

Adoption and Implications of Industry 4.0 technologies in Human Resource Practices: An Exploratory Study of Manufacturing Industries in Southern India

Udita Jhavar, School of Management Studies, Sankalchand Patel University, Visnagar, Gujrat.
Jitendra Sharma, School of Management Studies, Sankalchand Patel University, Visnagar, Gujrat.

Abstract: The rapid inception of Industry 4.0 digital technologies is altering manufacturing systems worldwide, however, empirical evidence on how this alteration restructures human resource (HR) practices especially in developing nations remains restricted. This study examines the range and pattern of digitalisation of HR processes in manufacturing organizations in Southern India, with a specific focus on the alignment between digital manufacturing initiatives and core HR practices. Using an empirical, cross-sectional research design, data were collected from 109 middle- and senior-level HR managers through a structured questionnaire. Reliability analysis to determine the suitability of testing tools was deployed, demographic, descriptive statistics, and exploratory factor analysis were used to assess implementation levels across Industry 4.0 dimensions and multiple HR practice domains. The findings divulge that most organizations are positioned in a transitional stage of digital transformation, characterized by uneven and selective adoption. Core human factors of HR practices like training and development, employee engagement, and performance appraisal display relatively higher levels of digital integration, whereas system-centric functions including compensation management, payroll, and retention lag behind significantly. This imbalance highlights a sociotechnical misalignment in which HR readiness outpaces technological infrastructure integration. The study contributes empirically to the industry 4.0 and HRM literature by displaying context specific indications from an emerging economy and establishes that partial digitalization of HR practices may constrain the realization of holistic Industry 4.0 benefits. The results accentuate the need for integrated, human-centred digital transformation strategies that align technological investments with HR policy design to support sustainable organizational performance.

Keywords: Human Resource management, HR functions, HR Challenges, Industry 4.0, HR digitalization.

Introduction

The emergence of the fourth industrial revolution has initiated a profound transformation in the global manufacturing sector. Key digital technologies such as artificial intelligence (AI), cyber-physical systems, big data analytics, the Internet of Things (IoT), cloud computing, and intelligent automation are now integrating with prevalent manufacturing processes transforming the manufacturing landscape and is being termed as Industry 4.0 (I4.0) (Lasi et al., 2014). This digitalisation of manufacturing has led to the transformation of organizational operations, design and competing techniques as they facilitate key enablers like decentralized decision-making, real-time data exchange, and highly adaptive production systems (Schuh et al., 2020; Devezas et al., 2024). I4.0 is not just an upgradation in technology or its automation, it has uniquely engaged itself in all the aspects of an organisation including process changes, managerial approach, resource handling, role and structure of workforce and many more aspects (Ghobakhloo, 2020; Yu et al., 2021). The adoption of all these advanced digital technologies also aids in efficient communication, better coordinated interdepartmental work thereby saving time and optimized use of resources (Frank et al., 2019). Among the various advantages associated with I4.0 which are well proven and matured its adoption however, still remains slow and uneven. Among the other barriers to its adoption the most significant barrier has been the size of the organisation. The small and medium enterprises (SMEs) are especially struggling to adopt these advanced digital technologies (Mittal et al., 2018) within its operational system due to various factors like high cost, scarcity of digitally skilled workforce, upskilling cost etc. (Cugno et al., 2021; Kumar, 2023; Hansen et al., 2024). Therefore, it might be inferred that interrelated subsystems within organisations play an equally substantial role in positioning advanced technology adoption within the organisation. Sheer technology adoption cannot confirm its successful implementation especially those concerning human resources (HR).

The role of HR during this paradigm shift towards digitalisation has gathered immense attention in organisations and thereby is a subject of deep research interest. It is evident that the digital technological upgradation will be highly dependent on skilled workforce giving human resources the centre stage to perform. During digitalisation of technology HR systems also invariably embarked on its journey of digitalisation. This integration of digitalisation into HR systems has led to a complete metamorphosis of HR from core administrative function to a strategic decision maker based on data (Hecklau et al., 2018; Appolloni et al., 2024). This transformation is not just limited to mere technology enhancement within HR systems rather it establishes a well knitted web of ecosystems where HR data enables enhancement in operational strategy in an organisation. Core HR functions like recruitment, training, performance management, employee retention and engagement should be restructured to meet the needs of this digital transformation such that it allows data driven changes in its systems. These changes thereby make the role of HR strategic. It was observed that most organisations adopting I4.0 went through major structural changes within the organisation for making work flow smoother, transforming the hierarchical approach to more horizontal systems. Ease of communication was the key driver that led this shift.

Role of HR in decision making has stemmed from its acquired strategic function which is based on the use of digital technologies like AI and data analytics facilitating the concept of eHRM. Digital HR systems aim at achieving clarity with open governance, enhanced capabilities and robust decision-making aiding in live operational monitoring and human resource planning (Margherita (2022); Zhou et al. (2022)). Chowdhury et al. (2022) projected that eHRM is not just a digital operational tool rather it is an enabler for strategic decision outcomes linking AI with digital maturity enhancing organizational performance outcomes. However, a need for deep empirical study which could be context specific could help establish proven relationship between advantage of digital HRM with organisational readiness, employee perception to change along with managing data generated through digitalisation. Research gradually perceives AI as a decision enhancement tool rather than a complete replacement mechanism for human decision in HR processes (Jarrahi, 2018). These developments further reinstate the significance of designing HR policies that balance technological efficiency with human-centric considerations. The focus of digitalised HR remains primarily on competency development and enhanced efficiency of systems and workforce. However, it has also branched to encompass other aspects of employee well-being like workers engagement and their experiences, psychological issues like stress and role confusions which are quite synonymous during such major technological and managerial restructuring (Santana and Bornay-Barrachina; 2024). Therefore, the method in which human resource strategies are implemented would greatly determine the employee engagement and enhance its capabilities (Rehman et al., 2024). Mbatha et al. (2024) emphasised that in manufacturing SME's due to improper change management digital adoption of HR gets affected and is therefore less effective leading to resistance and uneven adoption.

Even though the adoption of I4.0 in the manufacturing and its associated domains would be inevitable in the future, its current adoption level in the Indian subcontinent is slow and is mostly limited to large manufacturing units (Kamble et al., 2018). Developed economies are displaying significant research in the domain, with limited work has been reported from developing economies (Mittal et al., 2018; Younis & Shabaan, 2025). The readiness level, availability of skilled workforce, appropriate implementation design are still a concern for these developing economies (Kamble et al., 2018; Gupta et al., 2025). Studies reported from India highlight evident challenges like discrepancies in required skills, infrastructural disparities and resistance to change arising from lack of awareness and clarity from management (Bhatnagar & Sharma, 2020; Patel & Sharma, 2022).

