Machinery maintenance model for evaluating and increasing maintenance, repairs and operations within Industry 4.0 concept

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Abstract. Machinery maintenance is a crucial part of every manufacturing organization, as production, as maintenance evolved through the history. The upcoming 4th Industrial revolution has also impact on machinery and equipment in companies. Companies have already started adopting new approaches so machinery maintenance, based on various levels of readiness and maturity. This paper focuses primarily on creating a model for Maintenance 4.0. The aim is to determine key “components” or defining factors of new approaches to machinery maintenance in accordance with principles of Industry 4.0 implementation.

1. Introduction
The term Industry 4.0 conceals the current trend of digitization and production automation. Great social, political and economic changes in our memories are often connected to term "revolutionary". Not only led by politicians or generals, also by physicists and other science figures, technicians and engineers, inventors or entrepreneurs.

In 1837 the French revolutionary and socialist theorist L. A. Blanqui probably used the term "industrial revolution" as the first to compare the economic and social development [1]. The first industrial revolution happened at the end of the 18th century and J. Watts steam engine became a symbol of it. The second industrial revolution is driven by electrification and motorization, started less than a hundred years later in 1870. Electric power, mainly associated with the names of T.A. Edison, N. Tesla, W. Siemens and internal combustion engines (N. Otto, GW Daimler, K. Benz, R. Diesel, etc.) became the symbols of this period. Key points of the third industrial revolution are digitization and robotization. It is considered to begin in 1969 and is characterized by the advent of microprocessors and the use of computers.

The beginning of fourth industrial revolution dates back to 2011; but the main concepts were presented to the professional public in 2013 at the Hannover fair. It is represented by information technology and intelligent cyber-physical systems leading to the automation of production processes, gradually replacing the human workforce and provoking the demand for the establishment of modern workplaces. This will be helped by cameras, transmitters, sensors, code readers and other high-end technology devices that take over not only stereotyped and simple tasks and dangerous activities, but also intelligent decision-making processes that are currently being carried out by people. According to experts, this should lead to a productivity increase of up to one third compared to the current situation.
2. Maintenance as the tenth pillar of Industry 4.0.

Current academics [20,21,22] often talk about nine pillars of Industry 4.0., which “help” factories to be intelligent and that is what Industry 4.0 is all about.

- Horizontal and Vertical Integration

   Horizontal integration connects cyber-physical systems and enterprise systems (BIS), where all devices in the facility are connected with each other. Vertical integration makes involves systems and humans, when interfaces (humans and machines communicate in two different ways) are used during vertical integration.

- Industrial Internet of Things

   According to the world research company Gartner, the Internet of Things (IoT) can be defined as “a network of physical objects that contains built-in technologies for communication and perception; or affects their internal conditions or external environment” [2]. Accenture and the Bankinter Foundation of Innovation define IoT: "The Internet of Things consists of things connected to the Internet anytime, anywhere. In technical meaning the Internet of Things incorporates sensors and devices into the common objects that are connected to the Internet via wired or wireless networks. [3]. For the purpose of our research the concept of the Internet of Things describes that things can be connected to the Internet via transmission networks. Manufacturers are attaching sensors to machines and other physical assets on the plant floor to collect data which influences decisions real time and leads to increased efficiency and productivity.

- Big Data and Data analytics

   Big Data and Data analytics is mostly used in industries to reduce downtime and wastages. Also, data evaluation helps reducing downtimes and increasing productivity. This is useful when companies are adopting principles of predictive maintenance.

- Simulation

   A simulation is used to simulate a virtual environment of the factory (digital twins). The digital twin is a virtual copy of individual machines or entire, even very extensive production or logistics processes. It allows to model their activity and create variants as if it were a real machine or process.

