Human Roles, Competencies and Skills in Industry 4.0: Systematic Literature Review

Dajana Narandžić, Ivana Spasojević, Teodora Lolić, Darko Stefanović, Sonja Ristić
University of Novi Sad
Faculty of Technical Sciences
Department of Industrial Engineering and Engineering Management
Trg Dositeja Obradovića 6, 21000 Novi Sad
{narandzic, ivana.spasojevic, teodora.lolic, darko.stefanovic, sdristic}@uns.ac.rs

Abstract. *The complexity of production processes in Industry 4.0 is significantly increased, that arise the need to enable efficient process simulation, execution, monitoring, real-time decision making and control. One of the solutions is to use formal method to specify production processes and create process models that are suitable for automatic generation of instructions that are executed on smart resources. Within factories in Industry 4.0 humans communicate and cooperate with each other, and with other smart resources of a production process. In that way, their role has dramatically changed. Specifying the human roles, capabilities, and competencies within production process modelling is a great challenge. To deal with this problem it is necessary to first identify and determine the human characteristics that are crucial in Industry 4.0. As a starting point in this research, a review of the literature describing the role of humans in Industry 4.0 is performed and the results of this research are presented in this paper.*

Keywords. human, role, skill, competencies, Industry 4.0, production process modelling, domain-specific modelling languages

1 Introduction

Industrialisation has undergone remarkable transformations since its beginnings in the 18th century. Increasing mechanization, triggered with the appearance of steam machine, interrupted the dominance of human labor and started the first industrial revolution (IR). The use of electrical energy and the introduction of the assembly line paved the way for mass production of goods and characterized the second IR. The 1970s have brought the new paradigm shift in industry – the digitalization began to infiltrate the manufacturing process and to further automate it using electronics and information systems (IS). However, machines still had to be operated by humans and were not fully independent and self-adjustable to variations in the manufacturing processes. The beginning of the 21th century has brought the hope that the vision of fully automated and computer-centered manufacturing is achievable. The matured Internet infrastructure, focus on interconnected smart, independent ubiquitous context-aware computers embedded into every aspect of the manufacturing process triggered the fourth industrial revolution so called Industry 4.0. The one of the main challenges of Industry 4.0 is that the boundaries between physical, digital and biological world are blurred. The manufacturers need to reconsider their business models and resources, including human resources, to help the organization to adapt to inevitable changes. According to (Hermann et al., 2015): "*Within the modular structured Smart Factories of Industry 4.0, Cyber-Physical Systems* (CPSs) *monitor physical processes, create a virtual copy of the physical world, and make decentralized decisions. Over the Internet of Things CPSs communicate and cooperate with each other and humans in real time*." Therefore, communication and cooperation between CPSs and CPSs and humans is crucial in Smart Factories. Consequently, the role of humans in Industry 4.0 is very specific, and more and more attention has to be paid to humans' intellectual abilities as well as their skills, but also to their health, safety and environment.

Modelling of the production processes in Industry 4.0 is an important industrial informatics research topic. Production process models suitable for automatic code generation and execution in a simulation or at a shop floor could enable high-level of production flexibility. Different conceptual modeling languages are used to model production processes like Unified Modelling Language (UML) activity diagram, Business Process Modelling and Notation (BPMN), and Petri nets. In (Vještica et al., 2020) a domain specific modelling language (DSML) MultiProLan is proposed for modelling production processes. Nevertheless, all of these languages do not have adequate concepts to model humans and their role in the production processes. In order to investigate possibilities to create new or to extend an existing DSML with the concepts to model humans within Industry 4.0 we decide to find out and to determine the human characteristics that are necessary in Industry 4.0. As a starting point in this research, a review of the literature describing the role of humans in Industry 4.0 is performed and the results of this research are presented in this paper.

The paper is organised as follows. In Section 2, background and related work are described. Systematic literature review (SLR) methodology alongside with the planning and conducting the review phase employed in the current study are presented in Section 3. Discussion of SLR results is given in Section 4. Conclusions and the future work are presented in Section 5.

2 Background and Related Work

Fourth industrial revolution raises new challenges for future manufacturing which are driven by four disruptions (Pacaux-Lemoine et al., 2021): data volumes, computational power, and connectivity; the emergence of analytics and business–intelligence capabilities; new forms of human–machine interaction; and improvements in transferring digital instructions to the physical world.

The transformation of production due to both technological and paradigmatic drivers leads to fundamental changes of organisations and processes and finally also of human work. Changes are taking place in the global industrial system due to the use of smart technologies that enable new and more efficient processes, as well as new products and services (Strandhagen et al., 2017). Industry 4.0 will necessitate certain new skills and competencies from employees (Łupicka & Grzybowska, 2018).

The primary challenge now is moving beyond new technologies toward complete automation, and the competitive struggle between humans and machines for knowledge-intensive jobs in the field of computing, self-learning, algorithms and data analysis. The question that arises concerns is the best possible cooperation between humans and machines (Guerin et al., 2019).

Social and technological aspects can no longer be viewed separately (Geels, 2004). Collaborative types of learning and learning environments are critical to organizations for operationalizing knowledge and competencies, such as the use of virtual learning environments (Müller et al., 2018), augmented reality and collaborative environments between cobots and humans. In (Dregger et al., 2016) is proposed a model of Human Resource Management within Industry 4.0 (HRM 4.0) that puts the human in the centre of interest in Industry 4.0, in addition to technology and organization (Fig. 1). If a human is at the centre of interest in Industry 4.0, it is clear that investing in human capital as well as its constant measurement is necessary in order to have an insight into the value of human capital and their potential. The importance of human capital and its measurement is described in (Korobaničová & Kováčová, 2018).

The process of digital transformation that companies are called to deal with, in order to be competitive and protagonists in the markets is not just a technological issue, but also a question of competencies and skills.

