DIRECTIONS OF DEVELOPMENT OF METALLURGICAL ENTERPRISES IN THE ERA OF INDUSTRY 4.0

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Abstract: Industry 4.0 is a collective term meaning the integration of intelligent machines and systems, and the introduction of changes in production processes, aimed at increasing production efficiency and introducing the possibility of flexible changes in the assortment of products. Industry 4.0 is focused on the continuous improvement of manufacturing processes through the use of self-learning robots and personalized production. The aim of the article is to identify key directions of improvement of the heat treatment process of cylindrical products in the context of applications of Industry 4.0 solutions. The analysis of individual stages of the heat treatment process using an example of a metallurgical company became the basis for determining key organizational and technical problems at individual stages of product manufacture.

Keywords: enterprise transformation, Industry 4.0, heat treatment process.

1. Introduction

In a modern, highly competitive production environment manufacturing companies face the challenge of dealing with large amounts of data, the need to make quick decisions (even outside the workplace), and to make the production processes flexible (personalized product) (Dais, 2014). The contemporary nature of production is shaped by the paradigm shift from mass production to production at the customer's request. Industry 4.0[1] (a term used since 2010) is currently one of the most frequently discussed topics among practitioners and scientists, which makes it a priority for many research centres and enterprises. Industry 4.0 marks the fourth industrial revolution, in which it is assumed that this is a vision of intelligent factories built of intelligent cyber-physical systems. The implementation of this idea should allow the

[1] The name entered in Germany (German government and industrial centres initiated the Industrie 4.0 programme (industry 4.0) with its main idea: Smart Factory). Klaus Schwab, founder of the World Economic Forum in Davos, in his book The Fourth Industrial Revolution published in February 2016, gives examples of changes in the industry at level 4.0.

development of intelligent production systems, which, in addition to the aforementioned autonomy, will have the characteristics of self-configuration, self-control of self-repair and self-learning (quoted after: Schwab, 2016).

This article is based on a literature study and case example analysis, which served to propose improvements in the production process, taking into account the new solutions of Industry 4.0. The theoretical part of the article presents the general assumptions of production at the level of Industry 4.0, comparing its key components. In the practical part, the individual stages of the heat treatment process of rolled products in a metallurgical enterprise are presented. The technological process adopted for the analysis became the basis for determining organizational and technical problems at individual stages of product manufacture On the basis of the obtained results, in order to improve production the directions of improvement of the heat treatment process in the context of applications of Industry 4.0 solutions are indicated.

2. Industry 4.0

Industry 4.0 was initiated 8 years ago in Germany, and for several years has been strongly promoted by the governments of industrialized countries around the world, and leaders in some industries have already implemented pilot cybernetic production systems (production of equipment: household appliances, cars, machinery and equipment). The changes initiated in the 21st century will take place over decades in enterprises, as the creation of new cyber-production solutions will require many investments (Saniuk, and Saniuk, 2017).

The scope of the introduced changes in enterprises of various industries depends on their resource capabilities and awareness of the role of new production methods in business development. The company must sense, on the basis of research, intuition and experience, when to introduce changes to adapt production to the new requirements of Industry 4.0. In Industry 4.0, it is about increasing the share of robots and industrial manipulators in the manufacture of products, and the use of the Internet to control and communicate devices and man with devices, as well as to integrate all processes inside and outside the enterprise within the value chain using cybernetic solutions (Cyber-Physical Systems – CPS, production cyberphysical systems or Cyber-Physical Production Systems – CPPS) and general data availability (Schwab, 2016; Pentek, 2015; Jaspemeite, 2012; Kagermann, Wahlster, Helbig, 2013; Astor Whitepaper). The development of Industry 4.0 is driven by the openness of solutions – easy access to information, technologies, patents and licences (Schönegger, 2013[2]; Evans, 2012). Robotic

[2] Interview with Stefan Schönegger, general director of the organization Ethernet POWERLINK Standardization Group (EPSG). https://www.br-automation.com/pl/o-nas/customer-magazine/2013/201306/czwarta-rewolucja-przemyslowa-zalezy-od-powerlink-i-opensafety/.

production lines became the basis for new forms of organization of enterprises, referred to as smart factories (Mario, Pentek, Otto, 2015).

The production technology used is referred to as Advanced Manufacturing due to the automatic search and implementation of the best solutions for machine learning by the existing company resources and customer needs. Production planning and supervision of processes is transferred from employees to computers with a wide use of data from control and control systems (DCS / SCADA). Production control, based on digital modelling, allows taking into account every aspect of customer requirements at each stage of production. Production control systems are linked through the CPS with a digital product description, which allows the quick adaptation of the entire process of writing, from product design to production planning, development of manufacturing technology to production, and Internet service (IoS) to the expectations of the customer who has based on the course of the trial (Gracel, 2016, 2017, 2018; Olszewski, 2018; Buxmann et al., 2009).

