

The Convergence of Minds and Machines: A Bibliometric Analysis into HRM and Industry 4.0 Dynamics

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Abstract

Purpose: With the trends in smart technology in Industry 4.0 there have been notable changes in industries as well as towards human resources. This work aims to examine the creation of symbiosis between the human brain and intelligent machines in the area of HRM and Innovation 4.0. The main goal is to perform a bibliometric analysis of the literature, which will reveal emerging research trends, influential authors, pertinent nations, and potential future research directions in the area of HRM and Industry 4.0.

Methodology: An extensive bibliometric analysis of 176 articles drawn from the Scopus database was conducted. For analysis, the study utilized Biblioshiny and VOSviewer to identify the research hotspots, subject areas, and emergent trends. We employed co-occurrence and citation analysis to uncover the intellectual structure of research

Results: The findings of the study revealed that Industry 4.0 and HRM are vibrant and expanding fields. The adoption of disruptive technologies related to Industry 4.0 is altering workplace culture and HR procedures, enabling organizations to blend human insight with machine-driven analytics, and creating more adaptive, responsive, and financially efficient HR systems. Along with descriptive analysis, the research also unveiled a shift in focus toward sustainable HR practices, emphasizing long-term financial stability and talent retention.

Implications: This study has implications for both academia and practitioners by offering new perspectives on human dynamics in Industry 4.0. It not only considers the constant dynamics of Industry 4.0 regarding the subject area of HRM but also highlights the essence of the interaction between disruptive technology and human resource practices in the digital environment. Therefore, the study provides guidelines on the further research direction as well as gaps required to conduct a further investigation of this critical trend of technology and human resources management intersection.

Keywords: Industrial revolution, IR 4.0, Human Resource Management, HRM, Bibliometric

1. Introduction

The notion of Industry 4.0 has surfaced as a transformative force in the global business arena throughout the 21st century. The Fourth Industrial Revolution or IR 4.0, often known as Industry 4.0, is a substantial change in how businesses function and create commodities. 'Industry 4.0' refers to the incorporation of cutting-edge digital technologies into diverse

manufacturing and other industry sectors. Industry 4.0's historical development can be followed through a number of crucial stages:

The agrarian and handicraft-based nations gave way to mechanized and industrialized ones during the First Industrial Revolution in the late 18th century. Innovations like the steam engine and the mechanization of textile manufacture propelled it. During the Second Industrial Revolution (late 19th to early 20th centuries), mass production was made possible by the widespread use of electricity and the creation of the assembly line. The telegraph, telephone, and internal combustion engine were significant inventions. The proliferation of computers, automation, and the internet were the defining features of the Third Industrial Revolution (late 20th century), sometimes known as the Digital Revolution. It resulted in major improvements in information technology, communication, and manufacturing. The emergence of 'Industry 4.0' appeared in the Early 21st Century. The term was first used in Germany in the early 2010s as part of the 'High-Tech Strategy 2020' project at the Hanover Fair in 2011 (Sukhodolov, 2019). It depicts the combination of the digital, physical, and biological worlds. The Industry 4.0 term refers to the new production of organization strategies that aim to increase automation and, as a result, reduce production costs (Edwards & Ramirez, 2016). Earlier three industrial revolutions were based on the following: firstly 'Industry 1.0' related to the production mechanism, second 'Industry 2.0' based on assembly lines and mass production using electricity, and the third revolution 'Industry 3.0' based on the incorporation of computers and automation. Further, all three industrial revolutions are combined to create 'Industry 4.0' which comprises Artificial Intelligence (AI), big data analytics, robotics, Internet of Things (IoT), physical systems, and a dynamic and highly networked business environment. Industry 4.0 also known as IR 4.0 represents a paradigm shift in the way industries operate, through the integration of advanced digital technologies into diverse aspects of production and operations. This revolution has profound implications for Human Resource Management (HRM) within organizations.

The digitalization affects the human resource management due to the advancement in the technology. The management should cooperate with the employees to adjust to the organizational environment with the fast pace of change in technology (Greeven and Williams, 2017). In order to successfully navigate the obstacles of the Industry 4.0 revolution, an organization would need a strong Smart HR 4.0 strategy (Sivathanu & Pillai, 2018). The digital transformation implies a connected industry in an intelligent world towards an adaption plan of the digital environment to attain Industry 4.0 (Erro-Garces, 2021). According to Dhanpat *et al.* (2021) technical, managerial, and soft skills would be essential for competitive advantage in Industry 4.0. Human resource management (HRM) is crucial in the transition of the new technological paradigm (Jimén-Morenilla *et al.*, 2021; Maynard, 2015). 'Industry 4.0' has significantly impacted working routines and employees' habits (Fareri *et al.*, 2020). As a new competitive tool for competitiveness and a viable set of technologies to overcome the productive crisis, Industry 4.0 is transforming how people work, learn, lead, manage, recruit, and engage with one another (De Silva *et al.*, 2022). The practices that best distinguish companies are those that deal with evaluating employee performance in this context, estimating the time and financial requirements for Industry 4.0 training, and creating systems to identify talent among current employees (Pio *et al.*, 2022). Decentralization, individual empowerment, fewer formal norms, horizontal communication, and teamwork are acknowledged as significant elements of the Industry 4.0 scenario (Schafer *et al.*, 2023). Numerous adjustments are necessary for Industry 4.0 deployment, including the HR function. HR skills are crucial and give organizations an advantage in Industry 4.0 (Murugesan *et al.*, 2023).

Mantzaris & Myloni (2022) explored that organizations are undergoing considerable change as a result of the blending of the physical, digital, and biological worlds. Due to technological advancements, human resource professionals are finding it difficult to adapt to the blending of the physical, digital, and biological worlds. As a result, traditional HR has a new version called HR 4.0, which is revolutionary and has increased automation while putting more emphasis on strategic issues than on manual, bureaucratic, and repetitive tasks (Saini & Khan, 2023). As per the study of Zuchri *et al.* (2022), The IoT has assisted the domain of HRM as it allows job searchers to find work by using their cell phones instead of newspaper articles. Industrial production and manufacturing are being digitally transformed by IR 4.0, which further facilitates the value-creation process. Further, Marler & Fisher (2013) highlighted the body of research on HRM before analyzing the connection between Internet-based technology and HRM. This study sought to offer researchers and practitioners evidence-based recommendations on the interaction between e-HRM and strategic HRM. Companies must put HR procedures into place to support employee actions that are in line with the organization's strategy. Companies can achieve the finest digital transformation to attain superior performance when HR practices are in line with strategy (Nicolas-Agustín *et al.*, 2022).