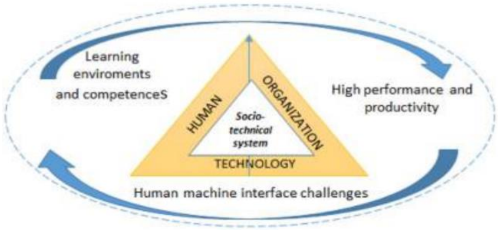

Figure 1. HRM 4.0 background (Dregger et al., 2016)

Leinweber identified and grouped required competencies to work in a 'smart company' which are technical competencies, methodological competencies, social competencies, and personal competencies (Leinweber, 2013).

The aim of this study is to systematically review literature in the context of the role of humans in Industry 4.0 and to identify the key competencies that every employee must possess in order to meet the requirements imposed by Industry 4.0.

3 Methodology

In order to conduct this literature review, we used guidelines by Kitchenham, B. (Kitchenham, 2004) that summarize the stages in a systematic review into three main phases: planning the review, conducting the review, and reporting the review. In Section 3.1 we discuss the planning phase, and in Section 3.2 we give the main points of the conducting the review, focusing on the analyzing and summarization of extracted information from selected primary studies.

3.1 Planning the Review

The initial stage of the review planning phase is the elaboration of the need for the systematic literature review in a particular subject (Kitchenham, 2004). To present the need and motivation to perform SLR, the authors reviewed the existing literature on the relevant topic. Accordingly, no explicit, systematic literature reviews are presenting the role of the human in Industry 4.0.

The research questions addressed by this study are:

RQ1: What is the role (nomenclature) of an employee in Industry 4.0?

RQ1.1: What terminology is used to represent the human factor in Industry 4.0?

RQ1.2: Which terms are most commonly used?

RQ2: What characteristics/competencies of employee in Industry 4.0 are addressed in reviewed literature?

RQ3: How are employees' characteristics/ competencies divided/grouped?

RQ4: What problems were detected when defining the employee characteristics/competencies in Industry 4.0?

For this literature review, the following databases were searched: Google Scholar, Scopus, and Web of Science.

Google Scholar allows users to search across a wide range of academic literature. It draws on information from journal publishers, university repositories, and other websites that it has identified as scholarly. Scopus is the largest abstract and citation database of peer-reviewed literature – scientific journals, books and conference proceedings. Web of Science is a collection of databases that index the world's leading scholarly literature in the sciences, social sciences, arts, and humanities, as published in journals, conference proceedings, symposia, seminars, colloquia, workshops, and conventions across the globe.

Search terms defined for search in these databases are presented below:

(role OR part OR function) AND
(human OR worker OR employee OR “operator 4.0”) AND
(“industry 4.0” OR “fourth industrial revolution” OR “smart factory”) AND
PUBYEAR > 2012 AND Language = ”English”.

The search strategy guides the identification of relevant publications to answer the research questions. This includes conceiving an appropriate search query and identifying relevant libraries to apply this clause to. Although we cannot exclude omitting a small number of possibly relevant publications that do not provide such discussions, searching this way yields better results than just searching titles and abstracts. Moreover, we included papers published until 2013. For Google Scholar we used its advanced search mode to split the search query by looking for articles that must contain the word human, with the exact phrase “operator 4.0” or “industry 4.0” or “fourth industrial revolution” or “smart factory”, with at least one of the words role, part, function, worker, and employee. We manually merged the resulting lists and removed the Scholar-internal duplicates obtained by our process manually. Of the selected databases, Google Scholar is the database that provides the least opportunities for advanced literature search, so searching through it was the most demanding. The number of papers selected according to the given criteria according to different sources is given in Table 1.

Since the keyword search returned a large number of papers, even 8.883, many of them were not even peer-reviewed. In order to reduce the number of papers and to extract only those that are most relevant to this research, we had to define the criteria by which it is necessary to do so. To reduce the corpus and enable reproduction of the study, we established the following inclusion criteria and exclusion criteria.

Table 1. Search results returned from the different digital libraries

Digital Library	URL	Papers
Google Scholar	https://scholar.google.com	2.104
Scopus	https://www.scopus.com/	819
Web of Science	https://www.webofknowledge.com	5.960
Total (incl. duplicates)		8.883

The inclusion criteria defined for this review are:

1. Peer-reviewed studies published in journals, conferences, and workshops.
2. Studies those are accessible electronically.
3. Based on the title, abstract, and keywords, the paper should present studies concerning the role of humans in industry 4.0 with the aim of determining the basic tasks of employees in companies, as well as identifying changes in human roles brought about by Industry 4.0 in relation to other industrial revolutions.

Exclusion criteria defined for the review are:

1. Duplicate papers found in different databases should be removed.
2. Studies those are not systematically peer-reviewed, such as books, slides, web sites.
3. Teasers and short papers of less than two pages, such as calls for papers, editorials, or curricula.
4. Studies where Industry 4.0 is mentioned as a future research, related work, background or in general context, where mentioning Industry 4.0 as a possible use case only.
5. If one author has more than one paper regarding the same approach, only one paper should be included in the review.

For this literature review, the data extraction strategy was developed. For each study, the following features are extracted in order to answer the research questions:

1. Publication year;
2. Source type;
3. Journal/conference of a publication;
4. The country of the paper's authors. If the paper has authors from different countries then the one with the most authors is recorded;
5. Commonly used terms for workers in Industry 4.0;
6. Employee role groups; and
7. Characteristics/competencies of employees that are the most used in the paper.

