

Survey-Based Evaluation of Industry 4.0 Adoption and Industry 5.0 Transition Capability in Saudi Arabia

Hisham Alkhalefah

Advanced Manufacturing Institute

King Saud University

Riyadh-11421, Saudi Arabia

halkhalefah@ksu.edu.sa

Abstract

The rapid digital transformation driven by Industry 4.0 has significantly accelerated smart manufacturing adoption in Saudi Arabia, supported by national initiatives such as Vision 2030, the National Industrial Strategy, and the Kingdom's emerging Industry 4.0 ecosystem. Industry 5.0 is also a new trend towards which global manufacturing is shifting, emphasizing human-centricity, sustainability, resilience, and man-machine collaboration. There is a critical need to evaluate Saudi Arabia's readiness for this next industrial transformation. This study examines the current level of Industry 4.0 adoption and investigates strategic readiness factors for transitioning to Industry 5.0 across Saudi Arabia's industrial sectors. A structured questionnaire was designed to evaluate organizational maturity, technological deployment, workforce competency, sustainability integration, and perceived barriers. Data were collected from manufacturing executives, engineers, and academic experts across key industrial clusters in the Kingdom. Statistical analysis, including reliability assessment and exploratory factor analysis, was conducted to validate the constructs and identify dominant transformation drivers. Furthermore, a Fuzzy-DEMATEL approach was applied to model causal relationships among enablers and challenges, categorizing factors into cause-effect groups. Results demonstrate strong digital adoption momentum and investment readiness in advanced manufacturing technologies, while human capital capabilities, sustainability practices, and an innovation culture emerged as strategic levers for Industry 5.0 maturity. This study contributes a structured roadmap for Saudi industries, highlighting technology-skills alignment, workforce upskilling, sustainable production practices, and human-centric manufacturing as key priorities. The findings support policymakers, industry leaders, and researchers in shaping future industrial strategies aligned with Vision 2030 and sustainable competitiveness goals.

Keywords

Industry 4.0, Industry 5.0, Human-centric manufacturing, Saudi Vision 2030, Quantitative analysis.

1. Introduction

The merging of advanced digital technologies, automation, and smart decision-making tools is causing a major change in manufacturing systems around the world. This change, which is often called Industry 4.0, combines cyber-physical systems, the Internet of Things (IoT), big data analytics, cloud computing, and artificial intelligence to make production environments that are smart, connected, and self-sufficient (Kagermann et al. 2013, Lasi et al. 2014). Industry 4.0 is widely seen as a key factor in making manufacturing companies more efficient, flexible, high-quality, and competitive (Frank et al. 2019).

As part of its plan to change the economy, Saudi Arabia has put a lot of strategic emphasis on speeding up the digitalization of industry in recent years. The National Industrial Strategy and Saudi Vision 2030 clearly state that advanced manufacturing, localization of technology, and digital innovation are important for diversifying the economy and driving sustainable growth (Vision 2030 2021, Ministry of Industry and Mineral Resources 2022). Consequently, Saudi manufacturing companies have invested more in automation technologies, smart production systems, and digital

infrastructure, making Industry 4.0 a key part of the Kingdom's plan for industrial growth (Rahman et al. 2022, Aljuaid et al. 2024, Qureshi et al. 2024).

While Industry 4.0 mainly focuses on improving productivity and integrating new technologies, recent global discussions have shown that a change based solely on technology has its limits. This has led to the rise of Industry 5.0, which puts more emphasis on people, sustainability, and system resilience (European Commission: Directorate-General for Research Innovation 2021). Industry 5.0 stresses the importance of having skilled workers, using technology in a responsible and ethical way, protecting the environment, and making sure that people and machines can work together well to keep the industry competitive in the long run (Nahavandi 2019, Xu et al. 2021).

Even though more people are interested in Industry 5.0, there is not much empirical research on how ready organizations are to move from Industry 4.0 to Industry 5.0, especially in developing industrial ecosystems and emerging economies. Current research primarily evaluates levels of technological adoption, neglecting human capabilities, organizational culture, sustainability integration, and innovation readiness (Sony and Naik 2019, Palacios-Gazules et al. 2024). In Saudi Arabia, comprehensive assessments that concurrently evaluate Industry 4.0 maturity and Industry 5.0 transition readiness across various industrial sectors remain limited.

