

Talent Management in Industry 4.0: A Bibliometric Review of Required Skills and Competencies

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ABSTRACT

This bibliometric study systematically analyzes the evolving field of talent management within the context of Industry 4.0, employing VOSviewer for mapping and visualizing key research themes, collaborations, and temporal trends from 2012 to 2024. The analysis revealed distinct thematic clusters focusing on the integration of digital transformation within traditional HR practices, emphasizing core competencies, firm capabilities, and the evaluation of job performance. Temporal trends indicate a shift from foundational topics to more complex issues such as leadership competencies and the strategic implications of digital technologies. Density visualizations highlighted areas with heavy research concentration and potential gaps, suggesting opportunities for future studies particularly in emerging and less explored themes. The co-authorship analysis provided insights into collaborative networks, indicating a mix of well-established research groups and emerging scholars. This study not only maps the current landscape but also guides future research directions in talent management amidst rapid technological advancements.

Keywords: Talent Management, Industry 4.0, Bibliometric Analysis, VOSviewer, Skills, Competencies

1. INTRODUCTION

The advent of Industry 4.0 has ushered in a transformative era in the manufacturing sector, characterized by the integration of advanced digital technologies such as artificial intelligence (AI), the Internet of Things (IoT), and robotics. This technological revolution has fundamentally altered the landscape of industrial operations, demanding new skills and competencies from the workforce. As organizations strive to adapt to these changes, the focus on talent management has become paramount, highlighting the need to identify, develop, and retain individuals who are proficient in these new technologies. The complexity of these technological integrations not only requires technical skills but also demands enhanced cognitive and interpersonal abilities, such as problem-solving, adaptability, and collaboration [1]–[4].

The impact of Industry 4.0 on the workforce is profound, as it reshapes the nature of jobs and the skills required to perform them effectively. Traditional roles are being redefined, and many tasks that were once manual are now automated, necessitating a shift in the skill sets that employees must possess. This shift has significant implications for talent management practices within organizations, which must now prioritize digital literacy alongside leadership and strategic thinking skills. The challenge for businesses is to not only attract but also cultivate a workforce that is versatile and equipped to handle the complexities of a digitalized industrial environment [5]–[9].

In the context of this technological shift, academic research has started to focus on the evolving requirements of talent management within Industry 4.0. However, while there is a growing body of literature on the subject, it remains scattered across various disciplines and industry reports, with no comprehensive synthesis of the knowledge accumulated so far. A bibliometric review can provide a structured overview of the existing research, identifying key trends, gaps, and the

evolution of themes over time. This would be invaluable for academics, industry professionals, and policymakers aiming to understand and address the human resource challenges posed by Industry 4.0 [1], [3], [10]–[12].

Despite the critical importance of managing talent in the context of Industry 4.0, there is a lack of a consolidated view on the specific skills and competencies that are emerging as essential. Current literature is fragmented and often focuses on isolated aspects of talent management or specific technological skills, without a holistic assessment of how these competencies integrate into the broader talent management strategies of organizations. This gap hinders the ability of organizations to effectively plan and implement talent management strategies that align with the demands of a rapidly evolving technological landscape.

This research aims to conduct a comprehensive bibliometric analysis of the literature on talent management in the context of Industry 4.0, focusing specifically on the skills and competencies that are deemed essential for the workforce. This study aims to map the existing academic and industry discourse, identify prevalent themes and trends, and highlight the competencies that are repeatedly emphasized across various studies. The analysis will help in understanding how the discourse on required skills has evolved over time and what future directions might look like.

2. LITERATURE REVIEW

2.1 *Evolution of Industry 4.0 and Its Impact on the Workforce*

The concept of Industry 4.0, often referred to as the fourth industrial revolution, encompasses a range of modern technologies that integrate physical production and operations with smart digital technology, machine learning, and big data to create a more holistic and better connected ecosystem for manufacturing industries. This technological shift, as described by [13], is not merely a continuation of the automation trend, but a substantial transformation that merges the capabilities of both humans and machines in unprecedented ways. The literature identifies critical skills such as systems analysis, programming, and digital literacy as fundamental to thriving in this new era [14]. Moreover, studies like that of [15] highlight that the automation of production processes shifts the skill requirements from manual tasks to oversight, maintenance, and optimization, indicating a significant transformation in job profiles.

