Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 180 (2021) 388–393

Procedia Computer Science

www.elsevier.com/locate/procedia

International Conference on Industry 4.0 and Smart Manufacturing

Industry 4.0 and human factor: How is technology changing the role of the maintenance operator?

Tommaso Gallo[a]*, Annalisa Santolamazza[b]

[a]*Department of Economy, Engineering, Society and Management (DEIM), University of Tuscia, via del Paradiso, 47, Viterbo 01100, Italy*
[b] *Department of Enterprise Engineering, "Tor Vergata" University of Rome, Via del Politecnico, 1, 00133 Rome, Italy*

Abstract

Industry 4.0 is revolutionizing not only the manufacturing industry but also maintenance strategies.
As consequence of the introduction of Industry 4.0 technologies, new skills are demanded to maintenance operators that has to be able to interact, as instance, with Cyber Physical Systems and robots. In this paper, we first investigate the state-of-the-art of Industry 4.0 technologies that are transforming operations and production management and finally we discuss how the role of maintenance operators is changed in a such digitalized environment.
We found that, the maintenance Operator 4.0 should be able to find relevant information and predict events by a proper use of Big Data analytics, in addition to the ability of interacting with computers, digital databases and robots. Finally, the ability to rapidly adapt his skills to innovations is also strongly demanded.

Peer-review under responsibility of the scientific committee of the International Conference on Industry 4.0 and Smart Manufacturing

Keywords: Industry 4.0, maintenance, maintenance Operator 4.0, smart factory

1. Introduction

The fourth industrial revolution (Industry 4.0) is supported by the so-called "nine pillars" of advanced technologies, that are able to transform the conventional factory into a "smart factory" [1,22,43] in particular through

* Corresponding author. *E-mail address:* tommaso.gallo@unitus.it

1877-0509
Peer-review under responsibility of the scientific committee of the International Conference on Industry 4.0 and Smart Manufacturing
10.1016/j.procs.2021.01.364

the introduction of the most representative technologies that are Cyber Physical Systems (CPS) and Internet of Things technology [21,23].

Such digitalized era is characterized by coupling manufacturing processes with information and communications technology (ICT) [25], resulting in the development of intelligent factories able to meet new management goals in a more flexible way [9,11,12,41].

Industry 4.0 also involved relevant changes in human resource management and tasks [22,39] and, therefore, it is possible to identify new skills that are demanded to operator, or, as one might call it, the "Operator 4.0".

On the other hand, such digitalized environment has raised complexities related to dynamics of processes and products, as well as the way in which operators have to manage and use new technologies [17].

The concept of the Operator 4.0 was already explored by Romero et al. [44], considering a context of human-CPS interaction towards "human-automation symbiosis work systems for a socially sustainable manufacturing workforce". The same authors also highlighted the evolution of the Operator in 4 main steps, that are: 1) Operator 1.0, "defined as humans conducting 'manual and dextrous work' with some support from mechanical tools and manually operated machine tools", 2) Operator 2.0 that "represents a human entity who performs 'assisted work' with the support of computer tools", 3) Operator 3.0 that "embodies a human entity involved in 'cooperative work' with robots and other machines and computer tools, also known as - human-robot collaboration", and 4) Operator 4.0 that represents "the 'operator of the future', a smart and skilled operator who performs 'work aided' by machines if and as needed".

In this study, we aim to define changes for maintenance Operator 4.0 in a "smart factory" and, in order to do this, a first literature review of recent articles has been needed. In fact, as reported by recent scientific studies [4,10,16,29,35-38], a comprehensive literature review allows to identify gaps in knowledge and provides theoretical foundations for the proposed study.

2. Methods

As first step to investigate how the role of the maintenance Operator 4.0 is changing, a literature review was needed to know the state-of-art of Industry 4.0 technology. As research source, only journals indexed by Scopus (scopus.com), IEEE (ieeexplore.ieee.org), Google Scholar (scholar.google.com) have been taken into consideration. We used Boolean operators to combine the following exploration keywords: "industry 4.0", "maintenance", "operator 4.0" or "human factor". Furthermore, through the use of key concepts raised from the first literature exploration, such as "augmented reality" and the "Big Data Analysis", further searches have been performed. We collected a total of 18 papers published from 2015 to 2020.

