How to Manage People Underutilization in an Industry 4.0 Environment?

Gianluca D'antonio, Paolo Chiabert

How to manage people underutilization in an Industry 4.0 environment?

Gianluca D'Antonio, Paolo Chiabert

Politecnico di Torino, corso Duca degli Abruzzi 24, 10129 Turin, Italy
{gianluca.dantonio, paolo.chiabert}@polito.it

Abstract. For long time, Lean manufacturing has been often mis-defined as "doing more with less" and relied on Taiichi Ohno's taxonomy made of seven classes of wastes. More recently, the definition of Lean Manufacturing has been mostly centered on the continuous improvement approach and an eighth class of waste has been defined: skills, or non-utilized talent. This kind of waste occurs when organizations introduce a huge separation between the management and the process operators, thus obstructing the continuous improvement routines. The spread of the Industry 4.0 paradigm, based on a massive ICT deployment, may lead to two possible risks. First, decisions may be taken based only on the data acquired on the process, without involving the people performing a task who are most capable and experienced to develop appropriate solutions. This would lead to enlarge the gap between management and operators and, in turn, the waste of skills. On the other side, appropriate skills are necessary to manage the Industry 4.0 tools. The latest literature advances in these two fields are discussed in the present paper.

1 Introduction

Today enterprises are required to face challenging scenarios: on the one hand, companies have to deal with competitors spread all over the world and working in a variety of different conditions. On the other hand, customers' expectations increase at a high pace: high quality products must be available at a low price, delivered in short times and provided with a high innovative content.

In order to profitably fulfill such expectations, different initiatives can be undertaken. Among them, the adoption of Lean Manufacturing practices is one of the most powerful approaches. This term has been introduced in 1990 [1] to denote the working philosophy developed in the Toyota Production System and then adopted by many Japanese companies. The power of this approach consists in the scientific, systematic approach for distinguishing the product features that match the value desired by the customer (or even increase the perceived value) from the low added-value characteristics. This analysis, in turn, can be reflected on the manufacturing processes, to focus efforts on the operations that really increase product value or are strictly necessary for its management, enabling to discard useless tasks, and deploy continuous improvement routines for performance increase.

For this reason, the Lean approach is often synthesized as “doing more with less”. Nonetheless, such synthesis may be misleading, as it does not include one of the foci of the Lean approach: the successful implementation of such practices is strictly committed to the active role of the human, who is the main source of intelligence and creativity in any manufacturing environment; thus, his role cannot be discarded in the continuous improvement journey.

The digitalization technologies are further enriching this framework, driven by the diffusion of the Industry 4.0 paradigm: this term has been introduced during the Hannover Fair in 2011; although a well-established and shared definition is still lacking, scientists and practitioners agree in stating that Industry 4.0 relies on the application of Internet of Things within industrial environment. The diffusion of technologies for non-invasive, easy-to-use monitoring systems (e.g. wireless sensors), the increased storage capacity available at low price, the enhanced available computing power led to the availability of intelligent systems for data acquisition, data analysis, decision making and information dispatching that are permeating manufacturing environments at a high-pace.

Such systems may boost the performance of a manufacturing environment, provided that an enterprise is able to extract value from the collected information. The role of human is crucial for this purpose: high-level professional functions and skills are necessary to take technical, organizational and strategical decisions in agreement with the Lean principles, supported by the information systems powered by the Industry 4.0 technologies. Nonetheless, a recent survey realized by Frey and Osborne [2] showed that automation and digitalization will result in deleting more than 700 occupation profiles in the USA and that 47% of total USA employment is at risk. A similar analysis performed in Europe [3] shows that 40% to 60% of workers may be displaced because of technological changes.

Therefore, the following research questions are dealt in the present paper: (i) How can information systems support human operators in taking the right decision at the right time? (ii) Which competences are necessary for an operator to profitably work into an Industry 4.0 environment? To answer such questions, a literature analysis has been performed.

The reminder of this paper is organized as follows: the background concerning the role of human according to the Lean approach is presented; in particular the issue of people underutilization is discussed. The research methodology is presented in Section 3. Sections 4 and 5 are devoted to answering the two research questions. Finally, conclusive remarks are provided in Section 6.

2 Background

Womack and Jones [1] use the term ‘waste’ to denote any activity that absorbs resources without creating value. In the late 1980s, Taiichi Ohno [4] proposed a classification of the wastes that may affect any manufacturing process; he defined the following 7 classes: transportation, inventory, unnecessary movements, waiting, overproduction, inappropriate processing and defects. Later, an eight waste has been added to this taxonomy, which is still quite under-investigated in literature: underutilized people [5].