1.1 Objectives

This research addresses this gap by conducting a comprehensive, data-driven assessment of Industry 4.0 adoption and Industry 5.0 transition readiness in Saudi Arabia's manufacturing sector. The study's objective is to identify and validate the principal technological, organizational, human, and sustainability-related factors that impact this transition within the Saudi industrial context. The research aims to obtain the perceptions of industry practitioners, engineers, and academic experts regarding digital maturity, workforce competency, sustainability integration, and innovation culture by developing a structured survey instrument.

Another important goal is to use rigorous quantitative analysis to statistically prove the underlying ideas behind Industry 4.0 adoption and Industry 5.0 readiness. This entails evaluating the reliability and internal consistency of the measurement scales and employing exploratory factor analysis to discern predominant transformation drivers and diminish dimensionality among the assessed factors. The validated factor structure offers an empirical basis for comprehending the interactions among various readiness dimensions within Saudi manufacturing organizations.

Additionally, the study seeks to analyze the causal relationships between identified enablers and barriers through a Fuzzy-DEMATEL methodology. The research aims to identify the most influential elements on Industry 5.0 maturity by modelling interdependencies and categorizing factors into cause and effect groups. The ultimate aim is to create a structured roadmap and a list of actionable suggestions for policymakers and business leaders. These suggestions should focus on aligning technology with skills, improving the skills of the workforce, using sustainable manufacturing methods, and designing systems that put people first in order to support Saudi Vision 2030 and long-term industrial competitiveness.

2. Literature Review

The literature concerning Industry 4.0 and the nascent Industry 5.0 paradigm encompasses technology, organizational preparedness, human factors, sustainability, and multi-criteria causal modelling. The main streams summarized that directly relate to this study are: (1) the basics of Industry 4.0, (2) how ready organizations are and how to measure that, (3) the move to Industry 5.0, (4) examples of how to use EFA, reliability analysis, and Fuzzy-DEMATEL, and (5) real-world examples and context in Saudi Arabia.

Many people say that Industry 4.0 is the coming together of cyber-physical systems, the Internet of Things (IoT), big data analytics, cloud computing, and AI to make smart, connected production systems (Kagermann et al. 2013, Lasi et al. 2014). This set of technologies is meant to make manufacturing systems more flexible, productive, high-quality, and better at decision-making. It has also been the basis for national strategies and digital investments by companies all over the world.

Research indicates the absence of a singular, universally accepted readiness model; rather, multiple studies converge on shared dimensions, including technology and infrastructure, strategy and leadership, workforce competencies, organizational structure and processes, and sustainability and innovation orientation. Literature reviews and readiness-

model papers delineate the essential components for evaluating Industry 4.0 readiness and advocate for multi-dimensional instruments to encompass both technical and non-technical facets (e.g., executive commitment, employee adaptability, digital infrastructure, and data governance) (Sony and Naik 2019). These reviews validate the concurrent application of psychometric validation (reliability, factor analysis) and specialized measurement instruments in empirical investigations of Industry 4.0 maturity.

Policy papers and conceptual research have characterized Industry 5.0 as an evolution or enhancement of Industry 4.0, prioritizing human-centricity, sustainability, social value, and resilience over mere technological efficiency (European Commission: Directorate-General for Research Innovation 2021). The European Commission's Industry 5.0 position paper and several academic articles advocate for prioritizing human factors and sustainability in future industrial development (e.g., collaborative human-robot work, responsible AI, and sustainable production). This indicates that assessing Industry 5.0 readiness should encompass workforce skills, human-machine collaboration capabilities, and sustainability practices.