This paper dwells in a comprehensive empirical study of manufacturing organisation located in southern India adopting digitalisation in its processes. It aims at specifically accessing the adoption level of advanced digital technologies in the domain of human resources. The underlying motivation of focusing southern India for this research was backed by prevailing ecosystems that fosters adoption of advanced technologies faster than their northern, eastern or western counterparts. Also, the concentration of emerging conglomerates is higher in southern India, thereby making the study easier. This paper dwells in a comprehensive empirical study of manufacturing organisation located in southern India adopting digitalisation in its HR processes. This article aims to extend the prevailing research in four different ways. Firstly, it encompasses primary empirical study on the current level and pattern of digitalisation across core HR domains, therefore substantiating the need of quantitative studies in this area. Secondly, this study depicts that the digitalisation of HR has been implemented in a non-structured pattern, which is non-uniform throughout its functions areas and is ongoing. This

pattern of digitalisation symbolises practical implementation levels revealing depth of HR transformation over assumptions of complete and uniform transformation. Thirdly, this article is a contribution from a developing economy whose study extends meaningful insights for future better implementation strategies for enhancing organisational efficiency. Finally, this study can be used as a foundation for future comparative and longitudinal research. Through these contributions, this paper moves beyond broad discussions of digital transformation and provides grounded evidence on how HR systems are evolving in response to Industry 4.0.

Literature Review

Industry 4.0 (I4.0), recognized as the fourth industrial revolution, signifies a paradigm transformation in the functioning of production systems through the integration of advanced technologies such as artificial intelligence (AI), the Internet of Things (IoT), big data analytics, intelligent automation, cyber-physical systems (CPS) and cloud computing, (Lasi et al., 2014; Ghobakhloo, 2020). While adopting I4.0, the manufacturing scenario is now enabled with enhanced flexibility and data driven insights leading to a more robust architecture where, real-time connectivity, dispersed decision-making and smart technologies form the key enablers, this transformation is in high contrast to previous industrial revolutions as they were characterised by mere upgradation or mechanisation in technology in silo (Devezas et al., 2024). Researchers believe that this gradual enhancement in technological adoption is not just limited to the integration of technology rather it simultaneously comprehends structural configurations, process flows and system integration that aid in enhancing the value architecture (Ghobakhloo, 2020). Few empirical evidence advocate that I4.0 can significantly boost the innovation competency of an organisation giving it a more ambitious leverage over others, when complemented with organizational strategy and capabilities (Frank et al., 2019; Gupta et al., 2025). Although, the integration of these technologies across organisations can be individualistic. Study of developing economies depicts the incremental and scattered nature of implementation of digital technology adoption across departments due to infrastructural shortcomings, scarcity of adequate knowledge, and lack of organizational readiness (Younis & Shabaan, 2025). These results highlight the need to test Industry 4.0 adoption not only from a technological purview but also through the human inferences.

Industry 4.0 enables transverse amalgamation of horizontal and vertical structure of an organisational facilitating enabling coordination between manufacturing, inventory management, process improvement management, and other endorsement activities (Frank et al., 2019). The culmination of real-time data transversely through departments allows organisation to harmonize processes, condense process lead times, and optimize deployed resources (Tortorella et al., 2020). This thereby led to a progressively evolved organisation leaving behind isolated functional structures toward a more intelligent, data driven and process-oriented character. From an administrative perspective, Industry 4.0 needs a change from traditional structurally tiered control models toward a more distributed, data-driven strategic administrative systems (Yu et al., 2021). Administrators are obligated to accept novel methods of administration, performance assessment, and strategic planning in digitally enabled environments (Devezas et al., 2024). These variations strengthen the opinion that Industry 4.0 is a sociotechnical evolution in which organizational methods, supervisory practices, and human systems must evolve in coordination with digitalisation of technology.

Human resource management (HRM) has been recognized as an enabler of Industry 4.0 transformation, given its function of handling employee's aptitudes, flexibility, and engagement (Hecklau et al., 2018). Skill enhancement framework, reported in the literature highlights digital knowledge, problem-solving aptitude, interdisciplinary association, and human-machine collaboration as essential skills for industry 4.0 workforce (Ammirato et al., 2023). Systematic reviews of HRM in Industry 4.0 contexts highlights that traditional HR practices are seldom inadequate to depict the dynamic skill requirements and flexible work provisions associated with digital manufacturing environments (Appolloni et al., 2024). Traditionally, human resource (HR) departments have served as a significant stakeholder of organizational steadiness, with primary function centred around governing obedience, payroll administration, and standardized job design. Empirical and meta-analytic studies establish that e-HRM implementation improves managerial competencies, transparency, and decision eminence, alongside supporting deliberate workforce planning (Zhou et al., 2022). Margherita (2022) hypothesized HR analytics as a strategic competence

that enables data-oriented decision-making and strengthens HR's participation in organizational performance. Adoption of smart technologies like Artificial intelligence (AI) enables HR to spread its proficiencies in its functions like performance appraisal, talent management, data driven recruitment and workforce forecasting (Chowdhury et al., 2022; Prikshat et al., 2023). However, researchers warn that effectiveness is complimented only by organisational readiness, efficiency of data handling and most significantly workforce acceptance, highlighting the importance of human judgment and ethical oversight (Jarrahi, 2018). Altering perceptions of independence, investigation, and job safety help redesign employee experience (Santana & Bornay-Barrachina, 2024). Rehman et al., 2024 reiterated these findings by showcasing empirical evidence on the significance of designing and implementation of HR policy. He suggested that there could be both positive or negative impact of HR digitalisation on employee engagement which considerably could be depended on the nature and design of HR policy implementation. Literature also depicts that in manufacturing SME's restricted change management abilities, leadership support, and HR participation deters the effective employment of digital HR initiatives (Mbatha et al., 2024).

To explain the complexities of Industry 4.0 transformation, scholars increasingly adopt sociotechnical systems and dynamic capability perspectives. The sociotechnical approach emphasizes the joint optimization of technological and human subsystems, warning that technological advancement without corresponding HR adaptation may lead to suboptimal outcomes (Pacaux-Lemoine et al., 2022; Vereycken et al., 2021). Complementarily, the dynamic capabilities framework highlights the role of HR practices in enabling organizations to sense opportunities, seize technological potential, and reconfigure resources to sustain competitiveness in volatile environments (Teece, 2018; Naghibi & Valmohammadi, 2025). These findings undermine the requirement for human-centric HR strategies that aligns with efficient technological enhancement promoting employee well-being and organizational culture.