Articles with title and abstract that matched the aim of our study have been first collected and, after analyzing the entire contents of the article, they were assessed for considering their final inclusion in our database. On the other hand, conference papers and articles in languages different from "English" were excluded. Results section defines the state-of-art of Industry 4.0 technologies and how such technologies are remodeling the figure of maintenance operator within a "smart factory". Table 1 summarizes the literature review process.

Table 1. Summary of the systematic literature review process.

Step 1 and **Step 2** *Finding and evaluation of articles*	**Electronic databases** Scopus (scopus.com), IEEE (ieeexplore.ieee.org), Google Scholar (scholar.google.com) **Search Period** 2015 - 2020 **Inclusion Criteria** Articles with title and abstract that matched the aim of our study have been first collected and, after analyzing the entire contents of the article, they were assessed for considering their final inclusion in our database. **Exclusion Criteria** Articles and conference papers and in languages different from "English" **Search Strings** "industry 4.0" AND "maintenance" Other combinations with:

	"operator 4.0", "human factor", "augmented reality", "Big Data Analysis", etc…
Step 3 *Assessment of findings*	**Analysis phase** Iterative collection of articles within the database
Step 4 *Reporting of findings*	**Synthesis phase** Relevant aspects are extracted from database and discussed

3. Results

3.1 Industry 4.0 technology: state of art

As aforementioned, Industry 4.0 is based on the introduction of the "nine pillars" of technologies. Such pillars are: 1) Industrial Internet of Things (IIoT); 2) Big Data; 3) Horizontal and vertical integration of systems; 4) Simulations; 5) Clouds; 6) Augmented Reality; 7) Autonomous Robots; 8) 3D printing and 9) Cyber Security.

The Industrial Internet of Things (IIoT) refers to all Cyber Physical Systems (CPS) introduced in smart factories. Such systems are interconnected using internet, in this way it is possible to establish a communication network able to exchange real time data, without any human interaction [20,42].

As stated by Kaisler et al. [24], Big Data is "the amount of data just beyond technology's capability to store, manage and process efficiently" [24]. In a smart factory, a relevant part of the overall digital data come from CPSs.

Horizontal and vertical system integration allows a full connection of all parts of the whole supply chain, through a highly dynamic system [30].

Simulations can be considered as the digital support to design production systems, and they can also elaborate real time data from CPSs [6].

Cloud technology refers to digital storage solution and cloud computing [43], making possible "on-demand" digital data exchange among CPSs and other smart devices [14,28].

Augmented Reality (AR) superimposes digital data on reality, allowing the interaction between humans and CPSs [15].

Robotic applications can have different purposes within a smart factory. They generally help operators in their task and are also able to interact with other cobots [34]. Robots represent another tool for acquiring and exchanging data during their activities.

Additive manufacturing refers to the 3D printing of physical objects. They can also use, as digital source, 3D CAD digital designs [7].

The ninth pill consists in Cyber Security, that aims to preserve digital data and smart devices from cyber-attacks [40].

3.2 The Maintenance Operator 4.0

As mentioned in the introduction section, Industry 4.0 context has amplified complexity and dynamics of operations and manufacturing processes, as well as changed protocols and human tasks [17].

Zolotová et al. [43] consider the transformation from operator to an Operator 4.0 possible through the increase of physical, sensing, and cognitive capabilities, and then able to support main aspects of maintenance processes.

According to Wittenberg [41], the main role of the Operator 4.0 is that of supervisor of the automated production, using enhanced monitoring systems. The same author also discusses how conventional interface for managing information is today unsuitable, because of the increased amount of available digital data.

Ansari et al. [2] define how to reach a proper collaboration between operators and CPSs for maintenance tasks, while Fantini et al. [13] establish a procedure to address situations where operators have to interact with CPSs.

According to Manyika et al. [27], for the Big Data Analysis, although it has a key role in the economical innovation, a general lack of operators able to obtain insight from Big Data has been observed, resulting in a deceleration for the technology establishment.

Operator 4.0 can increase own real-world perception by augmented reality technology, analyzing digital data collected in collaboration with robots, and this generally results in improved maintenance tasks in terms of control and execution [18].

