

Smart industry and the pathways to HRM 4.0: implications for SCM

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Abstract

Purpose – The purpose of this paper is to address the potential impacts of Industry 4.0 on human resource management (HRM) – with a particular focus on employment, job profile and qualification and skill requirements in the workforce – which can have implications for supply chain management (SCM). Consequently, exploratory relationships among Industry 4.0, HRM and SCM are presented based on a systematic review.

Design/methodology/approach – To explore Industry 4.0 literature and its impact on employment, the authors used a systematic literature review to identify, classify and analyze current knowledge, flagging trends and proposing recommendations for future research in this area. Using the Web of Science database, the authors utilized co-citation software to visualize the networks which emerged from recurrent terms and which were then used to develop the categories of analysis.

Findings – The authors can affirm that the literature in this field is in a transition process, from the early studies of German academics to the current development of new impacts worldwide. Industry 4.0 is the central theme of the literature analyzed and is accomplished through the development of employment, qualifications, skills and learning frameworks. The results reveal that most papers are conceptual, with quantitative studies still lacking. Developed countries have a leading role in terms of research production, while Latin America and Asia are far behind. Clustering reveals four dominant themes (educational changes, employment scenario, work infrastructure resources and work meaning and proposal). The first refers to labor changes around working conditions, the work environment and new skills which are required. The second main theme concerns the potentially unstable shift in the labor market has toward a high-level context. The third is about the technical interface of humans and machines, and finally, the fourth understands the German industry as a starting point for global industrial improvements and work proposal changes. Furthermore, socio-technical systems cover the implications of HRM for SCM in three different dimensions: qualification and education (human competences), collaboration and integration of SCM (organizational competences) and data and information management (technical competences).

Research limitations/implications – An original research agenda for further development of the topic. Additionally, the implications of the findings for SCM practitioners are presented.

Practical implications – SCM managers can benefit from the results of this paper by developing adjusted policies for organizational and human aspects. Specially about training programs to improve technology skills and education programs for cyber-human new platforms.

Originality/value – So far, Industry 4.0, HRM-related topics and implications for SCM have generally been considered separately. This paper elucidates the few important studies on the impacts of Industry 4.0 on human-related topics, such as the labor market, building a research framework using the main contributions highlighted in the literature. An original research agenda is presented, as well as potential implications for SCM.

Keywords Supply-chain management, SCM competency, SCM practices, Human factors

Paper type Literature review

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1. Introduction

Currently, because of the rapid development of digitalization and robotics, we are facing the next industrial revolution, known as “Industry 4.0”. Disruptive changes are taking place in the global manufacturing system (Strandhagen *et al.*, 2017) through the use of smart technologies that enable new and more efficient processes, products and services (Lee *et al.*, 2015; Zhong *et al.*, 2017). Digitalization develops in various sectors at different speeds, depending on the complexity of business models. This change represents risks, challenges and opportunities to industry stakeholders and communities (Roblek *et al.*, 2016; Strandhagen *et al.*, 2017; Hirsch-Kreinsen, 2016).

Such changes will not collapse the entire system (Rajnai and Kocsis, 2017); rather, society will react more slowly, remaining at least close to a steady state situation. One of the main reasons that abrupt transition is not possible is the integration between Industry 4.0 and HRM-related topics, such as a lack of skilled staff to promote radical changes across entire supply chains, as HRM issues can affect supply chains considerably (Gowen III and Tallon, 2003). Keynes (2010) affirmed that technical efficiency increases faster than we can deal with the problem of labor absorption. These employment changes are multifaceted and complex, making it difficult to attribute specific causal effects (Evangelista *et al.*, 2014) toward reaching conclusions on positive and negative perspectives.

Job numbers will generate redundancy effects across the global economy (Roblek *et al.*, 2016). While estimates show that 47 per cent of American (OECD, 2015) and 30 per cent of British (Elliot, 2017) jobs are under high risk in the next 20 years, and in China over 60,000 workers were rendered jobless in 2016 when Foxconn decided to replace them with robots (Wakefield, 2016), Berger (2016) asserts a 50 per cent level of job absorption in the Western European economy in the same time range.

Relocation of activities, leveraging new business models, reinvestment in new industrial products and equipment and new services also change the employment scenario (Berger, 2016). Old work activities are disappearing and being replaced, and entirely new ones are being created. The most in-demand occupations today did not exist 10 or even five years ago; 65 per cent of children entering primary school today will ultimately end up working in entirely new jobs that do not yet exist (WEF, 2016).

There will be a positive variation in wage and job impacts on different economies (Rajnai and Kocsis, 2017; WEF, 2016) depending on the competitive level of technological gaps between countries. Kergroach (2017) points to the trend of minimization of precarity in work conditions in developing countries. Employees in such countries tend to lose more jobs and comparative advantages, as the actual logic of low-cost labor is contradictory to rising labor costs and the decline of jobs due to technological efficiency, leading to companies restoring operations back to their home countries (Calitz *et al.*, 2017).

Labor constraints and amount of jobs are only the tip of the iceberg; in a broader view, the role of the human factor will be indispensable to smart industry and SCM. This consideration does not only influence production itself, but also the

occupational dimension, job dynamics, working conditions, educational system, skills demand and national policies (Benešová and Tupa, 2017; Rajnai and Kocsis, 2017). Specifically, qualifications and skills will be critical because companies will have to adapt to constant technological shifts (Harkins, 2008), turning knowledge management (Nonaka *et al.*, 1996) and IT knowledge (Pfeiffer, 2016) into the key to success for a highly innovative factory (Gehrke *et al.*, 2015), making digitalization of production possible (Rajnai and Kocsis, 2017).

The primary challenge now is moving beyond new technologies toward complete automation, and the resulting 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 the best possible cooperation between humans and machines (Benešová and Tupa, 2017) within SCM.

Horizontally, the challenge is focused across SCM, and vertically, throughout the levels of an organization (Hecklau *et al.*, 2016). Industry, as a whole, should be focusing on human resources management (HRM) (Legge, 1995; Huselid, 1995), and moreover, on people management (Thompson, 2013), suppressing traditional approaches to recruitment, selection, staffing in favor of hiring a workforce to train, developing employees and learning environments (Becker, 2013). Industry 4.0 transposes the traditional HRM onto a new model, one which is able to deal with the “not so new” but still challenging Learning 4.0 and Education 4.0 (Harkins, 2008).

HRM 4.0, as it is called, materializes the industry strategy for filling in the blanks around their dynamic capabilities (Teece *et al.*, 1997; Eisenhardt and Martin, 2000) to adapt and survive in the 4.0 market, combining real and virtual global information and IT management knowledge (Hecklau *et al.*, 2016). All of these terms are used to describe the managerial and market revolution that the reality of Industry 4.0 is bringing. The use of these terms helps to familiarize scholars and practitioners with the upcoming changes that Industry 4.0 is bringing and which are currently being discussed across different domains of knowledge.

These changes are coming rapidly, and virtual-human interface solutions are not always obvious, reaching organizationally, socially and culturally obscured paths. Qualifications, skills and adequate learning frameworks are relevant issues to support the future agenda for organizations and supply chains. The impacts of HRM 4.0 on supply chain management (SCM) are based on the natural and intrinsic relationships between human-related issues and the adoption of SCM practices and trends.

Consequently, transformations in HRM can impact SCM, as previously asserted by Gowen III and Tallon (2003). Moreover, the integration of HRM and SCM can still be considered an important area for further understanding SCM (Lengnick-Hall *et al.*, 2013). In a scenario in which Industry 4.0-related HRM occurs, SCM practices can achieve even higher levels of excellence. This perspective is supported by Ellinger and Ellinger (2014), authors who affirm that HRM can contribute to the success of SCM practices. Thus, any improvement in HRM across a supply chain can signify a move toward higher levels of SCM practices.

Overall, a relatively small number of important works (Gowen III and Tallon, 2003; Lengnick-Hall *et al.*, 2013; Ellinger and Ellinger, 2014) have contributed to the literature on the integration of HRM and SCM. Further, it is possible to suggest that the available literature on the integration of HRM 4.0 and SCM – as proposed here – is even more scarce than in the traditional HRM–SCM gap. This work, thus, proposes one of the first explorations on the relationships among Industry 4.0, HRM (with a focus on employment and workforce trends) and SCM. We hope that this discussion will pave the way toward a proper future research agenda, which will shed light on real-world problems facing SCM in the context of HRM 4.0.

In this sense, the purpose of this paper is to address potential impacts of Industry 4.0 on HRM – with a particular focus on employment, job profile and requirements for qualifications and skills of the workforce – which can have implications for SCM. The main contributions of this work are as follows:

- We present original results concerning a systematic literature review, through identification, classification and analysis of current knowledge concerning the effects of Industry 4.0 on HRM-related topics, such as employment and job profile, which can affect SCM.
- We develop an original research agenda for progressing the still-scarce discussion on the potential implications of Industry 4.0–HRM on supply chain management.
- We conclude this work by presenting implications for the supply chain community.

2. Theoretical background

Technical and economic changes arise from new combinations of knowledge, know-how (Lundvall and Johnson, 1994) that allows new ways of producing goods and services to infer a rescue from Schumpeter's (1985) "exchange economy".

Besides industry developments toward the digitalization of manufacture, the technological push of Industry 4.0 forces organizations and supply chains into adaptive behavior, driving them into new management processes which are promoted by evolutions in learning. Industry 4.0 will affect the way HRM and human-related trends are considered by companies.

In this work, human resources-related topics are understood to include the ways in which firms adapt recruitment, training, performance appraisal and rewards of employees in light of external trends, such as technological changes and competitive forces (Jackson *et al.*, 2014). From a broader perspective, HRM relates to methods for keeping the workforce updated, skilled and aligned with stakeholders' expectations (Jackson *et al.*, 2014). Regarding SCM, it is defined as "the integration of key business processes from end user through original suppliers, that provide products, services, and information that add value for customers and others stakeholders" (Lambert *et al.*, 1998, p.2).

According to Sivathanu and Pillai (2018), organizations will need to align their HRM strategies and practices with Industry 4.0, including topics such as workforce employment and skills development. In this sense, certain digital skills might be needed in this Industry 4.0 future, such as problem-solving, non-routine tasks and creation of digital outputs (Djumalieva and Sleeman, 2018). This is because some technologies, such

as the Internet-of-Things, Big Data and artificial intelligence, will automate most of the HR processes, resulting in efficient and leaner HR teams. Industry 4.0 will impact human-related topics across supply chains, such as training, development, employment, skills development, etc.