To explain the complications of Industry 4.0 changes, researchers increasingly follow the sociotechnical systems and robust capability perceptions. The sociotechnical method accentuates the joint optimization of technological and human subsystems, cautioning that technological advancement without its corresponding HR strategy may deliver underutilised outcomes (Pacaux-Lemoine et al., 2022; Vereycken et al., 2021). Complementarily, the dynamic capabilities framework highlights the role of HR practices in enabling organizations to sense opportunities, seize technological potential, and reconfigure resources to sustain competitiveness in volatile environments (Teece, 2018; Naghibi & Valmohammadi, 2025).

While there has been evident research on the theoretical and process centric approach of this digital era of automation, very little empirical research has been reported on the adoption of these advanced technologies especially pertaining to the various functions of HR. Prevailing research have predominantly targeted technological infrastructure, strategic decisions, or fragmented organizational performance. There was however very little attention given to the redesigning of core HR functions through digitalisation integrating both the avenues to facilitate organisational efficiency. To the best of authors knowledge empirical study on adoption of Industry 4.0 in HR systems especially pertaining to southern Indian subcontinent has not been reported so far.

Empirical Findings on HRM in Industry 4.0

While conceptual frameworks surrounding HR transformations in the era of digital manufacturing are becoming increasingly refined, empirical investigations, particularly within emerging economies remain limited. For instance, Nguyen and Nguyen (2024) analyzed shifts in human resource management across industrial zones in Vietnam and identified a substantial disconnect between technological investments and corresponding workforce development strategies. Likewise, Rehman et al. (2024), through structural equation modeling, demonstrated that senior employees in digitally enabled manufacturing environments experience elevated role ambiguity and diminished engagement levels, thereby underscoring the need for more adaptive and inclusive HR policy interventions.

In the context of public sector organizations, Mbatha et al. (2024) observed that digital HRM implementations frequently underperform, primarily due to inadequate change management practices and insufficient leadership backing. Collectively, these findings emphasize the influence of

organizational context and sector-specific challenges on the effectiveness of HR policy reforms, calling into question the universal applicability of standardized global models.

HRM in Industry 4.0: The Indian Context

In the Indian context, the role of human resource management (HRM) is undergoing a transformative shift under the influence of Industry 4.0. Scholars such as Bondarouk, T., Parry, E., & Furtmueller, E.; 2017, emphasize that HRM in India is increasingly adopting AI-enabled systems and digital tools to realign talent strategies with the demands of intelligent manufacturing ecosystems. The integration of HR analytics and digital HR platforms has enabled organizations to enhance workforce planning, recruitment, and performance evaluation (Patel & Sharma, 2022). Meanwhile, Margherita, A.; 2022 highlight specific challenges faced by Indian small and medium enterprises (SMEs), including limited digital readiness and the lack of structured employee training frameworks. Tiwari and Aggarwal; 2023 further argue that human capital development policies must evolve to foster digital competencies and adaptability at scale. Additionally, Strohmeier, S.; 2020 compared the Indian IT and manufacturing sectors, concluding that HR's strategic role in cultivating learning agility and managing organizational change is critical to sustaining competitiveness in the Fourth Industrial Revolution. Collectively, these studies underscore the growing importance of HR as a change enabler, skill architect, and digital transformation partner within India's industrial landscape.

The Indian manufacturing sector presents a complex landscape for HR policy evolution. On one hand, it is integrating Industry 4.0 technologies aggressively, particularly in automotive and pharmaceutical hubs. On the other, the workforce is predominantly semi-skilled and operating within traditionalist organizational cultures (Naghbi & Valmohammadi, 2025). This disjuncture often results in partial digitalization, where technology is deployed without corresponding HR transformation. Recent studies found that digital manufacturing in Indian firms is often introduced in a top-down manner, with limited involvement from HR (Vial, G.; 2019). As a result, upskilling initiatives are sporadic, and performance systems remain misaligned with digital workflows. Government initiatives like "Digital India" and "Skill India" aim to bridge these gaps, but their integration into firm-level HR policy remains inconsistent.

Contribution To Work

- This study strides to establish the significance and effect of digitalisation of all the core functions of HR and establish its relationship with organisational performance through empirical evidence.
- This Empirical study of correlation between digital technology adoption in Industry4.0 and HRM contributes to providing substantial evidence of prevailing HR practices, building a bridging between existing conceptual examination and on ground reality of adoption.
- This empirical study represents a developing economy, which remains unrepresented in the study of digitalisation of HR functions.
- Through reliability analysis and exploratory factor analysis, the study validates a robust measurement framework for assessing Industry 4.0 adoption and HR practice transformation, which can be replicated or extended in future studies.
- The study contributes by displaying a selective and phased digital transformation strategy by comparing HR practice adoption levels with overall Industry 4.0 implementation.
- Overall, the study contributes by displaying the significance of digitalisation of HR to enhance organisational output.

Methodology

This study adopts a quantitative, descriptive, and cross-sectional research design to examine the current state of Industry 4.0 implementation and associated human resource (HR) practices within the manufacturing sector of Southern India. A cross-sectional approach was employed to capture organizational practices at a single point in time without manipulating the study environment, thereby

enabling a factual assessment of prevailing implementation patterns. The target population comprised HR professionals from manufacturing organizations adopting I4.0 practices and located in major industrial hubs across Southern India. Using a purposive (judgmental) sampling technique, data were collected from 109 HR managers positioned at middle and senior management levels to ensure respondents possessed adequate strategic insight into firm-wide technological adoption and HR policy evolution. Primary data were gathered through a standardized, self-administered structured questionnaire consisting of two sections: Section A captured demographic and organizational characteristics, including turnover, workforce size, and general automation levels, while Section B assessed the extent of Industry 4.0 implementation through nine items and examined alignment of specific HR practices such as recruitment, training, and employee engagement etc. Responses were measured using a five-point Likert scale, ranging from “Not at all Implemented” (1) to “Extremely Implemented” (5) for technology adoption, and from “Strongly Disagree” (1) to “Strongly Agree” (5) for HR practice alignment. Data analysis was conducted using SPSS (version 25.0), employing reliability analysis through Cronbach’s alpha to assess internal consistency, descriptive statistics to summarize and rank implementation levels, and exploratory factor analysis (EFA) using principal component analysis with Varimax rotation to identify underlying construct dimensions. Sampling adequacy was confirmed using the Kaiser–Meyer–Olkin (KMO) measure and Bartlett’s Test of Sphericity. Consistent with prior methodological guidance (Sapnas & Zeller, 2002), the sample size was deemed adequate for identifying stable factor structures given the expected high communalities among variables. The entire research design and its process has been further explained using a flow diagram. Figure 1 outlines the overall research process workflow adopted in the study, illustrating the sequential stages from research design and data collection through data analysis and interpretation of findings.