Virtual reality is a powerful technology for both training and helping operators in decision-making for new maintenance procedures [43]. On the other hand, AR tablet are often used for maintenance purposes [3,18,32]. However, tablets have relevant limitations, such as battery power requirement and not being a hand-free technology. For this reason, wearable AR or head mounted devices (HMD) are becoming ever more popular [32].

As emerged from a survey dated 2016 [41], most of maintenance operators have a favorable consideration for smart devices, helping them to reduce uncertainties during tasks.

The maintenance Operator 4.0 can be defined as a smart operator with enhanced physical, sensorial and cognitive capabilities by means the integration with technologies of Industry 4.0. In Table 2, key aspects and critical aspects for the maintenance Operator 4.0 are summarized.

Finally, Fantini et al. [13] state how a proper design of workplaces is important to ease the human-automation symbiosis, while Koch et al. [26] discuss proper interfaces for an optimal interaction between operators and robots, including skills that are demanded.

Table 2. Key aspects and disadvantages for the maintenance Operator 4.0.

	Maintenance Operator 4.0
Relevant technologies and aspects	*- Improving operator training with the help of 3D printing or AR* *- Interaction with autonomous robots* *- AR (wearable, HMD, glass data, tablets)*
Critical Aspects	*- Interaction with a smart factory* *- Need of hand-free technology* *- Human-automation symbiosis*

4. Discussion and conclusion

The aim of this work was to define changes for maintenance operator in a "smart factory" and, in order to do this, a first literature review for defining state -of-art of Industry technology, has been performed.

We found that Industry 4.0 has introduced relevant changes concerning processes and manufacturing systems, through the introduction of the "nine pillars" technologies, and new skills are demanded to maintenance operator.

In a such digitized environment, although complexity and dynamics of manufacturing processes have been increased, a maintenance operator can take advantages by technologies such as AR and CPSs that allow real-time feedbacks and a more effective training. However, the possibility to have a hand-free technology appears to be mandatory.

The Operator 4.0 should be able to find relevant information and predict events by a proper use of Big Data analytics [5,33], in addition to the ability of interacting with computers, databases and robots.

The maintenance Operator 4.0 has been deeply remodeled during last five years, having to be not only smart and able to interact with CPSs, cooperate with robots and other smart technologies, but also able to perform different tasks in an enhanced physical, sensorial and cognitive environment. According to Gilchrist [19] and Perez et al. [31], Operator 4.0 has to have the capability to rapidly adapt his skills to a digital world, where innovations are continuously introduced. Finally, it can be assumed a continuous improvement of the skills and performance of maintenance technicians in the near future. However, the training process will be accelerated thanks to the same Industry 4.0 technologies, such as smart devices and virtual reality.

References

[1] Alqahtani AY, Gupta SM, Nakashima K (2019) Warranty and maintenance analysis of sensor embedded products using internet of things in industry 4.0. Int J Prod Econ 208:483–499. https://doi.org/https://doi.org/10.1016/j.ijpe.2018.12.022

[2] Ansari F, Khobreh M, Seidenberg U, Sihn W (2018) A problem-solving ontology for human-centered cyber physical production systems. CIRP J Manuf Sci Technol 22:91–106. https://doi.org/https://doi.org/10.1016/j.cirpj.2018.06.002

[3] Aschenbrenner D, Maltry N, Kimmel J, et al (2016) ARTab - using Virtual and Augmented Reality Methods for an improved Situation Awareness for Telemaintenance. Funded by the Bavarian Ministry of Economic Affairs, Infrastructure, Transport and Technology in its R&D program 'Bayern digital'. IFAC-PapersOnLine 49:204–209. https://doi.org/10.1016/j.ifacol.2016.11.168

[4] Belfiore G, Falcone D, Silvestri L (2018) Assembly line balancing techniques: Literature review of deterministic and stochastic methodologies. In: 17th International Conference on Modeling and Applied Simulation, MAS 2018. pp 185–190

[5] Chen H, Chiang RHL, Storey VC (2012) Business intelligence and analytics: From big data to big impact. MIS Q 1165–1188