Nevertheless, the intersection of Industry 4.0 and HRM is not merely operational but deeply financial as well. One of the most significant challenges that firms face is managing the financial impact of digital transformation on human capital. The cost of implementing Industry 4.0 technologies is substantial, often requiring significant investments in new infrastructure, training programs, and high-performance people management practices (Uzule & Verina, 2023). Additionally, businesses must navigate the complexities of cost-benefit analyses when determining the return on investment (ROI) from adopting these technologies. While initial investments may appear high, the long-term financial benefits—such as improved productivity, enhanced innovation, and sustainable competitive advantage—are key drivers for businesses aiming to remain relevant in this new industrial era. Strategic HR practices, such as reskilling and upskilling employees, fostering employee involvement, and redesigning jobs to accommodate new digital workflows, are essential not only for operational success but also for mitigating financial risks (Agarwal *et al.*, 2022). Companies must ensure that their workforce is capable of leveraging Industry 4.0 technologies to their fullest potential, reducing inefficiencies and maximizing the ROI of these technologies.

However, there is currently a dearth of research to support the theoretical application and implications of smart technologies in HRM. The necessity for additional research into the relationship between HRM and evolving technology was underlined by (Boundarouk & Brewster, 2016; Stone *et al.*, 2015).

To fill this gap, the underlying purpose of this study is to give an overview of the evolving trends, global distribution, the emerging thematic pattern of the research field, most influential work, prolific contributors, influential keywords, and dominating countries in Industry 4.0 and HRM. It aims to assess the link between Industry 4.0 and HRM and how far the line of research has progressed. To achieve this purpose, the study conducted a bibliometric analysis based on the big data research paradigm to systematically visualize and trace the scope and nature of current industry 4.0 and HRM literature by addressing the research questions as shown in ‘Table 1’.

Table 1: Research Questions

Question No.	Research Questions
RQ1	What are the key publication trends, co-occurrence of keywords, dominating countries, most relevant articles, evolving trends, and worldwide distribution in Industry 4.0 and HRM?
RQ2	Who are the influential authors in the industry 4.0 and HRM field?
RQ3	What are the emerging thematic areas in the domain of Industry 4.0 and HRM?

Source: Author

2. Research Methodology

The proposed objectives of the study can be achieved by applying the bibliometric technique for conducting quantitative analysis of published papers. The data pertaining to Industry 4.0 and Human Resource Management were retrieved from the Scopus Database by applying the advanced search query given in ‘Table 2’. The Scopus Database is used as it has a higher number of unique documents, making it a suitable choice as an information source for future studies. It covers almost two-thirds of the sources and articles of WoS (Web of Science) (Sánchez *et al.*, 2017). Further, the journal coverage of WoS in Social Sciences and Arts & Humanities is still quite low and these disciplines are underrepresented (Mongeon & Paul-Hus, 2014). Scopus offers the best coverage among these databases and could be used as an alternative to the Web of Science as a tool to evaluate the research impact in the social sciences (Norris & Oppenheim, 2007).

The raw data was tracked from the Scopus database, with the established search string. After going through the title, abstracts and keywords for the entire subject on the database, the study first located 420 documents as shown.

Table 2: Search Criteria in the Database

Selection Criteria	Exclude	Include
Database: “Scopus”		
Date of Search: “29 December 2023”		
Search Query: TITLE-ABS-KEY ("Industry 4.0" OR "Industrial revolution 4.0" OR "IR 4.0" AND "Human resource management" OR "HRM") AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (LANGUAGE , "English"))	-	420

Document type: Articles	231	189
Publication stage: Final	8	181
Language: English	5	176

The inclusion parameters used in the databases consisted of several keywords selected based on some review studies: 'Industry 4.0', 'Industrial revolution 4.0', 'IR 4.0' AND 'Human resource management', 'HRM' (Zabidin *et al.*, 2020; Kaushal *et al.*, 2023). The keywords were limited to appear in the title, abstract, and the keywords themselves of the articles consulted. In the selection process, the first step was limited to including articles only under the document type column, the second step was to include only articles in the English language, and only fully published articles were part of the study.

After the refining process, a total of 176 papers were found related to this study and downloaded for further analysis. This study analyzed the extracted data as performance and network analysis in the bibliometric domain. The use of descriptive or quantitative data will provide insights into publication and citation metrics to enhance the robustness of the findings. While conducting a co-word analysis will help to reveal the interconnectedness of research themes, and thematic evolution to map the progression of key topics over time. Co-word analysis has been widely employed in bibliometric research to explore thematic structures within scientific literature (Callon *et al.*, 1983). Additionally, the examination of thematic evolution is critical to understanding how research trends shift across time, a method advocated by Cobo *et al.* (2011). This paper utilized the Biblioshiny package, developed on the R- Studio and VOSViewer for further analysis. Various researchers have used this application because it provides a web interface, and secure data importing, conversion, gathering, and filtering data from collection frames like Scopus (Kaushal *et al.*, 2023).

3. Results

3.1 Performance Analysis: This section has employed performance or descriptive analysis to fetch detailed information on the research area of Industry 4.0 and HRM including publication trends, influential documents, prominent sources and prolific authors.

3.1.1 Trend of Year-wise publication of articles

Year-wise publication of articles since 2014 on Industry 4.0 and Human Resource Management (HRM) is analyzed. As shown in 'Table 3', most publications are done in the year 2023 (42) followed by 2022 (41), and then 2021 (34), respectively. However, there is no publication found in the year 2015, possibly due to the early stages of conceptualization and understanding of Industry 4.0. However, the plot depicts the continuous growth in the publications from 2016 onwards. 'Figure 1' reflects an evolving research landscape in this dynamic intersection of technology and HRM.