Smart factores, in which cyber-physical systems control physical processes, create virtual (digital) copies of the real world and make decentralized decisions, and through the Internet of Things (IoT) in real time communicate and cooperate with each other and with people. IoT is the equipping of all possible devices (home, production) with remote control systems (remote control of devices and communication with them at any place and time) (Lee, Jay, 2013; Magruk, 2016). IoT enables multilevel communication inside and outside companies (Hersent, Boswarthick, Elloumi, 2012; Chui, Löffler, Roberts, 2010; Kaliczyńska, Dąbek, 2015). The smart factory is intended to enable the entire production process to be carried out with a minimum of employees. The process of communication of production robots with clients is carried out through cloud computing – a collection of data storage, data processing and big data. Inside the Smart Factory there is automatic material transport, and the direct processing of materials on production lines. There are already devices on the market that are considered innovative (for Industry 4.0), e.g. CNC machines for machining, and their use by connecting robot arms as feeders for machine feed (integration of the robot with the machine), and transport devices (conveyors, self-tracking vehicles) in the production process create the beginnings of a smart factory.

Innovative materials are used for production, e.g. a customer can change clothes made of plastic, designing them on 3D printers. 3D printers are an important component in the Smart factory. Customers use them in the design of products according to their physical characteristics, such as surgical prostheses and expectations, e.g. clothing. Warehouse management is also the automatic replenishment of inventories in warehouses or their complete liquidation (e.g. Alibaba – the largest commercial network in the world, no warehouses).

Personalized production – tailored to the individual customer's requirements, as it is now based on the pull strategy, that is from the client's order to its implementation. The difference, however, is that the client designs a product made using 3D printers. Owners of smart factories and production lines can completely eliminate factors that cause increased costs, such as:

production delays, inventory, machine and equipment defects, production defects and errors, hardware deficiencies, human errors (Soldaty, 2017). Robot work is more flexible than the existing machine park, so there will be fewer downtimes and failures – thanks to prediction in the maintenance, based on the analysis of sensor data, allowing the identification of anticipated problems, and on algorithms to optimize inspections and repairs (Vavra, 2018). The use of machine learning, cloud computing and feedback information as part of robotic calibration based on real robot experiments (i.e. historical data also understood as Big Data) provides an unprecedented competitive advantage for the company, as it decreases employee engagement in setting up the production line and setting optimal performance parameters (parameters are set by the central computer system based on data). The level of technological complexity of a smart factory means that the management of such a factory requires, first of all, analytical skills. Computers count profitability and improve the production process, but the management team participates (although to a smaller extent than in the past) in controlling and supervising devices. K. Schwab indicates that the biggest challenge for leaders during the fourth revolution will be the delegation of operational matters, focusing on strategic thinking and disruptive thinking (Schwab, 2016).

The entire product development process is integrated with the process of its development and modification (Digital End-to-End engineering along the entire value chain (Digital End-to-end engineering across the entire value chain). Real-time end-to-end work supports resource planning at every stage of production and cooperation within the value chain. Deeper integration with suppliers will enable the use of cloud technology and track & trace solutions that will enable the management of the supply process (Lasi, Fettke, Feld, Hoffmann, 2014).

The aspects of product quality will also change. The product adjusted to the individual needs of the customer will have different quality artifacts than mass products (one can talk about a personalized product) (Kagermann, 2014). Quality is first and foremost the precision of the product made by robots. Quality, understood as the physical characteristics of the product, will be perfectly stable (accurate, the same, reproducible). Customers in new solutions can order products in line with their own expectations, e.g. they can order a bag, which they will design with the help of a wizard via the Internet, and the company will produce it without the need to carry out onerous changes on the production line (Plattform Industire 4.0). Precise and faster than ever recognition and adjustment to market needs takes place by combining external information from the value network with data on the functioning of the company, flexible configuration of manufacturing systems, and integration in the value network. The service process is faster because customers order products online (Matwiejczyk, 2018) – chatbots about sales and service use and handling complaints (using the John Lewis department store network). Figure 1 shows the components of Industry 4.0.

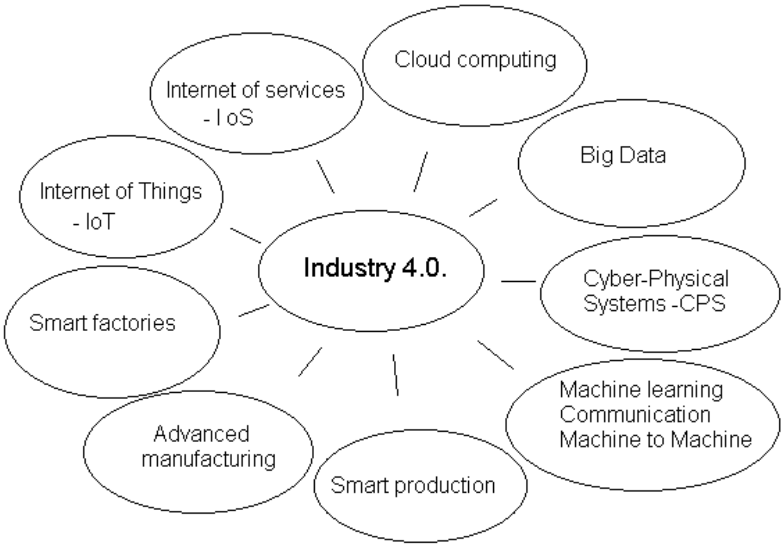

Figure 1. The components of Industry 4.0. Source: authors' own elaboration – literature study.