Organizations and supply chains that are in the process of implementing an innovation process or that display the organizational antecedents of innovation (Damanpour, 1991; Wolfe, 1994; Nelson and Winter, 2005) are more prepared for the required learning on human–machine interface management. An increased incorporation of technology components into HRM-related topics, with attendant implications for SCM, will need to be better understood.

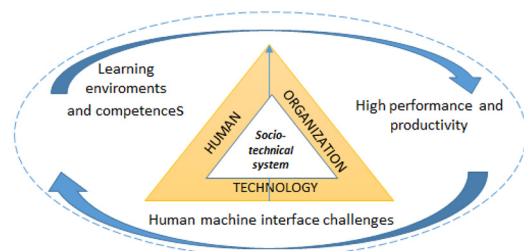
For this purpose, certain exploratory theoretical frameworks have been developed. Organizational competencies for Industry 4.0 have been designed, such as technical (domain), methodological, social and personal (Hecklau *et al.*, 2016). Kinkel *et al.* (2017) address the ability to build networks or to solve complex problems for innovativeness in the industry, which these competencies can provide when dynamically applied in HRM.

The socio-technical systems (STS) (Trist, 1981; Geels, 2004) perspective can be a successful way to understand this complex change. Social and technological aspects no longer innovate separately. This perspective presumes that it is necessary to develop novel approaches for work-integrated qualifications and instruments of learning organizational methods, especially about digitalization (Ropohl, 2009; Schuh *et al.*, 2015). Furthermore, collaborative types of learning and learning environments are critical to organizations for operationalizing knowledge and competencies, such as the use of virtual learning environments (VLEs) (Anjarichert *et al.*, 2016), augmented reality (Azuma, 1997) and collaborative environments between Cobots (service robots) and humans (Calitz *et al.*, 2017).

Dregger *et al.* (2016) and Hirsch-Kreinsen (2016) designed one of the proposed models for Industry 4.0 and STS change. HRM becomes the center of the human–technology interface relationship (Figure 1).

This ongoing change can also disrupt the status quo of educational systems. Industry 4.0 will strongly impact higher education (Baygin *et al.*, 2016). A trend of new education business models entailing high costs forces the privatization of some institutions and establishment of corporate universities

Figure 1 HRM 4.0 background



Source: Adapted from Dregger *et al.* (2016), and Hirsch-Kreinsen (2016)

and professional schools by big companies (Störmer *et al.*, 2014).

Industry 4.0 will change society and firms, humans and supply chains, launching a number of trends and challenges across supply chains. As HRM-related issues can have significant effects on operations, quality and excellence of supply chains (Gowen III and Tallon, 2003; Lengnick-Hall *et al.*, 2013; Ellinger and Ellinger, 2014), it is possible to understand that HRM 4.0 will change the way supply chains operate (Sivathanu and Pillai, 2018). HRM-related issues can be key either for the success or the failure of organizational initiatives (Jackson *et al.*, 2014), such as the adoption of Industry 4.0 across supply chains.

3. Method

A literature review in the field of management or organizational studies is the first step of scientific research and is presented as a brief introduction to an empirical study or as an extensive detailed account of a body of literature. Over recent years, new formal approaches and systematic methods have been created to locate, select, appraise, summarize and report evidence (Denyer and Tranfield, 2009; Tranfield *et al.*, 2003).

Research on emerging issues provides important support in portraying efforts to indicate the challenges faced by future studies of systematic literature reviews (Liboni-Amui *et al.*, 2017; Mariano *et al.*, 2015; Huisinigh, 2012). Systematic literature reviews enable the analysis of the past to prepare for the future, uncovering the body of knowledge by identifying research that is relevant to a specific subject (Kitchenham, 2004; Webster and Watson, 2002).

For Tranfield *et al.* (2003, p. 220):

The aim of the systematic review is to provide collective insights through theoretical synthesis into fields and sub-fields. For academics, the reviewing process increases methodological rigor. For practitioners/managers, systematic review helps develop a reliable knowledge base by accumulating knowledge from a range of studies.

Systematic reviews differ from traditional narrative reviews because of their replicable and transparent process. To reduce human error and bias, systematic reviews use data-extraction methods, which require documentation of all steps. Data extraction must contain general information, such as title, author, publication details, as well as the research specific information, such as method and notes on emerging themes (Tranfield *et al.*, 2003).

Jabbour (2013) and Lages Junior and Godinho Filho (2010) propose that a systematic literature review should involve certain steps, such as:

- survey the available articles published on the subject;
- develop and validate (i.e. in a research group) a classification code system to provide structure to the existing knowledge on the subject;
- identify and analyze the main results of the articles based on the coding system;
- explore and describe the gaps in the literature; and
- indicate the opportunities and challenges for future studies.

Therefore, the objective of this paper is to systematize the available knowledge on the impacts of Industry 4.0 on the labor market by:

- identifying articles on Industry 4.0 and labor;
- classifying and codifying characteristics of these articles;
- discussing the results of the literature review; and
- providing a framework for addressing the gaps in the current knowledge, contributing to a future research agenda.

This research, based on a systematic literature review, used an extraction process involving two rounds of analysis. After the first step – individual analysis conducted by different researchers – the findings were compared and reconciled when necessary, as suggested by Tranfield *et al.* (2003).

The database used was the ISI Web of Knowledge (Web of Science) because of its importance as an online subscription-based scientific citation indexing service. The systematic search used a group of key words to identify articles related to Industry 4.0 and employment. The terms used were: “Industry 4.0” and “labor”; “Industry 4.0” and “employee”; “Industry 4.0” and “employment”; “Industry 4.0” and “workforce”. All of the resulting studies from the search were incorporated, without the use of refinement mechanisms by area (management, engineering, education, among others) or type of research (proceedings, articles).

In addition, we expanded the search to include articles in two other languages – German and Spanish. German was included because Germany is the cradle of Industry 4.0, and Spanish because it is the most widely spoken language in the world. This additional searching provided one relevant article in German.

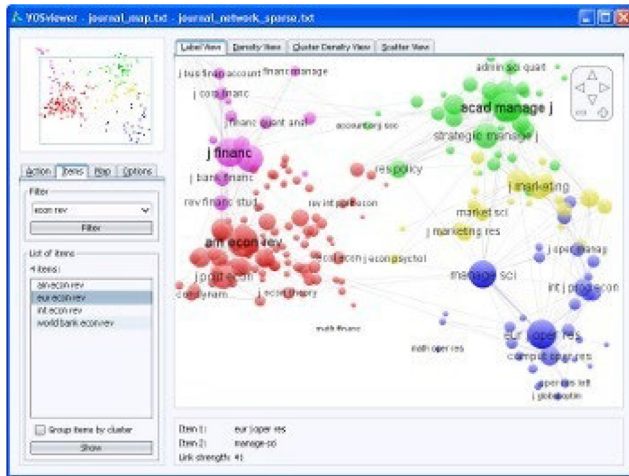
After collecting the relevant articles, an analysis was conducted to verify that all of them discussed Industry 4.0 from a labor market perspective. Therefore, all the articles were analyzed to better understand whether their nature genuinely concerned labor or employees in Industry 4.0. Some articles were excluded because they did not discuss these topics. Those that did not integrate both themes and those which were unavailable for download were removed from the study. The excluded papers represented less than 10 per cent of the total number of papers on the subject. From the 62 studies identified, six papers were excluded because they were unavailable for download and four were excluded because they were duplicates of existing results. Table I shows the results of the searches and the number of remaining papers considered for review.

Systematic reviews use a set of explicit selection criteria to assess the relevance of each study identified (Denyer and Tranfield, 2009). Before a careful codification of the papers, they were analyzed using the VOSviewer software (version 1.6.7), a tool for constructing and visualizing bibliometric networks (Figure 2). These networks, enabled by the text mining functionality, were used to construct and visualize co-occurrence networks of the important terms that appeared in the literature, representing a way of pointing out the main topics studied and the opportunities for future research.

The terms from abstracts that appeared in the networks as the most recurrent were used initially for the development of categories of analysis, as seen in the network below (Figure 3). Together with these categories, other general and specific information, such as method and research technique, as well as the dimensions adapted from Jabbour and Santos (2008), were used as categories to analyze the existing articles.

Table I Results of the search process and remaining articles after analysis

Words used as topics in the search mechanism	Initial results	Remaining studies
("Industry 4.0") AND (employee)	61	27
("Industry 4.0") AND (labor)	38	19
("Industry 4.0") AND (employment)	24	9
("Industry 4.0") AND (workforce)	22	7

Figure 2 VOSviewer software**Figure 3** Preliminary network for categories development

The classification framework was developed using the number and letters codes to classify the articles. The classification dimensions were (Table II):

- 1 Emphasis (1), coded on a scale A-B;
- 2 Aspects (2), coded A-C;
- 3 Research method (3), coded on a scale A-B;
- 4 Research design or technique (4), coded on a scale A-F;
- 5 The approach, coded on a scale A-B;
- 6 Focus, coded on a scale A-C;
- 7 Origin, coded on a scale from A-E;
- 8 Dimensions of HRM, coded A-H;
- 9 Changing and effects of Industry 4.0 on HRM, coded on a scale from A-C; and
- 10 SCM, coded on a scale from A-L.

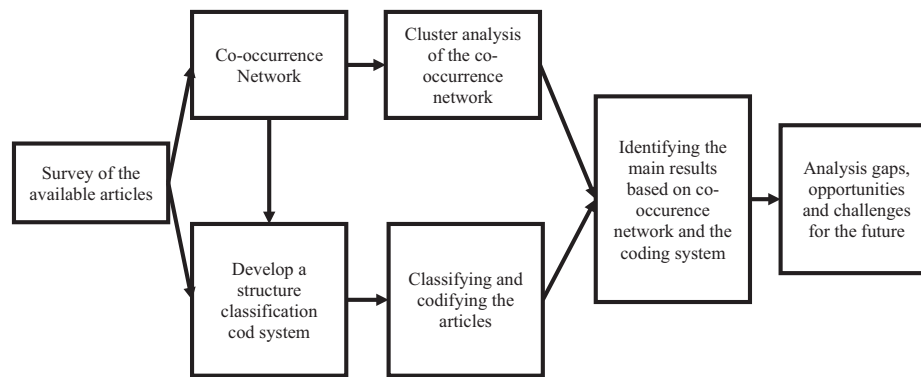
In summary, the methodological research scheme can be seen below (Figure 4).