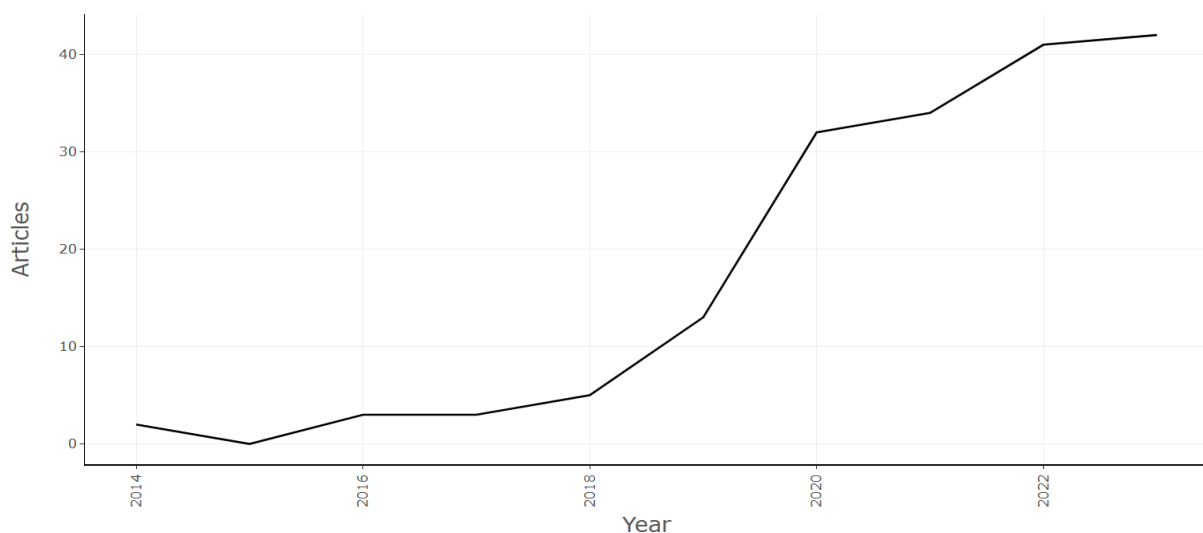


Figure 1: Trends of Yearly publication of articles published on Industry 4.0 and HRM

Source: Scopus Database

'Table 3' also provides a citation analysis for the past five years in the field of Industry 4.0 and HRM. A total of 3,977 citations have been registered from 2019 to 2023, revealing a continuous upward trend in the number of citations per year compared to previous years. It is evident that across the selected period, articles published in 2023 have received the largest number of citations. A total of 72 articles from the year 2023 have been cited 1625 times in the literature. It can also be observed that the citation trend has been positive from the year 2019 to 2023 showing that researchers are expected to increasingly focus on the research area.

Table 3: Yearly publication of articles published on Industry 4.0 and HRM

Year	Articles	Citations
2023	42	1625
2022	41	1124
2021	34	630
2020	32	406
2019	13	147
2018	5	45
Total	167	3977

Source: Scopus Database

3.1.2 Document by Subject Area

Figure 2 outlines that Industry 4.0 in HRM has been studied extensively in different subject areas. However, business, management and accounting, computer science, and engineering are the most significant subject areas with coverage of 60% of articles in the dataset which can be attributed to the technology-centric and operational nature of Industry 4.0.

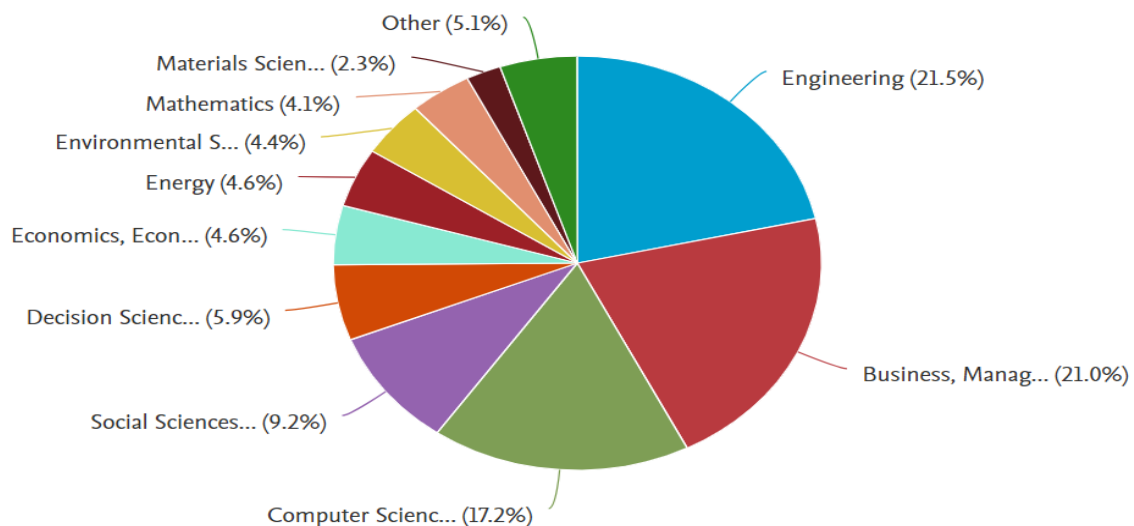


Figure 2: Document by Subject Area

Source: Scopus Database

In this respect, 9.2% of publications are from the social science subject area, and 5.9% of publications were published in the decision sciences. However, It is recommended that additional research be done in some subject areas, such as energy (5.1%), environmental sciences (4.6%), economics (4.0%), mathematics (4.0%), and material sciences (1.7%), because research in these areas is still lacking.

3.1.3 Most Relevant Sources

'Table 4' shows the most contributing sources in the area of Industry 4.0 and HRM with the number of articles published along with citations garnered. When the minimum count of documents of a source is set at two, out of 118 sources, 28 met the threshold. Data given in Table 4 reveal that the "Sustainability (Switzerland)" published by MDPI has the maximum number of publications (10) followed by "Computers and Industrial Engineering", "International Journal of Manpower and Journal of Manufacturing Technology Management" with 5 publications each. In terms of citation count, Computers and Industrial Engineering tops the list with 425 citations. The analysis reflects that research on the domain is taking a sustainability-driven approach, focusing on how technological transformations in human resource management can foster long-term, sustainable economic, environmental, and social impacts. For instance, Agarwal *et al.* (2022) highlighted the importance of aligning human resource (HR) practices with Industry 4.0 to support Sustainable Development Goal 8 (decent work and economic growth). Sumaiti *et al.* (2023) emphasized the significance of environmental awareness, green culture, and intensive training for SMEs to gain a competitive advantage and contribute to sustainability.

Table 4: Most Relevant Sources

Sources	Articles	Citations	Rank	Freq	Zone
"Sustainability (Switzerland)"	10	211	1	10	Zone 1
"Computers and Industrial Engineering"	5	425	2	5	Zone 1
"International Journal of Manpower"	5	145	3	5	Zone 1
"Journal of Manufacturing Technology Management"	5	156	4	5	Zone 1
"International Journal of Production Research"	4	146	5	4	Zone 1
"Kybernetes"	4	29	6	4	Zone 1
"Sa Journal of Human Resource Management"	4	60	7	4	Zone 1
"Computers in Industry"	3	245	8	3	Zone 1
"International Journal of Advanced Manufacturing Technology"	3	232	9	3	Zone 1
"International Journal of Computer Integrated Manufacturing"	3	36	10	3	Zone 1

Source: Scopus Database

Bradford's law can be used to find the most significant journals on the subject of Industry 4.0 and HRM, as illustrated in 'Figure 3'. Zone 1, the darkened area, contains journals the Sustainability (Switzerland), Journal of Manpower, and others. The 'Table 4' lists the core sources in order of importance. When considering publications on this issue, preference should be given to these journals as they form the foundation of Industry 4.0 in HRM and include the most pertinent research on the subject.

