Human resource competencies in the automotive Industry 4.0 – results of a systematic literature review

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Abstract: The advance of digitalisation in the business landscape has ushered in a new era characterised by complexity and innovation, with the Industry 4.0, a paradigm merging traditional manufacturing with cutting-edge information technology, at its core. The existing research underscores the critical need for comprehensive research into the precise human resource competencies essential for the Industry 4.0 in the automotive sector. To address this pressing need, this research embarks on a comprehensive literature review to determine the current state of research on human resource competencies in the context of Industry 4.0 and to provide the basis for further research. The stakeholders of this research include automotive industry leaders, policymakers, educators, and workers. The findings of this research will inform the development of effective training programs, talent management strategies, and policy decisions, ensuring that the workforce is optimally prepared to navigate the transformative journey in the automotive sector during the Industry 4.0 era.

Keywords: HR competencies; Automotive Industry 4.0; human-machine interaction; systematic literature review.

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1 Introduction

The digital surge has reshaped the business world, introducing complexities and innovations (Reis et al., 2020). Central to this shift is Industry 4.0, merging manufacturing with advanced technology (Olsen and Tomlin, 2020). As digitalisation progresses, organisations must adapt their workforce, automate tasks, and align capabilities with future demands (Bag et al., 2021). Research underscores the need for staff training, cost-benefit analysis, and data utilisation (Helming et al., 2019). To navigate Industry 4.0's landscape, it is imperative to identify precise human resource competencies (Bag et al., 2021).

The current research landscape stresses the integration of lean manufacturing and production flow modelling competencies (Niţu and Gavriluţă, 2019). These span technical, managerial, and social domains (Popkova and Zmiyak, 2019). The term 'Human Capital 4.0' encompasses digital literacy and emotional intelligence (Flores et al., 2020), highlighting the human-centric approach's importance (Kong et al., 2018).

While many studies acknowledge evolving skill requirements and emerging technologies (Bag et al., 2021; Grabowska et al., 2022; Olsen and Tomlin, 2020), they lack specificity on future skill sets. This underscores the need for tailored training programs (Bag et al., 2021).

Blockchain secures data sharing in the automotive supply chain (Fraga-Lamas and Fernández-Caramés, 2019). Digital manufacturing demands competencies like digital literacy (Demeter et al., 2020) and advocates for analytical and technology adaptation skills (Frazzon et al., 2018). Big data analytics, especially in supply chain management, is crucial for Industry 4.0 (Raut et al., 2019), but a skills gap exists in real-time data integration (Colombari et al., 2023).

Understanding indispensable human resource competencies for the automotive Industry 4.0 is vital for gauging current status and research focuses. It can reveal global or region-specific workforce requirements, informing training initiatives (Bag et al., 2021). Ultimately, the aim is to bridge knowledge gaps and ensure workforce readiness for the automotive sector's transformative journey.

Therefore, it is the original purpose of this research to investigate the human resource competencies required for the automotive industry's transition to Industry 4.0 by means of a systematic literature review. The goal is to identify precise competencies needed for the workforce to adapt to the evolving landscape of the automotive sector. The research aims to bridge knowledge gaps and ensure workforce readiness for the transformative journey of the automotive industry. In case precise and actual human resource competencies cannot be identified, hypothetical deductions in the fields identified in the literature, including blockchain technology, big data analytics, autonomous systems, and human-system interactions, shall be made. As will be shown, despite recognising the significance of these areas, the literature falls short of detailing the specific competencies and skills required by the workforce to address the challenges and opportunities presented by these technologies, thus inviting further research.

2 The systematic literature review process

The automotive industry has seen significant changes in recent decades, largely due to the rise of Industry 4.0 (Bigliardi et al., 2020; Malik et al., 2021). This new phase of industrial evolution integrates advanced technologies like AI, big data analytics, robotics, and IoT into manufacturing processes (Ito et al., 2020; Karataş et al., 2022; Malik et al., 2021), resulting in smart factories and agile supply chains that boost productivity and efficiency (Arcidiacono et al., 2019; Stawiarska et al., 2021). However, this technological shift also poses challenges for human resource management, necessitating a re-evaluation of employee competencies.

This study assumes that human resource capabilities are critical for organisational success, proposing that employees now require a blend of technical proficiency and digital literacy instead of solely traditional manufacturing skills. Additionally, it aims to explore the specific competencies needed in this evolving human resource landscape.