Many systematic reviews use two or more independent reviewers to extract data from studies (Denyer and Tranfield,

Table II Framework with classification and codes used in the analysis

Dimension	Classification	Code
(1) Emphasis (discussion)	Industry 4.0 as central emphasis	1A
	Industry 4.0 as support to other	1B
(2) Aspects	discussions/technical aspects	
	Technical	2A
	Human	2B
(3) Research method	Managerial	2C
	Qualitative	3A
	Quantitative	3B
(4) Research design/technique	Case study	4A
	Interviews	4B
	Survey	4C
	Focus group	4D
	Literature review	4E
	Simulation/programming/others	4F
(5) Approach	Theoretical/conceptual	5A
	Empirical	5B
(6) Focus	Emerging economies	6A
	Developed countries	6B
	Not applicable	6C
(7) Origin	North and Central America	7A
	Latin America	7B
	Europe	7C
	Asia and Oceania	7D
	Africa	7E
(8) Dimensions of HRM	Analysis and description of positions	8A
	Recruitment	8B
	Selection	8C
	Training and development	8D
	Performance appraisal	8E
	Rewards	8F
	Leadership and teamwork	8G
	Communication	8H
	Changes in the way of working (human-machine interfaces)	9A
	Training of the labor force (education)	9B
(9) Changing and effects of Industry 4.0 on HRM	Knowledge management (the role of knowledge)	9C
(10) SCM	Costs	10A
	Logistics	10B
	Communication	10C
	Integration	10D
	Suppliers	10E
	Product development	10F
	Risk and resilience	10G
	Strategy (values and culture)	10H
	People and leadership	10I
	Planning and process	10J
	Coordination	10K
	Not applicable	10L

2009). After creating the above codes and categories, a methodological step to strengthen the systematic research and validate the codes was implemented. The papers selected to be analyzed and codified were sent to six researchers from our

Figure 4 Methodological research scheme

Source: Adapted from Liboni-Amui *et al.* (2017), Shiao *et al.* (2015), Jabbour (2013), and Lages Junior and Godinho Filho (2010)

research group (CISS – Center on Innovation, Systems and Sustainability). Their objective was to read the papers, validate our categorization method and codify the articles. The code for SCM arose from this step, with all other codes and categories being validated.

4. Results and discussion

The research results are divided into three main topics. First, we present the coding systems which emerged. Second, the co-occurrence networks are analyzed. Finally, we discuss the results aligning the actual knowledge corpus and a research agenda for future studies.

4.1 Coding system results

After analyzing the papers, 52 articles were selected to be classified. These were mostly published between 2014 and 2018, with 12 publications already in 2018 (Figure 5). In this context, the subject can be seen as recent, and so far largely unexplored in the literature, but it has been rising during the last few years.

Descriptions of papers selected for this analysis are available in Appendix 1, while Appendix 2 shows the codifications for the systematic review performed in this research. Table III describes a summary of each of the 52 papers.

4.1.1. Emphasis of the discussion

This category verifies whether the paper treats Industry 4.0 as a central theme or uses it as a peripheral issue for other analysis. It can be seen from Figure 5 that the discussions of articles

focus primarily on aspects of Industry 4.0 as a central item. This analysis is also corroborated from the data in Figure 6, which presents a network of keywords of the categorized studies. It is noted that the core keyword is Industry 4.0, but there are simultaneously keywords in the areas of computer science, engineering and HRM, reaffirming the multidisciplinary emphasis of Industry 4.0.

4.1.2 Aspects covered

This category considers the sorting of the papers into technical, human or managerial aspects. Figure 7 shows that, in 44 of the 52 articles analyzed (more than 80 per cent), human aspects are discussed. It is interesting to note that, in 27 of the 52 articles (more than 50 per cent), there are discussions about more than one aspect, which corroborates a multifaceted view of the theme and reinforces the STS as a valid framework of analysis.

4.1.3 Method

This category aims to check the methods used in the analyzed articles: qualitative or quantitative (Figure 8). Almost 90 per cent of the papers developed qualitative research. This result may represent research opportunities for quantitative methods, to test given propositions and validate suggested hypotheses.

4.1.4 Research techniques

This category aims to verify the research techniques used in the analyzed papers: a case study, interviews, survey, focus group, reviews and simulation/programming/others (Figure 9). More than 59 per cent of the articles used literature review as the main method. The case study was also a highlight: almost 16 per cent of the papers developed research through this technique. It is relevant to emphasize that there were few (or no) studies using survey, focus group, simulation, programming or other different techniques.

4.1.5 Approach

The majority of the papers brought a theoretical/conceptual approach (65 per cent) (Figure 10). Empirical research has growth potential, as Industry 4.0 is an emergent and relevant theme. Researchers may be able to develop creative insights through empirical research to face challenging problems.

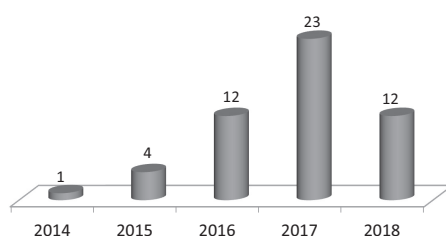
Figure 5 Number of articles per year

Table III Summary of the papers

No.	Authors	Summary
1	Muller, SL; Shehadeh, MA; Schroder, S; Richert, A; Jeschke, S	This paper addresses how human–robot teams will assume future production and the effects this will have on employees, workstations and companies as a whole
2	Buth, L; Blume, S; Posselt, G; Herrmann, C	In this paper, a four-step training concept for industrial employees in a learning factory environment is described
3	Enke, J; Glass, R; Kress, A; Hambach, J; Tisch, M; Metternich, J	This paper discusses competences to improve integration of lean management and Industry 4.0. Based on a literature review, a comprehensive Lean 4.0 curriculum is structured and presented
4	Antosz, K	This paper provides a competency assessment tool for maintenance workers. The conclusions show that companies are aware of the need for a maintenance worker competency assessment, but still face limitations during this process
5	Wulfken, BT; Muller, E	In this paper, the authors present how requirements can be structured to ensure employee selection and education in the context of technological and organizational changes. They suggest semi-standardized interview to identify how the parameters of HRM can be structured and exploited
6	Grzelczak, A; Kosacka, M; Werner-Lewandowska, K	This paper investigates which employee competences are necessary for the development of Industry 4.0 concepts in companies. As a result, it identifies core competences to develop an Engineer 4.0 profile. Besides, challenges faced by Polish companies are discussed
7	Kulyk, V; Parmova, DS	This paper summarizes the current basis for e-business development in the EU, with a focus on the Czech Republic in comparison with Ukraine. In this sense, HRM legislation is discussed in the future context of Industry 4.0
8	Seitz, KF; Nyhuis, P	This paper clarifies the advantages of cyber-physical systems in view of production planning, controlling and monitoring. Within this, the authors deal with logistics model performance and possible logistic cost reductions through cyber–physical production systems implementation
9	Salento, A	This paper presents an introductory overview of the main issues that the digitalization of industrial enterprises raise for social sciences. The author argues that Industry 4.0 can be read as a transnational re-industrialization program. Thus, Social Science must understand how technological changes will affect employment and the dynamic of capital accumulation
10	Setiawan, F; Yahya, BN	This paper develops a behavioral analysis framework for discovering relevant behavior models, using sequential rule mining. Monitoring employee behavior is one of the employers' ways to assess the accountability of the employee. Hence, understanding human behavior during the production process would be an important issue for fulfilling overall operational excellence in a software factory
11	Kotynkova, M	This paper discusses Industry 4.0 and its consequences for the world of work. It emphasizes predictions regarding the digitization of production, for instance, which may remove millions of jobs
12	Mourtzis, D; Vlachou, E; Dimitrakopoulos, G; Zogopoulos, V	This paper presents a systemic approach for moving from the common teaching factory to the 4.0 teaching factory, through the integration of cyber–physical systems and Industry 4.0 technologies
13	Nyikes, Z	In this paper, the authors discuss how digital knowledge must be increased to make it more accessible. Also, as many professions require a certain level of digital literacy, both employees and companies should be aware of the skills that are going to be required in the workforce in the future
14	Ozlu, F	The author demonstrates the benefits for Turkey in adopting an Industry 4.0 model and in what ways it could contribute to increasing workforce efficiency, production and the Turkish competitive advantage in the world
15	Freddi, D	The aim of the paper is to assess and understand the pace and degree of absorption of digital technologies in manufacturing, both in products and processes. To achieve this, a multiple-case study was conducted on seven leading Italian manufacturing companies
16	Ansari, F; Erol, S; Sihni, W	This paper discusses the challenges of mutual human–machine learning, trying to identify innovative learning patterns in highly digitalized industrial work scenarios, through the presentation of a case
17	Flynn, J; Dance, S; Schaefer, D	This paper has the goal of evaluating the potential impact of Industry 4.0 on future unemployment and the need for a different education system to develop the Industry 4.0 workforce for the future. The methodology of this research uses indicators related to the manufacturing sector, readiness for innovation, ICT utilization and key sector ratios
18	Johansson, J; Abrahamsson, L; Kareborn, BB; Falholm, Y; Grane, C; Wykowska, A	The paper discusses four knowledge gaps which should be given more importance by researchers in relation to the digitalization of work: the relationship between new technology, working conditions, qualifications, identity and gender; the future of the workers' collective; crowdsourcing in an industrial context; and human–machine interaction, with a focus on integrity issues
19	Eichhorst, W; Hinte, H; Rinne, U; Tobsch, V	The paper analyzes the relevance of digitalization in Germany and other developed countries, with a focus on the potential or actual impact it may have on the labor market
20	Palazzeschi, L; Bucci, O; Di Fabio, A	The main point is organizational innovation in the context of Industry 4.0. The authors discuss technological and psychological innovation, suggesting new pathways for researchers and practitioners regarding innovation and innovative work behavior
21	Strandhagen, JW; Alfnes, E; Strandhagen, JO; Vallandingham, LR	The paper investigates Industry 4.0 technologies applicable to manufacturing logistics and the role of the production environment in the applicability of these technologies. The results reveal that companies with a low degree of production repetitiveness do not see great potential in the application of Industry 4.0 technologies
22	Trompisch, P	The paper argues that the use of Industry 4.0 technologies in enterprises will not lead to full automation. Therefore, such a context should not be seen as a scenario of competition, but rather cooperation
23	Rajnai, Z; Kocsis, I	The paper discusses the labor market risks of Industry 4.0, digitization, robots and artificial intelligence. The authors suggest that companies should adapt their HR activities to changing labor market conditions, to attract and retain new staff and to develop new organizational models
24	Hedvicakova, M; Svobodova, L	The authors conclude that Industry 4.0 will bring the following changes to the current labor market: higher labor productivity; jobs with less-qualified workers will be at risk; new jobs with high skill requirements. In the business context, this could mean, for example, increasing production efficiency, reducing material, transportation and energy costs
25	Kharchenko, V; Illiashenko, O; Boyarchuk, A; Sklyar, V; Phillips, C	The paper claims that there are key points to be improved in the education system and industry in Ukraine. In this sense, there is a lack of specialists in the IoT area, which could be covered by the implementation of a new curriculum for students. The authors confirm that the project is ongoing, and the results will be useful for Ukrainian universities
26	Kergroach, S	The paper presents the general scenario of the latest technological trends of Industry 4.0 and their consequences on the structure of the labor market, through the emergence of different skills and some policy challenges, for instance. Therefore, different competencies and skills will be required
27	Bobkov, V; Kvachev, V	For these authors, the divisions of labor markets, Fourth Industrial Revolution and changing nature of labor brings inequality as a result. All these lead to the expansion of precarity in different ways, especially in the form of precarious employment