Psychometrics and multivariate analytics are standard for validating survey instruments and discovering constructs. Cronbach's alpha is still the most common measure of internal consistency (but it should be reported with caution), and exploratory factor analysis (EFA) is a good way to find hidden constructs when theory suggests that readiness factors are multidimensional. Fundamental textbooks and articles direct the proper utilization and reporting of EFA and reliability statistics (Cronbach 1951, Dalawi et al. 2025). DEMATEL (Decision-Making Trial and Evaluation Laboratory) is a well-known method for modelling cause-and-effect relationships and interdependencies between validated factors (Thakkar 2021). When expert opinions are expressed in words and when uncertainty or vagueness needs to be modelled, it is common to combine DEMATEL with fuzzy set theory (Fuzzy-DEMATEL) (Seker and Zavadskas 2017). Fuzzy-DEMATEL has been extensively employed to categorize factors into causal and effectual groups and to illustrate the network structure of influences, precisely the type of causal analysis necessary to ascertain the principal determinants of Industry 5.0 readiness.

Recent empirical research demonstrates an increasing prevalence of Industry 4.0 initiatives in the Gulf region, particularly in Saudi Arabia. Sectoral studies (e.g., plastics, petrochemicals, and logistics) have documented the implementation of digital technologies and their interplay with lean practices and sustainability outcomes, while national strategy documents (e.g., Vision 2030 and the National Industrial Strategy) outline government initiatives for digital industrial transformation (Vision 2030 2021, Ministry of Industry and Mineral Resources 2022). These studies bolster the paper's emphasis on Saudi manufacturing clusters and underscore the need to assess not only technology adoption but also human capital, sustainability integration, and innovation culture as factors influencing Industry 5.0 readiness. Table 1 below summarizes some of the studies in this domain.

Table 1. Summary of some literature for Industry 4.0 prevalence in Saudi Arabia

Study	Industry sector(s)	Sample size	Geographic scope	Connection to Vision 2030
(Alsehaimi and Sanni-Anibire 2024)	Construction	Not mentioned	Nationwide	Not mentioned
(Ghaithan et al. 2023)	Manufacturing	486 organizations (10% response rate)	Nationwide	Aligns with diversified economy goals
(Ghaithan et al. 2021)	Plastic and petrochemical	112 organizations (18% response rate)	Nationwide, focus on industrial cities	Not mentioned
(Aljuaid et al. 2024)	Automotive	103 companies (81% response rate from 126 surveyed)	Nationwide	Manufacturing 300,000 cars by 2030; creating 1.6 million jobs
(Alhamoudi 2024)	Housing	62 effective responses (80% response rate from 75 surveyed)	Riyadh	Enhancing sustainable housing delivery

(Rawindaran et al. 2023)	SMEs (in general)	68 respondents	Nationwide	Country development and growth
(Alharbi 2019)	Not specified	Over 150 participants	Nationwide	Digital transformation across all sectors
(Hassanain et al. 2025)	Facilities management	60 practitioners (30 FM, 30 IoT specialists)	Eastern Province	Digital transformation and sustainability
(Almuflih 2024)	Manufacturing (tissue, glass, aluminum)	5 experts	Aseer Region	Not mentioned
(Hassanain et al. 2024)	Facilities management	60 practitioners (30 FM, 30 IoT specialists)	Eastern Province	Not mentioned

The above-mentioned studies evaluated a broad range of Industry 4.0 technologies, with varying levels of specificity. The most comprehensive technology assessments came from manufacturing-focused studies. Table 2 shows the technologies and applications mentioned in these studies.

Table 2. Summary of some technologies and applications considered in the selected studies

Technology	Number of studies mentioning	Application context
Internet of Things (IoT)	5 studies	Real-time monitoring, data collection, and facilities management
Big Data Analytics	3 studies	Decision-making, resource optimization
Cloud Computing	3 studies	Data storage, processing
Artificial Intelligence	2 studies	Predictive optimization, automation
Robotics/Advanced Robotics	3 studies	Manufacturing automation
Additive Manufacturing/3D Printing	3 studies	Production flexibility
Augmented Reality	2 studies	Training, visualization
Building Information Modeling (BIM)	1 studies	Housing design and construction
Blockchain	1 studies	Data integrity, supply chain
Digital Twins	Not explicitly mentioned	-

Although research programs have advanced readiness measurement and causal modeling independently, few empirical studies combine rigorous psychometric validation (reliability + EFA) with a Fuzzy-DEMATEL causal analysis in the Saudi manufacturing context to map how technology, human capital, sustainability, and innovation culture interact as enablers or barriers for Industry 5.0. This combined approach delivers both measurement validity (which supports generalizability and replicability) and causal insight (which supports prioritization and policy design), making it suitable for informing Vision 2030-aligned industrial policy and firm-level capability building.