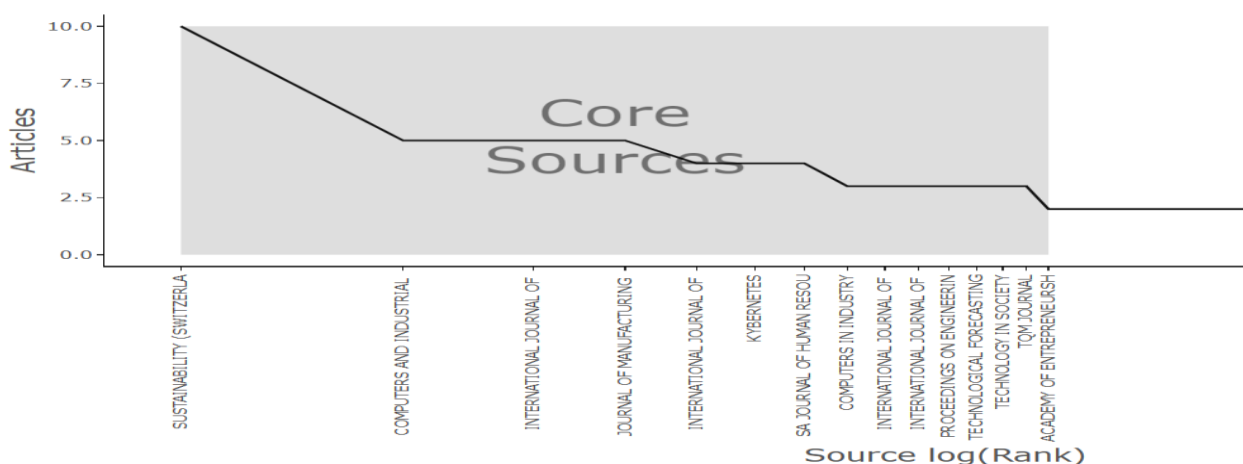


Figure 3: Core Sources

3.1.4 Most relevant articles

'Table 5' shows a brief description of the top 10 articles with maximum citations in the domain of Industry 4.0 and HRM. Out of 176 articles in the dataset, 68 articles met the threshold value of 15 citations of a document. The study conducted by Benešová & Tupa (2017) is mostly cited in the research area having 345 citations count which focuses on the challenges, drivers, risks, and opportunities of the transition, covering employees' education and qualification. The study propounded that education along with training systems need to be adapted to meet the changing needs of the workforce in Industry 4.0. This means providing students and workers with the opportunity to learn the skills and knowledge that they need to succeed in this new and challenging environment. The study conducted by Fantini *et al.* (2020) provides a comprehensive framework for modeling and assessing human activities within cyber-physical systems. The study has made a valuable contribution to the field of Industry 4.0. The authors' work highlights the importance of placing the operator at the center of Industry 4.0 design, as humans will continue to play a key role in the manufacturing process, even as CPSs become more sophisticated. Kaasinen *et al.* (2020) focused on the concept of 'Operator 4.0' and how it empowers and engages industrial workers within the context of Industry 4.0. It emphasizes the importance of designing Operator 4.0 solutions with a focus on the needs and preferences of industrial workers to ensure that technology enhances rather than hinders the worker's experience. The study conducted by Whysall *et al.* (2019) propounded an overview of the new challenges that organizations are facing and offer practical solutions for addressing these challenges, to prepare their workforce for the challenges and opportunities of Industry 4.0. Pejic-Bach *et al.* (2020) present a novel approach to extracting Industry 4.0 keywords from job advertisements, and they discussed the potential applications of the approach for identifying job opportunities in Industry 4.0 and for developing training programs for workers who need to acquire new skills for Industry 4.0 jobs.

Table 5: Top 10 Most Cited Articles

Paper	Title	Total citations
Benešová & Tupa (2017)	"Requirements for Education and Qualification of People in Industry 4.0"	345
Fantini <i>et al.</i> (2020)	"Placing the operator at the centre of Industry 4.0 design: Modelling and assessing human activities within cyber-physical systems"	171
Kaasinen <i>et al.</i> (2020)	"Empowering and engaging industrial workers with Operator 4.0 solutions"	169
Whysall <i>et al.</i> (2019)	"The new talent management challenges of Industry 4.0"	137
Pejic <i>et al.</i> (2020)	"Text mining of industry 4.0 job advertisements"	136
Fareri <i>et al.</i> (2020)	"Estimating Industry 4.0 impact on job profiles and skills using text mining"	124
Kipper <i>et al.</i> (2021)	"Scientific mapping to identify competencies required by industry 4.0"	115
Calzavara <i>et al.</i> (2020)	"Ageing workforce management in manufacturing systems: state of the art and future research agenda"	114
Cimini <i>et al.</i> (2021)	"How do industry 4.0 technologies influence organisational change? An empirical analysis of Italian SMEs"	109
Stachová <i>et al.</i> (2019)	"External partnerships in employee education and development as the key to facing industry 4.0 challenges"	95

Source: Scopus Database

The present analysis of literature collectively emphasizes the importance of human factors, education, and training in the transition to Industry 4.0 (Fareri *et al.*, 2020; Calzavara *et al.*, 2020; Kipper *et al.*, 2021; Stachová *et al.*, 2021; Cimini *et al.*, 2019). These studies focused on the need for a workforce that is not only technically proficient but also empowered, engaged, and adaptable. A human-centric approach to technology integration, coupled with strategic education and training

initiatives, is essential for organizations to thrive in the era of Industry 4.0. Additionally, addressing challenges and leveraging opportunities in Industry 4.0 requires a proactive and forward-thinking approach at both the organizational and educational levels.

3.1.5 Most Relevant Countries

'Table 6' shows the top 10 productive countries in the area of Industrial Revolution 4.0 and HRM. This research domain has a global reach, given that the 176 articles in the sample originate from 58 different countries. As depicted, India has the maximum number of publications i.e., 24 articles followed by Italy, the United Kingdom and Poland with 20, 18 and 13 publications respectively. India's prominence in Industry 4.0 and HRM publications signifies its growing emphasis on technological innovation and a proactive approach to adapting HR practices to the evolving industrial landscape.

Table 6: Top 10 Productive Countries in IR 4.0 and HRM

Sr. No.	Country	Documents	Citations	Citations/No. of Publications
1	India	24	403	16.79
2	Italy	20	890	44.5
3	United Kingdom	18	607	33.72
4	Poland	13	237	18.23
5	South Africa	10	163	16.3
6	Brazil	9	228	25.33
7	China	9	141	15.67
8	Malaysia	9	110	12.22
9	Czech Republic	8	372	46.5
10	Slovakia	8	166	20.75

Source: Vosviewer

As data elucidates, Italy researchers have garnered the most citations with 890 for their 20 publications. Followed by the United Kingdom and India with 607 and 403 citations, respectively, underscoring their significant impact. However, in terms of productivity, the Czech Republic is recognized as the most productive country with a score of 46.5, followed by Italy and the United Kingdom with scores of 44.5 and 33.72, respectively.