2.2 *Talent Management Strategies in Response to Industry 4.0*

Talent management in the context of Industry 4.0 has received considerable attention, focusing on how organizations can adapt their human resources practices to accommodate the shifts in required skills and competencies. As noted by [16], modern talent management must evolve from traditional models to more dynamic strategies that emphasize continuous learning and adaptability. Literature by scholars such [17] argues for the importance of developing strategic partnerships between educational institutions and industry to facilitate the continuous upskilling of the workforce. Additionally, the work by [18] stresses the necessity of fostering a culture that embraces ongoing innovation and technology integration at all organizational levels.

2.3 *Competencies Required in Industry 4.0*

Research into the specific competencies needed for Industry 4.0 focuses on a combination of technical skills, cognitive abilities, and interpersonal attributes. A study by [19] categorizes these into three broad areas: technical proficiency in new technologies, cognitive skills like problem-solving and analytical thinking, and soft skills such as teamwork and communication. The integration of AI and IoT in manufacturing processes not only enhances efficiency but also demands a higher level of cognitive engagement from employees, requiring them to manage complex systems and troubleshoot proactively. According to [20], there is also an increased need for skills in cybersecurity, data analysis, and network management as companies navigate the risks and opportunities presented by interconnected digital systems.

2.4 Gaps in Existing Research

While there is a substantial amount of research on the required skills for Industry 4.0, there remains a noticeable gap in comprehensive, systematic reviews that aggregate these findings into a coherent framework. Most studies tend to focus narrowly on specific sectors or technological applications, lacking a broader perspective on how these competencies are being integrated into general talent management strategies across industries. Furthermore, as identified by [21], there is a need for more empirical research that not only identifies required skills but also examines effective methods for teaching and cultivating these skills within existing workforces.

3. METHODS

This research employs a bibliometric analysis to systematically review and synthesize the existing literature on talent management within the context of Industry 4.0, focusing on the required skills and competencies. The initial step involves the collection of data from Google Scholar, utilizing keywords such as "Industry 4.0", "talent management", "skills", and "competencies". The search is refined to include papers published within 1962-2024 to ensure relevance to current technological contexts. Using VOSviewer software, the data is then analyzed for co-citation, co-authorship, and keyword co-occurrence to identify the most influential authors, seminal works, and emerging themes in the field. This bibliometric mapping facilitates the identification of trends, gaps, and the evolution of research interests over time. The analysis also includes a critical examination of the content of the most cited works to deepen the understanding of the consensus and debates within the scholarly community about essential skills and competencies for Industry 4.0, providing a comprehensive overview of the academic landscape in this area of study.

4. RESULTS AND DISCUSSION

4.1 Research Data Matriks

Table 1. Research Data Metrics

Publication years	: 1962-2024
Citation years	: 62 (1962-2024)
Paper	: 980
Citations	: 127054
Cites/year	: 2049.26
Cites/paper	: 129.65
Cites/author	: 75336.61
Papers/author	: 528.63

Author/paper	: 2.46
h-index	: 161
g-index	: 337
hI,norm	: 114
hI,annual	: 1.84
hA-index	: 49
Papers with ACC	: 1,2,5,10,20:783,705,503,297,159

Source: Publish or Perish Output, 2024

Table 1 presents a comprehensive set of bibliometric indicators derived from the Publish or Perish software, covering the period from 1962 to 2024. The dataset includes a total of 980 papers which have collectively garnered 127,054 citations, resulting in an average of 2049.26 citations per year and 129.65 citations per paper. This indicates a substantial impact and relevance in the field over the span of 62 years. The citations per author are exceptionally high at 75,336.61, suggesting the presence of several highly cited works within the dataset. The papers per author ratio stands at 528.63, and each paper has an average of 2.46 authors, reflecting a collaborative nature in research efforts. The h-index of the dataset is 161, confirming that a significant number of papers (at least 161) have been cited at least 161 times, highlighting the influential nature of the research. The g-index is even higher at 337, indicating that the top 337 papers have collectively received at least 113,569 citations. The normalized and annual h-indexes (hI,norm and hI,annual) stand at 114 and 1.84, respectively, providing a scaled measure of individual impact over time, adjusted for career length. The hA-index at 49 further refines the assessment of active author impact. The distribution of papers achieving various citation count milestones (ACC) demonstrates that a majority of the works have been highly cited, with 783 papers receiving at least one citation, and 159 papers receiving at least 20 citations, showcasing both breadth and depth in citation impact across the corpus.

