

IMPLEMENTING THE INDUSTRY 4.0 CONCEPT INTO THE ECONOMY ON THE EXAMPLE OF THE REALLOYS COMPANY

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Abstract: Intensive development of Industry 4.0 is a consequence of changes in many fields of science (social, technical). Information technology, automation and telecommunications continue to contribute to the dynamic development of the Internet, Artificial Intelligence systems, and Big Data. These achievements are also being increasingly applied in virtually all branches of industry. Implemented in industrial companies, they contribute to their development and increase their competitiveness. In addition to the technological aspect, these changes also imply a new way of working and a new approach to the production process by the employees. Drawing on the analyses of Industry 4.0 which already exist in the literature, the author of the paper aims at presenting the methods for implementing a few solutions contained in this concept and in a steel company, ReAlloys. The content presented and based on the results of the conducted research is a starting point for further analysis and scientific discourse on introducing changes in production processes, which result from the implementation of the concept of Industry 4.0.

Keywords: Industry 4.0, Energy Efficiency at ReAlloys, Cloud Computing.

1. Introduction

In technical, social, organisational and managerial sciences, the fourth industrial revolution is understood as a description of technologies and rules governing the operation of economic entities which permanently make use of cyber-physical systems (CPS) and modelling, the Internet of Things and Services, cloud computing capabilities, and the Internet of All Things (Szulewski, 2018; Furmanek, 2018). It is a smart factory (no human presence on-site, open-air factory) in which cyber-physical systems control the physical processes, create virtual (digital) copies of the real world and make decentralised decisions. The essence of Industry 4.0 lies in the creation of intelligent value chains based on dynamic, self-organising, and optimising socio-technical systems. They are created by spontaneously emerging virtual networks of employees,

machines and devices, and supporting IT systems (Miśkiewicz, 2019). They constitute a dynamic network – centred around a common cooperative object - subject to continuous reconfiguration depending on changing goals and circumstances. Based on this network, new work organisation ensures high flexibility and efficiency of production, and the virtualisation of economic processes enables access to and use of group intelligence by initiating, creating, and applying knowledge in practical activities. The analysis of both the literature and the experience of business practices shows that important factors enabling the development of the Industry 4.0 concept include: (i) a large number of available data and tools for their analysis, (ii) mobile communications, and (iii) digital channels of access to consumers. The digitisation of the production process and Artificial Intelligence determine the directions of contemporary industrial development and make it a part of the new market economy (Zhong, Xu, Klotz et al. 2017; Furmanek, 2018; Pająk, Krzakiewicz, 2018). Its basic pillars are ICT and the Internet as well as related components, including Smart Factory, Internet of Things (IoT), Big Data or cyber-physical systems (Nosalska, Mazurek, 2018; Ibarra, Ganzarain, Igartua, 2018). Today, the need for the development of the Industry 4.0 concept is generally acknowledged in many countries as well as in their internal legislation, despite the different nomenclature used. Germany, for instance, is implementing *Industrie 4.0*, the USA – Industrial Internet Consortium, China – *Made in CHINA 2025* and *Internet Plus*, Taiwan – *Productivity 4.0*, India – *Industry 4.0: Make in India* and *Skill India*, Japan – *IVI The Industrial Value Chain Initiative*, France – *Nouvelle France Industrielle*, the Netherlands – *Smart Industry*, the UK – *High Value Manufacturing Catapult (HMV Catapult)*, Spain – *Industria Conectada 4.0.*, Poland – *Przemysł 4.0* (Bujak, 2017; Garbowska, 2018; Zamasz, 2017). It has also been introduced to the official government programmes of individual countries, since the idea of Industry 4.0 is associated with the expected development of various fields of industrial activity (Berger 2016). Note that over the last few years more than thirty national or regional initiatives devoted to the Fourth Industrial Revolution have been announced in Europe and the European Union. They are consistent with each other in terms of legislation and standardisation. Their purpose is to implement measures aimed at unifying the digital market and exchanging best practices as well as to assess the progress of implementing individual European, national or regional initiatives (Sąsiadek, Basl, 2018). The rationale of these initiatives has already been confirmed by numerous studies and reports. The results of the 2016 survey of 300 companies in the USA, Germany, and Japan show that around 78-92% of respondents saw economic viability of Industry 4.0, 10-14% of respondents suggested an increase in business turnover, and 10-12% expected a decrease in production costs (Szulewski, 2016; Szczepańska-Woszczyzna, 2016; Popkova, Ragulina, Bogoviz, 2019). The implementation of new technical and IT solutions in manufacturing companies, related to Industry 4.0, has also created new Polish and international terminology. It is present in legal regulations, scientific and economic studies at the macroeconomic level, and in business studies at the microeconomic level. It is also of open nature and is constantly updated with new terms emerging with the growth of technical work