2.1 Used definition of literature review process

A systematic literature review is a structured and transparent method for gathering relevant literature in response to a specific research question, aiming to provide a comprehensive overview that is easily understandable by others (Okoli, 2015; Linnenluecke et al., 2020). Its goal is to outline procedures that, if replicated precisely, would yield similar results, accounting for some subjective interpretation and evaluation of material relevance (Paul et al., 2021). This approach, distinguished by its replicable, scientific, and transparent process, aims to minimise bias through exhaustive searches of published and unpublished studies, accompanied by an audit trail of decisions and conclusions (Tranfield et al., 2003).

Systematic reviews have gained prominence due to criticisms of traditional narrative reviews for their lack of structure, objectivity, and reproducibility, and their subjective data collection and interpretation. The proliferation of academic databases has underscored the need for more transparent and systematic approaches to account for the abundance and variety of available research (Kraus et al., 2020). However, it is important to acknowledge that researchers' agendas and biases may still influence the process (Kraus et al., 2020). While no universally applicable standard exists, various models provide similar structures for systematic literature reviews (Cocchia, 2014; Følstad and Kvale, 2018). According to Jan vom Brocke's recommendations, the process involves defining the study's object, conceptualising the topic, conducting literature searches, analysing and synthesising findings, and potentially refining the research agenda (Brocke et al., 2009, 2015).

2.1.1 Data and methodology

In proposing such an approach, vom Brocke refers to the work of Harris Cooper (1988) for a taxonomy of the literature search in order to concretise and operationalise the way of analysing. In that approach, the author aims for focus, has a clearly defined goal, is organised and has a perspective, pursues a specific audience and coverage (Brocke et al., 2009). More specifically, it needs to be defined what the authors intends to do with her or his research (e.g., providing an overview of theories and a critical review), what her or his actual intend is (e.g., an objective representation or espousal of position) and how extensive the review is going to be.

It needs also to be noted that after a selection of databases and relevant journals, both a forward and a backward search – i.e., related to the references mentioned in articles – can be applied.

In summary, the steps envisaged and the methodological approach can be described as follows [Okoli, (2015), p.44]:

1 Concretisation of the objective and the question of the work on the basis of the literature.

2 Design of query and search protocol.

3 election of meaningful filters.

4 Transparent search and selection process.

5 Analysis of the literature (including quality).

6 Synthesis.

2.1.2 Database queries and selection modes

Based on the approach summarised above, this section will detail the selected systematic literature review process in more detail. It is the intention to select the required information for the theoretical and conceptual input for this study based on peer-reviewed, scientific, and fully accessible research articles published in top-tier journals, indexed in Web of Science and Scopus databases and preferably not older than 10 years. In order to do so, several terms are applied, based on the previously discussed scope of the planned research, such as digitalisation, digital transformation, automotive industry, Industry 4.0, digital business management, human resource management, human resources, Management 4.0. Such terminology might be adapted and extended during the process, if the researcher sees the requirement to do so.

The web of science and the Scopus database were selected as focus for the literature research, due to their extensive coverage of journals and articles from a wider range of study fields (Singh et al., 2021; Zhu and Liu, 2020). The user interface permits the accurate filtering and analysis of search results for further processing.

Within these databases, and based on the literature previously discussed, the following initial searches are conducted:

- General inquiries
  - A ‘automotive industry’ AND ‘Industry 4.0’
  - B ‘automotive industry’ AND ‘digitalisation’
  - C ‘automotive industry’ AND ‘digitalisation’ AND ‘competencies’
  - D ‘automotive industry’ AND ‘digitalisation’ AND ‘competencies’ OR ‘human resource management’
  - E ‘automotive industry’ AND ‘digitalisation’ AND ‘skills’
  - F ‘automotive industry’ AND ‘Industry 4.0’ AND ‘skills’
- Specific inquiries:
  - G ‘human resource management’ AND ‘Industry 4.0’
  - H ‘human resource management’ AND ‘Industry 4.0’ AND ‘automotive’
  - I ‘human resource management’ AND ‘Automotive Industry 4.0’
  - J ‘human resources’ AND ‘Industry 4.0’
  - K ‘human resources’ AND ‘Automotive Industry 4.0’
  - L ‘human resource competencies’ AND ‘Industry 4.0’
  - M ‘human resource competencies’ AND ‘digitalisation’
  - N ‘human resource competencies’ AND ‘digital’ AND ‘transformation’
  - O human resource competencies’ AND ‘digital business management’
  - P ‘human resource competencies’ AND ‘Management 4.0’.