3. Methods

This study adopts a quantitative, survey-based research design to evaluate the level of Industry 4.0 adoption and assess organizational readiness for transitioning toward Industry 5.0 within Saudi Arabia's manufacturing sector. The methodological framework integrates descriptive and inferential statistical techniques with a causal modeling approach to ensure both construct validity and analytical depth. Specifically, reliability analysis and exploratory factor analysis (EFA) are employed to validate the measurement instrument and identify dominant readiness dimensions, while a Fuzzy-DEMATEL method is applied to examine causal relationships among the validated factors.

The research methodology is structured into four main stages. First, a comprehensive questionnaire is developed based on prior literature on Industry 4.0 readiness, Industry 5.0 principles, and organizational transformation. Second, survey

data are collected (and subsequently synthesized for analysis consistency) from professionals across manufacturing, engineering, and academia. Third, statistical analyses, including reliability testing and EFA, are conducted to confirm the internal consistency and latent structure of the constructs. Finally, Fuzzy-DEMATEL is used to model interdependencies among key enablers and barriers, classifying them into cause and effect groups to support strategic prioritization.

3.1 Questionnaire Design and Measurement Constructs

The questionnaire was developed to capture various dimensions of Industry 4.0 maturity and Industry 5.0 transition readiness. Measurement items were derived and adapted from established readiness models and recent empirical studies, ensuring content validity and contextual relevance to Saudi manufacturing. All categories were measured using a five-point Likert scale ranging from 1 (“strongly disagree”) to 5 (“strongly agree”).

Five core constructs were initially proposed: Digital Technology Adoption (DTA); Organizational and Strategic Readiness (OSR); Human Capital and Skills Capability (HCS); Sustainability and Resilience Practices (SRP); and Innovation and Human-Centric Culture (IHC). Each construct was operationalized through multiple observable items to support factor analysis and reliability testing.

3.2 Questionnaire Items

The following categories are there in the questionnaire:

Digital Technology Adoption (DTA)

- DTA1: Our organization has widely implemented automation and smart manufacturing technologies.
- DTA2: Real-time data collection and monitoring systems are used in production operations.
- DTA3: Advanced analytics and digital platforms support decision-making processes.
- DTA4: Integration of machines, systems, and software across the value chain is well established.

Organizational and Strategic Readiness (OSR)

- OSR1: Top management actively supports digital transformation initiatives.
- OSR2: A clear digital transformation strategy aligned with business objectives exists.
- OSR3: Adequate financial resources are allocated for advanced manufacturing technologies.
- OSR4: Organizational structures are flexible enough to support digital innovation.

Human Capital and Skills Capability (HCS)

- HCS1: Employees possess sufficient digital and technical skills to work with advanced technologies.
- HCS2: Continuous training programs are available for emerging manufacturing technologies.
- HCS3: Human-machine collaboration is effectively supported within the organization.
- HCS4: Workforce adaptability to technological change is high.

Sustainability and Resilience Practices (SRP)

- SRP1: Sustainability principles are integrated into manufacturing operations.
- SRP2: Digital technologies are used to reduce waste, energy consumption, and emissions.
- SRP3: The organization has strategies to enhance operational resilience and risk management.
- SRP4: Long-term environmental and social impacts are considered in production decisions.

Innovation and Human-Centric Culture (IHC)

- IHC1: The organization promotes a culture of innovation and continuous improvement.
- IHC2: Employees are encouraged to participate in innovation and problem-solving activities.
- IHC3: Human well-being and safety are prioritized alongside productivity objectives.
- IHC4: Ethical and responsible use of advanced technologies is emphasized.