3.1.6 Most Relevant Authors

The study further focused on the author-wise distribution of articles according to their respective number of publications, as shown in 'Table 7'. Stacho Z stands out as the most prominent author in the area of Industry 4.0 and HRM having the largest number of publications (4), followed by Stachova K, Upadhyay A and Kumar M having three publications each. The h-index and g-index are both metrics used to quantify the impact of a researcher's work (Ding *et al.*, 2020). Notably, Stacho Z is the most prolific author in the stated domain with a citation of 132 counts, h-index and g-index of 3 and 4 respectively, who is working on underscoring the importance of adapting to the Fourth Industrial Revolution for businesses to remain competitive.

Table 7: Author's Impact Factor

Author	h_index	g_index	m_index	TC	NP	PY_start
Stacho Z	3	4	0.6	132	4	2019
Stachová K	3	3	0.6	127	3	2019
Upadhyay A	3	3	1	101	3	2022
Kumar M	2	3	0.5	58	3	2020
Anholon R	2	2	1	7	2	2022

Antony J	2	2	1	18	2	2022
Asoba Sn	2	2	0.5	12	2	2020
Cazeri Gt	2	2	1	7	2	2022
Dobrowolska M	2	2	0.5	26	2	2020
Germani M	2	2	0.5	54	2	2020

Source: Biblioshiny

3.1.7 Most Relevant Affiliations

‘Figure 4’ depicts the top ten affiliations or organizations that have produced the most documents in the area of Industry 4.0 and HRM. University of Johannesburg from South Africa stands out as the most impactful institution, where ten articles have been published in the area of IR 4.0 and HRM. Likewise, Delhi Technological University in India and Vyatka State University in Russia rank as the second most prominent institutions with nine articles each in the research area. Furthermore, the remaining seven institutions, among the top ten, have also substantially contributed to the research field by producing six or more articles each.

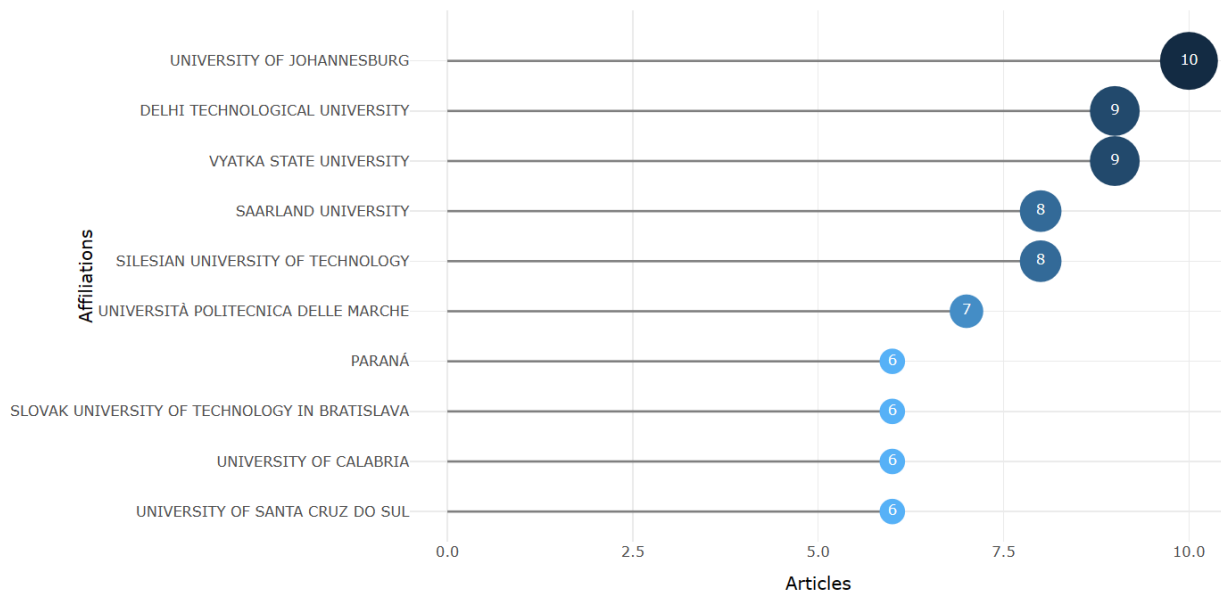


Figure 4: Prominent Sources in IR 4.0 and HRM

3.2 Network Analysis

Science mapping or network analysis provides a spatial representation of how different elements relate to one another to provide a clear overview of the pattern of emerging themes and interactions.

3.2.1 Co-Authorship of Countries

‘Figure 5’ depicts the analysis of the author's co-authorship network spanning interconnected nations. The lines interconnecting various points on the map symbolize co-authorship between countries, while the proximity of clusters indicates the strength of collaborative relationships. Notably, India, boasting a substantial number of publications, exhibits robust link strength with the United Kingdom, Italy, France, Brazil, Australia, Indonesia, and China, among others. Conversely, there is a weaker link strength with South Korea, South Africa, the United States, Greece, Austria, Hungary, Malaysia and similar nations. In essence, this map offers valuable insights into the potency of international collaborations within the realm of IR 4.0 and HRM among diverse countries.