The results of these queries will be narrowed down according to the following criteria, as far as the respective database allows:

1 time frame: 2013–2022 of the database search

2 only articles in full access

3 quality: peer-reviewed, if possible: top-cited quality

4 manual screening to ensure subject focus.

As far as quality is concerned, the decision is made to admit only scientific, peer-reviewed articles, which, if possible, can also be sorted and selected according to citation quantity. The results thus displayed are finally sorted and selected by means of a manual selection according to actual relevance in terms of the topic of human resource competencies required for the automotive Industry 4.0.

3 Research results

Discussing all identified articles resulting from the systematic literature review process is beyond the scope of this article. Additionally, not all articles identified are immediately relevant to the research topic. Thus, the focus will be on the most relevant publications in order to extract a status quo of research to guide further studies. The aim is to provide an overview of quantitative results and organise the sample into relevant subcategories, highlighting main contributions and research directions. Subheadings such as blockchain, big data analytics, autonomous systems, and human-systems interactions will summarise relevant publications offering a general consideration of the topic.

3.1 Visual overview of results of systematic literature review process

This chapter attempts to provide an overview of the resulting database inquiries, focusing on those that actually produced results in a quantity high enough to be measurable, so the following table is an accumulation of the data which was downloaded directly from the Scopus analytical toolset.

Table 1 Scopus Example of queries: documents per year

Scopus queries	*Year*				
	2018	*2019*	*2020*	*2021*	*2022*
'Automotive industry' AND 'Industry 4.0' (n = 85)	8	16	14	12	35
'Automotive industry' AND 'digitalisation' (n = 32)	3	9	6	7	7
'Human resource management' AND 'Industry 4.0' (n = 118)	6	13	28	31	40
'Human resources' AND 'Industry 4.0' (n = 233)	13	21	59	61	79
'Skills' AND 'Industry 4.0' (n = 463)	25	61	104	123	152

As shown in Table 1, there has been a steady increase in relevant published articles over the timeframe 2018 throughout 2022, emphasising a growing interest and research effort in the broader subject area.

As shown in Table 2, engineering, business/management and computer science are the three dominant areas throughout the years of relevant research providing publications for the sample, which outlines a clear interest for research in these fields by similar patterns.

The identified literature reveals a scarcity of direct mention of human resource competencies specific to the automotive industry's transition to the Industry 4.0. Rather, these must be inferred from broader discussions on transformative circumstances and expected outcomes. While various studies acknowledge the importance of talent development and technological impacts, they generally lack granularity and specificity in defining workforce competency requirements (Culot et al., 2020; Llopis-Albert et al., 2021; Tanwar et al., 2019; Yin et al., 2018; Arcidiacono et al., 2019; Bohn Sack et al., 2021; Martínez, 2019). Consequently, further targeted research is needed to provide detailed insights into Industry 4.0 workforce competencies in the automotive industry.

Table 2 Scopus example of queries: documents by subject area

Scopus queries		*Respective subjects*
'Automotive industry' AND 'Industry 4.0' (n = 85)	1	Engineering (30.2%)
	2	Computer science (17.4%)
	3	Business, management (14.6%)
	4	Materials science (5.5%)
	5	Decision science (5.0%)
		Others (27.3%)
'Automotive industry' AND 'digitalisation' (n = 32)	1	Engineering (30.0%)
	2	Business, management (23.7%)
	3	Computer science (13.6%)
	4	Economics (8.5%)
	5	Decision science (6.8%)
		Others: 17.4%
'Human resource management' AND 'Industry 4.0' (n = 32)	1	Engineering (21,5%)
	2	Business, management (20.0%)
	3	Computer science (17.4%)
	4	Social sciences (10.2%)
	5	Decision sciences (6.0%)
		Others: 24.9%
'Human resources' AND 'Industry 4.0' (n = 233)	1	Business, management (19.0%)
	2	Engineering (17.5%)
	3	Computer sciences (15.1%)
	4	Social sciences (12.1%)
	5	Environmental sciences (6.2%)
		Others: 30.1%
'Skills' AND 'Industry 4.0' (n = 463)		
	1	Social sciences (18.8%)
	2	Engineering (18.7%)
	3	Business, management (15.2%)
	4	Computer sciences (13.9%)
	5	Decision sciences (4.1%)
		Others: 29.3%

Note: The results regarding respective subjects focuses on the top-5 results.