(continued)

Table III

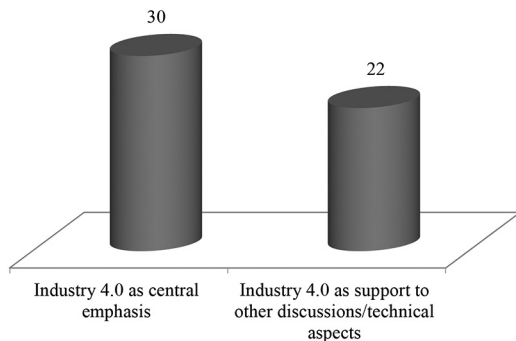
No.	Authors	Summary
28	Reuter, M; Oberc, H; Wannoffel, M; Kreimeier, D; Klippert, J; Pawlicki, P; Kuhlenkotter, B	This paper presents an innovative concept for transferring knowledge about the effects on workplaces and labor conditions for employees, using a learning factory setting. This approach enables some employees to recognize the possibilities for participating during technology design, development and implementation
29	Hirsch-Kreinsen, H	The paper presents some consequences of the growing use of digital technologies in industrial work. The author concludes that innovation of smart production systems is exceptionally paradoxical, as its structure changing effects have impacts of opposition and limitations to its realization
30	Pfeiffer, S	The empirical basis of the paper is 62 qualitative interviews in different assembly plants. The results show that assembly work should not be tagged as simply routine work. Thus it may be hard to replace humans by robotics in this kind of work
31	Strandhagen, JW; Alfnes, E; Strandhagen, JO; Swahn, N	The paper aims to investigate: which are the key elements of Industry 4.0 that are connected to production logistics and what is the role of the production environment in the applicability of these key elements. The authors conclude that the production environment has significant influence on the aforementioned applicability
32	Dregger, J; Niehaus, J; Ittermann, P; Hirsch-Kreinsen, H; ten Hompel, M	Thinking about the dilemma between what is technologically attainable and labor-politically desirable, the authors conclude that, to address Industry 4.0 challenges, practitioners and researchers should explore the organizational conditions needed to meet the potential of a human-oriented "Industry 4.0" project
33	Becker, T; Stern, H	The authors present a list of human task areas in existing and future cyber-physical production systems and estimate the evolutionary behavior of these tasks
34	Motyl, B; Baronio, G; Uberti, S; Speranza, D; Filippi, S	The main point is to investigate which are the necessary skills and expertise young engineers require to be ready for Industry 4.0. The authors identify that universities need to create a broader and better-structured knowledge of the basic concepts related to this new industrial revolution. It is necessary to improve and integrate this knowledge, considering revising the educational contents of courses, especially with regard to technical topics
35	Okuy, ZB	The main objective is to discuss the challenges related to women's participation in the workforce. The author holds the view that with the advent of the Fourth Industrial Revolution, current inequalities will become exacerbated if we do not start acting smart now. Besides, a diagnosis about Turkey is also made
36	Qu, SH; Wang, J; Govil, S; Leckie, JO	This research develops a multi-agent reinforcement learning approach for the optimal scheduling of a manufacturing system. By using a learning algorithm, this approach enables real-time cooperation between the workforce and machines and adaptively updates production schedules according to dynamically changing real-time events
37	Calitz, AP; Poisat, P; Cullen, M	The purpose of the research is to investigate the current use and future implementation of collaborative robots worldwide and its specific impact on the African workforce. The study highlights the importance of building employee trust, providing the relevant training and addressing the fear of retrenchment among employees
38	Benesova, A; Tupa, J	This article deals with identification of job roles in companies in the context of Industry 4.0. During Industry 4.0 implementation, various job positions may disappear, and some will be newly created. In this sense, it will be necessary to educate workers in the fields of computing, self-learning algorithms and data analysis
39	Hecklau, F; Orth, R; Kidschun, F; Kohl, H	The main point is to discuss the impact and consequences of future technologies, as well as the ongoing digitization within Industry 4.0 of employees' competencies. Using a systematic review, the paper points out the importance of training and developing new competences, not only in research organizations, but also within digitalized business
40	Plumanns, L; Printz, S; Vossen, R; Jeschke, S	The main topic is to build up and evaluate learning cultures in manufacturing companies by introducing a tool to collect data about the current status of learning cultures. The findings provide first guidance for personnel development and future learning activities to promote and measure strategic learning cultures that aim to strengthen effective lifelong learning in the workplace
41	Kinkel, S; Schemmann, B; Lichtner, R	Based on current literature, this paper identifies four clusters of competencies and explains under which conditions they should be rated as critical in Industry 4.0. This paper then proposes a five-step-process that enables companies to identify possible critical competencies and take suitable measures to avoid putting their innovativeness at risk
42	Reuter, M; Oberc, H; Wannoffel, M; Kreimeier, D; Klippert, J; Pawlicki, P; Kuhlenkotter, B	The main topic is to discuss how the implementation of Industry 4.0 technologies, as well as to comprehend their effects on workplaces and labor conditions in Industry 4.0 companies. The paper provides a technology-organization-personnel (T-O-P) approach to develop new learning factory modules, to focus on the facilitation of workers' representatives
43	Schlter, N; Sommerhoff, B	The purpose of this paper is to define basic professional positions in the field of quality engineering regarding quality assurance (QA) and quality management (QM), as well as from an operative to a strategic level. The authors provide an innovative and sustainable role model bundle to define quality occupations for future business models needed for the fourth digital revolution
44	Schuldt, J; Friedemann, S	This paper is devoted to the area of gamification in the context of Industry 4.0 and education. First, a general classification and description of gamification is outlined, and subsequently, the reasons why gamification is important for industry and education are described. Finally, challenges in the introduction of gamification are discussed
45	Fantini, P; Tavola, G; Taisch, M; Barbosa, J; Leitao, P; Liu, Y; Sayed, MS; Lohse, N	The main focus of the paper is to understand how employees can be better integrated to enable increased flexibility in manufacturing systems, whether this is a prerequisite to allow technological solutions, as well as how to harness humans' full potential. For this purpose, two different integration models are analyzed in the context of four industrial cases of deployment of cyber-physical systems in production
46	Hecklau, F; Galeitzke, M; Flachs, S; Kohl, H	The main topic of the paper is to design a strategic approach for employee qualification in Industry 4.0. The paper points out that the number of workspaces with a high level of complexity will increase, resulting in the need for a high level of education of the staff. The paper suggests that future studies focus on the development of specific job profiles, as well as on the integration of individual qualification methods
47	Prinz, C; Morlock, F; Freith, S; Kreggenfeld, N; Kreimeier, D; Kuhlenkotter, B	This article presents a variety of learning modules for the smart factory in Industry 4.0. It describes the new job profile of employees in Industry 4.0 and thoroughly discusses the various learning modules with their individual learning targets and mapped scenarios
48	Baygin, M; Yetis, H; Karakose, M; Akin, E	The article shows with statistical data the importance of education in Industry 4.0. The paper discusses that the most important disadvantage of Industry 4.0 is the shortage of qualified personnel trained in this area. As a result, the concept of Industry 4.0 will require quite significant innovations in terms of both the industry and education
49	Muller, U; Gust, P; Feller, N; Schiffmann, M	The paper discusses software solution development that guides the user continuously through their improvement processes in smart factories. A theoretical simulation study was conducted, and a future development agenda was proposed

(continued)

Table III

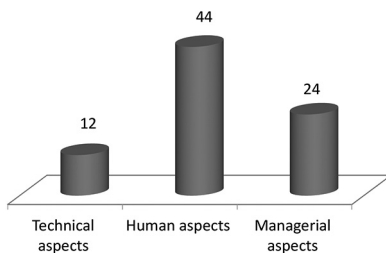
No.	Authors	Summary
50	Schuh, G; Gartzten, T; Rodenhauser, T; Marks, A	The paper discusses the importance of increasing the integration of working and learning in Industry 4.0. Using a demonstration factory inside the RWTH Campus, they empirically study measures for data transfer during pre-process data production
51	Bauer, W; Hammerle, M; Schlund, S; Vocke, C	The study examines initial design approaches in the areas of qualifications, leadership and demography-resistant work architectures. In terms of organization, Industry 4.0 throws up various challenges for companies, requiring them to find efficient structures and methods capable of achieving task-oriented networking of specialized knowledge carriers both within and outside the company
52	Dombrowski, U; Wagner, T	This paper describes future changes for employees in Industry 4.0. The theoretical foundations of a psychological work requirement analysis are presented, showing that relationships between future Industry 4.0 technologies and mental demands are not being addressed adequately

Figure 6 Distribution of Category 1 – emphasis



Notes: Where: Industry 4.0 as central emphasis - 1A; Industry 4.0 as support to other discussions/technical aspects - 1B

Figure 7 Distribution of Category 2 – aspects



Notes: Where: Technical aspects - 2A; Human aspects - 2B; Managerial aspects - 2C

Figure 8 Distribution of Category 3 – method

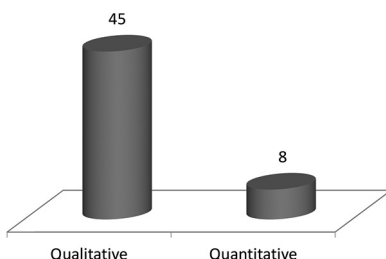


Figure 9 Distribution of Category 4 – research technique

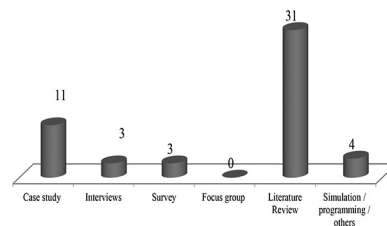
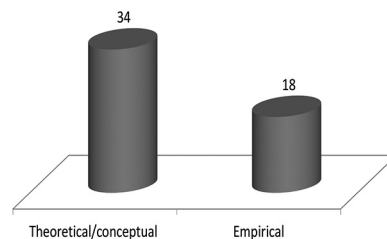


Figure 10 Distribution for Category 5 – approach



4.1.6 Focus

The objective in this category was to find out the principal geographic region of the paper: emerging economies, developed economies or not applicable. More than 40 per cent of the papers discuss the key theme with a focus on developed economies. Only 12 per cent focus on emerging economies (the others were not applicable – no specific focus) (Figure 11). These results show an avenue of research opportunity to explore how the “Industry 4.0” phenomenon will affect emerging economies and what are the possible upcoming changes and impacts.