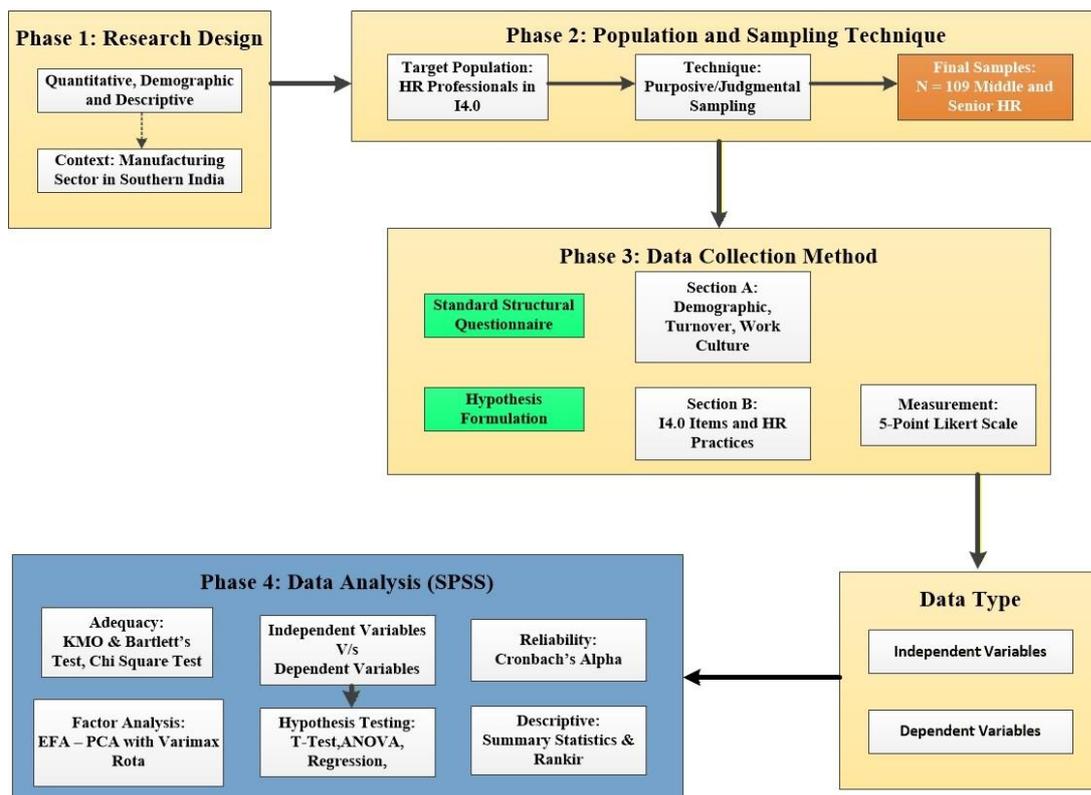


Figure 1. Research process workflow

Results and Discussion

This section presents the results of the empirical study conducted during the survey, where responses from 109 HR managers of various manufacturing organisations are reported and discussed. The sample is predominantly composed of semi-automated manufacturing organizations, which account for approximately 63.3% of the surveyed firms, followed by fully automated organizations representing 33.9%, while a relatively small proportion (2.8%) continue to operate at a largely manual level. This distribution indicates that the manufacturing sector in Southern India is largely positioned

in a transitional phase of Industry 4.0 adoption. Organizational scale of the sample includes firms across diverse employee strength and annual turnover categories, with a substantial representation of medium- and large-sized enterprises—approximately 39.4% of firms employ between 50 and 250 employees, while nearly 19.3% report annual turnover exceeding ₹500 crore—thereby capturing variations in economic capacity and operational complexity. Furthermore, responses were predominantly obtained from middle- and senior-level HR managers, who together constitute over 92% of the respondents, ensuring that the data reflect informed managerial perspectives on strategic HR policies and digital transformation initiatives. Collectively, these demographic characteristics underscore the diversity and adequacy of the sample and provide a robust contextual basis for examining how organizational scale, automation intensity, and managerial seniority influence the adoption of Industry 4.0 technologies and the evolution of HR practices within manufacturing organizations. These demographic characteristics are illustrated in Figure 2(a–d). Figure 2(a) illustrates the distribution of respondents by job/grade level, indicating that the majority of participants occupy middle- and senior-level HR management positions, thereby ensuring informed managerial perspectives. Very significantly Figure 2(b) portrays the level of automation across the surveyed manufacturing organizations, showing that most firms operate in a semi-automated environment, reflecting a transitional stage of Industry 4.0 adoption. Figure 2(c) demonstrates the annual turnover spread of the sampled organizations, demonstrating adequate representation across medium- and large-scale firms with varying financial capacities and Figure 2(d) exemplifies the employee strength of the surveyed organizations, focusing on a concentration of medium- and large-sized firms and capturing organizational diversity in workforce scale. This distribution indicates adequate organizational diversity and ensures that the findings reflect informed managerial perspectives on Industry 4.0–driven HR practices.