- Additive Manufacturing and 3D Printing

   Additive manufacturing (AM) is defined as the process of joining materials to produce objects from 3D data models, mostly layer by layer, as opposed to subtractive manufacturing methods [7]. The layering of the material is what fundamentally distinguishes additive production from other traditional production techniques. The material is layered using a laser or a print head [23]. Additive manufacturing would not be possible without the use of other technologies - CAD, CAM and CNC, thanks to which it is possible to create and print three-dimensional models and objects.

- Autonomous Robots

   Industrial robots are generally designed to work for people and they perform activities in a restricted area according to relatively complex programs. A collaborative robot (‘cobot’) is robot an industrial robot that is designed to cooperate with human operators and create values together. A traditional robot is limited by safety cages and sensors that are often expensive and prevent easy access, but collaborative robots are accessible for human operators (easier maintenance [4], lower costs for safety). They are equipped with features and detection sensors that allow them to recognize where the human operators are. They can be easily programmed. While traditional industrial robots require advanced knowledge and programming experience, collaborative robots are able to teach themselves [4].

- Cloud Services

   Cloud computing is a service implemented using the Internet (public IP network), represented by an imaginary network cloud, using virtual servers [5]. As a characteristic of this type of technology are speed of access, sharing of resources and high elasticity. Cloud computing is available in main three models:

   SaaS - Software as a Service - allows the user to run software applications over the Internet without the need to own them (Gmail, Microsoft Online).
PaaS - Platform as a Service - provides the user with a computing platform for supporting web applications via the Internet (Google Apps).

IaaS - Infrastructure as a Service - enables the use of computer hardware and software, including operating and communication systems. The service provider takes care of installation until maintenance. The benefits of the Cloud include: remote data storage, hardware performance, great variety of options, cost, location independence, reliability of the Cloud network and maintenance, which together with the management is in the hands of the service provider [6].

- Cyber Security in Industry 4.0
  Cyber security’s main role in accordance with Industry 4.0 principles is to prevent hacking company’s server and data and safeguarding the data and performance of the server. Any security breach could damage multiple areas of the business, from supply chain to operations.

- Augmented Reality
  Augmented Reality uses real environment and masks it with digital information. It displays digital content in real word through a device, such as a mobile phone or special eyeglasses. By connecting and writing digital information directly to real objects, people can process both physical and digital signals.

These 9 aspects can be defined as core key elements of Industry 4.0. We added another “tenth pillar” focused on machinery maintenance - Maintenance 4.0. Some recent research shown in the next section tries to present definitions of Maintenance 4.0.

3. Literature review on Maintenance 4.0.
Cachada et al. [8] consider maintenance as an integral part of the manufacturing process that contributes to the product quality, plant availability and ability to meet delivery schedules. This considers advanced and online analysis of collected data for earlier detection of the occurrence of possible machine failures, and supports technicians by providing a guided intelligent decision support. Galar & Kans [9] try to define maintenance with focus on Industry 4.0 as a smart manufacturing system consisting of physical assets and humans. Maintenance 4.0 is represented by self-learning and smart machines that predicts failure, makes diagnosis and triggers maintenance actions. The smart equipment is in form of embedded or cyber-physical systems (CPS), where physical and software components are intertwined. According to Aljabroun et al. [10] Maintenance 4.0 should be able to execute data gathering, monitoring, analyzing, planning, and data presenting. These tasks should be performed in environment of vertical and horizontal integrated systems with end-to-end engineering solutions. To perform these tasks, Maintenance 4.0 must take into account necessary elements such as sensors, actuators, network, processors, middleware, databases, software and applications. Kandemir and Celik [11,12] view Maintenance 4.0 as one of the most futuristic subjects. By proper implementation higher availability performance, reduced downtimes, optimized energy consumption and savings on general maintenance costs can be achieved. They put big emphasis on people here. Skilled workers’ adaptation into different roles and tasks must be provided. Furthermore, enhanced assessment skills for IT systems must be noted. Concept of Maintenance 4.0 has an important role to contribute future’s maintenance standard and it lies in the core of industry 4.0. According to Jantunen et al. maintenance 4.0”, comprises all topics related to the application of Industry 4.0’s techniques and technologies to maintenance [13]. Chiu et al. [14] deal with Maintenance 4.0, only from point of view of Predictive maintenance (PdM). It monitors equipment health and indicates when a maintenance event will be required in the future, when it has been raised to the top priority as the key enabler for maximizing tool availability. Franciosi et al. [15] define Maintenance 4.0, with another crucial actor – sustainability. The role of Maintenance 4.0 for sustainable manufacturing is still in its infancy and it has big potential. However, there is no contrast between old-new or conventional-sustainable, but probably a potential synergy. Thus it is necessary to understand how maintenance engineering can be combined with big data potentiality in order to obtain the better “configuration” of Big Data Analytics.