3.2 Conducting the Review

Due to the large number of papers selected based on the defined search string, after applying defined inclusion and exclusion criteria, papers were critically estimated based on their relevancy and type of information they contained. First, the search string is reduced only to the range of titles, abstracts and keywords. This condition significantly reduced the number of papers and eliminated those papers that only mentioned words in the text that are in the search criteria. After the second phase, 2.850 papers were left. The next step was to remove the duplicate records from different databases, where 389 duplicates were found, and they were excluded from further research. Based on other exclusion criteria, 132 papers were excluded from the selection. In the end, 63 primary studies are included for the final analysis in the review. The search flow is presented in Table 2.

Table 2. The search flow

	Scopus	WoS	Google S.
Results found	2104	819	5960
Review based on Title, Abstract, Keywords	903	417	1530
Duplicate content	613	417	1431
Initial selection	85	60	112
Final selection	26	21	16

The selected primary studies are summarised and presented in the following text using the data extraction strategy. The analysis of selected papers is complemented with tables and graphs which allow visual representation of primary studies based on the data extraction criterion.

Nearly all of the reviewed primary studies were carried out in the last nine years, while only one primary study per year was conducted from 2013 to 2015. As is displayed in Fig. 3, the majority of the papers were published in the last four years (84%). The peak in the number of conducted studies per year was, in 2020, which can be seen in the line diagram presented in Fig. 3.

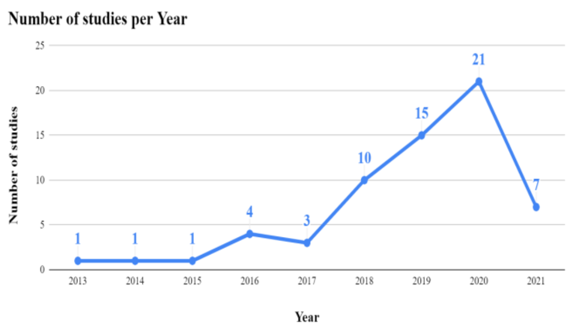

Figure 3. Visual representation of distribution of studies per year

Source types of the studies are presented in Fig. 4, indicating that the number of papers published at conferences is very close to the number of papers published in journals.

Out of the total number of studies, 33 of them were published in journals. It is not possible to single out one journal that is significantly stood out in the list by the number of published studies. The journals that are most often found in the list of selected studies are *International Journal of Advanced Manufacturing Technology* with five papers and *International Journal of Industrial Ergonomics* with four studies.

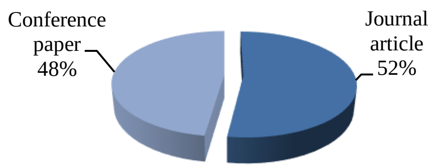

Figure 4. Source types of primary studies

Out of a total of 63 analyzed studies, 30 were published at conferences. The conferences that most often appear in the list of selected studies are *Procedia Computer Science*, with six of them, and *Advances in Intelligent Systems and Computing* with three studies.

The countries of origin of the reviewed studies were also analyzed. We consider that the country of origin of a study is the one from which the largest number of authors come from. If it happens that all the authors are from different countries, the country of origin is the country from which the first author is. It is important to emphasize that there were no studies in which the country of origin of the author was not known. The largest number of studies on this topic is from Italy, as many as thirteen studies. Right behind Italy is Germany with eleven studies. Then follow the USA, United Kingdom, Austria, Denmark, with three studies per country. The distribution of papers per country is shown in Fig 5.

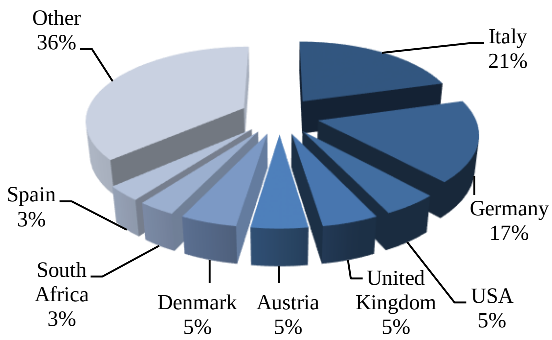

Figure 5. Percentage of studies per origin country

One of the basic tasks in this research was to show which the most commonly used terms are for a human as a participant in Industry 4.0. In Table 3 are shown all the terms used in the selected studies. Some papers use several terms and they are recorded for all these terms. The term *Human* is used in all studies, except three. The next very commonly used terms are *Employe* which is mentioned in as many as 35 studies and *Worker* which appears in 34 studies. They are followed with *Operator* that is used in various forms. It is also used in its common forms and these are *Operator 4.0* which appears in 15 studies, *Smart Operator* in three studies, *Augmented Operator* in one study. The pure term *Operator* without any additional terms appears in 12 studies. There are many studies where the term *Operator* is mentioned but not in the context of man as the only participant in Industry 4.0 but as a synergy between man and machine. Studies classified by used terms are presented in Table 3. Due to space restrictions we use the numbers (No) to reference the studies. In Table 5 in Appendix we associate numbers with appropriate study reference.

Table 3. Studies classified by used terms

Terms	Studies	Number of studies	%
Agent	1	1	1.6
Human	1, 2, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63	60	95.2
Employee	3, 4, 6, 8, 9, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 25, 26, 29, 30, 33, 34, 35, 38, 44, 45, 46, 47, 48, 50, 54, 56, 57, 58, 60, 62	35	55.6
Worker	2,5, 11, 13, 14, 15, 16, 17, 20, 23, 25, 27, 30, 31, 32, 36, 37, 38, 40, 42, 43, 44, 45, 46, 47, 48, 50, 54, 55, 56, 58, 59, 60, 62	34	53.9
Operator 4.0	7, 12, 15, 24, 25, 26, 40, 41, 44, 45, 49, 52, 58, 60, 61, 62	15	23.8
People	2,3, 9, 13, 34, 38, 47, 52, 54, 55	10	15.9
Operator	5, 9, 27, 30, 36, 37, 38, 39, 46, 47, 48, 54	12	19.1
User	5	1	1.6
Smart operator	7, 10, 40	3	4.8
Augmented operator	13	1	1.6
Engineer	27	1	1.6
Staff	33	1	1.6

The competencies mentioned in the selected studies are grouped according to (Benešová, & Tupa, 2017) and analyzed according to these groups. The result of this analysis is shown in Table 4. The studies are most often based on *Technical skills* that comprise all job-related knowledge and skills. As many as 41 studies out of a total of 63 studies deal with *Technical skills*.