Cattaneo et al. [6] recently made an effort to systematize knowledge on the connections between the Lean approach and the Industry 4.0 technologies through a systematic literature review. Over a basis of 42 documents (including both journal and conference papers), they found that about one third take into account human resources management, a strategic approach aimed to employ and develop qualified employees to achieve company's objectives [7]. The development of human resources plays a crucial role for the performance of any organization and may be split into three main functional areas: personal development (competencies), team development (collaboration) and organizational development (structure and processes) [8].

According to the Lean perspective, the waste of underutilized people can be considered from different points of view: for example, an uneven work distribution results in involving more people than necessary for a given task and, in turn, in wasting workforce. Nonetheless, considering people as simple workforce is a limited perspective: humans are the main source of creativity within any working environment. Therefore, people underutilization may also result from mis-using skills: this occurs when employees are not provided with the right information to correctly perform the assigned tasks and support the improvement process or, conversely, when they are lacking the skills necessary for a proper interpretation of the events that are taking place.

In a recent work, Ras et al. [9] identify four challenges for shop floor workers to perform well in modern manufacturing environments:

1. The workforce needs to understand the underlying processes and their dependencies, to develop the know-how needed for collecting and utilizing data, and leverage digitization in the intelligent production of smart products with flexible lot sizes.
2. Intelligent assistance systems need to be standardized, developed, and deployed in order to real-time guide operators, train workforce, and assess performance from observation.
3. Job profiles have to be updated as tasks needed in the Industry 4.0 context are more interdisciplinary and combine, for example, elements of mechatronics with design, data analytics, and business administration. Development and appraisal procedures for the existing workforce must be built, and a map for the new needed skills to be developed is to be drawn.
4. Socio-technical approaches are necessary to allow grounded participatory design of an interdisciplinary workplace, and re-organize lifelong learning in ways that positively impact on the work life balance.

Therefore, accordingly with our research questions, operators need to be properly guided by intelligent systems supporting observation and decision making. Some approaches available in literature concerning this issue are presented in Section 4. Further, operators need mental routines as well as interdisciplinary and social skills to profitably operate in complex environments cooperating with the rest of the company. A review of the existing models defining the necessary competences is presented in Section 5.

3 Methodology

To perform a literature review capable to answer our research questions, the two main databases of scientific papers have been consulted: Scopus and Web of Science (WoS). The search strings have been defined to find papers containing at least one of the keywords "Industr* 4.0" or "Smart manufactur*" and one of the keywords "skill*", "competenc*" and "knowledge". The wildcard "*" has been used to select papers containing nouns in both the singular and the plural forms and to include in the search also papers containing the German term Industrie 4.0.

The results provided by Scopus and WoS provided 419 and 222 papers, respectively. Some papers were available on both the two databases; thus, a cleaning operation has been made resulting in a sample made of 516 original papers. The first result of this search is the increasing impact over time of the investigated topic. Only 17 papers have been published before 2013; then, the number tends to roughly double every year: 25 papers in 2014; 64 papers in 2015; 142 papers in 2016; 229 papers in 2017. The sample of papers published in 2018 is already sized 36 (the research has been made on the February, 20th).

However, many of these papers do not tackle issues tied to the role of human in industrial environment. As an example, papers concerning information systems for knowledge management in smart factories may appear in the results, although is not related with the research questions at stake. Therefore, a sub-sample of papers has been defined: for each paper, we read title, keywords and abstract, and discarded the publications not significant for our scopes. After this selection, the sample has been restricted to 70 papers which have been read carefully.

4 Intelligent systems to support human operators

According to the Final Report of the Industrie 4.0 Working Group [10], the work of employees will be supported by smart assistance systems with multimodal, user-friendly interfaces. In this field, Longo et al. [11] propose a human-centered approach (HCA) aiming to align and enhance the capabilities and the competencies of operators with the new smart factory context. In particular, they define the paradigm of "augmented operator". The term "augmented" is used because the Industry 4.0 technologies enable the operator to enhance his ability to perceive and act within the physical world by providing a virtual reality (VR) environment where different levels of contents superimpose each other. Moreover, augmented reality (AR) applications enable to add digital resources to a current view of the physical world. Therefore, the augmented operator may own an increased knowledge of the working environment deriving from operational tasks and traditional procedures as well as from a variety of value added contents that are suited to increase his abilities to perceive and act within the working environment. An example of AR-based assistance system is provided by Kerpen et al. [12], who developed a solution for weaving machine operators in textile production. When an operator needs support to fix a broken weft, he can focus the insertion device with the camera of the developed tool. A software application detects the position where the weft yarn is broken and provides the operator with a case-specific, AR-based support. For this solution, smartphones, tablets, or smart glasses can be used as runtime platforms.