Enterprises undertaking implementation in the production of solutions characteristic for Industry 4.0 first select a part of production that will act as a cyber-physical system. This stage of action is referred to as pilotage. The implementation of a pilot production system based on the requirements of Industry 4.0 requires guaranteeing financial resources from the enterprise. Plants joining the implementation of production solutions defined as Industry 4.0 should be equipped with a technical and IT infrastructure serving the production process (selected devices), which will allow further automation and computerization of production. Investments in advanced technologies and in the software supporting them are a necessary condition for new production. Because investments in 4.0 industry are not a one-off but a continuous process, after the pilot project of robotics of the production line, the companies go to the next one, which requires further investment projects to be taken into account in the long-term (Gajdzik, 2018).

3. The heat treatment process of metallurgical products in a metallurgical company

In the case under consideration, the production enterprise produces square and flat bars of various sizes and narrow tolerances (even in small production batches) from semi-finished products purchased from the smelter. The most important products include: steels for turbines, stainless steels for the production of knives, tool steels and nickel alloys. In the enterprise, steel is rolled hot using a duo mill set in the line of a flat bar and a continuous line. Rolling mills cooperate with heating and cooling aggregates, allowing the enterprise to obtain an article with specific physical and chemical properties (heat treatment allows the improvement of the material and gives it appropriate properties according to the client's wishes), e.g. increasing hardness, resistance to high temperature, durability and plasticity.

The entire process is controlled by the use of devices controlling the parameters of the machines' operation and the control of the parameters of the products obtained, starting from planning the heat treatment of the material, to the final product. The individual parameters of devices and product features are processed by the computer system, until the results of laboratory tests are released. The process of controlling the operation of equipment at this stage is burdened with the probability of human error, which is incorrectly entering data from the plan in the computer system, which results in an inaccurate heat treatment plan at the entrance to the production system.

Each heat treatment process is planned by a specialist for production planning – the main technologist. The technological process is taken into account (depending on the species, it is necessary to perform a heat treatment up to 6h or 24h after the rolling), the order resulting from the dates confirmed to customers, the scope of furnaces work, and process optimization.

Based on the heat treatment plan, the employees prepare the material and load arrangement. The furnace operator, based on the heat treatment plan, enters data into the system and supervises the entire technological process. It carries a lot of responsibility, because a small mistake can lead to large losses of repetition. At the stage of material preparation (according to the production card), there may also be an error when allocating the load to a given order. The production card includes: card identification number, melting number, steel grade number, reference standard, required heat treatment, batch format, finished dimensions, possible range of deviations, type of required surface, and required product weight. Employees use standards that give guidance in the minimum and maximum chemical composition, but the employee assigns the batch itself based on the number of the melt. The furnace is loaded evenly, symmetrically in relation to its length and width. Employees carry out visual inspections, assessing cracks or other surface defects of the material.

Material with surface defects is withdrawn and is not hardened. For softening annealing it is necessary to bind the material in several places with a wire in order to avoid spillage. The faculty employees use pyrometers to control the temperature of, e.g., tempered material. During rolling, cracks, discontinuities or scratches on the mill are possible. Unnoticed defects during rolling can lead to material destruction. In the heat treatment department, the rolled material is marked with appropriate labels by employees. These labels are designed to determine the grade of steel. They are a very important element because their identification allows further production processes. Labels improperly marked by employees, from the moment of rolling, or improper identification of material by an employee, cause the process to be repeated. During annealing, the material may not exceed the permissible mass depending on the dimensions – e.g. max 3 tonnes for the dimensions of the rolled product 30x30 mm.

In the heat treatment department there is a work organization system: 2+1, namely 2 employees are assigned to supervise the processes (stacking material for thermal improvement), and one employee is designated to cut samples in the laboratory on several saws at the same time. Shortages in the crew (random, sickness and holiday factors) disrupt the organization of work. Workers' absences can't be replaced by new employees in a short time because professional experience is required. The machine park owned by the company is in need of repairs (the company records crane failures and furnace failures). Incorrect operation of the crane, such as: jamming and temporary stops causes a delay during hardening, as a result of, for example, sub cooling of the material. Furnace failure, mainly burner failure, causes temperature differences above 15°Celsius, which results in different temperatures in the furnace zones, and ultimately affects the uneven heating of the charge (material) during the process.

