.0 in business areas in metallurgical industry in Slovakia



Source: Author's own research

Industry 4.0 brings key opportunities that provide changes not only in production processes, but also affects the operation of the enterprise with the aim of digitalisation and the creation of a smart factory. We asked a sample of respondents which of the selected key opportunities they consider to be the most important in implementing Industry 4.0. With the largest percentage (58.6%) for the respondents, the application of Industry 4.0 represents the optimisation of business processes. Automatisation of business processes through digitalisation also achieved a high percentage share (55.2%) for enterprises from the metallurgical industry in Slovakia. By implementing Industry 4.0, enterprises reduce downtime. This option was indicated by 48.3% of the respondents. Enterprises from the metallurgical industry considered the security of business processes (34.5%) and the competitiveness of the enterprise (41.4%) to be the least important.

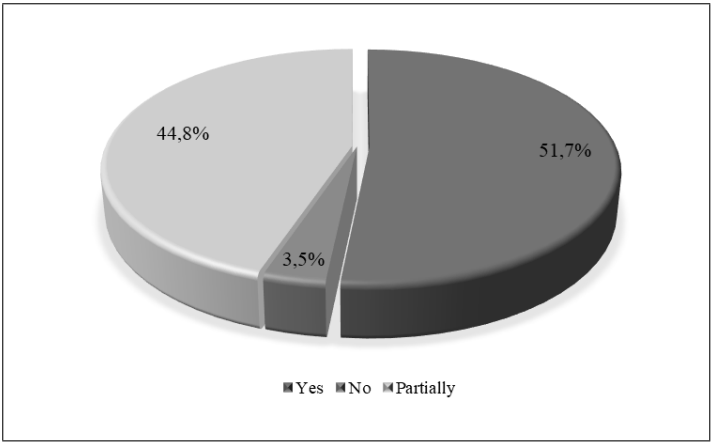
Figure 8: Key opportunities of Industry 4.0 in metallurgical industry in Slovakia



Source: Author's own research

With the implementation and utilisation of Industry 4.0, job losses are also becoming more prevalent in business processes. We have also addressed this issue in our research and identified that the enterprises will eliminate jobs due to the implementation of Industry 4.0. From the responses we obtained, we determined that 51.7% of the enterprises will eliminate jobs. An interesting view is that 44.8% of respondents will be partially cutting jobs. This can be explained by the fact that enterprises will be moving their employees to other departments and other positions that will not be fully digitalised and will need to use human labour.

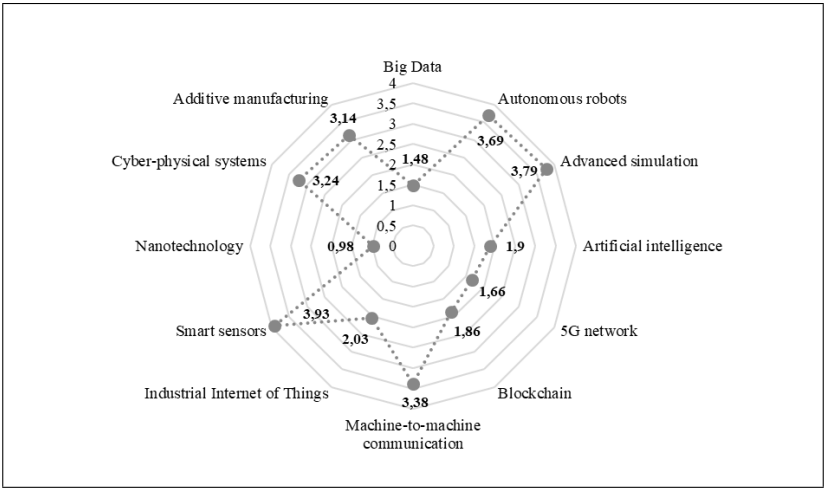
Figure 9: Impact of Industry 4.0 on job destruction in metallurgical industry in Slovakia



Source: Author's own research

The implementation of Industry 4.0 in metallurgical enterprises also brings the use of several Industry 4.0 technologies that are an integral part of this concept. Based on the aggregated average values, we have created the spider chart. Based on the data visualisation, we can observe that the use of smart sensors is dominant in metallurgical enterprises (3.93). Advanced simulation technology also achieved a high average value (3.79). This was followed by autonomous robots (3.69), machine-to-machine communication (3.38) and cyber-physical systems (3.24). Of the Industry 4.0 technologies, enterprises within the metallurgical industry are the least likely to use 5G network (1.66), big data (1.48) and nanotechnology (0.98).

Figure 10: Applying Industry 4.0 technologies in metallurgical industry in Slovakia



Source: Author's own research

The null hypothesis (H_{0A}) and the alternative hypothesis (H_{1A}) were tested using the non-parametric Spearman's rank correlation test. The results of the test are presented in Table 1. Based on the summary of the testing, we conclude that there is a moderately significant relationship between leveraging of Industry 4.0 in large metallurgical enterprises in Slovakia ($r = 0.353$); $p < 0.05$. Also, a moderately significant relationship was confirmed between leveraging of Industry 4.0 in medium-sized metallurgical enterprises in Slovakia ($r = 0.456$); $p < 0.05$. No significant relationship was identified for small metallurgical enterprises.