A further effort has been made by Krugh and Mears [13]: they extended the 5C architecture describing CPS [14] to humans, obtaining a paradigm for the Cyber Human System (CHS). They interestingly found that the most difficult activities in the cyber world are naturally performed by humans because of the inherent intelligence that can be naturally leveraged for self-adaptive, corrective, and preventative actions. Conversely, the easiest activities for the CPS are more complicated for humans: while instrumenting a machine with sensors for data collection is quite simple, issues concerning human privacy, ethical data usage and storage, or acceptance by workers must be considered in the CHS.

However, although many concepts for smart assistance systems can be developed, the implementation into a manufacturing environment is not trivial. Arndt et al. [15] attempted to fill this gap by defining a methodology based on five steps, with particular focus on assembly production systems: (1) Analysis of the actual condition and challenges for the process at stake; (2) Definition of the requirements for the system, for handling personal data, and for supply process information; (3) Creation of a concept for documenting and processing data, as well as for presenting process information; (4) Implementation of the concept; (5) Validation and eventual optimization.

Nonetheless, besides the changes in the workplace, manufacturers also have to deal with the changes in workforce that are already taking place. Demographic changes are reshaping work design. It is estimated that by 2050 around 20% of the world population will be aged 60 years or older [16]. Several changes take place in the human body as age increases, and some of them are significant for the working environment, e.g. sensory, senso-motoric and cognitive capabilities. Further, the degrade of capabilities occurs individually at different speeds; therefore, the inter-individual differences increase as a population gets aged and companies need to address such changes in order to remain competitive [17]. To tackle the issue of aging workforce, Peruzzini and Pellicciari [18] developed a human-centered system capable to take into account the individual workability for a woodworking NC machine. Before the intervention, the process exhibited a high impact of human errors and downtimes to manually adjust the machine, as well as a high number of manual operations. The assistance system is made by hardware components to improve process ergonomics and to monitor the state of the machine and the surrounding environment. When an unexpected behavior occurs, the system intelligence browses the past cases to find a similar event and propose a solution to the operator; in case the issue is totally new, the system manager defines a solution that is added to the database of rules. Further, the system is able to recognize the user and automatically adapts according to the user needs: for example, the graphical interface may change in case of vision or memory problems, or the task sequence can be adapted to support an operator with limited motion abilities. user is recognized and the system automatically.

A further role of assistance systems is to support workers in training to deal with increasingly complex environments. For example, before the operators are allowed to perform assembly operations in a manufacturing line, they perform a training program to learn and practice their duties. Hardware prototypes are commonly used;

nonetheless, they are costly and space-consuming. Further, a limited set of product variants can be tested and devices are available only at late development stages. Virtual training can play a significant role in overcoming such limitations. Gorecky et al. [19] developed an advanced training system for assembly in automotive industry based on affordable solutions like Microsoft Kinect and Nintendo Wii capable to access relevant data from the company information systems (e.g. Product Lifecycle Management) and automatically compile a training scenario. The system showed a high user-acceptation and exhibits a high potential for integration into diverse industries with complex products and processes, such as aerospace or train industries.

5 Competence models for Industry 4.0

This section aims to discuss the importance of competencies for workers operating into an Industry 4.0 environment. The increased level of automation generally leads to a reduced number of workers in the shop-floor environment. As an example, Pfeiffer [20] reports a plant for car body production with a high automation level. Each operator is responsible for around 8 robots for material handling and welding, and usually intervenes 20 to 30 times per shift to adjust the system in order to prevent possible issues. To do this, workers need formal qualification: operators in this plant have at least a three-years vocational training. This example shows that one of the Industry 4.0 effects is the shift of human jobs towards non-routine tasks. Further, the higher is the technological level, the higher is the need of highly-skilled and well-trained people to make systems resilient and fix the failures that inevitably take place.