equipment and technology development, as well as with the automation and robotisation of production processes (Gajdzik, Grabowska, 2018; Szwab, 2016; Soldaty, 2016). According to ASTOR, DELOITTE and PWC, Industry 4.0 has set high standards for Polish companies (Schwab, 2018; Wolniak, 2018). Many scientific papers and studies contain an abundance of literature indicating the barriers in the implementation of Industry 4.0. The analytical material contained in the *Industry 4.0. The new industrial revolution - how Europe will succeed* report, published in 2014 by Roland Berger Strategy Consultants, is interesting in this respect. It shows Poland as one of the countries that are hesitant, with low index of readiness for the implementation of Industry 4.0 and an average industrial base. On the other hand, the MarketsandMarkets report entitled *Manufacturing Execution System Market by Deployment Type (On-Premises, On-Demand, and Hybrid), Offering (Software and Services), Process Industry (Food & Beverages, Oil & Gas), Discrete Industry (Automotive, Medical Devices) – Global Forecast to 2022* and the research conducted by Astor show that only 15% of Polish companies are fully automated, and 76% declare partial automation (Astor, 2015). The phenomenon is also visible in the steel industry, hence the aim of the paper to present the methods for implementing some of the Industry 4.0 solutions applied by the steel company ReAlloys.

2. Practical application of the Industrial 4.0 concept in ReAlloys

ReAlloys specialises in the production of ferrosilicon and silicon-based alloys. It uses innovative technologies that are efficient and environmentally friendly. Main recipients of its offer comprise manufacturers of steel and the automotive, arms and aircraft industry. Its main activity consists in the production of ferroalloys based on silicon, mainly in the form of various types of ferro-silicon. ReAlloys produces up to 80,000 tonnes of this product annually, or about 10% of the total European production. The market share in Germany, the Czech Republic and Slovakia is as high as 30%. The company's products are sold on almost all European markets. Nonetheless, the modern metallurgical industry is still electro-intensive, and the consumption of electricity is the largest component of its production costs, which is confirmed by statistical data. An example of its consumption in the processing industry is shown in Figure 1.