3.2 Issues of specific relevance

Niţu and Gavriluţă (2019) offer insights into modern education methods for automotive manufacturing, particularly in lean manufacturing within Industry 4.0, emphasising skills in modelling, simulation, and integrating Industry 4.0 concepts into lean techniques. Krzywdzinski and Jo (2020) compare German and Korean car manufacturing processes, highlighting knowledge transfer and vocational education differences but lack specifics on required competencies in Industry 4.0. Jerman et al. (2020) identify technical, managerial, and social competencies crucial for smart factory participation, emphasising skills like automation, decision-making, and communication. Flores et al. (2020) propose a Human Capital 4.0 model, emphasising adaptability, resilience, and interdisciplinary collaboration for Industry 4.0. Most importantly, this work suggests key areas for human resource capabilities: blockchain, big data analytics, autonomous driving, and human-system interaction. The following chapter will thus follow this structure in order to organise the findings systematically.

The rationale behind this categorisation lies in the interconnectedness of these topics and their implications for the future of automotive manufacturing. For instance, the exploration of modern education methods and workforce competencies (Niţu and Gavriluţă, 2019; Jerman et al., 2020) sets the foundation for understanding the skills required to navigate the evolving landscape of Industry 4.0. This includes technical skills like automation and decision-making, as well as soft skills such as adaptability and interdisciplinary collaboration, as proposed by Flores et al. (2020). Moving into specific technological domains, the discussion on blockchain technology (Fraga-Lamas and Fernández-Caramés, 2019; Gupta et al., 2020; Sharma et al., 2019) highlights its potential to enhance cybersecurity and data integrity in automotive supply chains. This discussion naturally leads to considerations of the competencies required to implement and leverage blockchain technology effectively, although specifics in this regard are sometimes lacking. Similarly, the exploration of big data and data analytics (Da Silva et al., 2018; Demeter et al., 2020; Frazzon et al., 2018) underscores the importance of digital literacy, problem-solving skills, and teamwork in harnessing the power of data for improved decision-making and operational efficiency. Again, while the literature acknowledges the significance of these competencies, detailed insights into how they should be cultivated within the workforce are limited at some points. Autonomous systems (Klumpp et al., 2019) and human-system interaction (Mourtzis et al., 2019; Gervasi et al., 2021) emerge as critical areas for the integration of advanced technologies and human workers in automotive manufacturing. These discussions emphasise the need for workforce readiness to adapt to new work settings and collaborate effectively with automated systems, although specific skill sets required for this transition are not always clearly articulated. Consequently, this categorisation is chosen to organise the findings and guide deductions.

3.2.1 Blockchain technology

Fraga-Lamas and Fernández-Caramés (2019) consider the potential of blockchain technologies in particular to enhance the cybersecurity and resilience of the automotive industry. In their opinion, the advancements of robotics, manufacturing systems, cyber-physical systems (CPS), and augmented reality will have a significant impact on the automotive industry, arguably these developments might create vulnerability to cyberattacks. They argue that blockchain technology, with its decentralised and tamper-resistant structure, can provide a secure and reliable platform for managing and sharing data across the automotive supply chain (Fraga-Lamas and Fernández-Caramés, 2019). In a nutshell, the authors acknowledge the usability of blockchain technology in the automotive industry, for example, regarding vehicles connected to the IoT, smart and autonomous driving and even data forensics which might be a useful application for security and insurance related issues. Nonetheless, they fail to provide details regarding the required HR skill set (Fraga-Lamas and Fernández-Caramés, 2019).

Gupta et al. (2020) focus on the rapid progress regarding autonomous vehicles within the context of Industry 4.0 and especially consider the literature on blockchain-based security attack resilience schemes. According to the authors, such technology may entail potential threats such as data breaches, ransomware attacks, and denial-of-service attacks for customers and producers alike (Gupta et al., 2020). They argue that blockchain technology can provide a secure and reliable platform for managing and sharing data in the autonomous vehicle ecosystem, for example, by applying blockchain-based secure data sharing, blockchain-based secure communication protocols, and blockchain-based secure update mechanisms. The authors evaluate the strengths and weaknesses of each scheme and discuss their potential applications in the autonomous vehicle industry (Gupta et al., 2020). Similar to other literature in the context of technological advancements with regard to Industry 4.0 in automotive production, the contribution falls short of detailing the actual competencies and skills required by human resources, not only to implement blockchain technology, but also the introduced contextual technology and the respective security measures.