4. Analysis and evaluation of the production process of steel products

4.1. Application of the Ishikawa chart for the assessment of the technological process

The example production process shown was analyzed using the Ishikawa chart. The use of Ishikawa's structure to assess problems in the production process under investigation has become a form of non-compliance presentation in the following areas: men (employees), machine, method (technology), material and management. Figure 2 presents the results of the analysis – Ishikawa diagram.

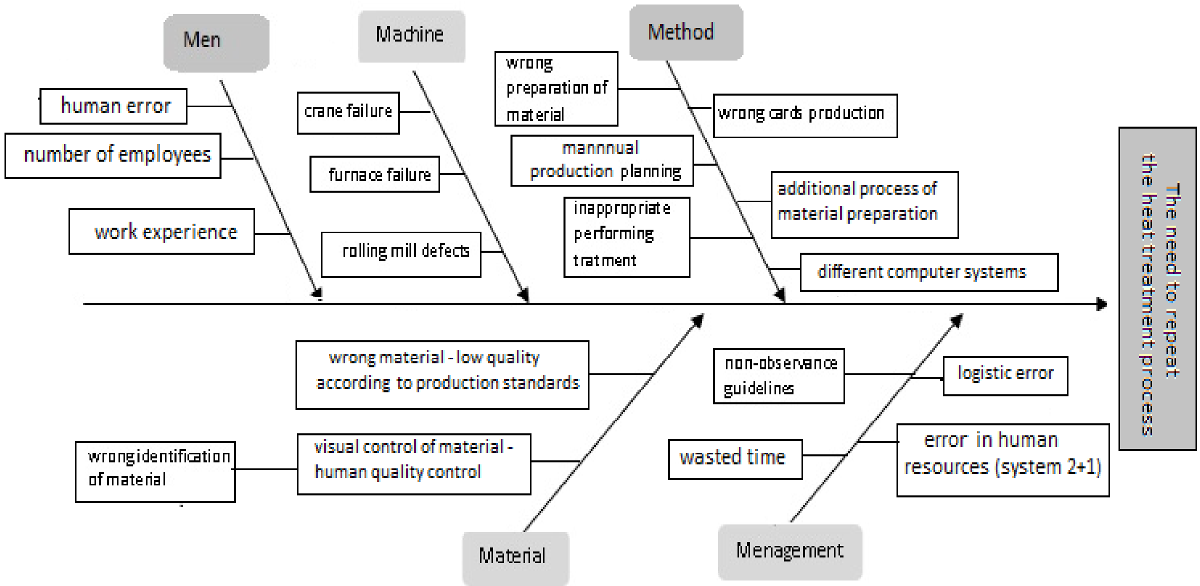

Figure 2. Ishikawa diagram – presentation of incompatibility of the analyzed production process. Source: authors' own elaboration.

4.2. Spot evaluation of non-compliance in the technological process

In the next step of the analysis, individual incompatibilities were assessed. The following incompatibility scale has been adopted: 1 – very small, 2 – small, 3 – average, 4 – large, 5 – very large. The assessment was made by the employees of the company with the participation of external experts. The evaluation team consisted of five people. Final assessments were agreed by team members during the discussion to eliminate the indication of extreme evaluations by study participants. On the basis of the frequency of non-compliance or problems in the correct course of the process, the severity of non-compliance was also indicated. The weighted value was calculated. The results of the assessment are summarized in Table 1.

Table 1.
Evaluation of non-compliance of the analyzed production process

There was a discrepancy	The causa of non-compliance	Assessment of non-compliance (1-5)	The severity of non-compliance	Weighted value
Erroneously entered data into the computer system from the heat treatment plan by employees	men	3	0.05	0.15
Visual assessment of the batch material by the employee (scratches, cracks or other surface defects) – inaccurate assessment of the quality of the batch material	men	3	0.05	0.15
Manual input of data from the heat treatment plan by the oven operator to the computer system (temperature, process time) – extending the working time	men	2	0.05	0.10
Error when allocating the batch to a given order because the standard gives guidelines in the minimum and maximum chemical composition, and the employee allocates the batch based on the smelting number	men	2	0.05	0.10
Inaccuracies (or missing information) in the description of material coming out of the milling line in the circulation card, and improper or incomplete marking of the material (stamped)	men	2	0.10	0.20
Incorrect batch material (scratches, cracks or other surface defects)	material	2	0.10	0.20
Rolling defects occurring during rolling: cracks, discontinuities or scratches of the rolling mill	method	3	0.10	0.30
No compatible data transfer system from the heat treatment plan to the furnace's computer system - time delays	method	2	0.05	0.10
Crane failure: jamming and temporary stop, resulting in delays during hardening, resulting in e.g. sub-cooling of the material	machine	5	0.15	0.75
Furnace failure: torch failure and temperature differences above 15°, which results in different temperatures in the zones of the furnace and ultimately affects the uneven heating of the charge (material) during the process	machine	5	0.15	0.75
Time delays (logistic) during the process – errors at the batch material control stage	manage ment	4	0.05	0.20
Time delays (logistic) during the process – errors in the labelling of the material and labels, no system for monitoring the completeness of filling labels and entering marks for heat treated material	manage ment	2	0.05	0.10
Shift system in the 2+1 system: problems with employee turnover during holidays, sick leave	manage ment	1	0.05	0.05
			1.00	3.15

Source: authors' own elaboration.