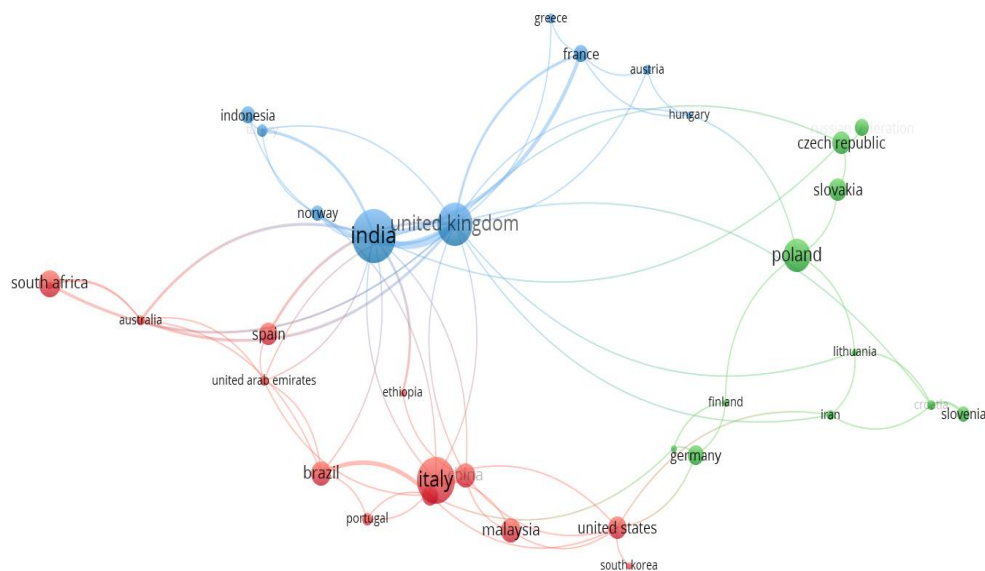


Figure 5: Co-Authorship of Countries

2.2 Three-field Plot: Sankey Diagram

Sankey diagrams are employed to visually represent quantitative insights about flows, their interrelationships, and transformations (Riehmann *et al.*, 2005). In our analysis, we utilized Biblioshiny to generate Sankey plots for a three-field analysis, encompassing authors' countries (on the left), individual authors (in the middle), and sources (on the right), as depicted in Figure 6. The diagram below provides an overview of research pertaining to IR 4.0 and HRM conducted by various countries and published across different journals. The varying sizes of rectangles convey performance levels, with India exhibiting a notable contribution from authors like Kumar M, Upadhyay A, Kumar G, and others. These Indian authors predominantly published their work in the “TQM Journal”, “Technological Forecasting and Social Change”, and “International Journal of Production Research”. Conversely, the rectangle sizes indicate that Stacho Z and Stachova K are significant contributors from Slovakia, showcasing their research in IR 4.0 and HRM, primarily in Sustainability (Switzerland). Rectangles representing Italy, Brazil, and the United Kingdom also suggest commendable performance in the specified research domain.

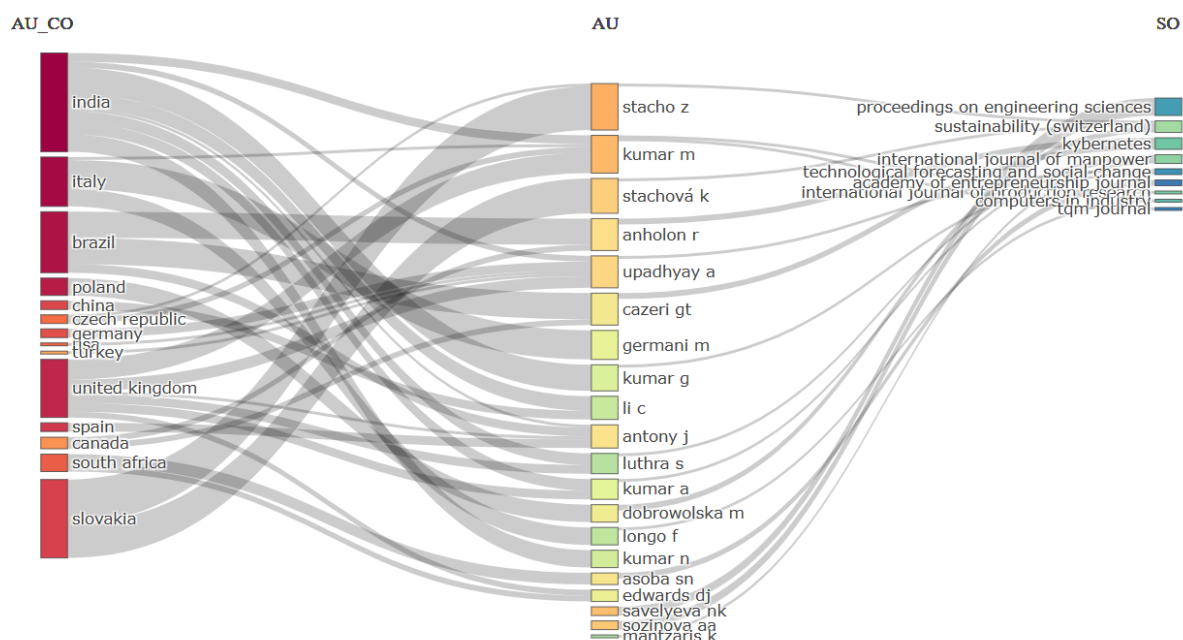


Figure 6: Three-field Plot of Country (left), Author (middle), And Source (right)

3.2.3 Co-Occurrence of Keywords

Co-occurrence keyword analysis utilizes the author's provided keywords to investigate links among the significant topics within the domain (Sedighi *et al.*, 2016). This section focuses on analyzing the co-occurrence of author keywords in Industry 4.0 and HRM based on the Scopus dataset. When co-occurrences of six keywords were used for the IR 4.0 and HRM, there appeared to be 1482 keywords and 33 met the threshold of co-occurrence criteria.

'Figure 7' illustrates the distribution of themes linked to Industry 4.0 and HRM using a tree map with specific keywords. The treemap displays the majority of pertinent terms in accordance with database inclusion criteria. These are "human resource management", "Industry 4.0", "decision making", "managers", "knowledge management", "human resource", "industrial research", "industrial revolution", "personnel training", "sustainable development", "employment", "resource management", "human resources management", "information management", "internet of things", "embedded systems" and many more, at a percentage of 19%, 14%, 3%, 3%, 3%, 3%, 2%, 2%, 2%, 2%, 2%, 2%, 2%, 2%, 2%, 2% of the total occurrence, respectively.