4. Maintenance 4.0 model
Based on above-mentioned, we try to propose a Maintenance 4.0 model. Our model was initially split into 3 main key concepts: maintenance aspect (Maintenance 4.0. “takes” features from previous forms of maintenance), technology aspect (describing advanced technologies to perform the maintenance itself) and “people” aspect (from TPM people are one of the crucial elements of maintenance). Before moving to describing the model itself, we realized that there is a need for “other” aspect of Maintenance 4.0. This was covered mostly by ecological and environmental aspects on company’s environment.

The key idea of Preventive Maintenance is that “prevention is better than cure”. An aid of intelligent software to schedule maintenance plan is also important. This is in a contrast with “old” maintenance approaches, where the main “strategy” was “run the device until its failure”. Predictive maintenance can be expressed in many ways. For our model, RUL is the key factor. Remaining useful life (RUL) is defined as duration left for a system before it fails. Other successful models of determining predictive maintenance based on recent research are Physic, Data-driven, Probabilistic, Stochastic and A.I.-method based. Here, we are dealing with a certain time frame (weeks usually). Another part of Maintenance aspect is called Prescriptive maintenance and analytics. This is nowadays the most advanced option in maintenance. Based on big data, graph analysis, simulations, complex event processing, neural networks, heuristic and machine learning. This not only reflects possible results, but also evaluates which of approaches is the fastest or most efficient. With daily use of smartphones, tablets or other devices such as special data goggles mobile maintenance is emerging. Operators and technicians can track the status of a chosen device (group of devices, plant) through special mobile applications, which are part of complex CMMS, what brings us to “technological aspect” of Maintenance 4.0. model. Prognostic maintenance helps to predict time, when system or its part is no longer capable to maintain its function. This is built in abovementioned predictive analysis and maintenance, BUT unlike them, use of modern technologies (machine learning, pattern recognition, neural networks) is implemented here.

Internet of Things is a key part here. Devices and objects through the company are linked and communicate together. From the technological point, 5G is crucial here (enables high data transfer at high speed and volumes), also combination of predictive maintenance with Big Data analysis. Big Data analysis provides a link information, which streams data from and to the company. Dealing with Maintenance 4.0, the hardest part will be how to filter data. Machinery health based on condition monitoring is here another key factor, where intelligent software plays a role. EDGE computing is a method to optimize cloud computing by performing data processing near the source of the data. Faster speed, safety and reducing of costs are the results of dividing between local and cloud data. Collaborative robots, which coexist and learn from humans with inspection drones and cleaning (maintenance) robots represent the Artificial Intelligence part of Maintenance 4.0. concept. Remotely controlled drones can repair damaged parts dangerous to humans. Blockchain technology enables higher level of automation, speeding up processes, cutting costs and decreasing interparty friction. Machine learning uses algorithms to detect anomalous patterns and identify threats of failure. With abovementioned CMMS and interconnected system reporting of failures is an automated process now.