[6] Chong S, Pan G-T, Chin J, et al (2018) Integration of 3D printing and industry 4.0 into engineering teaching. Sustain 10:. https://doi.org/10.3390/su10113960

[7] Chua CK, Leong KF, Lim CS (2010) Rapid prototyping: Principles and applications, third edition

[8] Di Bona G, Duraccio V, Silvestri A, Forcina A (2014) Productive line reengineering through simulation techniques. In: Proceedings of the IASTED International Conference on Modelling, Identification and Control. pp 291–296

[9] Di Bona G, Duraccio V, Silvestri A, Forcina A (2014) Validation and application of a safety allocation technique (integrated hazard method) to an aerospace prototype. In: Proceedings of the IASTED international conference on modelling, identification, and control, MIC. pp 284–290

[10] Di Bona G, Forcina A, Falcone D, Silvestri L (2020) Critical Risks Method (CRM): A New Safety Allocation Approach for a Critical Infrastructure. Sustainability 1–19. https://doi.org/10.3390/su12124949

[11] Falcone D, Silvestri A, Bona G, et al (2010) Study and modelling of very flexible lines through simulation

[12] Falcone D, Silvestri A, Forcina A, Pacitto A (2011) Modeling and simulation of an assembly line: a new approach for assignment and optimization of activities of operators. In: MAS (The International Conference on Modeling and Applied Simulation), Rome. pp 12–14

[13] Fantini P, Pinzone M, Taisch M (2018) Placing the operator at the centre of Industry 4.0 design: Modelling and assessing human activities within cyber-physical systems. Comput Ind Eng. https://doi.org/https://doi.org/10.1016/j.cie.2018.01.025

[14] Fernández-Caramés TM, Fraga-Lamas P, Suárez-Albela M, Vilar-Montesinos M (2018) A fog computing and cloudlet based augmented reality system for the industry 4.0 shipyard. Sensors (Switzerland) 18:. https://doi.org/10.3390/s18061798

[15] Figueiredo MJG, Cardoso PJS, Gonçalves CDF, Rodrigues JMF (2014) Augmented reality and holograms for the visualization of mechanical engineering parts. In: 2014 18th International Conference on Information Visualisation. pp 368–373

[16] Forcina A, Silvestri L, Di Bona G, Silvestri A (2020) Reliability allocation methods: A systematic literature review. Qual Reliab Eng Int

[17] Fusko M, Rakyta M, Krajcovic M, et al (2018) Basics of designing maintenance processes in industry 4.0. MM Sci J 2018:2252–2259. https://doi.org/10.17973/MMSJ.2018_03_2017104

[18] Gattullo M, Scurati GW, Fiorentino M, et al (2019) Towards augmented reality manuals for industry 4.0: A methodology. Robot Comput Integr Manuf 56:276–286. https://doi.org/https://doi.org/10.1016/j.rcim.2018.10.001

[19] Gilchrist A (2016) Introducing Industry 4.0. In: Industry 4.0. Springer, pp 195–215

[20] Gubbi J, Buyya R, Marusic S, Palaniswami M (2013) Internet of Things (IoT): A vision, architectural elements, and future directions. Futur Gener Comput Syst 29:1645–1660. https://doi.org/10.1016/j.future.2013.01.010

[21] Jazdi N (2014) Cyber physical systems in the context of Industry 4.0. In: Proceedings of 2014 IEEE International Conference on Automation, Quality and Testing, Robotics, AQTR 2014

[22] Jones M, Zarzycki L, Murray G (2019) Does industry 4.0 pose a challenge for the sme machine builder? A case study and reflection of readiness for a uk sme. IFIP Adv. Inf. Commun. Technol. 530:183–197

[23] Kagermann H, Wahlster W, Helbig J (2013) Recommendations for implementing the strategic initiative Industrie 4.0: securing the future of German manufacturing industry. Berlin

[24] Kaisler S, Armour F, Espinosa J, Money W (2013) Big Data: Issues and Challenges Moving Forward

[25] Kamble SS, Gunasekaran A, Gawankar SA (2018) Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives. Process Saf Environ Prot 117:408–425. https://doi.org/https://doi.org/10.1016/j.psep.2018.05.009