Sharma et al. (2019) propose a blockchain-based distributed framework for the automotive industry with a specific focus of application in a smart city. Key requirements, following the authors, for the automotive industry in that regard include supply chain management, security, evidence integrity and secure storage, mobility solutions, the ability to audit records, or the maintenance services, all of which will benefit from a blockchain-based distributed framework.

While the article does not discuss specific competencies or skills required by the workforce, it emphasises the need for a skilled workforce to develop and implement the proposed framework. What will be required is an understanding of the workforce of the possible co-integration with IoT platforms and blockchain technology.

3.2.2 Big data and data analytics

Da Silva et al. (2018) concentrate their analysis on the possibilities of collecting real-time information from vehicles after purchase by the customer in order to study the behavioural pattern through historical driver usage, fuel consumption, maintenance indicators and other factors via a sensory on-board diagnostics system. Any potential data privacy issues aside – as they remain unmentioned in their contribution – the authors hope to achieve an improvement of customer feedback and product improvement (Da Silva et al., 2018). While not explicitly referring to it, it can be assumed that such an approach would require an interface between marketing, customer service, and vehicle specific information systems and engineering in order to function. However, this would not necessarily impact the blue-collar workforce, but simply extend the application of information system engineering, data transfer as well as the analytics of big data. It is unclear to what extent this would require a different set of competencies or rather the hiring and training of respective experts (Da Silva et al., 2018).

Demeter et al. (2020) conduct a longitudinal case study analysis of the implementation of digital manufacturing technologies in a Hungarian automotive supplier. The study aims to identify the challenges and opportunities that arise during the implementation process and the competencies that the workforce needs to develop in order to succeed in a digital manufacturing environment. The authors find that the implementation of digital manufacturing technologies requires a significant shift in the organisation's culture and processes, as well as the competencies of its workforce (Demeter et al., 2020). Most importantly, digital literacy, problem-solving skills, and teamwork are mentioned as important skills to be promoted and extended throughout the organisation. Digital literacy is essential to understand and work with digital manufacturing technologies effectively.

The workforce needs to be familiar with various software and hardware tools used in digital manufacturing, such as computer-aided design (CAD), computer-aided manufacturing (CAM), and 3D printing. Problem-solving skills are critical to address the challenges that arise during the implementation of digital manufacturing technologies. The workforce needs to be able to identify problems, analyse data, and develop effective solutions. Teamwork is essential to ensure effective collaboration among different departments and stakeholders involved in the implementation process. The workforce needs to be able to communicate effectively, share knowledge, and work collaboratively to achieve common goals (Demeter et al., 2020).

Frazzon et al. (2018) discuss the implementation of data-driven production control for complex and dynamic manufacturing systems. The authors propose a framework that uses real-time data analysis to optimise production processes and improve productivity, namely data-driven simulation-based optimisation. Although not the focus, the authors' deductions permit the understanding that workforce competencies in successfully implementing this framework are relevant, as workers must be trained to use data analysis tools and understand the impact of their actions on production outcomes (Frazzon et al., 2018). It might be suggested that training programs should be developed to improve the workforce's analytical and problem-solving skills, as well as their ability to work with new technologies and adapt to changing production environments.

Ito et al. (2020) study the use of the IoT and simulation approach for decision support systems in lean manufacturing. The authors propose a framework that utilises devices equipped with the IoT to collect real-time data from manufacturing processes and a simulation model to analyse the data and provide decision support. As a result, the authors emphasise, amongst other things, the enabling of manufacturers to obtain benefits in communication based on real-time data output, which might impact, although not explicitly mentioned, workforce competencies, in order to develop and operate devices and simulation models equipped with the IoT effectively (Ito et al., 2020). Employees must be able to analyse the data collected from such devices and understand the results provided by the simulation model to make informed decisions.

Colombari et al. (2023) provide a strong example for the skills required when working for automotive suppliers. Most importantly, they apparently lack the required skill set to integrate real-time operational data from various sources for the purpose of data-driven decision making. While this is a serious problem, the authors demand more attention to data analytics in operations in order to provide the required competencies.