The maximum value of non-compliance may be 5 points. In the example, the weighted non-compliance value is 3.15. Many discrepancies in the analyzed process refer to the human factor. Individual errors caused by human work were evaluated at a relatively low level of validity. The highest evaluation of the significance of discrepancies for the correct course of the process involve machine park failures (threat to stop production). The evaluation of the distribution of individual non-conformities (the arithmetic average of indications in a given category of assessment) is shown in Figure 3. On the basis of the arithmetic mean of assessments of the significance of non-conformities for the course of the process within particular categories, the highest category was obtained by machine. The second position is occupied by men, the next methods, the next material, and the last management.

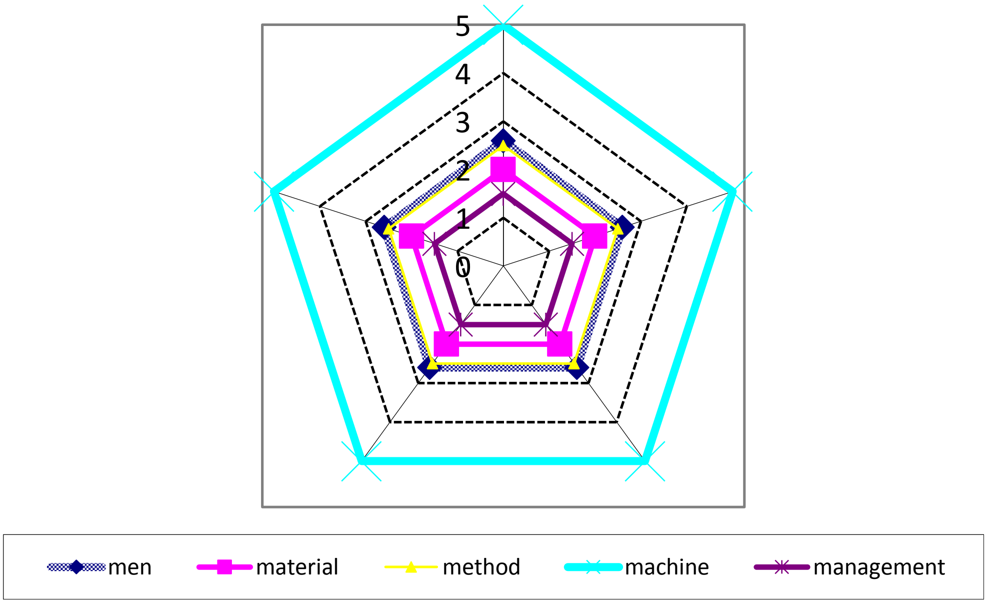

Figure 3. Evaluation of the significance of nonconformities for the proper course of the analyzed process. Source: authors' own elaboration.

5. Application of Industry 4.0 solutions in the heat treatment process

Analyzing the process, it was found that its course (precision of the product) depends to a large extent on man. The most important reason for the problem of re-heat treatment is "human error". In order to minimize it, it is proposed to increase the degree of process automation (in the initial stage – preceding the start of the enterprise to implement Industry 4.0 solutions) and to design robots replacing human work (the actual phase of implementing Industry 4.0 solutions). Robotization in the form of robotic production sockets with robot and human co-operation. The company should consider the purchase of a machine with enhanced intelligence in its investment plans.

For the "technological process" significant incompatibility was the inaccurate preparation of the material for heat treatment, in which the employee prepares the material based on the heat treatment plan, the position of the charges, and in which it is easy to overlook material defects, scratches, cracks or other surface defects. To eliminate this incompatibility, the company should use computer system solutions to broaden the scope of data analysis using advanced data processing and analysis software. The analysis should be carried out in real time (EMI) using advanced production control algorithms.

For the component "material" the most important incompatibility was the improper preparation of production cards in the allocation of the charge (material for processing) – the activity performed by the employee. The improvement proposal is to develop the structure of a computer program, analyzing the selection of a melt for a specific order. Computer programs equipped with robots with surface material rating sensors contribute to eliminating faulty material. The introduction of robots is also necessary at the stage of rolling the product, in order to obtain more precise parameters of the rolled product (the defects noticed by man during rolling may result during the heat treatment in the extension of the defect). The robots will eliminate the existing types of failures. At the current stage of production automation the company should increase the scope of machine operation monitoring, create the file "Failures", and in the next stage of changes eventually replace the existing machines with new ones. The gradual replacement of the machinery park with devices with a greater degree of automation, and robotics equipped with remote visualization and monitoring of the production process with extensive statistical analysis of production parameters should be considered strategic goals of the enterprise.