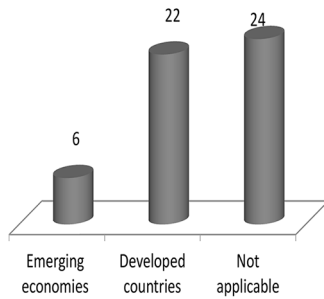
4.1.7 Origin

The majority of the database came from Europe – more than 90 per cent of the sample (Figure 12). Not a single paper came from Latin America, and only a few came from the other regions (North and Central America, Asia and Oceania and Africa). These results show that Latin America (as well as North and Central America, Asia and Oceania and Africa) can make great progress, for instance, by developing studies as a research alliance platform.

4.1.8 Dimensions of HRM

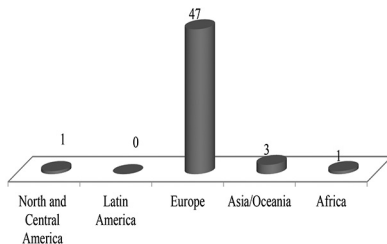
The most important dimension of HRM (Figure 13) in the sample of this systematic review was “Training and

Figure 11 Distribution of Category 6 – Focus



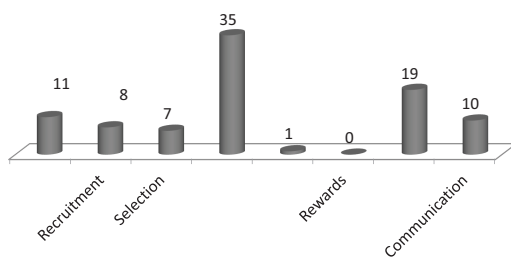
Notes: Where: Emerging economies - 6A; Developed countries - 6B; Not applicable - 6C

Figure 12 Distribution of category 7 – Origin



Notes: Where: North and Central America - 7A; Latin America - 7B; Europe - 7C; Asia/Oceania - 7D; Africa - 7E

Figure 13 Distribution of Category 8 – Dimensions of HRM



Notes: Where: Analysis and description of positions - 8A; Recruitment - 8B; Selection - 8C; Training and development - 8D; Performance Appraisal - 8E; Rewards - 8F; Leadership and teamwork - 8G; Communication - 8H

development” (almost 68 per cent), followed by “Leadership and teamwork” (almost 37 per cent) and “Communication” (almost 20 per cent) (Figure 12). Rajnai and Kocsis (2017) suggest that companies should adapt their HR activities to the changing labor market conditions; Reuter et al. (2017), using a learning factory setting, analyze the effects on workplaces and labor conditions for employees, showing that this approach

enables more engagement in technology-based processes. Meanwhile, Dregger et al. (2016) affirm that practitioners and researchers should explore the organizational conditions needed to bring a human-oriented “Industry 4.0” project.

4.1.9 Changes and effects of Industry 4.0 on HRM

The majority of the analyzed papers highlight changes in the way of working. Almost 64 per cent of the papers discuss this issue (Figure 14). Bobkov and Kvachev (2017) criticize the future changes as a manifestation of the new global order produced by the multitude of local disorders. On the other hand, Trompisch (2017) argues that the use of Industry 4.0 technologies in enterprises will not lead to full automation, suggesting a future scenario of cooperation.

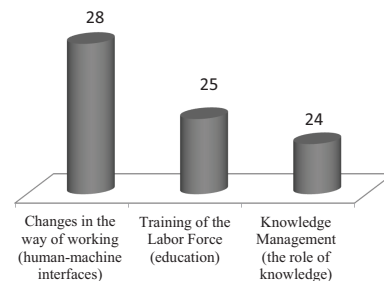
4.1.10 Supply chain management

Almost 29 per cent of the papers highlight “People and Leadership” as a dimension of SCM. This is a curious result, as this subject is directly connected within HRM. Thus, this represents that the integration between both themes (HRM and SCM) is being discussed in the literature (Figure 15).

4.2 Network analysis

To understand how the studied issues are related, two co-occurrence networks were developed. The first network was constructed considering all the keywords with at least two instances. We identified 22 such keywords (Figure 16).

Figure 14 Distribution for the Category 9 - Changing and effects of Industry 4.0 on HRM



Notes: Where: Changes in the way of working (human-machine interfaces) - 9A; Training of the Labor Force (education) - 9B; Knowledge Management (the role of knowledge) - 9C

Figure 15 Distribution for the Category 10 – SCM

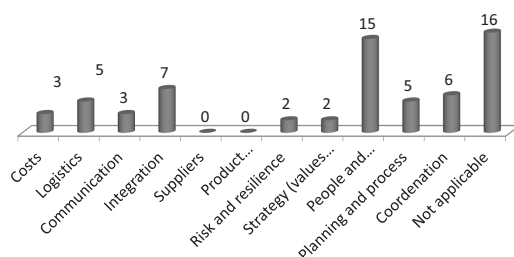
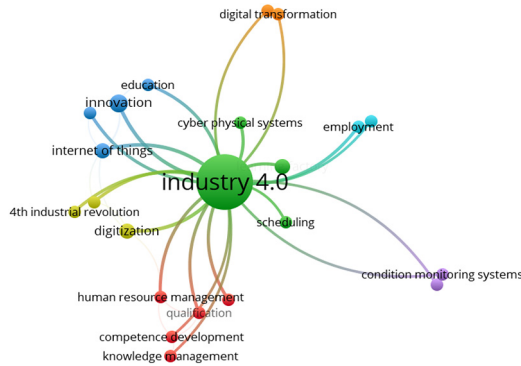


Figure 16 Co-occurrence network of keywords



The core keyword is Industry 4.0, but it is possible to identify ramifications linked to HRM, engineering and computer science. It should be emphasized that keyword categorization may be useful to other researchers through highlighting emerging topics and how they relate to each other. In this sense, a complete list of keywords per cluster is shown in Table IV.

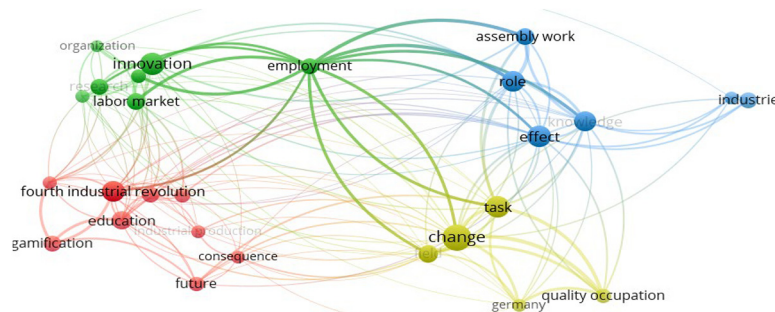
In turn, a second co-occurrence network (Figure 17) was elaborated based on the abstracts of the analyzed articles. The term “employment” has centrality in this network of words and connects the four clusters generated.

In this context, changes in employability issues are central to the discussion, although they have a distinct focus depending on the cluster to which they belong. The terms that appear in each cluster are pointed out in Table V.

Table IV Cluster of author’s keywords

Cluster	Keywords
Cluster 1	Competence development; HRM; knowledge management; qualification
Cluster 2	Cyber–physical system; Industry 4.0.; learning factory; scheduling
Cluster 3	Cyber–physical system; education; innovation; Internet-of-Things
Cluster 4	Fourth Industrial Revolution; digitalization; STS
Cluster 5	Condition monitoring; socio-cyber-physical systems
Cluster 6	Employment; labor market
Cluster 7	Digital transformation; sustainability

Figure 17 Co-occurrence network from abstracts terms



Clusters 1 (educational changes) and 2 (employment scenario) have as their central aspect the Fourth Industrial Revolution, the changes needed from the educational point of view and its consequences for the future. In this context, developing new technologies might generate new business models that consequently will change job patterns and create new employment opportunities (Rajnai and Kocsis, 2017).

The proposed state of Industry 4.0 will affect not only manual, heavy and repetitive work, but also intellectual and cognitive work (Kergroach, 2017):

In industry, this concerns not only the activities on the shop floor, but also the indirect areas, from planning and control systems to product development, and the demands on leadership and management will also change significantly (Dregger et al., 2016).

Table VI summarizes the main expected impacts on HRM through the digitization process.

It is expected that the digitization process will naturally generate the creation of new products, services, processes and business models. The papers suggest that work will change permanently as the application of digital technologies advances across the various sectors of the economy (Dregger et al., 2016). The changes in the methods of production and introduction of new technologies should lead to gains in efficiency and industrial productivity (Kergroach, 2017; Rajnai and Kocsis, 2017).

On the other hand, this process will lead to the loss of jobs and replacement of labor by machinery. “Where there were many factory workers in the previous era, there will be few highly-qualified engineers and programmers in the future” (Bobkov and Kvachev, 2017). Also, digitization can lead to new waves of job shifts in emerging countries with lower labor costs and the growth of precarious work, which is explained as a consequence of the division of labor markets and the changing nature of labor (Kergroach, 2017; Rajnai and Kocsis, 2017; Bobkov and Kvachev, 2017).

It is noted in the literature that the main limitation for the advancement of Industry 4.0 is the lack of skilled labor. This limitation acts as a constraint on the current development of Industry 4.0, as well as restrictions in the medium and long term, given the professional profile formed in educational institutions (Baygin et al., 2016; Motyl et al., 2017; Benešová and Tupa, 2017).