“People” are more and more important with evolved forms of maintenance. This became evident since TPM implementation when operators are taught to care about machines as “their own”. Operators played only a small or no-role in this process, but with Industry 4.0. technologies they now have to be fully involved in CMMS. But their role is not as important as role of data scientists. With technologies like Big Data they analyse complex patterns and provide advices based on them. People dealing with modern forms of maintenance need to be properly trained. Modern form of maintenance needs data scientists rather than “repairmen with a hammer”. collaboration between all these processes is crucial.

We labelled the last part of model as “other”. Environmental protection is a big thing now. Modern forms of maintenance try to achieve more efficient use of industrial plants and reduction in energy consumption and raw material wastage. Big data and predictive maintenance are catalysts for improving food efficiencies and food waste and hunger reduction is a result. By implementing
Maintenance 4.0. technologies we can achieve a significant reduction [19] of company’s carbon footprint.

| Maintenance aspect | Technology | People | Other |
|--------------------|------------|--------|-------|
| Preventive Maintenance | Internet of things | Operators | Environment |
| Predictive maintenance | 5G | Data analysts | efficient use of industrial plants and a reduction in energy consumption |
| Prescriptive maintenance and analytics | Big Data analysis | Specialists | Food waste and hunger reduction |
| Mobile Maintenance | EDGE computing | Training and onboarding | big data and predictive maintenance as catalysts for improving food efficiencies |
| Blockchain technology | Robotics | Collaboration | Carbon footprint reduction by implementing M 4.0. technologies |
| Artificial Intelligence | identify evolving failure and scheduling repairs | | |

Table 1 Maintenance 4.0. model

5. Case study on preparedness of companies for a new type of maintenance processes

According to Haarman et al. [16] the most “critical” role of well-implemented maintenance in company is to predict failures. Only 11% are prepared for most advanced maintenance. Some companies have plans for this, or intentions in near future. But the truth is, that most companies have no plans due to their budget (main) or other reasons. For implementing most advanced forms of maintenance companies use data sources, sensors, environmental data, production controls or maintenance information systems. People are also an important part, they employ data scientists, IT specialists and reliability engineers. Almost 95% companies that implemented these stated that Maintenance 4.0. is responsible for improving in one or most cases. Main reasons why companies want to adopt Maintenance 4.0 are related to improve asset uptime (51%), which can be particularly important in circumstances like current economic upturn. Other important objectives include reducing costs (11%), risks associated with safety, health, environment and quality (SHEQ) (8%), extending asset lifetime (7%) and improving customer satisfaction (12%). Energy savings are barely mentioned, but “going green” will be very important.

From the point of view of data collection, most important were data types traditionally used in maintenance (usage of the asset’ (from 72 to 83%) and maintenance history’ (from 73 to 84%)), then data types mostly associated with more mature levels of predictive maintenance, which included condition of asset, condition data and history of assets from other company, and environmental data. Most data is collected from sensors, (77%), instrument inspections (75%) and interfaces with production control systems [17, 18]. From HW and SW point of view most common are: MS Excel,
Access, Database, Condition monitoring, Statistical software, WIFI, IoT, Mobile networks, Data-warehouse, Cloud.

Functions involved with Maintenance 4.0. from “traditional” technicians and maintenance inspectors to “modern” reliability engineers, data scientists, quality inspectors, IT specialists and others.

6. Conclusions
The ongoing 4th Industrial revolution resulted in changes on machinery and equipment maintenance. Modern technologies and approaches are presented in the article, where main aim was to propose a maintenance model incorporating these technologies and approaches with regard to Industry 4.0. principles. Maintenance has changed from “not let the device work until it goes wrong” to predictions (and taken measurements) of equipment degradation. The article presented Maintenance 4.0. as “tenth pillar” of Industry 4.0. Based on modern research review 3 main key aspects (maintenance, technology, “people”) of model were introduced with 4th “other” aspect dealing mainly with environment and carbon footprint. From the case study it is obvious that companies that already implement most advanced forms of maintenance saw improvements in reducing costs, risks and improving processes and extending lifetime of their assets. However, this model is due to change, mainly because technical and maintenance aspects are still evolving and improving.

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