4.2 Network Visualization

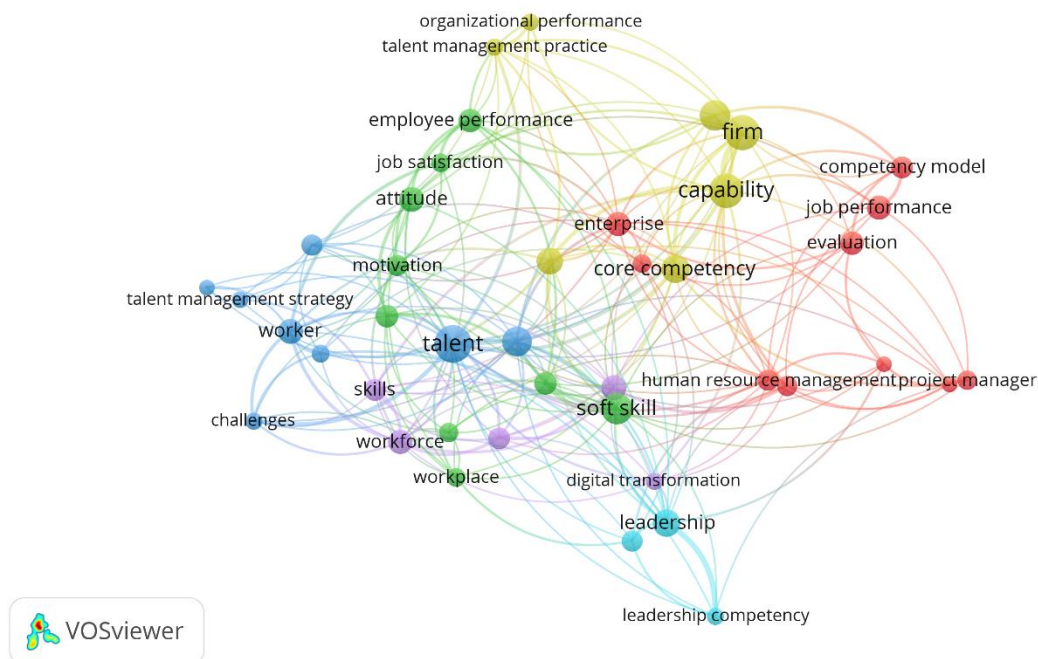


Figure 1. Network Visualization

Source: Data Analysis Result, 2024

This type of visualization helps to identify and interpret the relationships between different terms or topics within a particular field of research, in this case, likely related to talent management in the context of modern industrial environments like Industry 4.0. The network seems to have several distinct clusters, each represented by different colors, which indicate groups of related themes or concepts. Central to the network are terms like "talent", "skills", "workforce", and "talent management strategy", suggesting these are fundamental concepts within the literature being analyzed. These terms are closely linked to both technical aspects such as "soft skill" and "digital transformation" and more human-centric elements such as "motivation" and "attitude". This indicates a dual focus in the literature on both the human and technological dimensions of talent management.

The visualization shows strong linkages between "talent" and both "firm" and "capability", suggesting that the discourse extensively covers how firms can enhance their capabilities through effective talent management. Connections to "job performance" and "employee performance" underline the practical importance of these strategies in enhancing organizational outputs. Notably, the term "core competency" is closely connected to "capability", highlighting discussions on essential skills and competencies that firms need to develop within their workforce to maintain competitiveness in a digitalized industrial landscape.

Towards the periphery of the map, terms like "leadership competency" and "project manager" are linked, but less central, indicating that while these areas are discussed in the literature, they may not be as densely connected to the core themes of talent management as other topics. However, their presence reflects the specialized roles that require attention in studies on talent management within Industry 4.0—specifically, how leadership and project management roles evolve.