As pointed out by Ras et al. [9], the workforce operating in such scenario needs to integrate theoretical and practical knowledge. Technical competences and expertise is necessary to observe systems, extract implicit knowledge and use it for decision making. Nonetheless, technical skills are not sufficient to profitably operate in such a complex scenario: many additional competences are required, such as creativity, social intelligence, innovation competence and complex problem solving. In particular, they define three main categories of skills that are necessary to deal with a manufacturing environment: (i) STEM: Science, Technology, Engineering and Mathematics; (ii) MES: Mechanics, Electronics, Software and Manufacturing Technique; (iii) soft skills.

Also, the roles of the so-called “white” and “blue” collars are undergoing a transformation. The former class is now made of the designers of Industry 4.0 products and processes, while the latter group is shifting towards the Operator 4.0 defined by Romero et al. [21]. They envisage a human cyber-physical system where operators’ abilities are improved through the interaction with machines, which can be classified in the following two categories. Physical interactions take place through exoscheletons supporting correct movements and ergonomics, wearable systems to collect and access information, collaborative robots to execute complex tasks. Cognitive interactions occur through augmented and virtual reality, intelligent personal assistants, social networks and big data analytics.

Thus, given the increased technological level that characterizes an Industry 4.0 environment, the role of human is still crucial: employees have to contribute in organizational learning, and innovate processes. Further, the rate of change is accelerating with greater force and frequency, and firms have to be very sensitive to new needs of customers and new type of competitors. Shamim et al. [22] argue that, to remain competitive, companies have to foster a climate of innovation and learning.

As a result, scientists proposed different competence models for the employees of an Industry 4.0 environment.

Pinzone et al. [23] performed an exploratory study aimed to depict the skills that a company must own for a successful exploitation of Industry 4.0 technologies. The study resulted in a set of both hard and soft skills classified according to the following five functional, key areas:

1. Operations management, including the definition of a roadmap to adopt Industry 4.0 technologies, active technology skills to use and program collaborative robots, additive manufacturing, augmented and virtual reality, monitoring systems, ICT tools, and soft skills such as human resources management;
2. Supply chain management, including the abilities to design and build digital supply networks, to analyze Big Data for predicting market behavior, to develop IT strategies for supply chain management;
3. Product-service innovation management, including capabilities to analyze innovative materials and processes, to design smart products and to design the service model;
4. Data science management, including capabilities to design Big Data architectures and software platforms, to develop tools for Big Data analytics, to use cloud platforms for computing and storage, to design info-graphics for intuitive representations;
5. IT-OT integration management, based on the development of a strategic roadmap for integrating information technologies (IT) with operations technologies of industrial automation (OT). This requires the capability to implement IT architectures and networks, the selection of appropriate communication protocols, and the design of strategies for cybersecurity.

Conversely, the classification performed by Pinol et al. [24] is based on the type of skills that needs to be owned by an Industry 4.0 employee:

1. Technological skills: abilities to work with IoT, collaborative robots, additive manufacturing systems, simulation tools and big data analytics;
2. Skills techniques: languages, business management planning, expertise in coasching;
3. Soft skills: adaptation to changes, flexibility and autonomy, effectiveness and leadership, teamworking and networking.

Hecklau et al. [8] provide a more detailed mode by aggregating the necessary competencies in four categories:

1. Technical competencies, including state of the art knowledge and skills on process understanding, media, coding, IT security;
2. Methodological competencies, including creativity, entrepreneurship, problem and conflict solving, decision making, research orientation, analytical and research skills;
3. Social competencies, including languages, communication, networking, team working, cooperation, leadership and intercultural skills
4. Personal competencies, including flexibility, motivation, ability to work under pressure, compliance, sustainable mindset.

The taxonomy provided by Fantini et al. [25] takes into account two possible roles for human operators in manufacturing environment. The first type is named Human-in-the-Loop (HitL) and encompasses activities such as overseeing and adjusting machines, directly commanding the system, being a source of data (for identification, early detection, reporting, etc.), as well as introducing deviations or disturbances due to errors, oversights, voluntary of involuntary deviations from the standards. This scenario corresponds to the levels 1 and 2 defined in the ISA95 standard. The second integration type is named Human-in-the-Mesh (HitM) and involves activities related to the interactions with the CPS network and applications – including the supported interaction with other human roles – corresponding to the levels 3 and 4 in the ISA95 standard. Their analysis results in a skills classification based on three categories: Human resource management and organization; Production management and methods; Technology. However, these three categories contain different skills according to the scenario to be dealt.