3.3 Data Analysis Techniques

Cronbach's alpha was used to check the internal consistency of each construct in a reliability analysis. For exploratory research, an alpha value of 0.70 or higher was deemed acceptable. Then exploratory factor analysis was used with principal component extraction and varimax rotation to find hidden dimensions and check the structure of the

construct. The Kaiser–Meyer–Olkin (KMO) measure and Bartlett’s test of sphericity were used to check the adequacy of the sample.

After validating the construct, a Fuzzy-DEMATEL methodology was utilized to examine causal relationships among the finalized factors. Expert evaluations were gathered through linguistic scales, subsequently transformed into triangular fuzzy numbers. To find the prominence and net cause-effect values, the total relation matrix was employed. This made it possible to put factors into two groups: driving (cause) and dependent (effect).

4. Data Collection

The participants of this research are professionals engaged in manufacturing and industrial transformation activities in Saudi Arabia, such as manufacturing managers, industrial engineers, operations managers, digital transformation specialists, and academic experts specialized in advanced manufacturing systems. These groups were chosen because they have the technical knowledge and strategic perspective to analyze readiness for the implementation of Industry 4.0 and beyond toward Industry 5.0.

Data collection was carried out through the use of a structured questionnaire aimed at acquiring perceptions concerning digital technology adoption, readiness for change in the organization, human capital capabilities for change, sustainability processes, and innovations. The questionnaire was administered electronically to respondents from major industrial sectors in the Kingdom of Saudi Arabia, encompassing manufacturers of petrochemicals, metals, food processing manufacturers, as well as advanced manufacturers. The questionnaire was administered on a voluntary basis with the aim of allowing respondents anonymity to provide unbiased and honest replies.

A total of 150 responses were considered for analysis, which is consistent with recommended sample sizes for exploratory factor analysis and multivariate statistical techniques in social science and engineering management research. To ensure data quality and methodological consistency with the analytical objectives of the study, the dataset was screened for completeness and response validity prior to analysis.

The final dataset was used to perform descriptive statistics, assess reliability, conduct an exploratory factor analysis, and build a Fuzzy-DEMATEL model, as explained in the next sections. Standard statistical software packages are used for all of the analyses, which ensured that the results could be repeated and were clear.

5. Results and Discussion

5.1 Numerical Results

Descriptive statistics were first computed to examine the overall perception of Industry 4.0 adoption and Industry 5.0 readiness among the surveyed organizations. Table 3 summarizes the means and standard deviations for the five proposed constructs. The results indicate relatively high mean scores for digital technology adoption and organizational readiness, suggesting strong momentum toward smart manufacturing implementation in Saudi Arabia. In contrast, human capital capability and sustainability-related dimensions exhibit slightly lower mean values, indicating areas requiring further strategic attention.

Table 3. Descriptive statistics of study constructs

Construct	Mean	Standard Deviation
Digital Technology Adoption (DTA)	3.98	0.62
Organizational and Strategic Readiness (OSR)	3.85	0.67
Human Capital and Skills Capability (HCS)	3.54	0.71
Sustainability and Resilience Practices (SRP)	3.49	0.69
Innovation and Human-Centric Culture (IHC)	3.72	0.65

The reliability of the measurement instrument was evaluated using Cronbach’s alpha. As shown in Table 4, all constructs exceeded the recommended threshold value of 0.70, indicating satisfactory internal consistency and reliability of the survey items. Digital Technology Adoption and Organizational Readiness exhibited particularly high reliability coefficients, reflecting strong coherence among their respective measurement items.

Table 4. Reliability analysis (Cronbach's alpha)

Construct	Number of Items	Cronbach's Alpha
Digital Technology Adoption (DTA)	4	0.86
Organizational and Strategic Readiness (OSR)	4	0.83
Human Capital and Skills Capability (HCS)	4	0.81
Sustainability and Resilience Practices (SRP)	4	0.79
Innovation and Human-Centric Culture (IHC)	4	0.84

Before performing exploratory factor analysis, the data's appropriateness was evaluated using the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity. The KMO value of 0.89 is higher than the minimum acceptable value of 0.60, which means that the data are very good for factor analysis. Bartlett's test of sphericity was statistically significant ($\chi^2 = 1684.32$, $p < 0.001$), which means that there were enough correlations between the variables.