After agreeing with the company's management, a schedule for the implementation of individual investments was agreed – table 2.

Table 2.
Time of completion of individual investments

Investment	up to 5 years	5-10	10 and more
Implementation of the data extraction program from the heat treatment plan – advanced data processing and analysis software. Real-time analysis (EMI)	x		
Purchase of a device evaluating the parameters of batch material, installation of diagnostic sensors on individual devices, assembly of RFID gates	x		
Advanced algorithms ensuring the maintenance of the assumed product quality (incompatible incorrect batch material). Expansion of the statistical quality control system. Iinstallation of sensors measuring production parameters and the whole production line		x	
Analysis of production data – advanced data processing and analysis software. Real-time analysis. Advanced algorithms eliminating errors at every stage of production		x	
Creation of a data centre on the course of the process – data should be collected in one place - data centre (leaving the collected data in separate files will make it difficult to use them due to the multiplicity of computer systems) – Information and Communications Technology – ICT		x	
Tools supporting maintenance and preventive activities in the machinery park. Failure algorithms. Remote support systems. Maintenance management systems (CMMS, EAM)	x		
Intelligent logistics. Mobile interfaces – multifunctional equipment that increases communication efficiency of production employees. Support for augmented reality		x	
Integration of machines and computer systems, self-learning machines, communication: machine-machine, machine-worker			x
Replacement of automated devices for intelligent work. Integration of devices at IT (information technology) and OT (operational technology) levels			x

Source: authors' own elaboration.

For the analyzed company the following approach was proposed in the implementation of Industry 4.0 solutions. The implementation of changes should start with the entries in the company's development strategy. One of the strategic goals of the company should be striving to achieve production at the level of Industry 4.0. A managerial position should be created in the organization's structure – Industry Director 4.0 – as the person responsible for the implementation of the strategic goals defined as Industry 4.0.

Strategic goals for Industry 4.0 and included in the company's strategy should be passed on to tasks that should be included in the company's investment plans. The Act of 28 July 2017 on Amendments to the Personal Income Tax Act and the Corporate Income Tax Act, also referred to as the Act on Robotization (Official Journal of the Republic of Poland, 28 July 2017, item 1448) enables enterprises to implement an annual one-off settlement of expenditures on fixed assets (innovative) up to 100,000 PLN (Article 1 of the Act). The management company of the investment plan should select the task that will be implemented first (Industry 4.0 pilot program – task 1). The pilot programme can be implemented on an already existing technical and IT infrastructure of the company provided that it allows for further automation and robotization of the production cycle. After the implementation of the pilot programme and its completion, go to the next task. Works at the operational (IT) level and IT level (IT) must be linked – the correlation of IT and OT systems. (Figure 4 – the path of implementing Industry 4.0 solutions in the enterprise).