It is important to say that if a study emphasizes several groups of competencies, such a study is included in both groups. The groups of competencies *Social characteristic* and *Personal* are mentioned in 15 analyzed studies. They are followed by *Cognitive skills* which are represented in 14 papers. *Soft skills* are mentioned in 13 papers. *Psychosocial skills* are used in 6 studies, *Methodological skills* in 4 studies, *Ethical* in 3 studies, and only 2 studies dealt with human health or a group called *Health skills*.

4 Discussion

The results and the findings from the conducted SLR are discussed in this section.

If we take into account Fig. 3, we can notice that there is a tendency of growth in the number of papers on this topic from year to year. The largest number of papers is in 2020, while in 2021. there are fewer papers, but it should be taken into account that the papers that have already been published so far have been analyzed. Based on that, we can conclude that the topic of human in Industry 4.0 is a very current topic and that this role is still being explored in scientific studies. In Fig. 4 is shown that interest in this topic is equal at conferences and in journals and that there is no significant difference between them. As for the countries from which studies in this field come, and on this topic, we see that economically and industrially developed European countries are more interested in this topic. These are countries in which the industry has advanced a lot and which pay great attention to human as a participant in the industry perhaps that is the reason why they have the largest number of works in this area.

Table 3 provides an answer to the first research question RQ1. What we wanted to show through this paper is whether there are any special terms that are introduced for human as a participant in Industry 4.0. The answer to this question would be that the most commonly used terms are precisely those that have been used so far, such as *Human*, *People*, *Employee*, *Worker*, *Engineer*. The term still most commonly used is the term *Human*. In only three analyzed papers, this term was not used. An industry-specific term 4.0 is the term *Operator*, as are all variations of this term such as *Operator 4.0, Smart Operator* and *Augmented operator*. These terms are also very often used terms for the interaction between humans and machines because today's industry cannot be imagined without that interaction. The selected studies also place great emphasis on this interaction.

The key human competencies in Industry 4.0 are shown in Table 4. All competencies are shown individually and grouped according to (Benešová, & Tupa, 2017). Based on this analysis, we can answer the questions RQ2 and RQ3. The key features are still the *Technical skills* and *Knowledge skills*. But in addition to technical characteristics, more and more attention is paid to personal, cognitive and social skills. What is crucial in this analysis is that not enough attention is paid to humans' physical capabilities, i.e. their health in industry and physical and mental capabilities, which should be significantly taken into account in the future. Only two studies (Romero et al., 2016) and (Jongprasithporn et al., 2020) mention these characteristics without their detailed analysis. As the answer to the RQ4 research question, it can be concluded that human in reviewed literature is less seen as a human being, but more seen as an addition or extension of technology. A disadvantage is the fact that physical characteristics such as height, weight as well as many others are also not taken into account when analyzing the competencies/characteristics of employees in Industry 4.0.