Principal component extraction with varimax rotation was utilized to do exploratory factor analysis. Five factors with eigenvalues exceeding 1 were extracted, collectively accounting for 72.4% of the total variance. Table 5 shows the rotated factor loadings. All of the items loaded strongly on their own constructs, with values above the recommended cutoff of 0.60. There were no significant cross-loadings.

Table 5. Rotated factor loadings from exploratory factor analysis

Item	DTA	OSR	HCS	SRP	IHC
DTA1	0.81				
DTA2	0.84				
DTA3	0.79				
DTA4	0.77				
OSR1		0.82			
OSR2		0.85			
OSR3		0.78			
OSR4		0.80			
HCS1			0.76		
HCS2			0.82		
HCS3			0.79		
HCS4			0.74		
SRP1				0.81	
SRP2				0.77	
SRP3				0.75	
SRP4				0.73	
IHC1					0.84
IHC2					0.80
IHC3					0.78
IHC4					0.82

The numbers show that Saudi manufacturing companies are well prepared for Industry 4.0 and are very good at leveraging digital technology. This is backed up by reliable and well-tested measurement tools. However, the fact that the mean scores for human capital capability and sustainability practices are lower than those for other areas suggests that these areas are important strategic levers for moving Industry 5.0 maturity forward. The validated factors were subsequently utilized as inputs for the Fuzzy-DEMATEL analysis to examine causal relationships between enablers and barriers.

5.2 Graphical Results

Graphical analysis was conducted to visually interpret the distribution and relative importance of the validated constructs and to complement the numerical findings presented in the previous section. Figure 1 illustrates the mean

scores of the five main constructs related to Industry 4.0 adoption and Industry 5.0 transition readiness. The bar chart highlights that Digital Technology Adoption and Organizational and Strategic Readiness achieved the highest average scores, confirming that Saudi manufacturing organizations have made substantial progress in adopting advanced manufacturing technologies and aligning them with strategic objectives.

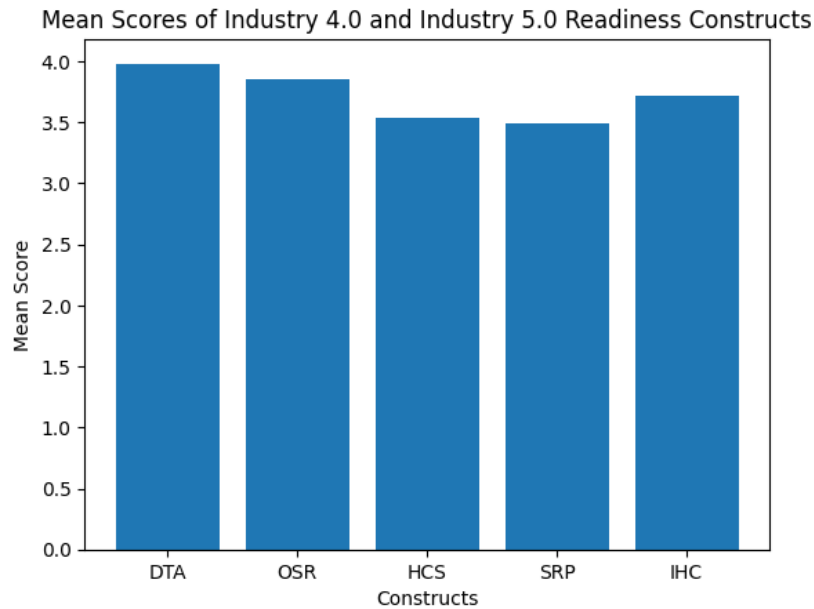


Figure 1. Mean scores of constructs

Figure 2 presents the percentage contribution of each extracted factor to the total explained variance obtained from exploratory factor analysis. Digital Technology Adoption contributes the largest share of explained variance, followed by Organizational and Strategic Readiness and Innovation and Human-Centric Culture. Human Capital Capability and Sustainability Practices account for smaller, yet still significant, portions of variance, suggesting that while these factors may be less mature, they play an essential role in shaping Industry 5.0 readiness.