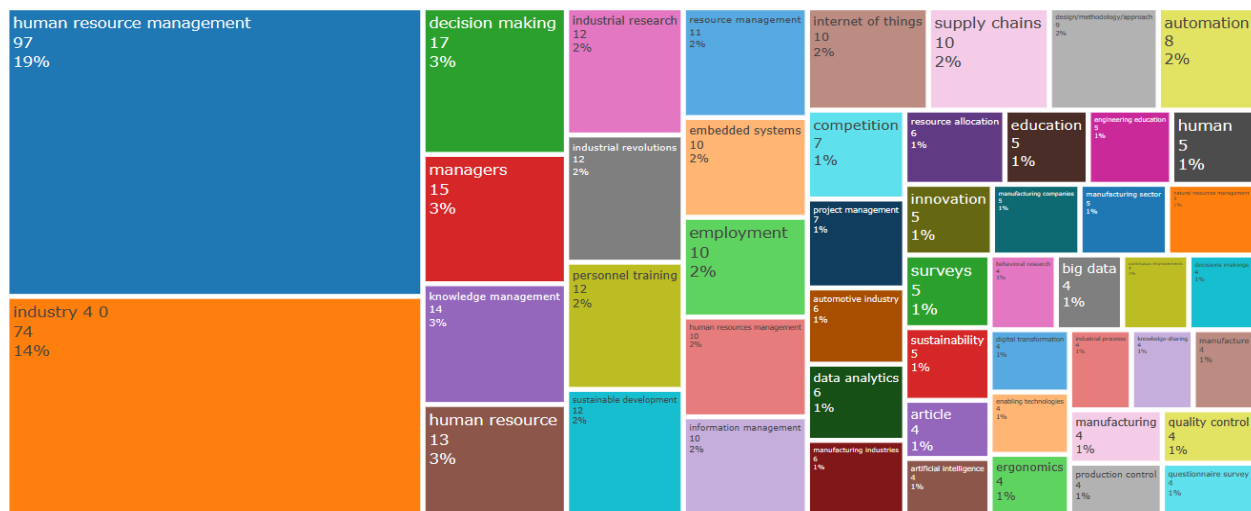


Figure 7: Tree Map

'Table 8' provides information for identifying the relationships between Industry 4.0 in the context of HRM. It reveals that Industry 4.0 is the most prominent keyword in the research area with a total of 32 links and a link strength of 339 in number, followed by Human Resource Management with 32 links having 329 link strength in total. Analyzing the distribution of authors' keywords is pertinent to identifying popular research trends in the domain.

Table 8: Keywords Co-occurrence

Sr. No.	Keywords	Total Links	Total Link Strength
1	Industry 4.0	32	339
2	Human Resource Management	32	329
3	Decision Making	26	76
4	Human Resources Management	23	58
5	Industrial Revolutions	22	55
6	Managers	21	67
7	Knowledge Management	20	50
8	Personnel Training	19	56
9	Industrial Research	17	49
10	Internet Of Things	17	49
11	Automation	17	40
12	Sustainable Development	16	44
13	Sustainability	15	33

14	Human Resource	14	46
15	Human Resources	11	26

Source: Vosviewer

The visualization of the co-word network is displayed in 'Figure 8'. The Three thematic clusters are being formulated to serve the study objective, namely Integrating AI, Automation, Analytics and HRM, Strategic HRM in Industry 4.0: Fostering Digital Transformation, Competitiveness, and Managerial Excellence and Harmonizing innovation and Human Resource Optimization for Sustainable Development.

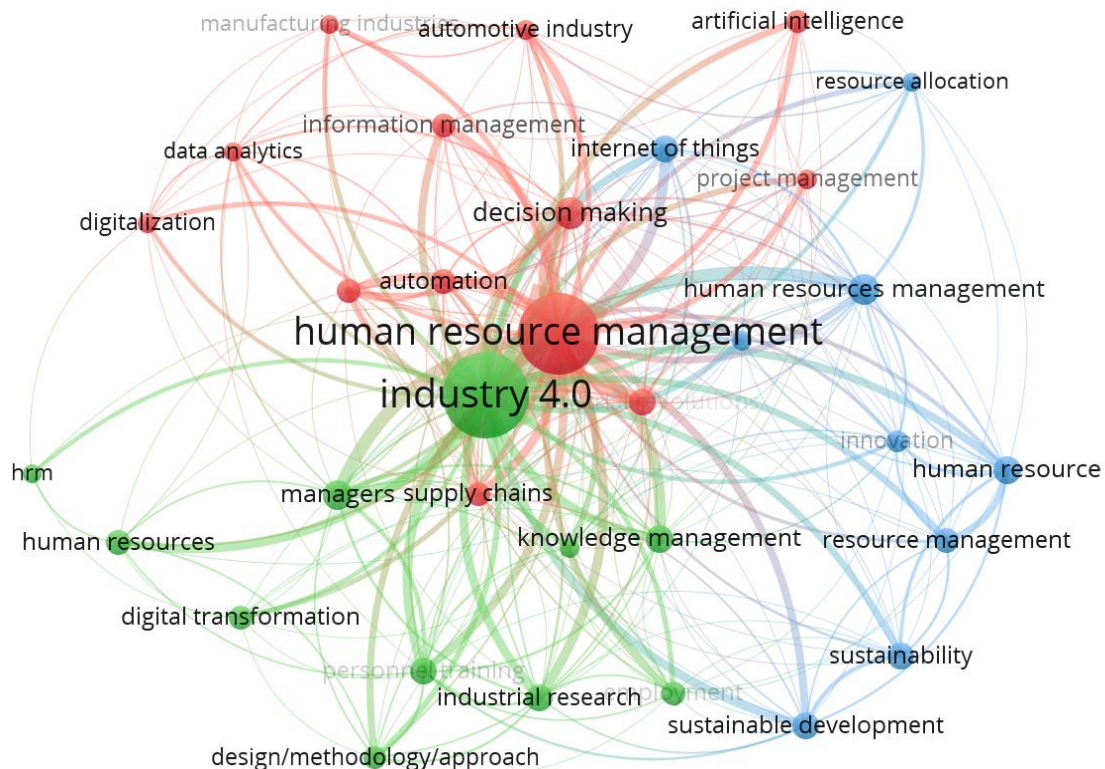


Figure 8: Co-Occurrence of Keywords

3.2.3.1 Cluster Analysis

As we can see in Figure 8, the three colored clusters (red, green and blue) have emerged which represent three distinct emerging research themes in the field of Industry 4.0 and HRM. "Table 9" provides the keywords that fall under each cluster.

Table 9: Clusters and Keywords Used

Clusters	Keywords
Cluster 1 (Red Colour) (13 Keywords)	Artificial intelligence, automation, automotive industry, Data Analytics, decision making, digitalization, embedded systems, Human Resource Management, industrial revolutions, information management, manufacturing industries, project management, supply chains.
Cluster 2 (Green Colour) (11 Keywords)	Competition, design/ methodology/ approach, digital transformation, employment, HRM, human resources, Industrial Research, industry 4.0, knowledge management, managers, personnel training

Cluster 3 (Blue Colour) (9 Keywords)	<i>Human resource, human resources management, innovation, internet of things, manufacturing, resource allocation, resource management, sustainability, sustainable development</i>
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Note: Number of Clusters = 3