Table 4. Distribution of studies by represented groups of characteristics

Group	Competencies	Studies	Number of studies	%
Technical skills	Technical skills	2, 3, 4, 6, 7, 11, 12, 13, 14, 15, 16, 23, 24, 29, 32, 33, 34, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 48, 49, 50, 52, 55, 56, 58, 60, 61	36	57.2
	Media skills	15, 24, 29, 36, 37, 44, 55, 61, 62	9	14.3
	Coding skills	15, 44, 45, 54, 55, 56, 62	7	11.2
	IT skills	15, 21, 22, 23, 24, 27, 36, 37, 42, 44, 45, 50, 52, 56, 57, 61, 62, 63	18	28.6
	Data analytic	44, 50, 54	3	4.8
Cognitive skills	State-of-the-art knowledge	2, 6, 7, 13, 14, 15, 16, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 38, 40, 42, 43, 44, 45, 48, 54, 58, 62, 63	27	42.9
	Knowledge of technical documentation	9, 44	2	3.2
	Process understanding	1, 15, 17, 37, 44, 55, 56, 62	8	12.7
Methodological skills	Problem solving	1, 3, 6, 14, 13, 17, 21, 22, 31, 36, 41, 42, 43, 44, 45, 46, 47, 51, 53, 54, 55, 56, 62	23	36.6
	Conflict solving	35, 40, 41, 56	4	6.4
	Decision making	1, 4, 5, 7, 13, 16, 22, 24, 28, 29, 32, 34, 35, 36, 40, 41, 42, 43, 44, 46, 48, 49, 51, 52, 55, 57, 59, 60	28	44.5
	Controlling	5, 7, 22, 54, 62	5	8
	Planning and organizing	3, 14, 5, 9, 4, 13, 18, 22, 24, 25, 35, 42, 44, 46, 47, 51, 52, 54, 57, 58, 60, 63	22	35
	Monitoring	16, 28, 41	3	4.8
	Analytical skills	27, 49, 52, 53, 56	5	8
	Research skills	45, 50, 56	3	4.8
Social skills	Language skills	9, 13, 44, 55, 56	5	8
	Communication skills	2, 3, 14, 8, 9, 10, 12, 15, 19, 21, 22, 26, 27, 29, 31, 33, 34, 35, 36, 40, 41, 42, 43, 44, 45, 47, 49, 51, 52, 54, 56, 57, 58, 59, 60, 61, 63	37	58.8
	Networking skill	8, 13, 37, 40, 43, 52, 53	7	11.2
	Ability to work in a team	3, 6, 14, 8, 13, 16, 26, 30, 35, 37, 40, 43, 44, 45, 49, 54, 56, 58, 62	20	31.8
	Collaboration	15, 28, 37, 40, 41, 45, 49, 52, 58, 60	10	15.9
	Social intelligence	13, 15, 28, 37, 50, 53	6	9.5
Psychosocial skills	Respect	8	1	1.6
	Strength of self	8	1	1.6
	Empathy	8, 50	2	3.2
	Independency	8, 45, 48	3	4.8
	Work satisfaction	20, 46, 50	3	4.8
	Personal achievement	20, 24, 28, 62	4	6.4
Personal skills	Cooperation	3, 7, 14, 5, 9, 19, 27, 32, 37, 39, 42, 44, 52, 53, 57, 58, 61, 63	18	28.6
	Ability to transfer knowledge	4, 13, 28, 29, 33, 35, 42, 44, 56, 61, 62, 63	12	19.1
	Learning ability	20, 34, 40, 44, 45, 50, 61	7	11.2
	Motivation to learn	3, 6, 9, 14, 20, 28, 35, 62	8	12.7
	Leadership skills	1, 4, 6, 8, 13, 15, 17, 18, 19, 26, 34, 35, 43, 44, 45, 50, 53, 54, 55, 56, 60	21	33.4
	Self-management and self-development	3, 4, 8, 9, 11, 14, 15, 22, 31, 40, 44, 48, 51, 54, 57, 58, 63	17	27
	Acceptance of change	7, 10, 11, 13, 22, 24, 31, 37, 40, 44, 50, 59, 61	13	20.7
Ethical skills	Intercultural skills	34, 35, 49, 55, 62	5	8
	Responsibility	4, 9, 15, 23, 40, 44	6	9.6
	Adaptability	50, 61	2	3.2
Health skills		7, 42	2	3.2
Soft skills	Critical thinking	44, 50, 53	3	4.8
	Creativity	3, 14, 8, 9, 13, 22, 26, 34, 44, 45, 49, 51, 55, 56, 60, 62	16	25.4
	Innovation	6, 13, 32, 40, 44, 49, 53	7	11.2

5 Conclusion

The role of human in Industry 4.0 is a very widespread topic around the world and very interesting to many scientists. It shows the growing trend of studies on this topic as well as an equal representation at conferences and journals and the interest of researchers around the world on research on this topic. Based on the presented SLR it can be concluded that there is a lack of the researches about the physical, mental and health features, capabilities and risks in the context of human role and specification within Industry 4.0. The presented research was conducted to obtain information about the role of human in Industry 4.0 and to enable domain analysis in order to create formal modelling language aimed to model human as an actor within production process. The obtained results show that not all characteristics are equally represented in studies, and that some characteristics are given considerable attention while others are neglected.

Also, this research has shown that there is no significant progress and difference in relation to previous reviews of the literature, where the emphasis is on technical and cognitive characteristics, but still much less on cognitive (Benešová, & Tupa, 2017). Progress and difference are seen only in the analysis of cognitive skills on which a stronger emphasis is placed but other characteristics are neglected.

Next step of our research would be the SLR on general purpose and domain-specific modelling languages aimed at modelling human resources within the production process modelling. In conjunction with the results presented in this paper it would be the start point to make the domain analysis in order to identify key concepts of production process modelling language aimed at modelling human resource for Industry 4.0.

References

Aichouni, A.B.E., Kolsi, L., & Aichouni, M. (2020). The Engineering Students Innovation Club Project for Human Capital Development in the areas of Industry 4.0–From the Design to Implementation. In 2020 Industrial & Systems Engineering Conference (ISEC) (pp. 1–4).

Ali, M.S., & AlSadoon, G. (2019). The Role of E-Learning to Improve Staff Performance in Bahrain Airport Services. In 2019 International Conference on Fourth Industrial Revolution (ICFIR) (pp. 1–6).

Angelopoulou, A., Mykoniatis, K., & Boyapati, N.R. (2020). Industry 4.0: The use of simulation for human reliability assessment. Procedia Manufacturing, 42, 296–301.

Ansari, F., Erol, S., & Sihn, W. (2018). Rethinking human-machine learning in industry 4.0: How does the paradigm shift treat the role of human learning?. Procedia manufacturing, 23, 117–122.

AnTosz, K. (2018). Maintenance–identification and analysis of the competency gap. Eksploatacja i Niezawodność – Maintenance and Reliability, Vol. 20 No. 3, pp. 484-494.

Ayinde, L., & Kirkwood, H. (2020). Rethinking the roles and skills of information professionals in the 4th Industrial Revolution. Business Information Review, 37(4), 142–153.

Benešová, A., & Tupa, J. (2017). Requirements for education and qualification of people in Industry 4.0. Procedia Manufacturing, vol. 11, pp. 2195–2202.

Bongomin, O., Gilibrays Ocen, G., Oyondi Nganyi, E., Musinguzi, A., & Omara, T. (2020). Exponential disruptive technologies and the required skills of industry 4.0. Journal of Engineering, 2020, pp. 1–17, 2020.

Carfì, A., Villalobos, J., Coronado, E., Bruno, B., & Mastrogiovanni, F. (2020). Can human-inspired learning behaviour facilitate human–robot interaction?. International Journal of Social Robotics, 12(1), 173–186.

Chacón, A., Angulo, C., & Ponsa, P. (2020). Developing Cognitive Advisor Agents for Operators in Industry 4.0. New Trends in the Use of Artificial Intelligence for the Industry 4.0, IntechOpen 2020.