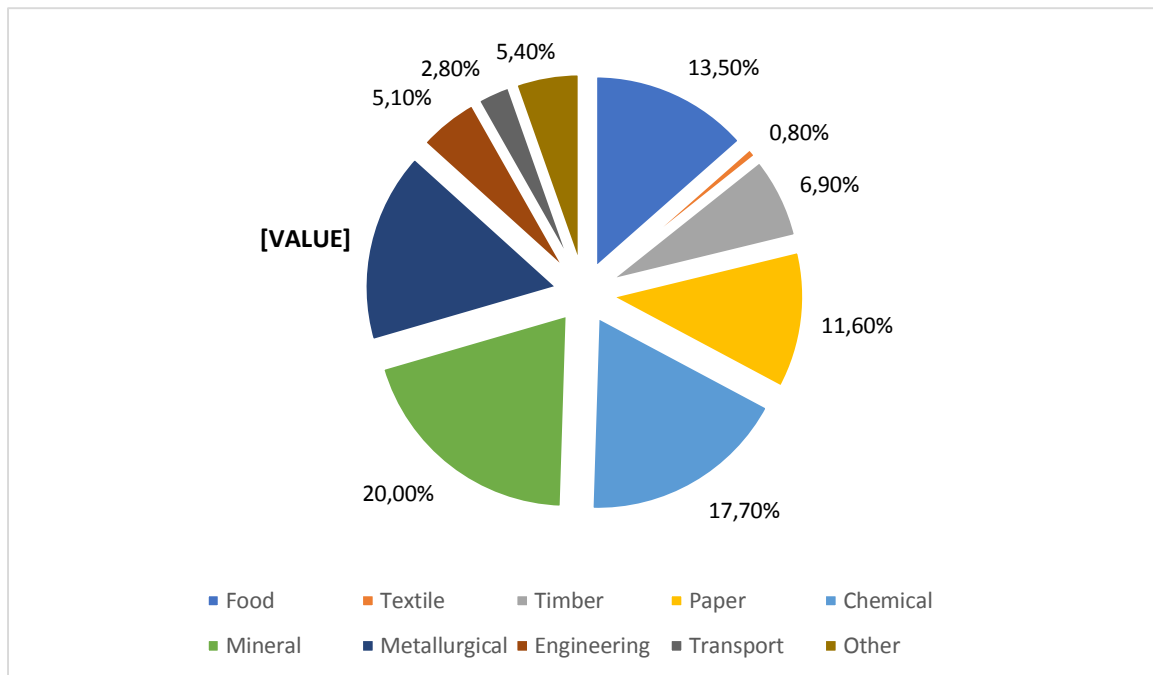


Figure 1. Final energy consumption in the processing industry in 2017. Source: Author's own study based on *Efficiency of energy use, 2007-2017 (in Polish)*, GUS, p. 19.

This also applies to ReAlloys. Its energy costs account for about 33% of all operating costs, and the volume of electricity it plans to use in 2020 is 720,570 MWh. Table 1 shows detailed data.

Table 1.

Planned electricity consumption at ReAlloys in 2020 (MWh)

Volume	720,570
Manufacturing Energy	663,727
Auxiliary Energy	56,843

Source: Author's own study based on ReAlloys' operational data.

The assumption that energy efficiency of a steel company results from the sum of partial energy efficiencies of individual machines became the basis for ReAlloys to introduce innovative solutions resulting from the Industry 4.0 concept. An interesting methodology used in order to improve these processes is the Kaizen philosophy (Łangowska, 2018), which relies on continuous, focused improvement, but carried out in small steps. This methodology seems to be perfect for continuous improvement of energy efficiency of a company. The main and rational reason to increase the efficiency of production is to save on energy costs, which in the long run can increase the profit. An attempt was also made to adapt the Overall Equipment Effectiveness (OEE) method to the area of truck management; it was aimed at increasing production efficiency. This became a substantive premise for ReAlloys to carry out the ReA-1/8/2018 *Optimising the key areas of a company's business activity by monitoring the location of assets and supervising the casting process in real time (Vizum Factory)* project.

The research procedure assumed theoretical and practical objectives of the project. The first objective was to verify the accuracy of the indications provided by individual radio and sensor location technologies and the accuracy of the calculations regarding the position of an asset based on the indications provided by individual location technologies in the real environment (the conditions found in the production plant). The practical objective was to monitor the position and operation of 44 internal transport vehicles on an ongoing basis in order to analyse the possibilities of optimising their use and to test how the monitoring equipment affects the power supply system of the monitored asset (Project, 2018, p. 3). Stage 1 of the project involved testing the technology provided by Vizum Lab in order to monitor forklift and platform truck performance at ReAlloys. The assumed functional assumptions referred to (i) tracking the position of the trucks in a continuous manner in an open and confined space; (ii) visualising the current position of a selected truck and the history of its positions within a selected time range, and (iii) comparing the work of trucks on a given day or during a given shift. Then, on the basis of the indicators obtained, an analysis regarding their compliance with the established labour standards and schedule was carried out.

These assumptions implied a solution that took into account (i) active devices (Vizum Box) mounted on trucks and equipped with a number of sensors collecting data, pre-processing them and sending them to the Vizum cloud; (ii) cloud computing, processing the data received from all terminal devices and regularly calculating the current status and position of the monitored assets; and (iii) the user having access to the data via an administration panel accessible from a web browser (Project, 2018, p. 6). Detailed solutions in this respect are presented in Figure 2.