4.3 Overlay Visualization

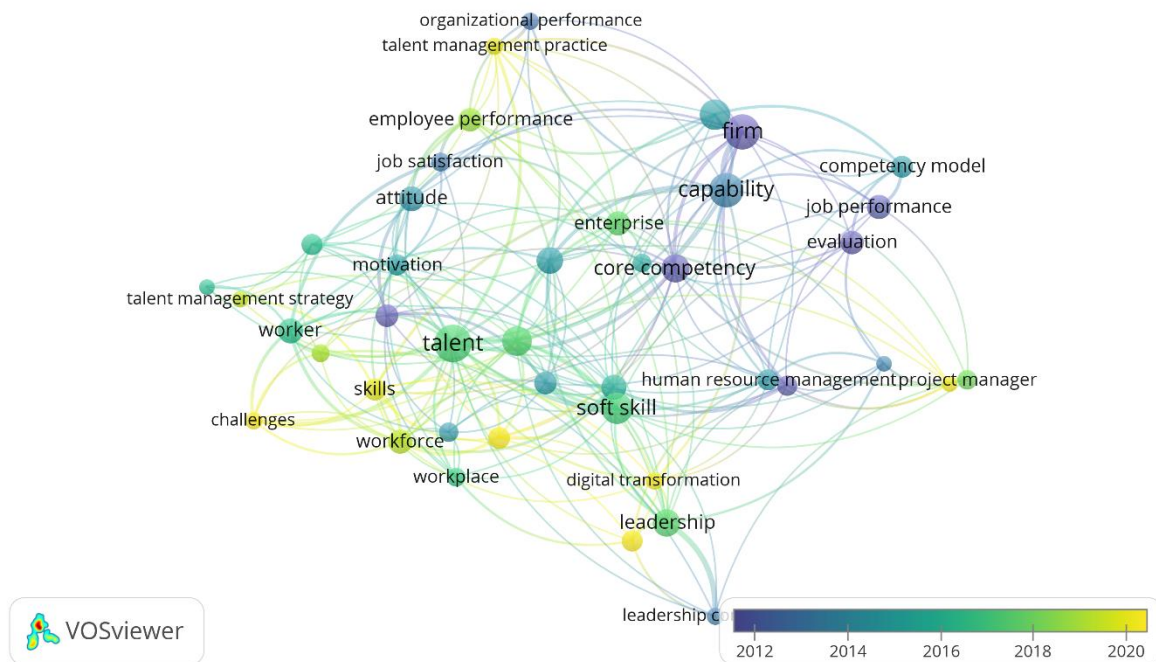


Figure 2. Overlay Visualization

Source: Data Analysis Result, 2024

This second figure is a temporal bibliometric map created using VOSviewer, depicting the evolution of various themes within the field of talent management from 2012 to 2020. This

visualization integrates the aspect of time, with color gradients representing different years, thus providing insights into how the focus of research has shifted over the years.

In the early years, as indicated by the green nodes, the focus appears to be primarily on foundational concepts such as "talent," "skills," "talent management strategy," and "workforce." This suggests that during this period, the discourse was centered around establishing the basic principles and frameworks of talent management. Terms like "motivation" and "attitude" also appear in these early years, highlighting an interest in the psychological and motivational aspects of talent management.

As we move towards the middle years, represented by the yellow nodes, there is a visible shift towards more specific and complex themes. Notably, "digital transformation" and "leadership" start to emerge during this period. This shift indicates a growing recognition of the impact of digital technologies on leadership practices and the need for digital literacy within the talent management processes. The emergence of "leadership competency" around this time points to a refined focus on what specific capabilities leaders need to navigate the evolving industrial landscape.

In the later years, as shown by the blue nodes, there is a pronounced emphasis on "competency model," "job performance," and "evaluation." This trend reflects an advanced stage of research where the emphasis is not just on identifying skills but also on assessing and optimizing performance through structured competency models. The connection of these themes with both earlier (green) and middle (yellow) period terms suggests a cumulative build-up of knowledge that links foundational talent strategies with performance outcomes.

4.4 Citation Analysis

Table 2. The Most Impactful Literatures

Citations	Authors and year	Title
5769	[22]	The strategic analysis of intangible resources
5660	[23]	The professionalization of everyone?
4214	[24]	Customer power, strategic investment, and the failure of leading firms
3871	[25]	Knowledge management enablers, processes, and organizational performance: An integrative view and empirical examination
3507	[26]	Transforming the balanced scorecard from performance measurement to strategic management: Part 1
3454	[27]	How business schools have lost their way
3339	[28]	A framework for quality management research and an associated measurement instrument
3120	[29]	Performance management
2541	[30]	Uncertainty and quality in science for policy
2003	[31]	Effective succession planning: Ensuring leadership continuity and building talent from within

Source: Publish or Perish Output, 2024

Table 2 lists the ten most impactful papers from the research dataset, ranked by the number of citations each has received according to the Publish or Perish software output for 2024. Leading the table is R Hall's 2009 work on the strategic analysis of intangible resources, cited 5,769 times, indicating its significant influence in strategic management studies. Close behind, with 5,660 citations, is HL Wilensky's 1964 seminal paper on the professionalization of various occupations, reflecting its longstanding impact on professional studies and organizational sociology. Other notable works include Christensen and Bower's 1996 study on customer power and firm strategy, and Lee and Choi's 2003 research on knowledge management, both highlighting critical aspects of

business strategy and organizational performance. Kaplan and Norton's 2001 paper on evolving the balanced scorecard into a strategic management tool, and Bennis and O'Toole's 2005 critique of business schools, further underscore the breadth of impactful research spanning strategic management, education theory, and quality management. Notably, Aguinis's recent 2023 work on performance management has already amassed 3,120 citations, showcasing its immediate relevance and impact. The distribution and focus of these citations across different years and topics illustrate the diverse and evolving nature of business and management research, as well as the significant influence these authors and their works have had on both academic literature and practical applications in their respective fields.