Cimini, C., Lagorio, A., Pirola, F., & Pinto, R. (2019). Exploring human factors in Logistics 4.0: empirical evidence from a case study. IFAC-PapersOnLine, 52(13), pp.2183-2188.

Cimini, C., Pirola, F., Pinto, R., & Cavalieri, S. (2020). A human-in-the-loop manufacturing control architecture for the next generation of production systems. Journal of manufacturing systems, 54, 258–271.

Cotet, G.B., Balgiu, B.A., & Zaleschi, V.C. (2017). Assessment procedure for the soft skills requested by Industry 4.0. In MATEC web of conferences (Vol. 121, p. 07005). EDP Sciences.

D'antonio, G., & Chiabert, P. (2018). How to Manage People Underutilization in an Industry 4.0 Environment?. In IFIP International Conference on Product Lifecycle Management (pp. 455–464). Springer, Cham.

Di Pasquale, V., Miranda, S., & Neumann, W.P. (2020). Ageing and human-system errors in manufacturing: a scoping review. International Journal of Production Research, 58(15), 4716–4740.

Dregger, J., Niehaus, J., Ittermann, P., Hirsch-Kreinsen, H., & ten Hompel, M. (2016). The digitization of manufacturing and its societal challenges: a framework for the future of industrial labor. In 2016 IEEE international symposium on ethics in engineering, science and technology (ETHICS) (pp. 1–3).

Fantini, P., Tavola, G., Taisch, M., Barbosa, J., Leitão, P., Liu, Y., Sayed, M.S., & Lohse, N. (2016). Exploring the integration of the human as a flexibility factor in CPS enabled manufacturing environments: Methodology and results. In IECON 2016-42nd Annual Conference of the IEEE Industrial Electronics Society (pp. 5711–5716).

Farsi, M.A., & Zio, E. (2019). Industry 4.0: some challenges and opportunities for reliability engineering. International Journal of Reliability, Risk and Safety: Theory and Application, 2(1), 23–34.

Fayomi, O.S.I., Akande, I.G., Esse, U.C., & Oladipupo, S. (2020). Examining the roles and challenges of human capital influence on 4th industrial revolution. In AIP Conference Proceedings (Vol. 2307, No. 1, p. 020039). AIP Publishing LLC.

Flores, E., Xu, X., & Lu, Y. (2020). Human Capital 4.0: a workforce competence typology for Industry 4.0. Journal of Manufacturing Technology Management, vol. 31, no. 4, pp. 687–703.

Gallo, T., & Santolamazza, A. (2021). Industry 4.0 and human factor: How is technology changing the role of the maintenance operator?. Procedia Computer Science, 180, 388–393.

Gazzaneo, L., Padovano, A., & Umbrello, S. (2020). Designing smart operator 4.0 for human values: a value sensitive design approach. Procedia Manufacturing, 42, 219–226.

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. Research policy, 33(6-7), 897–920.

Gorecky, D., Schmitt, M., Loskyll, M., & Zühlke, D. (2014). Human-machine-interaction in the industry 4.0 era. In 2014 12th IEEE international conference on industrial informatics (INDIN) (pp. 289–294).

Guerin, C., Rauffet, P., Chauvin, C., & Martin, E. (2019). Toward production operator 4.0: modelling human-machine cooperation in industry 4.0 with cognitive work analysis. IFAC-PapersOnLine, 52(19), 73–78.

Hahm, S., 2018. Attitudes and Performance of Workers Preparing for the Fourth Industrial Revolution. TIIS, 12(8), 4038–4056.

Hermann M., Pentek T., & Otto B. (2015). Design principles for Industrie 4.0 scenarios: a literature review. Working Paper No. 01–2015, Technische Universität Dortmund, Dortmund.

Jędrzejczyk, W. (2019). Human-Organization Relation in the Perspective of Industry 4.0. In International Scientific-Technical Conference MANUFACTURING (pp. 14–24). Springer, Cham.

Jerman, A., Pejić Bach, M., & Aleksić, A. (2020). Transformation towards smart factory system: Examining new job profiles and competencies. Systems Research and Behavioral Science, 37(2), 388–402.

Jongprasithporn, M., Yodpijit, N., Phaisanthanaphark, C., Buranasing, Y., & Sittiwanchai, T. (2020). Effects of Industry 4.0 on Human Factors/Ergonomics Design in 21 st Century. In International Conference on Applied Human Factors and Ergonomics (pp. 437–443). Springer, Cham.

Kadir, B.A., & Broberg, O. (2020). Human well-being and system performance in the transition to industry 4.0. International Journal of Industrial Ergonomics, 76, p.102936.

Kadir, B.A., & Broberg, O. (2021). Human-centered design of work systems in the transition to industry 4.0. Applied Ergonomics, 92, p.103334.

Kadir, B.A., Broberg, O., & da Conceicao, C.S. (2019). Current research and future perspectives on human factors and ergonomics in Industry 4.0. Computers & Industrial Engineering, 137

Kannengiesser, U., & Müller, H. (2013). Towards agent-based smart factories: A subject-oriented modeling approach. In 2013 IEEE/WIC/ACM International Joint Conferences on Web Intelligence (WI) and Intelligent Agent Technologies (IAT) (Vol. 3, pp. 83–86).

Khalifa, R.B., Tliba, K., Diallo, M.T., Penas, O., Yahia, N.B., & Choley, J.Y. (2019). Modeling and management of human resources in the reconfiguration of production system in industry 4.0 by neural networks. In 2019 International Conference on Signal, Control and Communication (SCC) (pp. 246–249).

Kiesel, M., & Wolpers, M. (2015). Educational challenges for employees in project-based Industry 4.0 scenarios. In Proceedings of the 15th International Conference on Knowledge Technologies and Data-driven Business (pp. 1–4).