Table 1: Evaluation of the hypotheses H_{0A} and H_{1A}

Spearman's Correlation Rho		**Small enterprises**	**Medium-sized enterprises**	**Large enterprises**
Leveraging Industry 4.0	Correlation Coefficient	0.288**	0.456**	0.353**
	Sig. (2-tailed)	0.130	0.013	0.003
	N	29	29	29

** *Correlation is significant at the 0.05 level*

Source: Author's own research

Pearson's chi-square test of independence was applied to evaluate the following null (H_{0B}) and alternative (H_{1B}) hypotheses. Based on the results from Table 2, we conclude that there is a significant relationship between the implementation of Industry 4.0 in metallurgical enterprises in Slovakia and the business area – production $\left(\chi^2 = 46.722, p = 0.026\right)$.

Table 2: Evaluation of the hypotheses H_{0B} and H_{1B}

Chi-Square Test	**Value**	**df**	**Asymp. Sig.**
Pearson Chi-Square	46.722	30	0.026
Likelihood Ratio	40.525	30	0.095
Linear-by-Linear Association	1.095	1	0.295
N of Valid Cases	29		

Source: Author's own research

Subsequently, the strength of association was performed through Phi and Cramer's coefficient. The results are presented in Table 3. From the results, we conclude that the Phi coefficient indicates a very strong relationship (1.269) and the Cramer's coefficient indicates a relatively strong relationship (0.568).

Table 3: Evaluation of the association

Symmetric Measures		Value	Approx. Sig.
Nominal by Nominal	Phi	1.269	0.026
	Cramer's V	0.568	0.026
N of Valid Cases		29	

Source: Author's own research

Testing the following null (H_{0C}) and alternative (H_{1C}) hypotheses required testing for homogeneity of variance. This was examined by using the Levene's test. After its evaluation, we concluded that homogeneity of variance was violated. Based on this fact, the non-parametric Kruskal-Wallis test was used in further testing.

Table 4: Evaluation of the hypotheses H_{0C} and H_{1C}

Kruskal-Wallis Test	Chi-Square	df	Asymp. Sig.
Big Data	2.821	5	0.728
Autonomous Robots	10.902	5	0.039
Advanced Simulation	11.786	5	0.038
Artificial Intelligence	8.968	5	0.110
5G Network	5.483	5	0.360
Blockchain	5.280	5	0.383
Machine-to-machine Communication	11.646	5	0.040
Industrial Internet of Things	9.794	5	0.081
Smart Sensors	13.969	5	0.016
Nanotechnology	8.122	5	0.150
Cyber-physical Systems	11.202	5	0.041
Additive Manufacturing	10.336	5	0.046

Source: Authors' own research

Table 4 evaluates the null and alternative hypotheses. The test results indicated a statistically significant relationship (at 0.05 level of significance) by business area – production with the following selected Industry 4.0 technologies: autonomous robots $\left(\chi^2 = 10.902, r = 0.039\right)$; advanced simulation $\left(\chi^2 = 11.786, r = 0.038\right)$; machine-to-machine communication $\left(\chi^2 = 11.646, r = 0.040\right)$; smart sensors $\left(\chi^2 = 13.969, r = 0.016\right)$; cyber-physical systems $\left(\chi^2 = 11.202, r = 0.041\right)$ and additive manufacturing $\left(\chi^2 = 10.336, r = 0.046\right)$. No statistically significant relationship was identified for Industry 4.0 technologies: big data, artificial intelligence, 5G network, blockchain, industrial internet of things, nanotechnology.

V. Conclusion

Within the selected summarised responses related to Industry 4.0 in the metallurgical industry in Slovakia, we obtained that medium-sized enterprises participated in the research with the highest percentage (48.3%). In terms of the legal form of business, limited liability companies prevailed with a percentage share (62.1%). According to the regions of Slovakia, enterprises from the metallurgical industry participated in the research with the largest percentage (27.6%) from the Banská Bystrica Region. Respondents with the share of 51.7% have partial information about Industry 4.0 and at the same time 34.5% of the surveyed enterprises are implementing Industry 4.0. 31% of respondents use a consulting firm for the implementation of Industry 4.0 in enterprises of metallurgical industry. Data evaluation also revealed that 65.5% of the respondents are applying Industry 4.0 in production. Industry 4.0 optimise business processes with the highest percentage (58.6%). From the responses we obtained, we determined that 51.7% of the enterprises will eliminate jobs. The use of smart sensors from Industry 4.0 technologies, as well as advanced simulation, is dominant in metallurgical enterprises in Slovakia. Hypothesis testing confirmed the moderately significant relationship between leveraging of Industry 4.0 in large and medium-sized metallurgical enterprises in Slovakia. The significant relationship was also demonstrated between the implementation of Industry 4.0 in metallurgical enterprises in Slovakia and the business area – production. At the same time, the results of the testing indicated a statistically significant relationship between the business area – production with the following selected Industry 4.0 technologies: autonomous robots, advanced simulation, machine-to-machine communication, smart sensors, cyber-physical systems and additive manufacturing.

The research conducted is the basis for further, next research, which would analyse the key challenges and opportunities for Industry 4.0 in other sectors of industrial production in Slovakia. At the same time, the potential is created to conduct again research related to the ongoing Fourth Industrial Revolution in the metallurgical industry in Slovakia, which would be complemented by the Industry 5.0 strategy, which aims to develop a competitive advantage in the market through the implementation of smart technologies, in addition to thriving with technological improvements with respect to human and environmental aspects.

Industry 4.0 is the key to increasing productivity, promoting economic growth and ensuring the sustainability of industrial enterprises. In today's dynamic and changing world, it is imperative to understand the nature and vision of Industry 4.0 and its technologies to ensure the transformation of business processes. The transformation aims to achieve a digital factory end-to-end based on cyber-physical systems, industrial IoT and smart technologies.

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