Similarly, but in a more general sense, Giacosa et al. (2022) highlight the shift towards an industry 4.0 work environment, as well as a broader understanding what this might mean for human resource competencies, without providing more in-depth specifics. For example, the authors refer to a digital transformation within modern automotive organisations which would require an appropriate overall IT-infrastructure to manage and analyse real-time big data streams (Giacosa et al., 2022). This, so the authors, demands a flexible and agile mindset by employees, as well as digital skills, without elaborating further.

Also, in the context of supply chain management, Bag et al. (2020) study the impact of big data management in order to improve the organisational performance. According to the authors, assessing and applying information will be one of the core capabilities of Industry 4.0. and requires the staff capabilities to do so. This included mainly the analytical capabilities with regard to big data to facilitate organisational learning. Also, in the context of supply chain management but with specific reference to the concept of circular economy, Del Giudice et al. (2020) study the potentially moderating role of a supply chain which is managed and guided with the help of big data. Their main result states that a "big-data-driven supply chain acts as a moderator of the relationship between circular economy HR management and firm performance for a circular economy supply chain" [Del Giudice et al., (2020), p.1]. While lacking a more explicit elaboration on how this can be achieved, considering the crucial role of HR in this process, the underlying plea for big data as an enhancement of related HR practices requires and appropriate skill set to apply and use on the retrieval, management, and utilisation of big data in general, a skill set to be acquired by the responsible management and employees alike. Similarly, and again for the field of supply chain management, Raut et al. (2019) also make a strong argument for the critical role of big data and its analytics for the field. In this wake, the authors conclude that 'management and leadership style, state and central-government policy, supplier integration, internal business process, and customer integration have a significant influence on big data analytics and sustainability practices' [Raut et al., (2019), p.10].

This is either hampered or facilitated by the relatively high cost of the relevant infrastructure, computer technology, privacy-security concerns and all related specific employee capabilities and skills to deal with various issues. Also here, more details on how this skill sets are precisely organised, taught, and shared are, unfortunately, not provided.

3.2.3 Autonomous systems

Klumpp et al. (2019) emphasise, within the context of production and manufacturing in general, including the automotive industry, the increasing importance of autonomous systems, covering not only production by actuators of robotics systems but also distributed decision making. The relevance with regard to the automotive industry specifically includes logistics and the required data transparency and coordination of material supply. Thus, human-computer interaction, according to the authors gains significant relevance, as well as their integration of motivated workforce, advanced logistic networks, and automated human-robot work environments. Consequently, the authors, though lacking a distinction of different work settings and more specifics on necessary skill sets, suggest that it is necessary to inform and adjust the workforce to these new work settings and robotics interaction, and provide them with a chance to test it in order to learn about its potential (Klumpp et al., 2019). The study focuses thus more on the flexibility and mental readiness of the workforce than on the required skill set.

3.2.4 Human-systems interaction

Mourtzis et al. (2019) present a very specific application of advanced production technology that is automated production as a part of an Industry 4.0 production strategy in order to suggest augmented reality as a means to facilitate assembly workstations operated by humans. It is the intention of the authors to support the increased requirements of the human workforce in terms of flexibility and adaptability as a response to more customised production. While a more dynamic knowledge transfer is needed, the authors believe that augmented reality technology can help to retrieve assembly instructions by incorporating product design data and adding order-specific details for customisation (Mourtzis et al., 2019). While this process is elaborated on in detail, the authors provide little insight for its application. The actual described real life application in their case study, however, while being focused in technology-affine environments, suggests that no novel skill set is required, or that the necessary competencies are easily obtained on the job. The study mainly refers to the use and functionality of the augmented reality device and getting used to its application in everyday work (Mourtzis et al., 2019).

Gervasi et al. (2021) explicitly focus on the issue of human-robot collaboration in decision making. This results in a strong plea for providing the necessary skill set to employees to implement related approaches and to work in such an environment. The overall organisations must consider the skills and competencies required by human workers to effectively collaborate with robots. In more detail, this can be interpreted as requiring the necessity for appropriate safety requirements, adjusting productivity goals, and allowing organisations to determine the most suitable configuration for human-robot interaction (Gervasi et al., 2021).