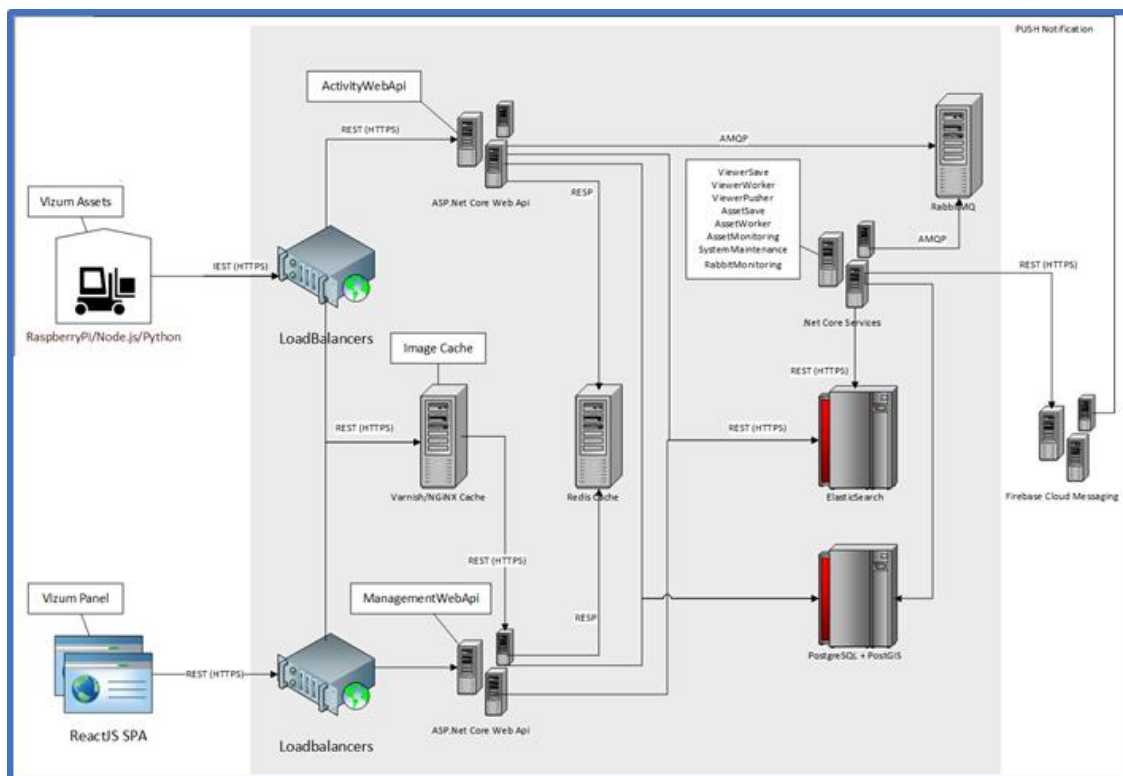


Figure 2. Architecture of Vizum Factory solution. Source: author's own study.

The following technological and methodological solutions have been adopted for research purposes. The technological solutions included:

- 1) Vizum Box – active monitoring devices based on Raspberry Pi + Arduino architecture with a number of sensors and communication interfaces (including GPS, accelerometer, gyroscope, Bluetooth, Wi-Fi, 3G), a voltage stabilising module and UPS providing backup to enable safe shutdown of the system in the event of a complete system failure. From the software side, the device works under the control of a universal Linux system with software developed in Python and Node.js.
- 2) Cloud computing – server software developed with the use of NETcore technology that allows to embed server software in any cloud computing (currently used: Microsoft Azure), and a set of relational (PostgreSQL+PostGIS) and non-relational (ElasticSearch) databases collecting large data. Databases are divided into 3 logs: (i) operational log – collecting all data flowing from the terminal equipment on an ongoing basis; (ii) business log – collecting current data ready to be displayed to the user in the Internet panel, built from raw data processed on an ongoing basis by the server software from the operating log; (iii) archive log - collecting all historical data compressed and optimised for storage, built periodically by the server software on the basis of older data from the business log (Project, 2018, p. 7).