Thus, the academic curriculum must be redesigned, taking into account the principles of Industry 4.0 (Baygin et al., 2016). The development of soft skills should be encouraged as they will be necessary for the advancement of the industry, and

Table V Clusters from the abstract network

Cluster 1 Educational changes	Cluster 2 Employment scenario	Cluster 3 Work infrastructure resources	Cluster 4 Work meaning and proposal
Consequence	Employment	Assembly work	Change
Context	Framework	Effect	Field
Czech Republic	Innovation	Industry	Germany
Education	Labor market	Knowledge	Quality occupation
Fourth Industrial Revolution	Organization	Role	Task
Future	Precarity	Workplace	
Gamification	Research		
Industrial Production			
Need			

Table VI Digitization impacts

Positive	Digitization impacts Negative
Creating new jobs, changing current jobs	Losing repetitive and manual jobs and substituting human workforce
Improvement in industrial productivity	Relocating and outsourcing job changes, worsening work conditions in emerging countries
Developing new products, processes or new business models	Rising and intensifying inequalities and social gaps around the world, especially between emerging and developed countries
Managing challenges and risks of digitization is a joint responsibility of all stakeholders	
Sources: Kergroach (2017); Rajnai and Kocsis (2017)	

because they are difficult to automate, will concentrate job opportunities for humans rather than machines (Kergroach, 2017). “University needs to create broader and better-structured knowledge of the basic concepts related to this new industrial revolution” (Motyl et al., 2017).

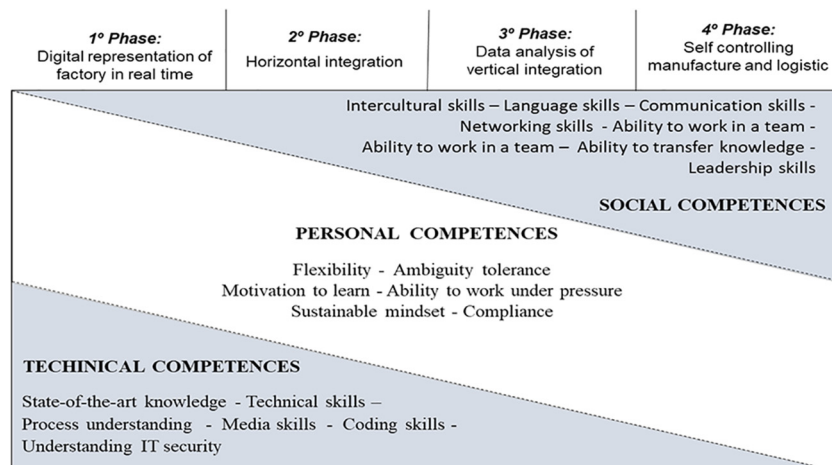
In this sense, it will be necessary to have new jobs with high skill requirements (Hedvicakova and Svobodova, 2017), and nowadays, there is a lack of specialists, which could be covered

by the implementation of a new curriculum for students (Kharchenko et al., 2017). It is expected that “the number of workspaces with a high level of complexity will increase, resulting in the need for a high level of staff education” (Hecklau et al., 2016). The papers have listed human tasks in existing and future cyber-physical production systems and estimate the evolutionary behavior of these tasks (Becker and Stern, 2016). Thus, based on the works of Benešová and Tupa (2017) and Hecklau et al. (2016), it is possible to identify key competencies to be encouraged throughout the deployment phases of Industry 4.0 (Figure 18).

Figure 18 presents, at the top, the four-phase implementation sequences of Industry 4.0 (Benešová and Tupa, 2017). Throughout these phases, HRM should encourage technical, personal and social skills (Hecklau et al., 2016). However, as the stages progress, the importance of social skills such as intercultural skills and leadership increases.

The first phase consists of the introduction of ERP and ERP II information systems. This phase will initially require engineers with a technical background in business process mapping. Increasing scanned data will also require IT professionals (Benešová and Tupa, 2017). In this context, technical skills on process understanding, data security and IT will be key success factors (Hecklau et al., 2016).

Figure 18 Key competencies to be encouraged within Industry 4.0



The importance of technical skills persists in the second phase, where horizontal integration and implementation of automatic machines are expected. Thus, the technical knowledge of process engineers will be critical at this stage. In addition, personal skills such as tolerance and motivation to learn should be encouraged, as phase 2 begins to generate significant changes in methods of working (Benešová and Tupa, 2017; Hecklau et al., 2016).

The third phase involves data analysis and vertical integration:

And here we will find the biggest problem of Industry of 4.0. Education systems did not predict the rapid demand for data analysts, so the data analysis as a field of study is very small and underdeveloped at this time (Benešová and Tupa, 2017).

One of the alternatives in this context is the development of learning factories, in which it is possible to adequately train this new work profile, getting acquainted with new technologies in business process mapping and data analytics (Prinz et al., 2016).

As vertical integration occurs, one must be attentive to how to integrate employees in this context of changes in the social and technical system. This integration will be fundamental to increase the flexibility of the manufacturing system while taking advantage of the best technological solutions and human potential installed (Fantini et al., 2016). For example, the challenges of this transition are how the labor market will be affected by the implementation of partnerships with collaborative robots (Calitz et al., 2017) and artificial intelligence (Rajnai and Kocsis, 2017).

In the fourth phase, it is expected that the production systems will be almost autonomous. Operators, data analysts and quality control systems will be needed. The integration in this model will overcome the vertical structure, connecting factories in regions or even different countries. In this sense, logistics and transportation activities will be essential (Benešová and Tupa, 2017). To deal with hyperconnected systems, social skills such as intercultural skills, language skills, leadership and teamwork will be essential (Hecklau et al., 2016), as several technical processes at this stage can be performed by robots and artificial intelligence (Kergroach, 2017; Calitz et al., 2017).

Cluster 3 (work resources infrastructure) has a technical approach, focusing on the effects and role of knowledge in this context of changes in employment. Studies are focusing on the current and future implementation of collaborative robots and its impacts on the workforce and workspace (Calitz et al., 2017). Furthermore, the general scenario of the latest technological trends of Industry 4.0 and their consequences on the structure of the labor market is also a significant highlight (Kergroach, 2017):

- Artificial intelligence (AI) can contribute to the development of new types of software and robots directing their learning and operation independently of human decisions, becoming autonomous agents.
- Robots with AI will significantly impact logistics and manufacturing processes, as they can ensure greater safety, speed, accuracy and productivity.
- The benefits of such emerging technologies will be gained through the adaptability of labor markets.
- Technological change is one of the main factors that can influence employment markets.

In the case of assembly plants, it may be hard to replace humans with robotics, and assembly work should not be tagged as simply routine work, as complex work environments depend on

human skills, and even more, on their experiential abilities. These aspects are the opposite of simple routine (Pfeiffer, 2016). Besides, how to evaluate learning cultures in the context of Industry 4.0 is also a relevant research question (Plumanns et al., 2015). There are also papers addressing how the Fourth Industrial Revolution will change the nature of labor, leading to inequality as a result. All this may lead to the expansion of precarious employment – the deconstruction of standard employment relations is based on four factors:

- 1 the dynamics of labor market divisions;
- 2 the Fourth Industrial Revolution;
- 3 the changing nature of work; and
- 4 the intervention of neoliberal ideology (Bobkov and Kvachev, 2017).

At the same time, businesses and society do not have the option of not pursuing Industry 4.0 and collaboration-based practices (Calitz et al., 2017).

Finally, Cluster 4 (work meaning and proposal) shows the importance of the change process in Industry 4.0. The starting point was German conferences and working papers, but the development of innovative behaviors (Lukes and Stephan, 2017) and culture of innovation (Patterson et al., 2005; Reicher, 2011) ensure that the shift to digitalization is global. Changes in the socio-technical production system (changes in the technological system, the human operating system or in the organization system) will affect people in the workplace (Dombrowski and Wagner, 2014), and research regarding ergonomic work systems is gaining space. A significant finding by Dombrowski and Wagner (2014) is that there is less research on the relationship between Industry 4.0 technologies and how these technologies are going to impact mental issues.

Regarding HRM in the Industry 4.0 scenario, changes can be divided into two types (Dombrowski and Wagner, 2014):

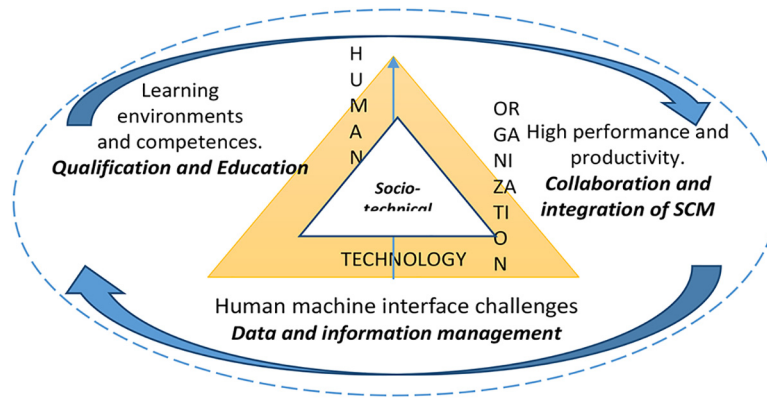
- 1 *Job profile change*: from the execution of specific manufacturing tasks to interdisciplinary cooperation-based tasks; and
- 2 *Competency change*: from specific technical abilities to problem-solving and complexity abilities.

The evolutionary behavior of job profile and competency change in the context of Industry 4.0 (Dombrowski and Wagner, 2014) corroborates the conclusions of Benešová and Tupa (2017) and Hecklau et al. (2016) and is related to the ideas presented in Figure 18.

The balance between job losses in the medium-term economy and the promise of highly qualified occupations is more feasible in Germany, as this country presents dedicated reports such as Rajnai and Kocsis (2017). Differences will be focused on the level of automation of each nation, leading developed countries more naturally adapted to perform changes in organizational and social support systems. The trend shows that this balance is a part of the overall industry change, which is approaching all countries in the long-range perspective. Also, as pointed out by Rajnai and Kocsis (2017), all stakeholders must be engaged with the challenges, risks and opportunities of digital transformation, at all levels: individuals, companies, countries and governments.

The STS of HRM4.0 for SCM is summarized in Figure 19. To manage the three-competency model (technical, social and personal/human), designed based on the results of the

Figure 19 STS of 4.0 HRM for SCM



systematic literature review, we present an STS framework. The association demonstrates that the necessary challenges of the digitization process and the smart industry cross the borders of HRM tasks, enabling it to connect a strategy of education with technology, forcing a more integrated STS by prioritizing technical (technological) issues over human aspects. We understand that human relations with technology will be recursive: humans create new business and organizational models to manage technology, and organizations provide infrastructure to adapt other humans to technology.