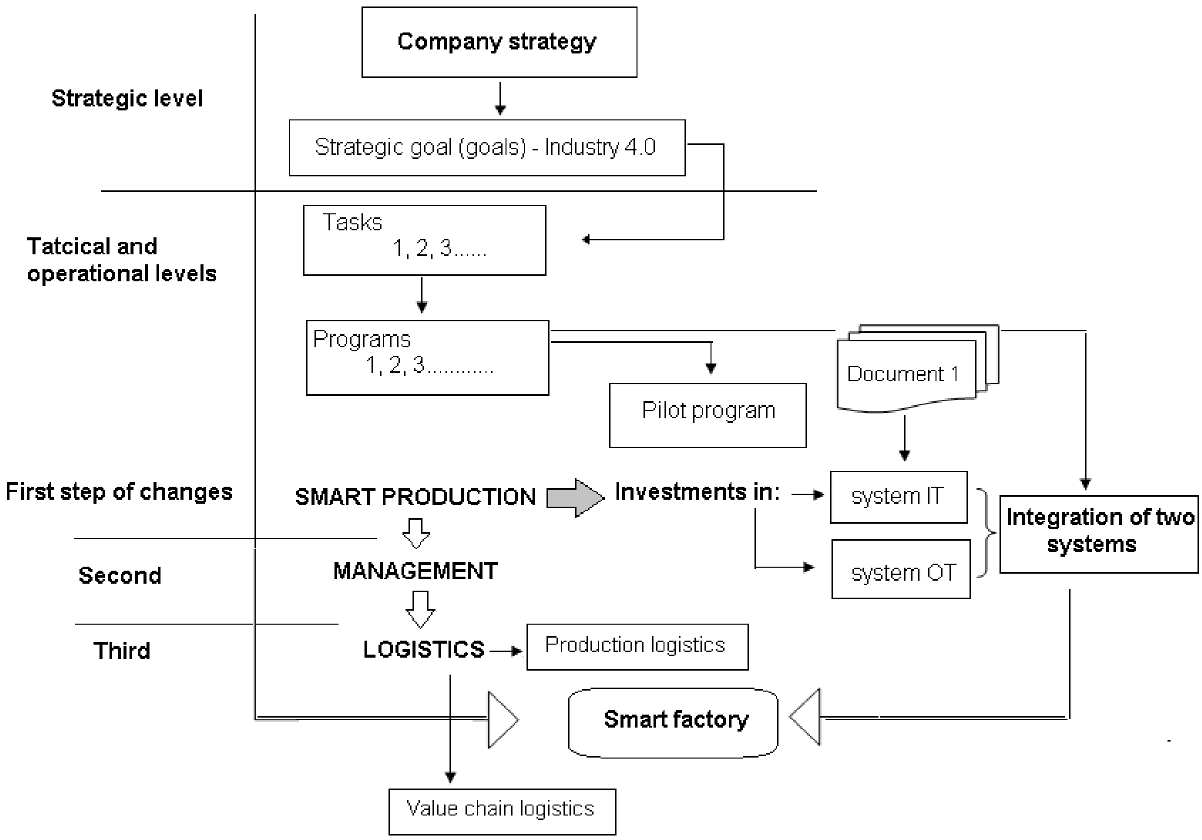

Figure 4. The path of implementing Industry 4.0 solutions. Source: authors' own elaboration.

The company's entry into industry 4.0 requires not only changes in production, but also in management and logistics. Production, management and logistics are three important components of changes in the company's pursuit of reaching 4.0.

Changes at the management level should include the concept stream Management 3.0 – referred to as modern management. It is a collection of constantly evolving practices, games and ideas for better management with fewer managers. According to the assumptions of this concept, the most effective management systems are network systems, the key element of which involves dependencies between people (and in Industry 4.0 – the relationship between the "intelligent machine" and the human). These are systems in which the leader ensures proper care for the team, streamlining its operation, and the members naturally adjust to each other (Bauer, and Erdogan, 2016).

It will be necessary to change HR programmess, taking on new staff – an increase in the demand for engineers who can combine automation and robotics with IT, and forecasting and simulation engineers.

The improvement of logistic processes concerns both internal logistics (production logistics) through the purchase and assembly of autonomous vehicles and conveyors or other self-steering devices for internal transport of materials and products, as well as external logistics within the supply chain. Cooperating enterprises will create a network of values (in the value chain in the sense of M. Porter, in which a product or service moves one-dimensionally to subsequent organizational units, each adding value) (Porter, 1992). It will be a multi-dimensional structure in which the source of values is the combination of network links, based on interoperability (devices, platforms) (Jeschke, 2016; Pfohl, Yahsi, & Kurnaz, 2015; Angeleanu, 2015).

6. Conclusions

The problem being investigated, which is the necessity of performing repeated heat treatment processes, negatively affecting the entire production process, was analyzed and evaluated on the basis of the Ishikawa diagram. Due to the fact that we are currently at the threshold of the industrial revolution, solutions to the problem resulting from the transformation of the production enterprise to Industry Factory 4.0 have been proposed. The implementation of modern technology, techniques and management methodologies appropriate for Industry 4.0 should cover the entire production process as well as management processes. It can be argued that only in such a case will there be a sufficiently strong effect of complementarity and synergy, indispensable in the world of the fourth industrial revolution for the transformation of the studied enterprise from its current status to Factory 4.0.

References

1. Angeleanu, A. (2015). New Technology Trends and Their Transformative Impact on Logistics and Supply Chain Processes. *International Journal of Economic Practices and Theories, 5(5),* 413-419.
2. Bauer, T., and Erdogan, B. (2016). *Principles of Management v3.0.* Boston: FlatWord, 10-15.
3. Buxmann, P., Hess, T., and Ruggaber, R. (2009). Internet of Services. *Business & Information Systems Engineering 5,* 341-342.
4. Chui, M., Löffler, M., and Roberts, R. (2010). The Internet of Things. *TheMcKinsey Quarterly*, *2(47),* 1-9.
5. Dais, S. (2014). Industrie 4.0 – Anstoß, Vision, Vorgehen. In T.M. Bauernhansl, ten Hompel, and B. Vogel-Heuser (Eds.), 2014: *Industrie 4.0 in Produktion, Automatisierung und Logistik. Anwendung, Technologien und Migration*, 625-634.
6. Evans, P.C., Annunziata, M. (2012). Industrial Internet: Pushing the Boundaries of Minds and Machines. Retrieved from http://www.ge.com/docs/chapters/Industrial_Internet.pdf, 6 November 2014.
7. Gracel, J. (2016). Industry 4.0 – kluczowe pytania i odpowiedzi. *Automatyka, Podzespoły, Aplikacje*, *6(10),* 36-39.
8. Gracel, J. (2017, March 24). Czwarta rewolucja przemysłowa: automatyzacja i życie w świecie technologii. *Harvard Business Review Polska*. Retrived from https://www.hbrp.pl/b/czwarta-rewolucja-przemyslowaautomatyzacja-i-zycie-w-swiecie-technologii-2/2/XNHp6tJb.
9. Gracel, J. (2018, May 20). Czwarta rewolucja przemysłowa: zmiana już tu jest. *Harvard Business Review Polska.* Avaiable at: https://www.hbrp.pl/b/czwarta-rewolucja-przemyslowa-zmiana-juz-tu-jest-1/2/OmImRGYW, 20 May 2018.
10. Hermann, M., Pentek, T., Otto, B. (2015). Design Principles for Industrie 4.0 Scenarios. A Literature Review. Technische Universität Dortmund. *Working Paper, 1*. Avaiable at: http://www.thiagobranquinho.com/wp-content/uploads/2016/11/Design-Principles-for-Industrie-4_0-Scenarios.pdf.
11. Hersent, O., Boswarthick, D., Elloumi, O. (2012). *The Internet of Things: Key Applications and Protocols*. Chichester: Wiley.
12. Jasperneite, J. (2012). *W*as hinter Begriffen wie Industrie 4.0 steckt. *Computer & Automation, 19 grudnia,* 27 January 2016.
13. Jeschke, S. (2016). Quo Vadis Logistik 4.0. available at: www.ima-zlw-ifu.rwth-aachen.de/fileadmin/user_upload/INSTITUTSCLUSTER/Publikation_Medien/Vortraege/download//Quo_vadis_Logistik4.0_17March2016.pdf, 18 February 2017.
14. Kagermann, H. (2014). Chancen von Industrie 4.0 nutzen. In T.M. Bauernhansl, ten Hompel, and B. Vogel-Heuser, Industrie 4.0 in Produktion, Automatisierung und Logistik. Anwendung. *Technologien und Migration,* 603-614.