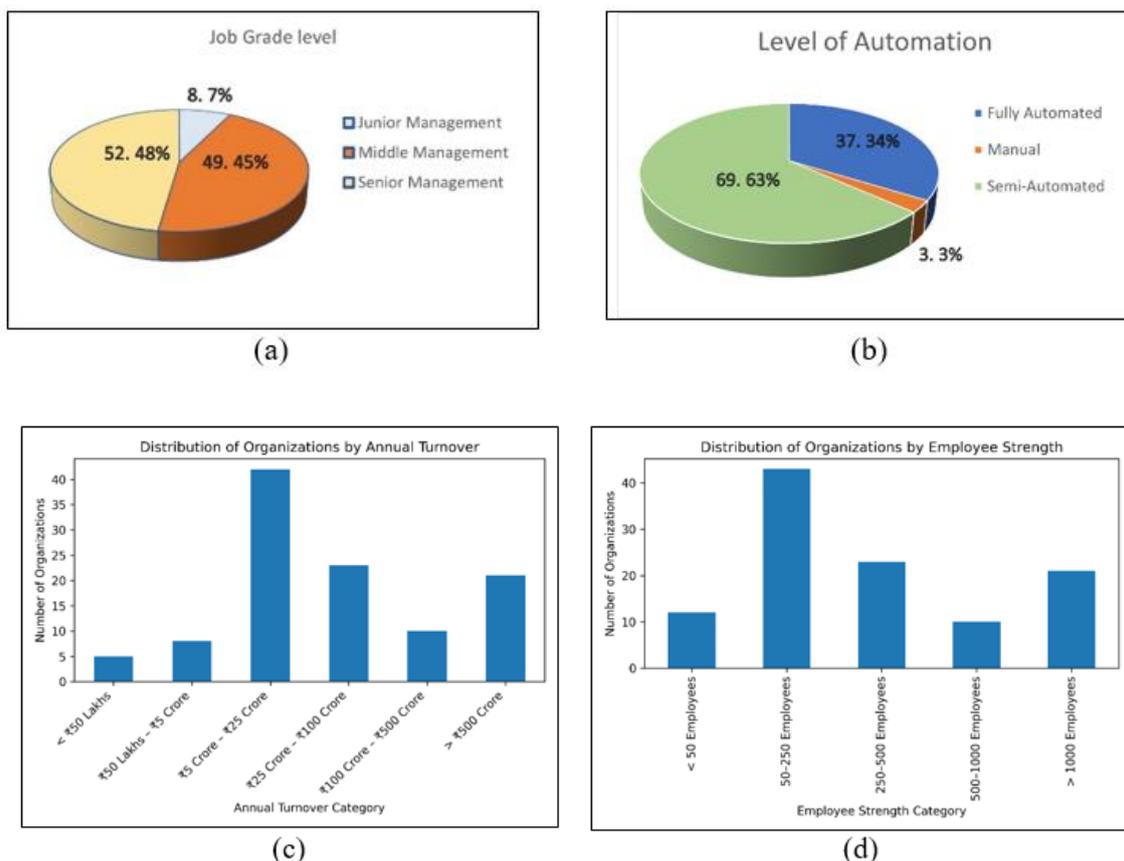


Figure 2. Demographic profile of surveyed manufacturing organizations and respondents: (a) job/grade level of respondents, (b) level of automation, (c) annual turnover, and (d) employee strength

Prior to conducting further statistical analyses, the internal consistency reliability of the measurement scales was assessed using Cronbach’s alpha. Cronbach’s alpha is widely employed to evaluate the extent to which items within a construct consistently measure the same underlying concept. The reliability coefficients for all constructs examined in the study are presented in Table 1. These results indicate satisfactory internal consistency across all study constructs, with Cronbach’s alpha (α) values ranging from 0.760 to 0.899, thereby confirming the reliability and acceptability of the measurement

scales used. Constructs such as Recruitment and Selection ($\alpha = 0.899$) and Attendance and Payroll ($\alpha = 0.886$) demonstrated particularly strong reliability.

Table 1: Compiled Cronbach Alpha Scores

| Construct | No. of Items | Cronbach's Alpha α | Acceptability |
|--|--------------|------------------------------|---------------|
| Implementation Of Industry 4.0 | 9 | 0.796 | Acceptable |
| Recruitment & Selection | 8 | 0.899 | Acceptable |
| Training And Development Practices | 5 | 0.835 | Acceptable |
| Employee Engagement & Relation Practices | 5 | 0.846 | Acceptable |
| Performance Appraisal & Feedback Practices | 4 | 0.848 | Acceptable |
| Attendance & Pay Roll | 4 | 0.886 | Acceptable |
| Compensation Management Practices | 4 | 0.861 | Acceptable |
| Retention Practices | 5 | 0.829 | Acceptable |
| Safety And Health Practices | 4 | 0.877 | Acceptable |
| Employee Motivation | 5 | 0.803 | Acceptable |
| Organisation Culture Related Practices | 4 | 0.760 | Acceptable |
| Challenges Of HR | 12 | 0.891 | Acceptable |

Descriptive statistics as depicted in Table 2, further reveals moderate levels of Industry 4.0 implementation in HR functions, with mean scores generally ranging between 2.91 and 3.51. Among the HR practices examined, Training and Development (Mean = 3.51), Performance Appraisal and Feedback (Mean = 3.45), and Employee Engagement and Relations (Mean = 3.42) recorded relatively higher mean values, while Industry 4.0 implementation in HR (Mean = 2.91), Compensation Management (Mean = 2.92), and Attendance and Payroll (Mean = 2.97) reflected comparatively lower levels of adoption across the surveyed organizations. These results signify that the survey instrument is a statistically robust and valid tool for measuring digital HR transitions within the South Indian manufacturing ecosystem. The moderate implementation score of 2.91 suggests that the sector is currently in a "transitional phase," moving away from legacy systems but not yet reaching full digital maturity. Higher mean scores for training and development, performance appraisal, and engagement practices indicate that organizations are prioritizing technology-enabled learning systems, feedback mechanisms, and employee interaction platforms, likely due to their direct relevance in supporting skill development and workforce adaptability in a digital environment. They are prioritizing "Human Capital Readiness"—focusing on building the social subsystem to support technological change. Figure 3 presents the mean scores of key HR practice dimensions across the surveyed manufacturing organizations. The results indicate relatively higher adoption levels for people-centric HR practices such as training and development, employee engagement, and recruitment and selection. In contrast, system-centric practices including compensation management,

payroll, and retention mechanisms exhibit comparatively lower mean scores, highlighting uneven progression in HR digitalization. In contrast, the relatively lower adoption levels observed in core HR infrastructure areas such as compensation management, payroll, and broader Industry 4.0 implementation point to structural, financial, or integration-related constraints that may hinder full-scale digital transformation. These results signify a phased and selective approach to HR digitalization, where organizations initially focus on high-impact, employee-facing practices before extending Industry 4.0 technologies to more complex administrative and strategic HR systems. Collectively, the findings underscore the transitional nature of HR transformation in the manufacturing sector and highlight the need for more comprehensive, organization-wide digital strategies to fully leverage Industry 4.0 capabilities.

Table 2: Descriptive Statistics Summary of HR Practices (N = 109)

| HR | N (No. of Study) | No. of items in construct | Mean | Std. Deviation |
|--|------------------|---------------------------|------|----------------|
| Implementation of industry 4.0 in HR | 109 | 9 | 2.91 | 1.259 |
| Recruitment & Selection | 109 | 8 | 3.41 | 1.28 |
| Training And Development Practices | 109 | 5 | 3.51 | 1.3 |
| Employee Engagement & Relation Practices | 109 | 5 | 3.42 | 1.32 |
| Performance Appraisal & Feedback Practices | 109 | 4 | 3.45 | 1.24 |
| Attendance & Pay Roll | 109 | 4 | 2.97 | 1.37 |
| Compensation Management Practices | 109 | 4 | 2.92 | 1.35 |
| Retention Practices | 109 | 5 | 3.09 | 1.30 |
| Safety And Health Practices | 109 | 4 | 3.07 | 1.30 |
| Employee Motivation | 109 | 5 | 3.04 | 1.36 |
| Organisation Culture Related Practices | 109 | 4 | 3.35 | 1.29 |