For the HitL scenario, competences in the area of human resource include flexibility, teamworking, confidence with feedback mechanisms, technological competences, ability to perform process and quality analyses. Conversely, Humans-in-the-Mesh need responsibility and authority, decision-making skills, complex systems modeling and simulation, capability to align objectives and incentives with the desired performances and to transfer knowledge.

The skills in production methods required for HitL include routine training, monitoring of human tasks and generation of alerts in case of possible errors or unexpected events, development of condition-based instructions to support diagnosis and reporting and to guide interventions. HitM need confidence with incremental models, multi-objective (multi-stakeholder) decision making, caption of decision-making patterns by experts.

Finally, technological skills for HitL comprise the deployment of mobile devices, the deployment of (wearable) sensors for inspection, testing and monitoring, multimodal interaction (voice, image, gesture recognition, sound lights, etc.) , asset tracking to detect tools and spare parts. HitM are required to support the deployment of mobile devices, the intuitive representation of alternatives and trade-offs, and the decision support enhanced by experts' decision- making patterns.

6 Conclusions

The present paper aimed to present the major literature trends concerning the role of humans within Industry 4.0 environments. The discussion in the previous sections shows that the developers of IT systems are beginning to take into account the needs of individual workers: customized interfaces can be realized to compensate with workers shortcomings (e.g. sights issues or concentration lacks) and to provide personalized information. On the other side, workers need to extend the range of their knowledge: technical competences are necessary but no more sufficient, and need to be complemented with social and soft skills. A general competence model, however, is not sufficient to deal with the complexity of Industry 4.0: different models for different job profiles have to be designed. In this field, a first interesting step has been made by Fantini et al. [25].

Acknowledgements. The results presented in this paper has been developed within the research program DISLOMAN - *Dynamic Integrated ShopfLoor Operation MANagement for Industry 4.0*, funded by Regione Piemonte (Italy).

References

1. Womack, J.P., Jones, D.T., Roos, D.: The machine that changed the world. Free Press (1990).
2. Frey, C.B., Osborne, M.A.: The future of employment: How susceptible are jobs to computerisation? Technological forecasting and social change 114, 254-280 (2017). doi: 10.1016/j.techfore.2016.08.019
3. Bowles, J.: The computerisation of European jobs (2015). Available at: http://bruegel.org/2014/07/the-computerisation-of-european-jobs/.
4. Ohno, T.: Toyota production system - Beyond large scale production. Productivity Press, New York, USA (1988).
5. Abdul Wahab, A.N., Mukhtara, M., Sulaiman, R.: A conceptual model of Lean Manufacturing dimensions. Procedia Technology 11, 1292-1298 (2013). doi: 10.1016/j.protcy.2013.12.327.
6. Cattaneo, L., Rossi, M., Negri, E., Powel, D., Terzi, S.: Lean Thinking in the Digital Era. In: Ríos, J., Bernard, A., Bouras, A., Foufou, S. (eds.): Product Lifecycle Management and the Industry of the Future. PLM 2017. IFIP Advances in Information and Communication Technology, vol 517. Springer, Cham (2018). doi: 10.1007/978-3-319-72905-3_33.
7. Armstrong, M., Taylor, S.,: Armstrong's handbook of human resource management practice. 13th edn. Kogan Page, London (2014).
8. Hecklau, F., Galeitzkea, M., Flachsa, S., Kohlb, H.: Holistic approach for human resource management in Industry 4.0. Procedia CIRP 54, 1-6 (2016). doi: 10.1016/j.procir.2016.05.102.
9. Ras, E., Wild, F., Stahl, C., Baudet, A.: Bridging the skills gap of workers in Industry 4.0 by Human performance augmentation tools - Challenges and roadmap. In: Proceedings of the 10th International Conference on Pervasive Technologies Related to Assistive Environments (PETRA2017), pp. 428-432 (2017). doi: 10.1145/3056540.3076192
10. BDI (the Federation of German Industries), Berger R: The digital transformation of industry. How important is it? Who are the winners? What must be done now? (2013) Available at: https://www.rolandberger.com/publications/publication_pdf/roland_berger_digital_transformation_of_industry_20150315.pdf.
11. Longo, F., Nicoletti, L., Padovano, A.: Smart operators in industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context. Computers & Industrial Engineering 113, 144-159 (2017). doi: 10.1016/j.cie.2017.09.016
12. Kerpen, D., Löhrer, M., Saggiomo, M., Kemper, M., Lemm, J., Gloy, Y.-S.: Effects of cyber-physical production systems on human factors in a weaving mill: Implementation of digital working environments based on augmented reality. In: Proceedings of the 2016 IEEE International Conference on Industrial Technology (ICIT), pp. 2094-2098 (2016). doi: 10.1109/ICIT.2016.7475092.
13. Krugh, M., Mears, L.: A complementary Cyber-Human Systems framework for Industry 4.0 Cyber-Physical Systems. Manufacturing Letters (2018 – in press). doi: 10.1016/j.mfglet.2018.01.003.