4.5 Author Visualization

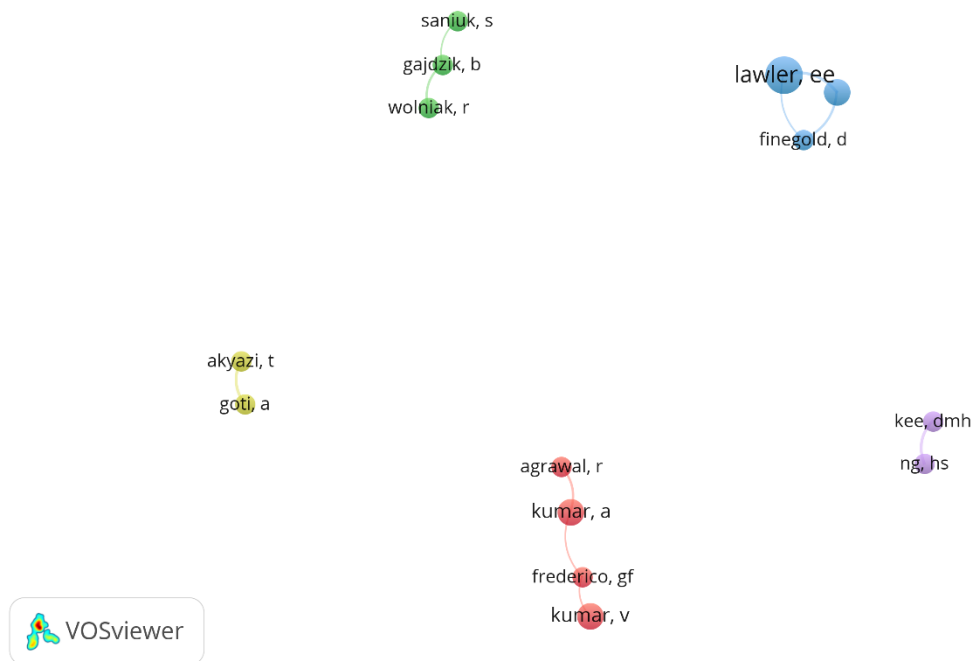


Figure 4. Density Visualization

Source: Data Analysis Result, 2024

This figure bibliometric map of co-authorship among researchers within a specific academic field, likely related to talent management or a related area, based on the visualization generated using VOSviewer. Each node (labeled with an author's name) represents an individual scholar, while the lines between the nodes indicate collaborative relationships between these authors. The size of the nodes typically reflects the number of publications or the prominence of the author in the dataset, although this specific graphic does not show varying node sizes.

From the configuration, it is evident that there are a few clusters of authors who frequently collaborate. For instance, "lawler_ee" and "finegold_d" form a closely connected duo, suggesting they have co-authored multiple works. Similarly, the cluster featuring "kumar_r," "kumar_a," "kumar_v," and "frederico_gf" indicates a robust collaborative network, possibly around a common theme or within a specific research institution or geographic location.

In contrast, some authors like "sanjuk_s," "gajdzik_b," "wolniak_r," "akyazi_t," "goti_a," "kee_dmh," and "ng_hs" are shown as isolated nodes, implying that their work, within the context of this dataset, is either solitary or with collaborators not included or prominent in this specific bibliometric analysis. This kind of visualization helps identify key contributors and their

relationships in the field, offering insights into collaboration patterns and potentially influential research groups within the academic community.