The methodological solutions concerned the location of trucks operating in two areas: outdoor and indoor. In the first one, the GPS signal enabled the location with a repeatable accuracy of +/- 5m. In addition, in order to exclude the so-called drifting of the truck position when the truck does not move, the Vizum Box used signals from the accelerometer and gyroscope. The iBeacon transmitters (Bluetooth technology) were installed in enclosed spaces (indoor) in production halls and facilities. These devices are maintenance-free, battery operated and serve as a beacon - they propagate their identification number while at the same time their position is defined in the plant layout, in the Vizum system. The Vizum Box mounted on the truck detects the iBeacon transmitters passing by and takes into account the accelerometer and gyroscope signals to detect the movement performed by the truck. Based on these signals, it was possible to determine the position of the truck with an accuracy of a few metres. When necessary, the Ultra-Wide Band (UWB) technology was used for locations requiring higher positional accuracy (1m). For this purpose, instead of iBeacons, so-called anchors were installed in the plant space (they require a permanent main supply) (Project, 2018, p. 7). This solution facilitated the process of monitoring the previously assumed parameters, such as the distance travelled, working time of the truck, its presence in individual zones in time, log of events (stopping, starting) and its current location. The implementation of this stage of the project was related to (i) manufacturing the Vizum Box (16 installed, 25 awaiting installation), (ii) developing the necessary server software, (iii) developing the software for the administration panel as shown in Figures 3, 4, 5, (iv) installing 39 iBeacon transmitters on the site, and (v) configuring 70 control zones on the site (40 in 19 buildings and 30 external zones) (Project 2018, p. 8).

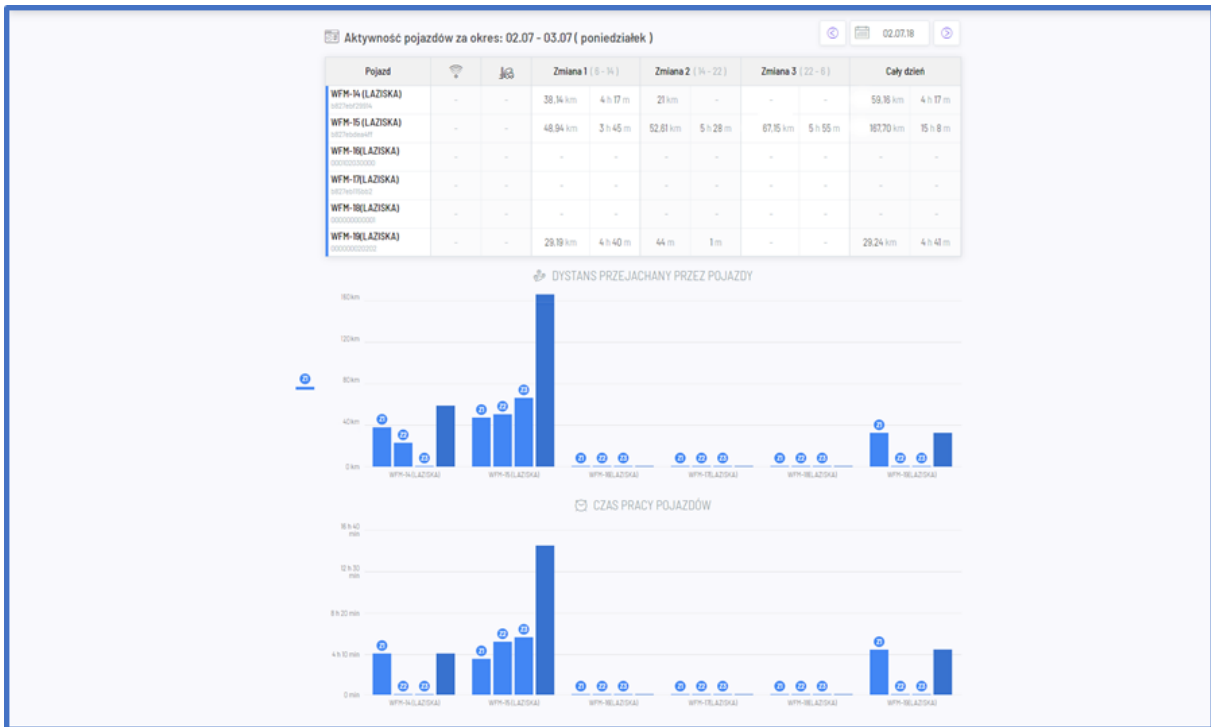


Figure 3. View of the administrative panel of the VIZUM Factory system. Source: author's own study.