Kitchenham, B. (2004). Procedures for performing systematic reviews. Keele, UK, Keele University, 33(2004), 1–26.

Klumpp, M., Hesenius, M., Meyer, O., Ruiner, C., & Gruhn, V. (2019). Production logistics and human-computer interaction—state-of-the-art, challenges and requirements for the future. The International Journal of Advanced Manufacturing Technology, 105(9), 3691–3709.

Korobaničová, I., & Kováčová, N. (2018). Human capital investment: Practices and measurement in Slovak enterprises. Int. J. Ind. Eng. Manag.(IJIEM), 9(3), 139–146.

Krupitzer, C., Müller, S., Lesch, V., Züfle, M., Edinger, J., Lemken, A., Schäfer, D., Kounev, S., Becker, C. (2020). A Survey on Human Machine Interaction in Industry 4.0. arXiv preprint arXiv:2002.01025.

Leinweber, S. (2013). Stage 3: Competence Management, Management for Professionals, Springer Fachmedien; 2013. p. 109–133.

Llinas Sala, D., & Abad Puente, J. (2019). The role of high-performance people management practices in Industry 4.0: The case of medium-sized Spanish firms. Intangible Capital, 15(3), 190–207.

Longo, F., Nicoletti, L., & Padovano, A. (2017). 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.

Longo, F., Nicoletti, L., & Padovano, A. (2019). Modeling workers' behavior: A human factors taxonomy and a fuzzy analysis in the case of industrial accidents. International journal of industrial ergonomics, 69, 29–47.

Longo, F., Padovano, A., Gazzaneo, L., Frangella, J., & Diaz, R. (2021). Human factors, ergonomics and Industry 4.0 in the Oil&Gas industry: a bibliometric analysis. Procedia Computer Science, 180, 1049–1058.

Łupicka, A., & Grzybowska, K. (2018). Key Managerial Competencies for Industry 4.0 - Practitioners', Researchers' and Students' Opinions. Logistic and Transport. 3(39), 39-46

Mohammadian, H.D., & Rezaie, F. (2020). The role of IoE-Education in the 5 th wave theory readiness & its effect on SME 4.0 HR competencies. In 2020 IEEE Global Engineering Education Conference (EDUCON) (pp. 1604–1613).

Mucha, H., Roecker, C., Ludwig, T., Ogonowski, C., Stein, M., Robert, S., Galla, L., Hill, M., & Wulf, V. (2018). The Industrial Internet of Things: New Perspectives on HCI and CSCW within Industry Settings. In Companion of the 2018 ACM Conference on Computer Supported Cooperative Work and Social Computing (pp. 393–400).

Müller, S. L., Shehadeh, M. A., Schröder, S., Richert, A., & Jeschke, S. (2018). An overview of work analysis instruments for hybrid production workplaces. AI & SOCIETY, 33(3), 425–432.

Munsamy, M., & Telukdarie, A. (2019). Digital HRM Model for Process Optimization by Adoption of Industry 4.0 Technologies. In 2019 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM) (pp. 374–378).

Nankervis, A., Connell, J., Cameron, R., Montague, A., & Prikshat, V. (2021). 'Are we there yet?'Australian HR professionals and the Fourth Industrial Revolution. Asia Pacific Journal of Human Resources, 59(1), 3–19.

Nardo, M.D., Forino, D., & Murino, T. (2020). The evolution of man–machine interaction: The role of human in Industry 4.0 paradigm. Production & Manufacturing Research, 8(1), 20–34.

Nelles, J., Kuz, S., Mertens, A., & Schlick, C.M. (2016). Human-centered design of assistance systems for production planning and control: The role of the human in Industry 4.0. In 2016 IEEE International Conference on Industrial Technology (ICIT) (pp. 2099–2104).

Neumann, W.P., Winkelhaus, S., Grosse, E.H., & Glock, C.H. (2021). Industry 4.0 and the human factor–A systems framework and analysis methodology for successful development. International Journal of Production Economics, 233, p.107992.

Oosthuizen, R.M., & Mayer, C.H. (2019). At the edge of the Fourth Industrial Revolution: Employees' perceptions of employment equity from a CIBART perspective. SA Journal of Industrial Psychology, 45(1), 1–11.

Pacaux-Lemoine, M.P., Berdal, Q., Guérin, C., Rauffet, P., Chauvin, C., & Trentesaux, D. (2021). Designing human–system cooperation in industry 4.0 with cognitive work analysis: a first evaluation. Cognition, Technology & Work, 1–19.

Park, S.C. (2018). The Fourth Industrial Revolution and implications for innovative cluster policies. AI & SOCIETY, 33(3), 433–445.

Reiman, A., Kaivo-oja, J., Parviainen, E., Takala, E.P., & Lauraeus, T. (2021). Human factors and ergonomics in manufacturing in the industry 4.0 context–A scoping review. Technology in Society, 65, p.101572.

Rødseth, H., Eleftheriadis, R., Lodgaard, E., & Fordal, J.M. (2018). Operator 4.0–Emerging job categories in manufacturing. In International Workshop of Advanced Manufacturing and Automation (pp. 114–121). Springer, Singapore.

Romero, D., Stahre, J., Wuest, T., Noran, O., Bernus, P., Fast-Berglund, Å., & Gorecky, D. (2016). Towards an operator 4.0 typology: a human-centric perspective on the fourth industrial revolution technologies. In proceedings of the international conference on computers and industrial engineering (CIE46), Tianjin, China (pp. 29–31).

Ruppert, T., Jaskó, S., Holczinger, T., & Abonyi, J. (2018). Enabling technologies for operator 4.0: A survey. Applied sciences, 8, 1650.