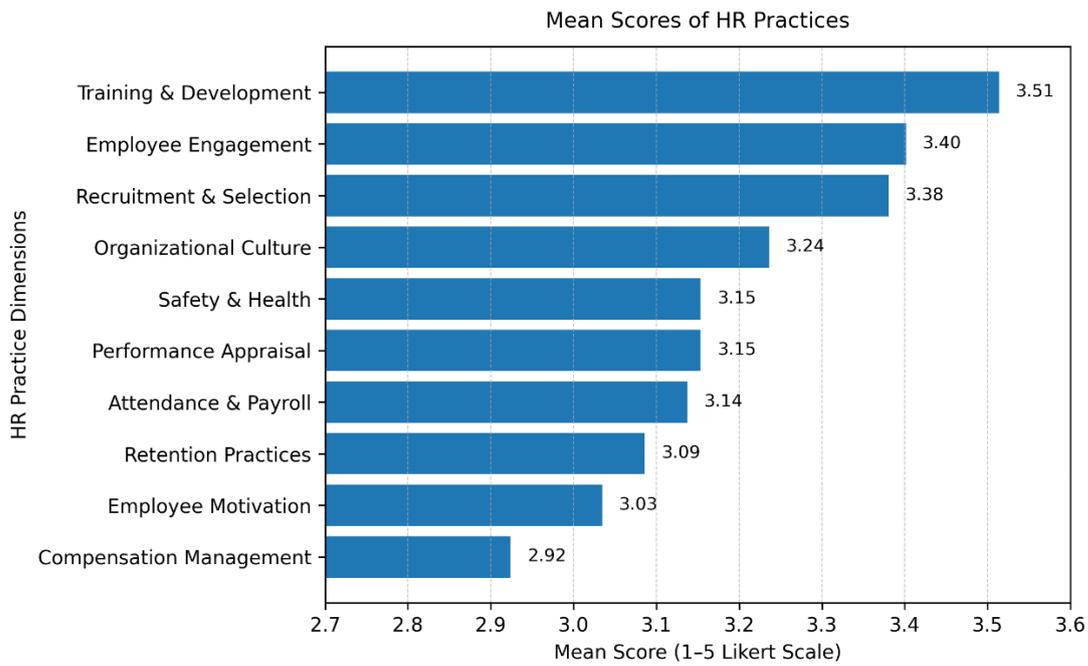


Figure 3. Mean scores of HR practices across manufacturing organizations

The observed pattern underscores a transitional phase in HR transformation, wherein organizations prioritize capability-building and engagement-oriented practices while lagging in the digital integration of administrative and compensation-related functions. This imbalance suggests that HR digitalization in Industry 4.0 environments may be driven more by developmental and relational imperatives than by full-scale system automation. Industry 4.0 technologies are being embedded in core HR functions to not just enhance accuracy and eradicate biases but it also elevates the role HR in these organisations to a more strategic decision maker. The gap observed between Industry 4.0 adoption and HR practice adoption highlights a sociotechnical imbalance within manufacturing organizations. Although HR systems appear to be relatively more developed, the lower level of technological adoption indicates partial rather than holistic integration of Industry 4.0 initiatives. This finding suggests that HR readiness alone may not be sufficient to drive digital transformation unless accompanied by commensurate investments in advanced manufacturing technologies and digital infrastructure. Figure 4 compares Industry 4.0 adoption with HR practice adoption across key HR dimensions. The results reveal that HR practices generally demonstrate higher levels of adoption than Industry 4.0 technologies across most dimensions. Notably, people-centric practices such as training and development, employee engagement, and recruitment and selection exhibit substantially higher mean scores relative to the overall level of Industry 4.0 adoption, whereas system-centric practices such as compensation management, payroll, and retention display narrower gaps.

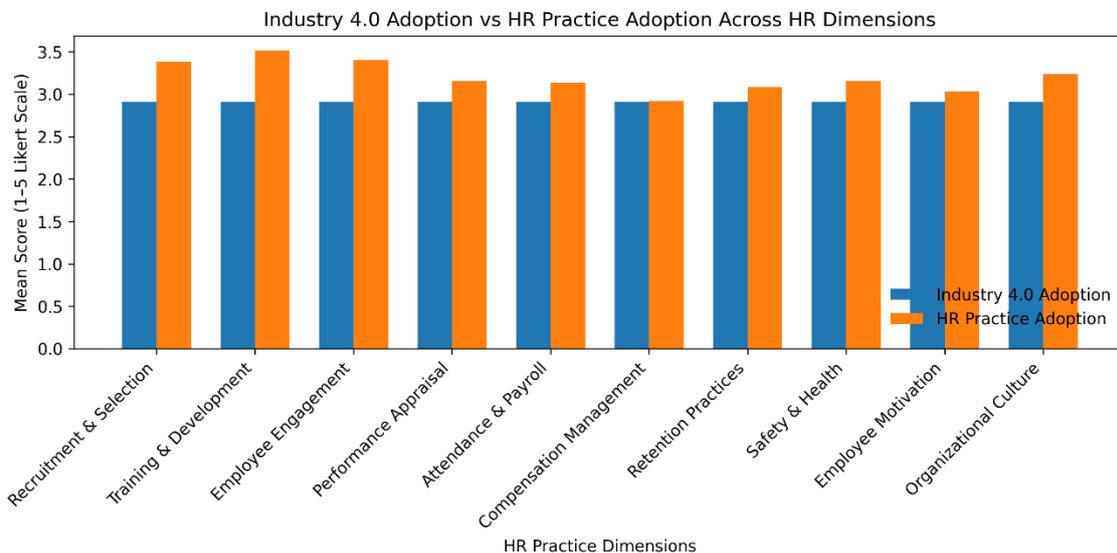


Figure 4. Comparison of Industry 4.0 adoption and HR practice adoption across HR dimensions

Exploratory Factor Analysis (EFA) was then conducted to examine the underlying factor structure of the measurement scales and to establish construct validity of the HR practices and Industry 4.0 dimensions included in the study. Principal Component Analysis (PCA) with Varimax rotation was employed, as the objective was to identify distinct and interpretable factor groupings while minimizing cross-loadings among items. Prior to factor extraction, the suitability of the data for factor analysis was assessed using the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett’s Test of Sphericity.

The results of the KMO and Bartlett’s Test, presented in Table 3, indicate that the data were appropriate for factor analysis across all constructs. The KMO values ranged from 0.757 to 0.901, exceeding the minimum recommended threshold of 0.60, thereby confirming adequate sampling adequacy. Bartlett’s Test of Sphericity was statistically significant ($p < 0.001$) for all constructs, indicating sufficient inter-item correlations and rejecting the null hypothesis that the correlation matrices were identity matrices. These findings collectively confirm the factorability of the data and support the application of EFA.