Figure 4. View of the administrative panel of the VIZUM Factory system. Source: author's own study.



Figure 5. View of the administrative panel of the VIZUM Factory system. Source: author's own study.

In this part of the project – as a result of the work and tests carried out – the equipment was modified, which made it possible to improve the monitoring of the working trucks to which the new solutions – Vizum Box Version 2 – were applied. Additional protection against overvoltage and voltage drops was implemented: a fully automatic UPS was incorporated in order to maintain the voltage during its drop and prevent sudden shutdown of the components. By introducing a gyroscope confirming full stop periods, the calculation of the distances travelled by the truck was improved, and the so-called graph mechanism, which corrected the path of the truck's movement along the permitted routes, was implemented. In order to improve the functionality of the truck, it is planned to introduce further modification of the Vizum Box (version 3), which will also enable detecting its condition – empty/loaded – with the use of image analysis, and which requires a small camera mounted on the monitored vehicle (Report, 2018, p. 4). On the other hand, a work on functionality, entitled *Studies of compliance of the registered work of a truck with the established work standards and schedule* included (i) continuous tracking of the position of trucks in an open and confined space; (ii) visualising the current position of a selected truck and the history of its position within a selected time range; (iii) comparing the work of trucks on a given day or during a given shift (Raport, 2018, p. 5).

An integral part of the research process concerning the operation of the truck was to monitor the furnace charging process. At this stage of the research, theoretical objectives were adopted; they assumed verifying the accuracy/quality of the indications provided by the UWB location technology and image analysis technology as well as comparing the accuracy of the calculations of the asset's position based on the indications provided by the UWB technology and image analysis technology. For practical purposes, permanent monitoring of the furnace charging process was assumed in order to compare its actual performance with the theoretical assumptions and analyse the opportunities for process optimisation. This also meant testing the

robustness of the infrastructure and electronic equipment under extreme temperature conditions. At this stage of the research, it was assumed that continuous automatic monitoring of the furnace charging process carried out by feeding trucks – in accordance with the adopted guidelines for charging operations at furnace buildings II, III and IV – stabilises the process of the melting of ferroalloys, so that the furnace units consume less electricity and melt more metal. Taking into account the difficult environmental conditions in the immediate vicinity of the furnace, it was necessary to use two different location technologies: image analysis with AI and the Ultra-Wide Band technology (Project, 2018, p. 9 et seq.). Based on the Deep-Learning technology, computer image analysis enabled the view of the zone around the furnace to be processed in search of objects and people. Through appropriate neural network algorithms, the system is used to detect, i.a.: the position of the truck feeding the furnace at a given moment, making it possible to monitor the charge level in a given sector of the furnace (1-2 m), or unwanted behaviour in the vicinity of the furnace, such as a person approaching the furnace too closely or losing consciousness and falling. Using an appropriate density of the CCTV camera points, it was possible to combine the recorded images into a single panoramic view, enabling advanced analysis of the surroundings. The Ultra-Wide Band technology made it possible to determine the position of many devices in a confined space on the basis of the propagation time of a signal with wide emission spectrum and with high accuracy of position indication (about 1 m). The applied locating system consisted of three main elements: (i) markers – active elements, mounted on the monitored trucks, sending signals on the basis of which the location of the trucks is determined; (ii) anchors – devices located in fixed, known points on the perimeter of the furnace location area; they are used as reference points and are responsible for processing the signals received from the markers; (iii) communication gates where the data from the anchors are collected and transmitted to the Vizum Factory system.

3. Conclusion

To recapitulate Stage 1 of the research project at ReAlloys, the forecast is that the energy consumption of furnaces 22 and 23 will be annually reduced by 1% (2,824.51 MWh) compared to the budgeted value. The results are shown in detail in Table 2.