A more detailed consideration of specific skill sets required in order to interact with robots and other related machinery is also lacking in further literature, although the issue is certainly recognised and acknowledged. Bruno and Antonelli (2018, p.1) address related issues in the context of Industry 4.0 in assembly and manufacturing and state that problems include ‘correct assessment of the economic profitability, definition of a suitable process plan, task assignment to humans and robots, intuitive and fast robot programming’. Their main contribution lies in addressing the task assignment problem in the collaboration between humans and robots. Similarly, Fantini et al. (2020) consider explicitly CPSs, i.e., human-robot-interactions, and refer to this concept as a key driver within Industry 4.0. According to their findings, workplaces need to be adjusted and designed accordingly in order to reap the benefits of such systems, most importantly physical and sensorial characteristics need to be recognised and integrated, including workers with disabilities. This might be extended to skills and capabilities, however, in terms of machinery design and programming this might require even more sophisticated skills as such CPSs also demand an a priori analysis of individual human requirements, going beyond programming (Fantini et al., 2020).

The somewhat sensitive issue of moving beyond the simple focus on human-robot interaction and returning to a more humanised perspective of modern industrial work is picked up by Grabowska et al. (2022, p.3120), introducing the term Industry 5.0 as an extension of Industry 4.0, meaning ‘returning the human factor to industry, i.e., increasing cooperation between people and intelligent production systems and combining the best of two worlds – the speed and accuracy guaranteed by automation with humans' cognitive skills and critical thinking'. It needs to be noted that a more human-centred perspective of Industry 4.0 is not novel per se, as elements of this are also found in Industry 4.0 articles, which makes the actual contribution of referring to it as Industry 5.0 doubtful. Moreover, the article fails to actually detail in depth the skills required by employees, but mentions emerging roles like Chief Robotics Officer (CRO), device teacher, and solution mentor. This reflects the evolving landscape of skills and professions. It also highlights the necessity for an education and training system tailored to equip workers with the requisite competencies for these new roles (Grabowska et al., 2022).

The work of Gualtieri et al. (2021) provides a slightly different perspective with regard to human-robotics interaction in the automotive workplace, addressing occupational health and safety criteria as key factors to reconsider in the interaction with robotics. In that sense, this might also aim towards the reconsidering of the human factor such as in the mentioning of Industry 5.0 above, although with a far more common focus. As a review article, the contribution also does not mention any specific skill sets or capabilities required, however, it must be assumed that human-robot interactions and the focus on safety and ergonomics might require production line and workplace design to integrate and deepen their knowledge of the arising challenges and adjust their planning accordingly (Gualtieri et al., 2021).

Di Nardo et al. (2020) study the issue of human-machine interaction from a much more general perspective, referring to the internet of things (IoT), and CPS specifically. Their main concern are specific challenges and the centrality of humans in that respect. As a final result they suggest a novel framework referring to workforce skills but lacking any clear suggestion as of how those would differ from previous ones. The authors focus specifically on robotics, what they refer to as CPSs, as a means to combine such with inimitable human qualities and unique capabilities (Di Nardo et al., 2020). By ergonomic improvements of workstations, the authors are able to make suggestions on avoiding overload and strain for humans in production. Interestingly, it appears as such measures would not require any specific alteration of blue-collar workforce, and as if introducing related measures is within the usual spectrum of production line designers.

The work of Malik and Bilberg (2019) somewhat contradicts such impression, as they do see a need to address the specific challenges related to human-robot interaction. Similarly, Sciutti et al. (2018) make an implicit argument for non-altered skill sets, because the integration of human and robotic skills might be seen as complementing each other.

4 Discussion

The literature on Industry 4.0's impact on the automotive industry provides valuable insights into the competencies and skills required to navigate this transformative era. While some articles offer specific guidance, many lack a detailed discussion of the essential skills and competencies that employees and students will need to succeed in the rapidly evolving automotive landscape.