Further examination of the correlation matrices revealed meaningful correlations among items without evidence of multicollinearity, reinforcing the suitability of the dataset for factor extraction. Communality values for all retained items exceeded the acceptable threshold of 0.50, indicating that a substantial proportion of variance in each item was accounted for by the extracted factors. This suggests that the observed variables were well represented within their respective factor structures.

The factor extraction results demonstrated clear and stable loading patterns across constructs, with all items exhibiting factor loadings above 0.60 on their respective dimensions and no problematic cross-loadings observed. The extracted factors collectively explained a substantial proportion of total variance for each construct, exceeding the recommended benchmark of 60%, thereby confirming the robustness of the measurement model.

Overall, the EFA results provide strong empirical support for the multidimensional structure of HR practices and Industry 4.0 implementation constructs within the manufacturing sector. The validated factor structure confirms that the measurement scales used in this study reliably capture distinct yet related dimensions of digital HR transformation and associated challenges in the context of Industry 4.0. These validated constructs were subsequently utilized for descriptive and interpretive analysis to examine the extent and nature of HR practice transformation among manufacturing organizations in Southern India.

Table 3. KMO and Bartlett’s Test Results for Study Constructs

| | Kaiser-Meyer-Olkin Measure of Sampling Adequacy. | Bartlett's Test of Sphericity | |
|---|---|-------------------------------|---------------------------|
| | | Chi-Square (App.) | df (Degree of freedom) |
| Implementation of industry 4.0 in HR | .762 | 329.613 | 36 |
| Recruitment & Selection | .901 | 440.724 | 28 |
| Training And Development Practices | .822 | 220.283 | 10 |
| Employee Engagement & Relation Practices | .809 | 173.377 | 6 |
| Performance Appraisal & | .762 | 189.208 | 6 |

| | | | |
|--|--|-------------------------------|------------------------|
| Feedback Practices | | | |
| Attendance & Pay Roll | .838 | 229.924 | 6 |
| Compensation Management Practices | .804 | 201.799 | 6 |
| Retention Practices | .836 | 194.058 | 10 |
| Safety And Health Practices | .810 | 220.425 | 6 |
| Employee Motivation | .832 | 248.527 | 10 |
| Organisation Culture Related Practices | .757 | 107.659 | 6 |
| | | | |
| | Kaiser-Meyer-Olkin Measure of Sampling Adequacy. | Bartlett's Test of Sphericity | |
| | | Chi-Square (App.) | df (Degree of freedom) |
| Implementation of industry 4.0 in HR | .762 | 329.613 | 36 |
| Recruitment & Selection | .901 | 440.724 | 28 |
| Training And Development Practices | .822 | 220.283 | 10 |
| Employee Engagement & Relation Practices | .809 | 173.377 | 6 |
| Performance Appraisal & Feedback Practices | .762 | 189.208 | 6 |
| Attendance & Pay Roll | .838 | 229.924 | 6 |
| Compensation Management Practices | .804 | 201.799 | 6 |
| Retention Practices | .836 | 194.058 | 10 |
| Safety And Health Practices | .810 | 220.425 | 6 |
| Employee Motivation | .832 | 248.527 | 10 |
| Organisation Culture Related Practices | .757 | 107.659 | 6 |

Conclusion

The study analyses the association between Industry 4.0 adoption and human resource practices in manufacturing organizations in Southern India and provides quantitative insights into the current state of HR transformation in a digitally developing industrial context. Relying on empirical data from 109 HR managers the study employed reliability analysis, demographic characterisations, descriptive statistics, and exploratory factor analysis. It therefore, displayed a comprehensive assessment of adaptations of HR functions within the broader trajectory of Industry 4.0 adoption.

The measurement scales demonstrated satisfactory internal consistency, with Cronbach's alpha (α) values ranging from 0.760 to 0.899, representing acceptable to high reliability across all constructs and confirming the wholesomeness of the questionnaire used for the study. Descriptive analysis depicted mean values across HR practice dimensions ranging from 2.91 to 3.51 with standard deviations between 1.24 and 1.37, indicating moderate levels of Industry 4.0 adoption with reasonable variability in implementation across organizations. It can therefore be concluded that there is a lot of resistance while adopting automation especially in core functions of HR and I4.0 still has miles to go to reach higher automation leading to high efficiency output.

These observations also direct that most organizations are positioned at a transitional stage of Industry 4.0 adoption, having properties of selective and uneven execution across HR domains. People-centric practices such as training and development, employee engagement, recruitment, and performance appraisal show relatively higher levels of digital integration, while system-centric functions, including compensation management and payroll, lag behind.

The distribution of automation levels demonstrates that a majority of organizations function in a semi-automated environment (63.3%), followed by fully automated systems (33.9%), while only a small proportion remain largely manual (2.8%), reinforcing the characterization of HR digitalization as transitional rather than fully mature. The observed gap between Industry 4.0 adoption and HR practice digitalization signifies a sociotechnical inequality, wherein HR systems progress rapidly than aiding technological infrastructure, leading in partial rather than holistic digital transformation.

Theoretically, the study reinforces sociotechnical systems perspectives by demonstrating the need for alignment between human and technological subsystems. Virtually, the findings underline the significance of integrated transformation strategies that concurrently address technology deployment and HR system development to realize the full potential of Industry 4.0. By presenting context specific indication from an emerging economy, this study contributes to the limited empirical literature on HRM in Industry 4.0 and provides a foundation for future longitudinal and comparative research.

Limitation of the Study

The study while dwelling into the empirical evidence of adopting industry 4.0 in the various facets of manufacturing industries however, many more sectors can be considered for deducing standard change in HR practises. The study depends on data collected from HR managers themselves, which may be prejudiced by perceptual bias or socially acceptable norms, although the selection of middle- and senior-level respondents was used to improve data reliability. As the study use a cross-sectional research design, the findings are based on data collected at a single point in time and therefore, it does not establish causal relationships between variables. The results should be interpreted as descriptive and indicative rather than causal. Further, the sample is restricted to manufacturing organizations located in Southern India, which may limit the generalization of the results to other regions, sectors, or national contexts with contradictory institutional and technological atmospheres.

As the study adopts a cross-sectional research design, the findings are based on data collected at a single point in time. Therefore, while the study identifies patterns and associations in Industry 4.0 adoption and HR practice digitalisation, it does not establish causal relationships between variables. The results should be interpreted as descriptive and indicative rather than causal. Future research employing longitudinal or panel data designs may provide stronger insights into the direction and evolution of HR transformation over time.