Table 2.
Improvement of energy efficiency indicators for FeSi75

	Furnace 22	Furnace 23
Budget level	8,445	8,445
Bonus level III	8,411	8,411
Bonus level I	8,361	8,361
Improvement in MWh	0.084	0.084
Improvement in %	1.0%	1.0%

Source: author's own elaboration.

Since it was possible to obtain, process and analyse detailed location data, the process of charging the arc-resistance furnace could be controlled in such a way so as to keep the specific electricity consumption per tonne of the product to a minimum. The control algorithms continuously provided feedback to the truck operator enabling making real-time adjustments to the position and dwell time of the truck as the charge was being fed into the furnace. The optimal number of trucks needed in the production process was determined. Reducing the number of trucks from 44 to 36 made it possible to rationalise the fixed costs associated with their maintenance.

Lower production costs were achieved, increasing the competitiveness and profitability of the company in terms of savings resulting from lower electricity consumption. For example, in the analysed period, the planned electricity consumption was to amount to 720,570 MWh, and the preliminary results forecast a decrease by 6,632.32 MWh, which will result in a decrease in total electricity costs by PLN 1,832,841.28. A detailed forecast concerning the savings on the furnaces covered by the survey is presented in Table 3.

Table 3.

Improvement of operating efficiency in Furnaces 22 and 23 in the analysed period

	Furnace 22	Furnace 23
Planned energy consumption/furnace [MWh]	141,982	141,982
Energy volume reduction/furnace [MWh]	1,419.82	1,419.82
Energy cost reduction/furnace (PLN)	390,276.05	390,276.05

Source: author's own study.

By improving the performance of the examined furnaces, CO₂ emissions were reduced, which is part of Poland's and the EU's climate policy, and builds positive relations between the company and its environment. It was also possible to reduce the manufacturing costs through the launch of a tool enabling much faster reaction in case of undesirable events taking place, such as an employee falling down in a dangerous zone close to a furnace unit, and, consequently, to eliminate downtime in the work of trucks.

The results obtained after the completion of Stage 1 of the research constitute a basis for continuing the activities and formulating new research goals, as well as including the remaining 5 furnaces (14, 15, 16, 17, 18) in the project. Stage 2 of the project assumes finding the connection between the way furnaces are charged and their operation so as to keep them stable, finding the connection between the way furnaces are charged and electricity consumption and reducing the costs through the rational use of raw materials for production.

References

1. ASTOR (2016). *Przemysł 4.0. Rewolucja już tu jest. Co o niej wiesz?* Raport ASTOR Whitepaper, http://www.astor.com.pl/images/Industry_4-0_Przemysl_4-0/ASTOR_przemysl4_whitepaper.pdf, 30.08.2019.
2. Berger, R. (2016). *The Industrie 4.0 transition quantified. How the fourth industrial revolution is reshuffling the economic, social and industrial model*. Monachium.
3. Bieńkowski, M. (2018). Innowacyjne rozwiązania dla Przemysłu 4.0. *Automatyka*, 5.
4. Bujak, A. (2017). Rewolucja przemysłowa – 4.0 i jej wpływ na logistykę XXI wieku. *Autobusy*, 6, 1338-1344.
5. *Efektywność wykorzystania energii w latach 2007-2017*. Warsaw: GUS, 19.
6. Furmanek, W. (2018). Najważniejsze idee czwartej rewolucji przemysłowej (Industrie 4.0). *Dydaktyka Informatyki*, 13, 55-63.
7. Gajdzik, B., Grabowska, S. (2018). Leksykon pojęć stosowanych w przemyśle 4.0. *Organizacja i Zarządzanie*, 132, 221-238.
8. Grabowska, M. (2018). Innowacyjność w porządku prawnym Unii Europejskiej. In: J.K. Opolski, J. Górski (eds.), *Innowacyjność polskiej gospodarki: wybrane aspekty* (pp. 15-27). Warsaw: Faculty of Economic Sciences, University of Warsaw.
9. Ibarra, D., Ganzarain, J., Igartua, J.I. (2018). Business Model Innovation through Industry 4.0. *Procedia Manufacturing*, 22, 4-10.
10. Łangowska, D. (2018). Kaizen w zarządzaniu logistyką wyjściową na przykładzie spółki Malow w Suwałkach. *Transport*, 120, 241-251.
11. Miśkiewicz, R. (2019). *Organisational structure in the process of integration on the example of iron and steel industry enterprises in Poland. Process digitisation in the Industry 4.0 concept*. Warsaw: PWN.
12. Nosalska, K., Mazurek, G. (2018). Przemysł 4.0 a sektor chemiczny gospodarki. *Przemysł Chemiczny*, 5(97), 1000-1003.
13. Pająk, K., Krzakiewicz, K. (2018). Zarządzanie bezpieczeństwem energetycznym – uwagi metodologiczne. In: K. Pająk (ed.), *Nowe zarządzanie publiczne. Aspekty teoretyczne i praktyczne* (pp. 145-168). Warszawa, PWN.
14. Popkova, E.G., Ragulina, Y.V., Bogoviz, A.V. (2019). *Industry 4.0: Industrial Revolution of the 21st Century*. Berlin: Springer International Publishing.
15. ReA-1/8/2018 Project: Optimising the key areas of a company's business activity by monitoring the location of its assets and supervising the casting process in real time. Vizum Factory.
16. Report on the implementation of Stage 1 (2018) of the Project: Optimising the key areas of a company's business activity by monitoring the location of its assets and supervising the casting process in real time (*in Polish*) (Vizum Factory).