14. Lee, J., Bagheri, B., Kao, H-A.: A cyber-physical systems architecture for Industry 4.0-based manufacturing systems. Manufacturing Letters 3, 18-23 (2015) doi: 10.1016/j.mfglet.2014.12.001.
15. Arndt, A., Auth, C., Anderl, R.: Guideline for the implementation of human-oriented assistance systems in smart factories. In: Trzcielinski, S. (ed.): Advances in ergonomics of manufacturing: Managing the enterprise of the future. Advances in Intelligent Systems and Computing 606 (2018). doi: 10.1007/978-3-319-60474-9_8.
16. Fornalczyk, A., Stompor-Swiderska, J., Slazyk-Sobol, M.: Age management within organizations-employees' perceptions of the phenomenon - research report. Journal of Intercultural Management 7(3), 39–51 (2015). doi: 10.1515/joim-2015-0020.
17. Schinner, M., Calero Valdez, A., Noll, E., Schaar, A.K., Letmathe, P., Ziefle, M.: 'Industrie 4.0' and an aging workforce - A discussion from a psychological and a managerial perspective. In: Zhou, J., Salvendy, G. (eds.): Human Aspects of IT for the aged population. Applications, services and contexts. ITAP 2017, pp. 537-556. doi: 10.1007/978-3-319-58536-9_43.
18. Peruzzini, M., Pellicciari, M.: A framework to design a human-centred adaptive manufacturing system for aging workers. Advanced Engineering Informatics 33, 330-349 (2017). doi: 10.1016/j.aei.2017.02.003.
19. Gorecky, D., Khamis, M., Mura, K.: Introduction and establishment of virtual training in the factory of the future. International Journal of Computer Integrated Manufacturing 30(1), 182-190 (2017). doi: 10.1080/0951192X.2015.1067918.
20. Pfeiffer, S.: Robots, Industry 4.0 and humans, or why assembly work is more than routine work. Societies 6(2), paper no.16. doi:10.3390/soc6020016.
21. Romero, D., Stahre, J., Wuest, T., Noran, O., Bernus, P., Fast-Berglund, A., Gorecky, D.: Towards an Operator 4.0 typology: A human-centric perspective on the fourth industrial revolution technologies. In: Proceedings of the International Conference on Computers & Industrial Engineering (CIE46) (2016).
22. Shamim, S., Cang, S., Yu1, H., Li, Y.: Management approaches for Industry 4.0 - A human resource management perspective. In: Proceedings of the 2016 IEEE Congress on Evolutionary Computation (CEC), pp. 5309-5316. doi: 10.1109/CEC.2016.7748365.
23. Pinzone, M., Fantini, P., Perini, S., Garavaglia, S., Taisch, M., Miragliotta, G.: Jobs and skills in Industry 4.0: An exploratory research. In: Lödding H., Riedel R., Thoben KD., von Cieminski G., Kiritsis D. (eds).: Advances in production management systems. The path to intelligent, collaborative and sustainable manufacturing. APMS 2017. IFIP Advances in Information and Communication Technology, vol. 513. Springer, Cham (2017).
24. Curià Piñol, T., Artigas Porta, S., Rodríguez Arévalo, M.C., Minguella-Canela, J.: Study of the training needs of industrial companies in the Barcelona area and proposal of training courses and methodologies to enhance further competitiveness. Procedia Manufacturing 13, 1426-1431 (2017). doi: 10.1016/j.promfg.2017.09.159.
25. Fantini, P., Tavola, G., Taisch, M., Barbosa, J., Leitao, P., Liu, Y., Sayed, M.S., Lohse, N.: Exploring the integration of the human as a flexibility factor in CPS enabled manufacturing environments: methodology and results. In: Proceedings of the 42nd Annual Conference of the IEEE Industrial Electronics Society (IECON 2016), pp. 5711-5716. doi: 10.1109/IECON.2016.7793579.