The Red cluster explores the integration of Industry 4.0 technologies, particularly AI and automation, within HR, shedding light on both the benefits and challenges encountered by employees and organizations. The focus extends to the critical success factors for implementing and improving these technologies in manufacturing companies. For instance, research conducted by Malik *et al.* (2022) stressed understanding both the challenges (like technostress, job insecurity, and skill gaps) and opportunities (like flexibility, innovation, and improved job performance) AI brings, especially in the context of HRM and broader Industry 4.0 transformations. Organizations can optimize human resource planning by incorporating AI in HR practices which can lead to enhanced scheduling of shifts and task allocation (Ansari *et al.*, 2023). The Green Cluster spans fostering digital transformation, enhancing competitiveness, and achieving managerial excellence through HRM strategies. The articles in this cluster delved into the evolving requirements for education and qualification of individuals in the Industry 4.0 era, and the empowerment and engagement of industrial workers through Operator 4.0 solutions thereby enhancing operational and financial sustainability. Integrating HRM with Industry 4.0 technologies enhances competitiveness and managerial excellence by optimizing workforce management through AI and IoT, leading to higher productivity and reduced costs (Romanello & Veglio, 2022). Digital HR tools streamline recruitment, training, and performance evaluations, saving resources while improving efficiency and quality (Stacho *et al.*, 2022). This alignment also brings financial benefits by reducing turnover, optimizing labor forecasting, and lowering operational inefficiencies (Sousa & Nunes, 2020). The Blue cluster explores the integration of Sustainable HRM practices and innovation strategies within the context of Industry 4.0, with a specific emphasis on fostering Corporate Social Responsibility (CSR). The articles within this cluster collectively investigate how organizations can strategically align HRM practices and innovative approaches to contribute to sustainable development. The adoption of Industry 4.0 technologies in HR supports sustainable production models by aligning workforce capabilities with sustainability initiatives. Technologies like Big Data Analytics (BDA) and IoT improve decision-making processes and help achieve sustainable operations, reducing environmental impact and increasing long-term competitiveness (Kumar *et al.*, 2021). “Table 10” provides an overview of articles categorized under each cluster, highlighting key themes and contributions in the field.

Table 10: Thematic Clusters

<i>Thematic Clusters</i>	<i>Documents</i>	<i>Title</i>	<i>Citations</i>
“Integrating AI, Automation, Analytics and HRM”	Pozzi <i>et al.</i> (2023)	“Industry 4.0 technologies: critical success factors for implementation and improvements in manufacturing companies”	66
	Qamar <i>et al.</i> (2021)	“When technology meets people: the interplay of artificial intelligence and human resource management”	37
	Vereycken <i>et al.</i> (2021)	“Human resource practices accompanying industry 4.0 in European manufacturing industry”	28
	Maisiri & Van (2021)	“Industry 4.0 skills: A perspective of the south african manufacturing industry”	18

<i>“Strategic HRM: Fostering Digital Transformation, Competitiveness, and Managerial Excellence”</i>	Benešová & Tupa (2017)		345
	Kaasinen et al. (2020)	“Requirements for Education and Qualification of People in Industry 4.0”	169
	Fareri et al. (2020)	“Empowering and engaging industrial workers with Operator 4.0 solutions”	124
	Jerman et al. (2020)	“Estimating Industry 4.0 impact on job profiles and skills using text mining” “Transformation towards smart factory system: Examining new job profiles and competencies”	66
<i>“Harmonizing Innovation and Human Resource Optimization for Sustainable Development”</i>	Piwowar-Sulej (2021)	“Human resources development as an element of sustainable HRM – with the focus on production engineers”	71
	Mukhuty et al. (2022)	“Strategic sustainable development of Industry 4.0 through the lens of social responsibility: The role of human resource practices”	58
	Scavarda et al. (2019)	“An analysis of the corporate social responsibility and the Industry 4.0 with focus on the youth generation: A sustainable human resource management framework”	43
	Sharma et al. (2022)	“Analysing the impact of sustainable human resource management practices and industry 4.0 technologies adoption on employability skills”	27

Future Implication of Industry 4.0 on HRM

Degree of Automation Industry 4.0 technologies will bring a seismic change to how HRM practices are operated in organizations across the board:

Skills and Talent Development: Adoption of such advanced technologies would require the upskilling & retraining of the existing workforce. HR intervention will help by identifying Skill gaps, Designing Learning Interventions & Ensuring that employees are continuously learning to be relevant in the digital age.

Recruitment and Talent Acquisition: Industry 4.0 is ushering in an era that seeking entirely new skill sets such as SEO, Cyber Security, Analytics, AI development, and IoT be it to bring efficiency but also for Threat Mitigation policies now have become more important than ever. HRM will need to develop strategies for hiring those skilled in these areas.

Change Management: The adoption of Industry 4.0 technologies tends to involve considerable organizational transformation. Change management is therefore the remit of the HRM since they are supposed to address employee issues, promote the culture of innovation, and manage change.

Employee Engagement: It can be difficult to navigate maintaining people's interest and encouraging them to excel in a fast-growing tech environment. With certain aspects, HRM can then Decide on how it can use data analytics to track the morale of the employee, how this employee can be trained and developed to fit into the organization and to make the employee understand and appreciate the purpose of being in the organization.

Workforce Planning: Skills development must be predicted and carried out for future changes so that human resource management can make the necessary preparations. This falls under one's ability to fully grasp the extent to which processes such as automation, and digitization are likely to affect employment status.

Data-Driven Decision-Making: This paper identifies how human resource management can benefit from data analytics to make important decisions concerning talent management, performance, and workforce.

Flexible Work Arrangements: Industry 4.0 tends to allow working from home and flexibility. Organizational development is an important facet of human resource management because it oversees the new policies and working styles which call for flexibility and policy formulation for better working productivity and quality family time.

Ethical Considerations: HRM now faces several emerging issues because of the advancement in artificial intelligence and automation technologies; privacy issues; bigotry of/deep illusion in/of algorithms; and good usage of employees' data.

Leadership Development: Experience shows that leadership skills need to adapt to the goals of Industry 4.0. HRM needs to determine potential leaders dealing with digitalization and encourage them to invent options for changes.

Employee Well-being: In today's world where work increasingly is digitized and increasingly remote, HMRC again must approach employee well-being as a priority, address such as digital burnout, and a signposting service for mental health support.

Financial Optimization: The implementation of Industry 4.0 in the HRM function proves to improve financial performance. By integrating local human resource activities like selection, appraisals, or training, organizations can cut down the costs of almost all general operations and administration. This streamlining helps make room for more important and resourceful endeavors that are critical to the growth of the business. Furthermore, employee training and retention are not only effective in ensuring high productivity returns, but they also limit a corporation's potential losses due to high turnover rates or shortage of skilled workers.

Therefore, Industry 4.0 is revolutionizing business and reforming Human resource management in organizations. Human resource management in the new age highlights the need for it to be responsive to change, knowledgeable on the usage of technology and proactive in managing human capital in a global village. This study therefore finds out that Organizations that have successfully integrated Human resource management practices with the needs of Industry 4.0 are poised for success in this new dispensation of industrial change.

Limitations of the Study

1. It is important to note that this study only used the Scopus database only meaning that this research was restricted by not using other databases like Web of Science and others.
2. The study included only the published articles, thereby excluding book chapters, reviews, conference papers, and editorials.
3. The type of articles reviewed in this study was restricted to those in the English language, which shortened the linguistic focus of the research articles.

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