5. Final remarks

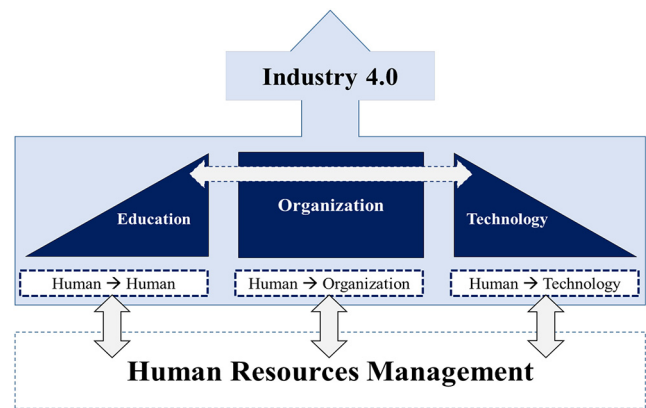
The analyzed articles point to the development context of Industry 4.0, highlighting how technology and knowledge are revolutionizing the operation of organizations. It is clear that this Fourth Industrial Revolution presents risks, opportunities and challenges. Risks are related to eventual job losses and the extension of the gap between developed and emerging economies. The opportunities can be summarized as a more efficient production system, combining low costs with customized products and services. When it comes to challenges, organizations are in a position to utilize intra-organizational processes to move toward HRM 4.0. This shift leads the traditional approach of hiring, selecting, assessing and rewarding to a new business model that has its basis in collaborative learning and competency development, leading to paths toward changes in education systems.

From this perspective, organizations are responsible for moving themselves into a socio-cyber-technical perspective and providing creative solutions to the unfolding human-machine interface. Figure 20 summarizes the theoretical contributions of this research corpus.

5.1. Key topics for a research agenda on Industry 4.0, HRM and SCM

In this context, the articles also show the importance of HRM for the development of Industry 4.0. Industry 4.0 is supported by advances in production and technology. However, the “glue” of the system is HRM. This implies changes in the way people relate to each other (human to human), the way they relate to the new business model and the way they relate to the innovations and technologies emerging in this new

Figure 20 A theoretical framework of actual knowledge corpus



manufacturing smart industry (human to organization and human to technology) (Figure 21).

As a result of the systematic review conducted in this study, a framework with an agenda for future research is shown in Figure 22.

We can affirm that the literature is in the transition process from the early studies of German academia to the development of new impacts worldwide. Industry 4.0 is the central theme of the analyzed literature corpus, being accomplished through the development of employment, qualifications, skills and learning frameworks.

The results reveal that the existing papers are mostly conceptual, and quantitative methods are still lacking for

Figure 21 Research avenues on HRH and Industry 4.0

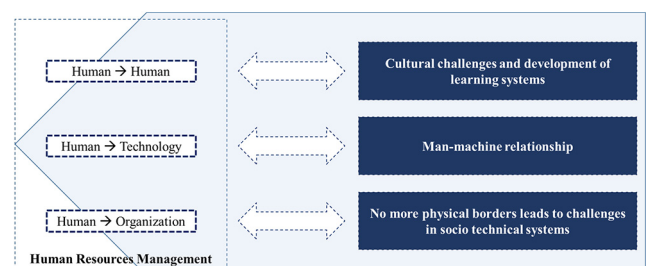
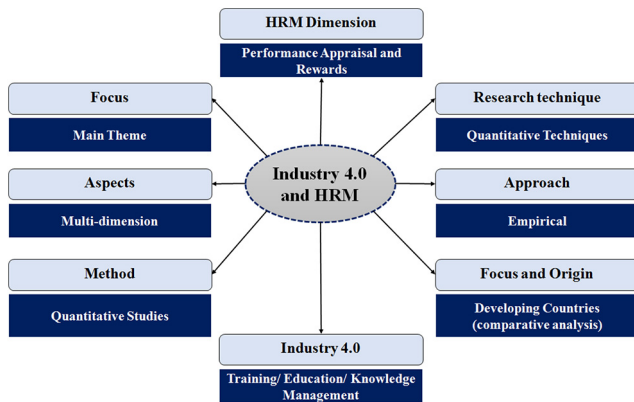


Figure 22 Opportunities for a research agenda

empirical applications. Developed countries, and especially the Central European region, figure as the center of the research production, while Latin America and Asia do not appear in any paper on the list. Empirical research has growth potential because Industry 4.0 is an emergent and relevant theme, seeking to develop insights through empirical research to face challenging problems.

The majority of the papers analyzed highlight changes in the way of working. There are also opportunities for studies that analyze other HRM dimensions, as the focus has been on training and development, leadership and teamwork and communication. It will be necessary to study new selection and recruitment models, as well as performance and new competencies.

Clustering has shown four main themes: labor changes, work conditions, environment and new skills demanded. Also, the labor market appears to be undergoing an unstable shift toward high-level context. The third theme relates to the technical interface of humans and machines, and finally, the fourth understands German industry as a starting point for global industrial improvements.

There is a great opportunity to discuss new demands on qualifications and education, to create a broader and better-structured knowledge of the basic concepts related to this new industrial revolution. Research into new jobs and new skill requirements will be necessary, and the role of universities and education from this perspective must be discussed.

Research focusing on how the labor market will be affected by the implementation of partnerships with collaborative robots is also on the agenda for future studies, as well as discussion about technological changes resulting in inequality and a possible expansion of precarious employment.

There is also an opportunity for studying the differences between countries, as the level of automation of each nation naturally adapts a faster performance in the organizational transformations towards Industry 4.0. Also, the social and technological impacts of this industrial revolution are felt differently in each nation, and this should present a rich research topic.

5.2 Potential implications for the SCM community

While the relationships among Industry 4.0, human-related aspects and SCM remain a scarcely studied topic, we believe

that the development of this theme will affect the SCM community and practitioners. Selected implications are:

- Industry 4.0 will require an adapted and well-equipped HRM. It is important that SCM managers and departments work closely with HR departments to understand the main skills, knowledge gaps and training necessities to keep the company competitive;
- global supply chains, spread across different nations, will need to be well managed and will need to align and coordinate efforts in terms of the adoption of Industry 4.0 and HRM initiatives that will support change management;
- SCM managers will need strong support from supply chain associations to further develop their understanding on the implications of Industry 4.0; and
- focal companies in a supply chain will most likely lead the adoption of Industry 4.0 technologies across the chain, and these focal companies will, therefore, need to carefully understand the impacts of new technologies on human resources-related topics, to maintain the competitiveness of their supply chains.

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Further reading

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Appendix 1

Table AI Articles used in the systematic review

Authors (Year)	Title
Ansari et al. (2018)	Rethinking Human-Machine Learning in Industry 4.0: How Does the Paradigm Shift Treat the Role of Human Learning?
Antosz (2018)	Maintenance - identification and analysis of the competency gap
Bauer et al. (2015)	Transforming to a hyper-connected society and economy - towards an "Industry 4.0"
Baygin et al. (2016)	An Effect Analysis of Industry 4.0 to Higher Education
Becker and Stern (2016)	Future trends in human work area design for cyber-physical production systems
Benešová and Tupa (2017)	Requirements for Education and Qualification of People in Industry 4.0
Bobkov and Kvachev (2017)	Precarity: Local Disorders or New Global Order?
Buth et al. (2018)	Training concept for and with digitalization in learning factories: An energy efficiency training case
Calitz et al. (2017)	The future African workplace: The use of collaborative robots in manufacturing
Dombrowski and Wagner (2014)	Mental strain as field of action in the 4th industrial revolution
Dregger et al. (2016)	The Digitization of Manufacturing and its Societal Challenges A Framework for the Future of Industrial Labor
Eichhorst et al. (2016)	How Big is the Gig? Assessing the Preliminary Evidence on the Effects of Digitalization on the Labor Market
Enke et al. (2018)	Industrie 4.0-Competencies for a modern production system A curriculum for Learning Factories
Fantini et al. (2016)	Exploring the integration of the human as a flexibility factor in CPS enabled manufacturing environments: methodology and results
Frynn et al. (2017)	Industry 4.0 and Its Potential Impact on Employment Demographics in the UK
Freddi (2018)	Digitalisation and employment in manufacturing
Grzelczak et al. (2017)	Employees competences for industry 4.0 in Poland-preliminary research results
Hecklau et al. (2016)	Holistic approach for human resource management in Industry 4.0
Hecklau et al. (2017)	Human Resources Management: Meta-Study - Analysis of Future Competences in Industry 4.0
Hedvicakova and Svobodova (2017)	The labor market of the Czech Republic in the context Industry 4.0
Hirsch-Kreinsen (2016)	Digitization of industrial work: development paths and prospects
Johansson et al. (2017)	Work and Organization in a Digital Industrial Context
Kergroach (2017)	Industry 4.0: New Challenges and Opportunities for the Labour Market
Kharchenko et al. (2017)	Emerging Curriculum for Industry and Human Applications in Internet of Things
Kinkel et al. (2017)	Critical Competencies for the Innovativeness of Value Creation Champions: Identifying Challenges and Work-integrated Solutions
Kotýnková (2016)	Industry 4.0: will the concept affect the world of work?
Kulyk and Škodová (2017)	E-business development: the comparative study of the Czech Republic and the Ukraine
Motyl et al. (2017)	How will change the future engineers' skills in the Industry 4.0 framework? A questionnaire survey
Mourtzis et al. (2018)	Cyber- Physical Systems and Education 4.0-The Teaching Factory 4.0 Concept
Muller et al. (2018)	An overview of work analysis instruments for hybrid production workplaces
Müller et al. (2015)	WorkDesigner: Consulting application software for the strain-based staffing and design of work processes
Nyikes (2018)	Contemporary digital competency review
Okyay (2016)	Industry 4.0: increasing women's participation in the workforce
Özlü (2017)	The advent of turkey's industry 4.0
Palazzeschi et al. (2018)	Re-thinking Innovation in Organizations in the Industry 4.0 Scenario: New Challenges in a Primary Prevention Perspective
Pfeiffer (2016)	Robots, Industry 4.0 and Humans, or Why Assembly Work Is More than Routine Work
Plumanns et al. (2015)	Strategic Management of Personnel Development in the Industry 4.0
Prinz et al. (2016)	Learning Factory modules for smart factories in Industrie 4.0
Qu et al. (2016)	Optimized Adaptive Scheduling of a Manufacturing Process System with Multi-Skill Workforce and Multiple Machine Types: An Ontology-Based, Multi-Agent Reinforcement Learning Approach
Rajnai and Kocsis (2017)	Labor Market Risks of Industry 4.0, Digitization, Robots and AI
Reuter et al. (2017)	Learning factories' trainings as an enabler of proactive workers' participation regarding Industrie 4.0
Reuter et al. (2017)	Learning factories' trainings as an enabler of proactive workers' participation regarding Industrie 4.0
Salento (2018)	Digitalisation and the regulation of work: theoretical issues and normative challenges
Schlüter and Sommerhoff (2017)	Development of the DGQ role bundle model of the Q occupations
Schuh et al. (2015)	Promoting work-based learning through Industry 4.0