17. Sasiadek, M., Basl, J. (2016). Świadomość i poziom wdrożenia koncepcji Przemysł 4.0 w wybranych polskich i czeskich przedsiębiorstwach. *Innowacje w zarządzaniu i inżynierii produkcji*, 2, 189-198.
18. Schwab, K. (2016). *The Fourth Industrial Revolution*. Davos: World Economic Forum.
19. Schwab, K. (2018). *Czwarta rewolucja przemysłowa*. Warsaw: Studio Emka.
20. Soldaty, A. (2016). Czwarta rewolucja przemysłowa i Przemysł 4.0 – co oznaczają te pojęcia. *Control Engineering Polska*. wydanie specjalne „Fabryka 4.0”.
21. Stadnicka, D., Litwin, P., Antonelli, D. (2019). Human Factor in Industry of the Future – Knowledge Acquisition and motivation. *FME Transactions*, 44(4), 823-830.
22. Stadnicka, D., Zielecki, W., Sęp, J. (2017). Koncepcja Przemysł 4.0 – ocena możliwości wdrożenia na przykładzie wybranego przedsiębiorstwa. In: R. Knosala (ed.), *Innowacje w zarządzaniu i inżynierii produkcji* (pp. 472-483). Opole: Polskie Towarzystwo Zarządzania Produkcją.
23. Szczepańska-Woszczyzna, K. (2016). *Kompetencje menedżerskie w kontekście innowacyjności przedsiębiorstwa*. Warszawa: PWN.
24. Szulewski, P. (2016). Koncepcje automatyki przemysłowej w środowisku Idusty 4.0. *Mechanik*, 7, 574-578.
25. Szulewski, P. (2018). Efektywne łączenie systemów podstawą inteligentnej produkcji. *Mechanik*, 1, 7-11.
26. Wolniak, R. (2018). *Internacjonalizacja a dojrzałość systemów zarządzania jakością w przedsiębiorstwach*. Gliwice: Wydawnictwo Naukowe Politechniki Śląskiej.
27. Wolniak, R., Sułkowski, M. (2018). Determinanty jakości w przedsiębiorstwach branży obróbki metali. *Zeszyty Naukowe Politechniki Śląskiej. Seria Organizacja i Zarządzanie*, 131, 560-572.
28. Zamasz, K. (2017). *Efektywność ekonomiczna przedsiębiorstwa energetycznego w warunkach wprowadzania rynku mocy*. Warszawa: PWN.
29. Zhong, R.Y., Xu, X. Klotz, E. et al. (2017). Intelligent Manufacturing in the Context of Industry 4.0. *Engineering*, 3, 5, 613-630.