15. Kagermann, H., Wahlster, W., and Helbig, J. (Eds.) (2013). *Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group.* Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution, VDI-Nachrichten, April 2011, 2016.01.27.
16. Kaliczyńska, M., Dąbek, P. (2015). Value of the Internet of Things for the Industry – An Overview. *Mechatronics: Ideas for Industrial Applications*, 51-63.
17. Lasi, H., Fettke, P., Feld, T., Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering, (6),* 239-242.
18. Lee, J. (2013). Industry 4.0 in Big Data Environment. *German Harting Magazine*, 8-10.
19. Magruk, A. (2016). The Internet of things as the future technological trend of the innovative development of logistics. *Research in Logistics and Production, 6(1),* 15-24.
20. Matwiejczyk, L. (2018, May 10). Czy twoi klienci chcą być obsługiwani przez sztuczną inteligencję? Available at: https://www.hbrp.pl/b/czy-twoi-klienci-chca-byc-obslugiwani-przez-sztuczna-inteligencje/PmuU8QdwJ, wyniki, 10 May 2018.
21. Olszewski, M. (2016). Mechatronizacja produktu i produkcji – przemysł 4.0. *Pomiary, Automatyka, Robotyka*, *20(3),* 13-28.
22. Pentek, H., Otto, B. (2015). *Design Principles for Industrie 4.0 Scenarios*, 27 January 2016.
23. Pfohl, H.Ch., Yahsi, B., & Kurnaz, T. (2015). The impact of Industry 4.0. on the supply chain. In W. Kersten, T. Blecker, & Ch.M. Ringle (Eds.), *Innovations ad strategies for logistics and supply chains. Technologies, business models and risk management.* Proceedings of the Hamburg International Conference of Logistics, 31-58.
24. Plattform Industire 4.0 (2013). Plattform Industrie 4.0, 2013: Industrie 4.0 – Whitepaper FuE Themen. Retrieved from http://www.plattformi40.de/sites/default/files/Whitepaper_Forschung%20Stand%203.%20April%202014_0.pdf, 13.12.2014.
25. Plattform Industrie 4.0 (2014). Plattform Industrie 4.0, 2014: Industrie 4.0 – Whitepaper FuEThemen. Retrieved from http://www.plattformi40.de/sites/default/files/Whitepaper_Forschung%20Stand%203.%20April%202014_0.pdf, 30 November 2014.
26. Porter, M.E. (1992). Startegia konkurnejci. Metody analizy sektorów i konkurentów. Warszawa: PWE.
27. Przemysł 4.0. Rewolucja jest tuż tuż, co o niej wiesz (2016). ASTOR Whitepaper. Available at: https://www.astor.com.pl/images/Industry_4...4.../ASTOR_przemysl4_whitepaper.pdf.
28. Saniuk, S., and Saniuk, A. (2017). Analiza sytuacji polskich przedsiębiorstw w sieciach przemysłowych w dobie Industry 4.0. *Management Sciences Nauki o Zarządzaniu, 2(31),* 12-15.
29. Schwab, K. (2016). *The Fourth Industrial Revolution.*
30. Vavra, B. (2018, August 12). Redaktor naczelny Plant Engineering: Zmiany są konieczne. Avaiable at: http://www.utrzymanieruchu.pl/menu-gorne/artykul/article/zmiany-sa-konieczne/, 12 August 2018.