Exemplary, Nitu and Gavriluta (2019) are commended for their focus on educating and preparing students and employees within the automotive manufacturing sector, particularly in the context of lean manufacturing and Industry 4.0. Their approach is notable for outlining the specific skills necessary for different education levels and professional roles, providing a clear roadmap for skill development and workforce preparation. This targeted approach recognises the diverse requirements for the multifaceted roles within the automotive industry during the Industry 4.0 era. In contrast, Krzywdzinski and Jo (2020) provide an informative study comparing German and Korean car manufacturing processes, with an emphasis on manufacturing ramp-ups, knowledge transfer, and vocational education. However, the study falls short of detailing the specific skill sets required, especially concerning Industry 4.0. The lack of specificity regarding skills is a limitation that hinders its practical application in workforce development efforts. One recurring theme across multiple studies, including Jerman et al. (2020), is the agreement that specific job profiles related to programming, mechatronics, robotics, data analysis, the IoT, system design, and maintenance are crucial in smart factory systems. This underlines the critical importance of technical skills and knowledge. Furthermore, the inclusion of soft competencies like continuous learning, flexibility, creativity, problem-solving, critical thinking, and analytical thinking underscores the multifaceted nature of the skills required for the Industry 4.0 workforce.

Despite these valuable insights, a common limitation in the literature is the lack of detailed discussion on the specific skills and competencies required to navigate the impacts of Industry 4.0 technologies, such as blockchain, big data analytics, autonomous systems, and human-systems interaction. While the potential benefits and challenges of these technologies are discussed, the specific skills necessary for employees to effectively adapt to these advancements are often overlooked.

For instance, in the context of blockchain technology, authors like Frage-Lamas and Fernández-Caramés (2019) and Gupta et al. (2020) highlight its potential in enhancing automotive cybersecurity but overlook the necessary skill set. The digitalisation of processes and shifting value propositions in the industry would necessitate expertise in programming, problem-solving, automation, IoT, and business model reengineering. The lack of discussion on the required human resource skills in these articles is a significant shortcoming. Similarly, when exploring big data and data analytics, authors like Da Silva et al. (2018), Demeter et al. (2020), and Frazzon et al. (2018) emphasise the collection and analysis of real-time data for various purposes, but do not delve into the competencies required for effective integration across marketing, customer service, and data analytics. Regarding autonomous systems and human-systems interaction, some articles, such as Klumpp et al. (2019) and Mourtzis et al. (2019), acknowledge their importance but often focus more on the adaptability and flexibility of the workforce rather than providing detailed discussions on the specific skills needed.

While the literature offers essential insights into the competencies and skills necessary for the automotive industry's transition to Industry 4.0, there is a recurring deficiency in detailed discussions about the specific skills and competencies necessary to address the challenges and opportunities presented by the evolving landscape. The complexity and diversity of roles in the automotive industry's future workforce, in light of Industry 4.0 technologies, demand a more robust and comprehensive analysis of the skills needed to thrive in this transformative era. Addressing these skill gaps and implementing appropriate training programs are pivotal to ensuring a competent and adaptable workforce that can successfully navigate the automotive industry's Industry 4.0 journey. Most notably, while the intention of this research has also been to shed light on any similarities and differences in that regard between Germany and the USA, none of the identified publications addressed this issue.

5 Conclusions

The systematic literature review conducted in this article reveals that digitalisation is rapidly transforming the automotive industry, emphasising the fusion of manufacturing with information technology, which necessitates significant changes in the workforce. Competencies required for Industry 4.0 span technical, managerial, and social domains, encompassing skills such as digital literacy, emotional intelligence, and proficiency in emerging technologies like blockchain and big data analytics. However, many studies lack specificity when defining the necessary skill sets, underscoring the need for further research and focused training programs.

Consequently, a compelling need exists for extensive research into the human resource competencies essential for the successful transition of the automotive industry to Industry 4.0, especially, if one is interested in specific similarities and differences, such as between Germany and the USA. The dynamic nature of this industrial transformation, driven by digitalisation and automation, demands a comprehensive understanding of the specific skills, knowledge, and adaptability needed by the workforce in both countries. A comparative analysis of these requirements is imperative to inform policy decisions, training programs, and talent development strategies that align with the distinct needs of each nation's automotive sector, ensuring competitiveness and sustainability in the Industry 4.0 era.

A suggestion to approach this might be an actual comparative study, for example using available secondary data from the program for the international assessment of adult competencies (PIAAC), allowing to compare Cycle 1 and Cycle 2 results. The specific information contained here with regard to human skill sets in the context of Industry 4.0 from a global perspective, could easily permit to uncover disparities and commonalities in human resource demands, particularly between two main nations with large automotive expertise, being Germany and the USA. The research approach could integrate quantitative and qualitative methods, making use of PIAAC data and expert interviews, thus addressing the here identified research gap.

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