(continued)

Table AI

Authors (Year)	Title
Schuldt and Friedemann (2017)	The Challenges of Gamification in the Age of Industry 4.0 Focusing on man in future machine-driven working environments
Seitz and Nyhuis (2015)	Cyber-Physical Production Systems Combined with Logistic Models - A Learning Factory Concept for an Improved Production Planning and Control
Setiawan and Yahya (2018)	Improved behavior model based on sequential rule mining
Strandhagen et al. (2016)	Importance of Production Environments When Applying Industry 4.0 to Production Logistics - A Multiple Case Study
Strandhagen et al. (2017)	The fit of Industry 4.0 applications in manufacturing logistics: a multiple case study
Trompisch (2017)	The implications of Industry 4.0 on the future of work
Wulfken and Müller (2017)	How to Improve Employee Education - Methodological Approach to Structure Specialist and Interdisciplinary Requirements

Appendix 2

Table AII Results of the categorization (systematic review)

Authors	Emphasis	Aspects	Method	Research technique	Approach	Focus	Origin	Dimensions of Human Resource Management	Changing and effects of the Industry 4.0 on HRM	Supply Chain Management
Ansari, F; Erol, S; Sihni, W	1A	2B, 2C	3 ^a	4A	5B	6B	7C	8D, 8G	9B, 9C	10I, 10K
Antosz, K	1B	2B	3B	4C	5B	6B	7C	8D, 8E	9B, 9C	10L
Bauer, W; Hammerle, M; Schlund, S; Vocke, C	1A	2B, 2C	3A, 3B	4E	5A	6B	7C	8D, 8G	9A, 9B	10D
Baygin, M; Yetis, H; Karakose, M; Akin, E	1A	2B	3B	4E	5B	6B	7C	8B, 8C, 8D	9B	10L
Becker, T; Stern, H	1B	2B	3 ^a	4E	5A	6B	7C	8D	9A	10C, 10D
Benesova, A; Tupa, J	1A	2B, 2C	3 ^a	4E	5A	6C	7C	8A, 8C, 8D	9A, 9B, 9C	10 ^a
Bobkov, V; Kvachev, V	1B	2B	3 ^a	4E	5A	6C	7C	8B, 8C	9A	10L
Buth, L; Blume, S; Posselt, G; Herrmann, C	1A	2A, 2B	3 ^a	4E	5A	6C	7C	8D	9B, 9C	10I
Calitz, AP; Poisat, P; Cullen, M	1A	2A, 2B	3 ^a	4B	5B	6A	7E	8D, 8G, 8H	9A, 9C	10J
Dombrowski, U; Wagner, T	1A	2B	3 ^a	4E	5A	6C	7C	8G	9A	10A
Dregger, J; Niehaus, J; Ittermann, P; Hirsch-Kreinsen, H; ten Hompel, M	1B	2B, 2C	3 ^a	4E	5A	6B	7C	8D	9A	10L
Eichhorst, W; Hinte, H; Rinne, U; Tobsch, V	1B	2B, 2C	3 ^a	4E	5A	6B	7C	8A, 8D	9A	10L
Enke, J; Glass, R; Kress, A; Hambach, J; Tisch, M; Metternich, J	3A	2B, 2C	3 ^a	4E	5A	6C	7C	8G	9A	10D
Fantini, P; Tavola, G; Taisch, M; Barbosa, J; Leitao, P; Liu, Y; Sayed, MS; Lohse, N	1A	2A, 2B, 2C	3 ^a	4A	5B	6B	7C	8D, 8G	9A, 9C	10I
Flynn, J; Dance, S; Schaefer, D	1B	2B, 2C	3 ^a	4E	5A	6B	7C	8D	9B	10I
Freddi, D	1B	2A, 2B	3 ^a	4A	5B	6B	7C	8H	9C	10A, 10I
Grzelczak, A; Kosacka, M; Werner-Lewandowska, K	1A	2B	3B	4C	5B	6A	7C	8A, 8D	9A, 9B	10I
Hecklau, F; Galeitzke, M; Flachs, S; Kohl, H	1A	2B, 2C	3 ^a	4E	5A	6C	7C	8A, 8D, 8G	9B	10I
Hecklau, F; Orth, R; Kidschun, F; Kohl, H	1B	2B	3 ^a	4E	5A	6C	7C	8A, 8D	9A, 9C	10I
Hedvicakova, M; Svobodova, L	1A	2B	3B	4F	5B	6B	7C	8B, 8C, 8D	9A, 9B	10L
Hirsch-Kreinsen, H	1B	2B, 2C	3 ^a	4E	5A	6B	7C	8G, 8H	9A	10B
Johansson, J; Abrahamsson, L; Kareborn, BB; Falholm, Y; Grane, C; Wykowska, A	1A	2B, 2C	3 ^a	4E	5A	6B	7C	8A, 8D	9A, 9C	10I, 10J, 10K
Kergroach, S	1A	2B	3 ^a	4E	5A	6C	7C	8B, 8C, 8D	9B, 9C	10G
Kharchenko, V; Illiashenko, O; Boyarchuk, A; Sklyar, V; Phillips, C	1B	2B	3 ^a	4A	5A	6A	7C	8D	9B	10I
Kinkel, S; Schemmann, B; Lichtner, R	1A	2B	3 ^a	4E	5A	6C	7C	8A, 8D	9B, 9C	10I
Kotynkova, M	1A	2B, 2C	3 ^a	4E	5A	6B	7C	8A, 8D	9A	10K
Kulyk, V; Parmova, DS	1B	2B, 2C	3 ^a	4E	5A	6A	7C	8B	9C	10D
Motyl, B; Baronio, G; Uberti, S; Speranza, D; Filippi, S	1A	2B	3B	4C	5B	6B	7C	8B, 8C, 8D	9B	10L
Mourtzis, D; Vlachou, E; Dimitrakopoulos, G; Zogopoulos, V	1B	2B	3 ^a	4A	5B	6C	7C	8D	9B	10I
Muller, SL; Shehadeh, MA; Schroder, S; Richert, A; Jeschke, S	1A	2A, 2B	3 ^a	4E	5A	6C	7C	8A	9A	10L
Muller, U; Gust, P; Feller, N; Schiffmann, M	1B	2A	3 ^a	4F	5A	6C	7C	8G, 8H	9A	10L
Nyikes, Z	1B	2B	3 ^a	4E	5A	6B	7C	8D	9B, 9C	10I, 10K
Okay, ZB	1B	2B	3 ^a	4B	5A	6C	7D	8A	9B	10L
Ozlu, F	1A	2C	3 ^a	4E	5A	6A	7D	8D	9B, 9C	10D, 10I
Palazzeschi, L; Bucci, O; Di Fabio, A	1B	2B	3 ^a	4E	5A	6C	7C	8G	9C	10L
Pfeiffer, S	1B	2B, 2C	3 ^a	4A	5B	6B	7C	8B, 8D	9A	10G
Plumanns, L; Printz, S; Vossen, R; Jeschke, S	1A	2B, 2C	3 ^a	4A	5B	6A	7C	8D, 8G	9A, 9C	10H
Prinz, C; Morlock, F; Freith, S; Kreggenfeld, N; Kreimeier, D; Kuhlentotter, B	1A	2B, 2C	3 ^a	4E	5A	6C	7C	8D, 8G, 8H	9A, 9C	10L
	1A	2A, 2B	3B	4F	5A	6C	7A	8G	9A	10J

(continued)

Table All

Authors	Emphasis	Aspects	Method	Research technique	Approach	Focus	Origin	Dimensions of Human Resource Management	Changing and effects of the Industry 4.0 on HRM	Supply Chain Management
Qu, SH; Wang, J; Govil, S; Leckie, JO										
Rajnai, Z; Kocsis, I	1A	2B	3 ^a	4E	5A	6C	7C	8B, 8C, 8D, 8G, 8H	9A, 9B, 9C	10B
Reuter, M; Oberc, H;	1B	2B	3 ^a	4A	5B	6B	7C	8D	9B	10L
Wannoffel, M; Kreimeier, D; Klippert, J; Pawlicki, P; Kuhlenkotter, B										
Reuter, M; Oberc, H; Wannoffel, M; Kreimeier, D; Klippert, J; Pawlicki, P; Kuhlenkotter, B	1A	2B, 2C	3 ^a	4E	5A	6C	7C	8D, 8G, 8H	9A, 9C	10J
Salento, A	1A	2B, 2C	3 ^a	4E	5A	6C	7C	8D, 8G	9A, 9B	10K, 10H
Schlter, N; Sommerhoff, B	1B	2C	3 ^a	4E	5A	6C	7C	8G, 8H	9C	10I
Schuh, G; Gartzten, T;	1A	2A	3 ^a	4A	5B	6B	7C	8H	9C	10K
Rodenhauser, T; Marks, A										
Schuldt, J; Friedemann, S	1B	2A, 2C	3 ^a	4E	5A	6C	7C	8D	9B, 9C	10C
Seitz, KF; Nyhuis, P	1A	2A, 2C	3 ^a	4E	5A	6C	7C	8D	9B	10B, 10D, 10J
Setiawan, F; Yahya, BN	1B	2B	3B	4F	5B	6C	7D	8G	9B	10L
Strandhagen, JW; Alfnes, E;	1A	2A, 2C	3 ^a	4A	5B	6B	7C	8A	9A, 9C	10B
Strandhagen, JO; Swahn, N										
Strandhagen, JW; Alfnes, E; Strandhagen, JO;	1A	2A, 2C	3 ^a	4A	5B	6B	7C	8H	9A, 9C	10B, 10C, 10D
Vallandingham, LR										
Trompisch, P	1A	2B	3 ^a	4E	5A	6C	7C	8G	9A	10L
Wulfken, BT; Muller, E	1B	2B	3 ^a	4B	5B	6B	7C	8D	9B	10L

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