[26] Koch PJ, van Amstel MK, Dębska P, et al (2017) A Skill-based Robot Co-worker for Industrial Maintenance Tasks. Procedia Manuf 11:83–90. https://doi.org/https://doi.org/10.1016/j.promfg.2017.07.141

[27] Manyika J, Chui M, Brown B, et al (2011) Big data: the next frontier for innovation, competition, and productivity

[28] Mourtzis D, Vlachou E (2018) A cloud-based cyber-physical system for adaptive shop-floor scheduling and condition-based maintenance. J Manuf Syst 47:179–198. https://doi.org/https://doi.org/10.1016/j.jmsy.2018.05.008

[29] Nosi C, Pucci T, Silvestri C, Aquilani B (2017) Does value co-creation really matter? An investigation of Italian millennials intention to buy electric cars. Sustainability 9:2159

[30] Peres RS, Dionisio Rocha A, Leitao P, Barata J (2018) IDARTS – Towards intelligent data analysis and real-time supervision for industry 4.0. Comput Ind 101:138–146. https://doi.org/10.1016/j.compind.2018.07.004

[31] Perez D, Alarcón F, Boza A (2017) Industry 4.0: A classification scheme. Lect Notes Manag Ind Eng

[32] Roy R, Stark R, Tracht K, et al (2016) Continuous maintenance and the future – Foundations and technological challenges. CIRP Ann 65:667–688. https://doi.org/https://doi.org/10.1016/j.cirp.2016.06.006

[33] Russom P, others (2011) Big data analytics. TDWI best Pract report, fourth Quart 19:1–34

[34] Sadik AR, Urban B (2017) An ontology-based approach to enable knowledge representation and reasoning in Worker-Cobot agile manufacturing. Futur Internet 9:. https://doi.org/10.3390/fi9040090

[35] Silvestri L, Falcone D, Belfiore G (2018) Guidelines for reliability allocation methods. In: The International conference on modelling and applied simulation, MAS 2018, pp. 191-198

[36] Silvestri L, Forcina A, Arcese G, Bella G (2020) Recycling technologies of nickel–metal hydride batteries: an LCA based analysis. J Clean Prod 123083. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.123083

[37] Silvestri L, Forcina A, Arcese G, Bella G (2019) Environmental Analysis Based on Life Cycle Assessment: An Empirical Investigation on the Conventional and Hybrid Powertrain. In: Conference on Sustainable Mobility. SAE International

[38] Silvestri L, Forcina A, Silvestri C, Ioppolo G (2020) Life cycle assessment of sanitaryware production: A case study in Italy. J Clean Prod 251:119708. https://doi.org/https://doi.org/10.1016/j.jclepro.2019.119708

[39] Vaidya S, Ambad P, Bhosle S (2018) Industry 4.0 – A Glimpse. Procedia Manuf 20:233–238. https://doi.org/https://doi.org/10.1016/j.promfg.2018.02.034

[40] Wells LJ, Camelio JA, Williams CB, White J (2013) Cyber-physical security challenges in manufacturing systems. Manuf Lett 2:74–77. https://doi.org/10.1016/j.mfglet.2014.01.005

[41] Wittenberg C (2016) Human-CPS Interaction - requirements and human-machine interaction methods for the Industry 4.0. IFAC-PapersOnLine 49:420–425. https://doi.org/https://doi.org/10.1016/j.ifacol.2016.10.602

[42] Xu LD, He W, Li S (2014) Internet of Things in Industries: A Survey. IEEE Trans Ind Informatics 10:2233–2243. https://doi.org/10.1109/TII.2014.2300753

[43] Zolotová I, Papcun P, Kajáti E, et al (2018) Smart and cognitive solutions for Operator 4.0: Laboratory H-CPPS case studies. Comput Ind Eng. https://doi.org/https://doi.org/10.1016/j.cie.2018.10.032

[44] Romero, D., Bernus, P., Noran, O., Stahre, J. & Fast-Berglund, Å. The Operator 4.0: Human Cyber-Physical Systems & Adaptive Automation Towards Human-Automation Symbiosis Work Systems BT - Advances in Production Management Systems. Initiatives for a Sustainable World. in (eds. Nääs, I. et al.) 677–686 (Springer International Publishing, 2016).