4.6 Density Visualization

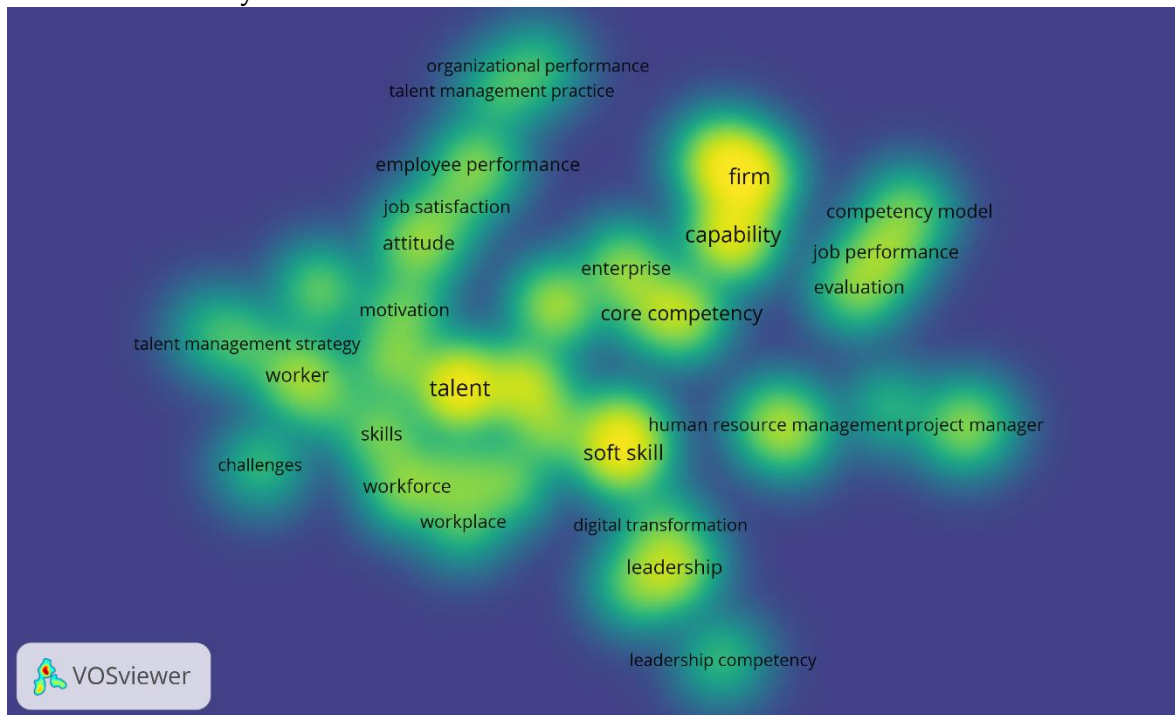


Figure 4. Density Visualization

Source: Data Analysis Result, 2024

The figure above is a density visualization created using VOSviewer, illustrating the concentration of topics in a bibliometric map related to talent management and associated domains. This type of visualization uses color gradients to indicate the density of connections between terms, with warmer colors (yellows) representing higher densities and cooler colors (blues and greens) indicating lower densities.

In this map, the terms "firm," "capability," "core competency," and "talent" are highlighted with warmer colors, suggesting these are the most discussed or central themes within the dataset. This indicates a strong focus in the literature on how firms can build capabilities and core competencies, particularly in relation to managing talent effectively. The concentration of terms like "job performance," "competency model," and "evaluation" in close proximity and also highlighted suggests a significant emphasis on measuring and evaluating job performance as part of talent management strategies.

Conversely, terms like "leadership," "digital transformation," and "leadership competency" are shown in cooler colors, implying that while these areas are indeed part of the academic discourse, they might not be as densely connected or as frequently discussed as the central themes. This could point to these being either emerging areas of interest or more specialized topics within the broader field of talent management.

CONCLUSION

The bibliometric analysis presented through various VOSviewer visualizations provides a comprehensive overview of the field of talent management, particularly in the context of evolving industrial and digital landscapes. The thematic cluster analysis revealed a strong emphasis on integrating traditional human resource practices with advanced technological capabilities,

underscoring the necessity for organizations to enhance their core competencies and strategic capabilities in talent management. The temporal trend analysis illustrated a shift in research focus from foundational HR themes towards more complex issues like digital transformation and competency evaluation, reflecting the dynamic nature of the field influenced by technological advancements and changing organizational needs. The density visualization highlighted the most concentrated areas of research, suggesting that while certain themes like firm capabilities and talent strategies are well-explored, emerging areas such as digital transformation and leadership competencies represent significant opportunities for future research. Finally, the analysis of author collaborations indicates a field marked by both robust partnerships and individual contributions, with potential for further collaborative research to explore underrepresented areas and integrate diverse perspectives. Together, these insights not only enhance our understanding of the current landscape of talent management research but also pinpoint critical areas for continued academic inquiry and practical application.

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