Sahinel, D., Akpolat, C., Görür, O.C., & Sivrikaya, F. (2019). Integration of human actors in IoT and CPS landscape. In 2019 IEEE 5th World Forum on Internet of Things (WF-IoT) (pp. 485–490).

Scafà, M., Papetti, A., Brunzini, A., & Germani, M. (2019). How to improve worker's well-being and company performance: A method to identify effective corrective actions. Procedia CIRP, 81, 162–167.

Sgarbossa, F., Grosse, E.H., Neumann, W.P., Battini, D., & Glock, C.H. (2020). Human factors in production and logistics systems of the future. Annual Reviews in Control 49: 295–305.

Shamim, S., Cang, S., Yu, H., & Li, Y. (2016). Management approaches for Industry 4.0: A human resource management perspective. In 2016 IEEE Congress on Evolutionary Computation (CEC) (pp. 5309–5316).

Sivathanu, B. and Pillai, R. (2018). Smart HR 4.0–how industry 4.0 is disrupting HR. Human Resource Management International Digest, 26, 7–11.

Strandhagen, J. W., Alfnes, E., Strandhagen, J. O., & Vallandingham, L. R. (2017). The fit of Industry 4.0 applications in manufacturing logistics: a multiple case study. Advances in Manufacturing, 5(4), 344–358.

Tinz, P., Tinz, J., & Zander, S. (2019). Knowledge Management Models for the Smart Factory: A Comparative Analysis of Current Approaches. In KMIS (pp. 398–404).

Trist, E. L. (1981). The evolution of socio-technical systems (Vol. 2). Toronto: Ontario Quality of Working Life Centre.

Vještica M., Dimitrieski V., Pisarić M., Kordić S., Ristić S., & Luković I. (2020). The Syntax of a Multi-Level Production Process Modeling Language. 15th Conference on Computer Science and Information Systems (FedCSIS), pp. 751–760.

Vodenko, K.V., & Lyausheva, S.A. (2020). Science and education in the form 4.0: public policy and organization based on human and artificial intellectual capital. Journal of Intellectual Capital, vol. 21, no. 4, pp. 549–564.

Wurhofer, D., Meneweger, T., Fuchsberger, V., & Tscheligi, M. (2018). Reflections on Operators' and Maintenance Engineers' Experiences of Smart Factories. In Proceedings of the 2018 ACM Conference on Supporting Groupwork (pp. 284–296).

Zaouga, W., Rabai, L.B.A., & Alalyani, W.R. (2019). Towards an Ontology Based-Approach for Human Resource Management. Procedia Computer Science, 151, 417–424.

Zarte, M., Pechmann, A., & Nunes, I.L. (2020). Principles for Human-Centered System Design in Industry 4.0–A Systematic Literature Review. In International Conference on Applied Human Factors and Ergonomics (pp. 140–147). Springer, Cham.

Zolotová, I., Papcun, P., Kajáti, E., Miškuf, M., & Mocnej, J. (2020). Smart and cognitive solutions for Operator 4.0: Laboratory H-CPPS case studies. Computers & Industrial Engineering, 139, p.105471.

Appendix

Table 5. References marked with the numbers

No	Reference	No	Reference	No	Reference
1	(Kannengiesser & Müller, 2013)	22	(Kadir et al., 2019)	43	(Fayomi et al., 2020)
2	(Gorecky et al., 2014)	23	(Munsamy & Telukdarie, 2019)	44	(Bongomin et al., 2020)
3	(Kiesel & Wolpers, 2015)	24	(Cimini et al., 2019)	45	(Flores et al., 2020)
4	(Fantini et al., 2016)	25	(Scafà et al., 2019)	46	(Sgarbossa et al., 2020)
5	(Nelles et al., 2016)	26	(Jędrzejczyk, 2019)	47	(Kadir & Broberg, 2020)
6	(Shamim et al., 2016)	27	(Farsi & Zio, 2019)	48	(Angelopoulou et al., 2020)
7	(Romero et al., 2016)	28	(Sahinel et al., 2019)	49	(Zarte et al., 2020)
8	(Cotet et al., 2017)	29	(Tinz et al., 2019)	50	(Ayinde & Kirkwood, 2020)
9	(Benešová & Tupa, 2017)	30	(Khalifa et al., 2019)	51	(Vodenko & Lyausheva, 2020)
10	(Longo et al., 2017)	31	(Longo et al., 2019)	52	(Zolotová et al., 2020)
11	(Hahm, S., 2018)	32	(Klumpp et al., 2019)	53	(Aichouni et al., 2020)
12	(Ruppert et al., 2018)	33	(Ali & AlSadoon, 2019)	54	(Nardo et al., 2020)
13	(D'antonio & Chiabert, 2018)	34	(Llinas Sala & Abad Puente, 2019)	55	(Mohammadian & Rezaie, 2020)
14	(AnTosz, 2018)	35	(Zaouga et al., 2019)	56	(Jerman et al., 2020)
15	(Rødseth et al., 2018	36	(Cimini et al., 2020)	57	(Nankervis et al., 2021)
16	(Wurhofer et al., 2018)	37	(Krupitzer et al., 2020)	58	(Reiman et al., 2021)
17	(Ansari et al., 2018)	38	(Di Pasquale et al., 2020)	59	(Longo et al., 2021)
18	(Sivathanu & Pillai, 2018)	39	(Carfì et al., 2020)	60	(Kadir & Broberg, 2021)
19	(Park, 2018)	40	(Gazzaneo et al., 2020)	61	(Gallo & Santolamazza, 2021)
20	(Mucha et al., 2018)	41	(Chacón et al., 2020)	62	(Neumann et al., 2021)
21	(Oosthuizen & Mayer, 2019)	42	(Jongprasithporn et al., 2020)	63	(Pacaux-Lemoine et al., 2021)