Acknowledgement

The authors would like to express their sincere gratitude to all the HR managers of the manufacturing organizations who participated in the survey and generously shared their time and insights, which were crucial to the successful completion of this study. The authors also wish to acknowledge the invaluable guidance and supervision provided by the research guide, whose expert insights, constructive feedback, and continuous support significantly contributed to the design, execution, and refinement of the research. The authors would also like to acknowledge that suitable AI tool was used to enhance the flow of writing to improve readability.

REFERENCE

- Ammirato, S., Linzalone, R., Felicetti, A. M., & Peluso, A. M. (2023). Digital skills and competences for Industry 4.0: A systematic literature review and future research agenda. *Technological Forecasting and Social Change*, 188, 122300.
- Appolloni, A., Colasanti, N., Fantauzzi, C., Fiorani, G., & Frondizi, R. (2024). Human resource management in the era of Industry 4.0: A systematic literature review. *Journal of Business Research*, 169, 114254.
- Bondarouk, T., Parry, E., & Furtmueller, E. (2017). Electronic HRM: Four decades of research on adoption and consequences. *The International Journal of Human Resource Management*, 28(1), 98–131.
- Chowdhury, S., Dey, P. K., Joel-Edgar, S., Bhattacharya, S., Rodriguez-Espindola, O., Abadie, A., & Truong, L. (2022). Unlocking the value of artificial intelligence in human resource management through HR analytics: A systematic literature review. *Journal of Business Research*, 150, 1–15.
- Cugno, M., Castagnoli, R., & Büchi, G. (2021). Digitalization, labor productivity and employment: Evidence from manufacturing firms. *Industrial and Corporate Change*, 30(3), 699–731.
- Devezas, T., Leitao, J., & Sarygulov, A. (2024). Industry 4.0 as a sociotechnical system: Implications for organizational design and governance. *Technological Forecasting and Social Change*, 197, 122874.
- Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics*, 210, 15–26.
- Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. *Journal of Cleaner Production*, 252, 119869.
- Gupta, S., Modgil, S., & Gunasekaran, A. (2025). Industry 4.0 adoption in emerging economies: A dynamic capability perspective. *International Journal of Production Economics*, 259, 108820.
- Hansen, E. G., Grosse-Dunker, F., & Reichwald, R. (2024). Sustainability innovation and Industry 4.0: Bridging technology and people. *Business Strategy and the Environment*, 33(1), 65–81.
- Hecklau, F., Galeitzke, M., Flachs, S., & Kohl, H. (2018). Holistic approach for human resource management in Industry 4.0. *Procedia CIRP*, 54, 1–6.
- Jarrahi, M. H. (2018). Artificial intelligence and the future of work: Human–AI symbiosis in organizational decision making. *Business Horizons*, 61(4), 577–586.
- Kamble, S. S., Gunasekaran, A., & Gawankar, S. A. (2018). Sustainable Industry 4.0 framework: A systematic literature review. *International Journal of Production Research*, 56(6), 2271–2296.
- Kumar, A. (2023). Digital transformation challenges in manufacturing SMEs. *Journal of Manufacturing Technology Management*, 34(4), 812–829.
- Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering*, 6(4), 239–242.
- Margherita, A. (2022). Human resources analytics: A systematization of research topics and directions. *Human Resource Management Review*, 32(2), 100795.

- Mbatha, N., Singh, S., & Sibiyi, M. (2024). Digital HRM and change management challenges in manufacturing SMEs. *South African Journal of Human Resource Management*, 22, a2156.
- Mittal, S., Khan, M. A., Romero, D., & Wuest, T. (2018). A critical review of smart manufacturing and Industry 4.0 maturity models. *Journal of Manufacturing Systems*, 49, 194–214.
- Naghibi, H. S., & Valmohammadi, C. (2025). Dynamic capabilities and Industry 4.0: The mediating role of human resource practices. *Technological Forecasting and Social Change*, 202, 123098.
- Nguyen, T. H., & Nguyen, T. T. (2024). Human resource management transformation under Industry 4.0: Evidence from industrial zones. *Asia Pacific Journal of Human Resources*, 62(1), 120–138.
- Pacaux-Lemoine, M. P., Trentesaux, D., Zambrano Rey, G., & Millot, P. (2022). Designing human-centered Industry 4.0 systems: A sociotechnical perspective. *Computers & Industrial Engineering*, 169, 108191.
- Patel, R., & Sharma, A. (2022). Digital HRM practices and organizational performance. *Global Business Review*, 23(6), 1401–1417.
- Prikshat, V., Malik, A., & Budhwar, P. (2023). Artificial intelligence in talent management: A review and future research agenda. *Human Resource Management Review*, 33(3), 100881.
- Rehman, S., Khan, M. A., & Imran, M. (2024). Digital HRM, employee engagement, and role ambiguity in Industry 4.0 environments. *Personnel Review*, 53(2), 487–505.
- Santana, M., & Bornay-Barrachina, M. (2024). Digital HRM, employee well-being, and psychological outcomes. *Human Resource Management Journal*, 34(1), 88–104.
- Sapnas, K. G., & Zeller, R. A. (2002). Minimizing sample size when using exploratory factor analysis for measurement. *Journal of Nursing Measurement*, 10(2), 135–154.
- Schuh, G., Anderl, R., Gausemeier, J., ten Hompel, M., & Wahlster, W. (2020). Industrie 4.0 maturity index: Managing the digital transformation of companies. *Acatech*.
- Strohmeier, S. (2020). Digital human resource management: A conceptual clarification. *German Journal of Human Resource Management*, 34(3), 345–365.
- Teece, D. J. (2018). Business models and dynamic capabilities. *Long Range Planning*, 51(1), 40–49.
- Tortorella, G. L., Fettermann, D., Frank, A. G., & Sousa, R. (2020). Lean manufacturing implementation: The role of organizational culture. *International Journal of Production Economics*, 220, 107460.
- Tiwari, S., & Aggarwal, A. (2023). Human capital development for Industry 4.0. *Vision: The Journal of Business Perspective*, 27(1), 45–56.
- Vial, G. (2019). Understanding digital transformation: A review and research agenda. *MIS Quarterly*, 43(1), 223–246.
- Vereycken, Y., Ramioul, M., & Van Hootehem, G. (2021). Industry 4.0 and human resource management: A sociotechnical systems perspective. *Economic and Industrial Democracy*, 42(4), 853–878.
- Yu, K., Cadeaux, J., & Luo, B. (2021). Operational flexibility and digital transformation in manufacturing. *Industrial Marketing Management*, 93, 450–462.
- Zhou, Y., Zhang, Y., & Li, Y. (2022). E-HRM, decision quality, and organizational performance. *Human Resource Management Review*, 32(4), 100889.