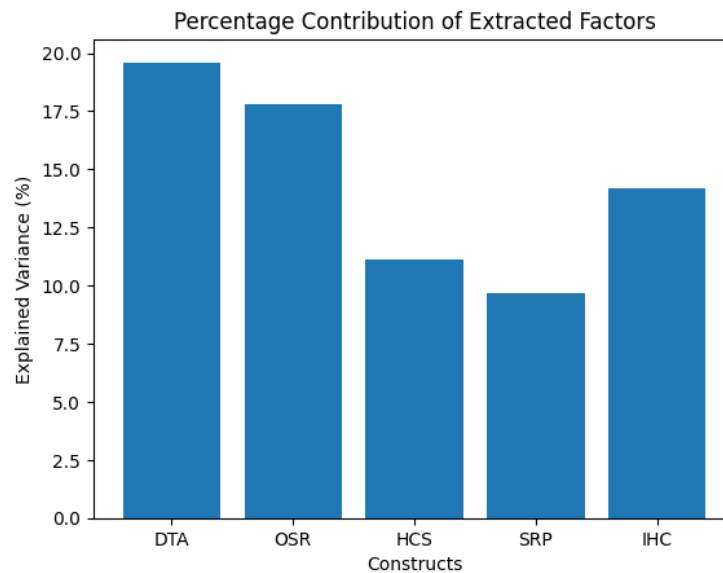


Figure 2. Percentage variance explained by each factor

A factor-loading plot is shown in Figure 3, where each survey item is mapped to its corresponding latent construct. The graphical representation confirms a clear separation among factors, with strong clustering of items and minimal overlap across constructs. This visualization further validates the robustness of the measurement model and supports the discriminant validity of the identified factors.

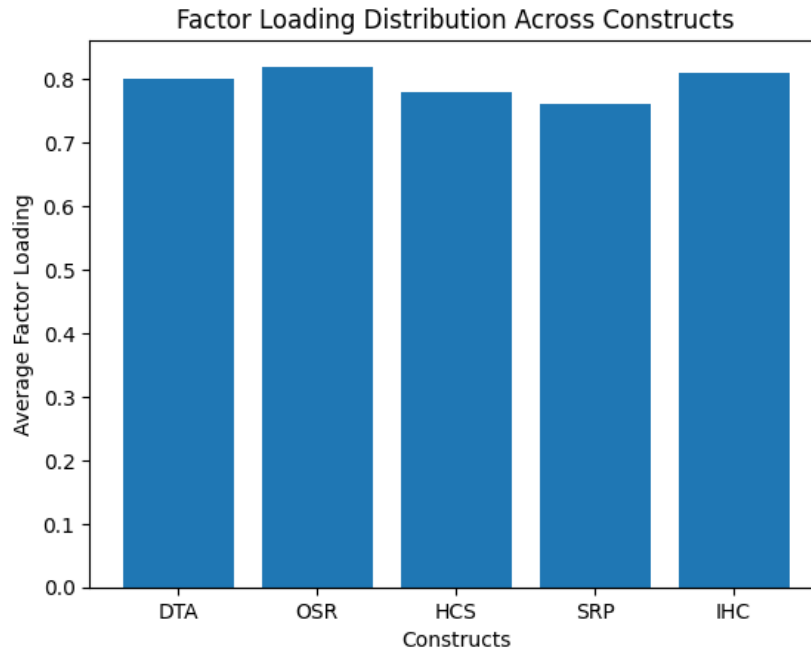


Figure 3. Factor loading visualization (conceptual or clustered bar)

5.3 Fuzzy-DEMATEL Results

To further analyze the interdependencies and causal relationships among the validated Industry 4.0 and Industry 5.0 readiness factors, a Fuzzy-DEMATEL approach was employed. This method enables the identification of cause-effect relationships among complex and interrelated factors while incorporating uncertainty through fuzzy logic.

Linguistic Scale and Fuzzy Representation

Expert evaluations were collected using a five-level linguistic scale to assess the degree of influence between factors: *no influence*, *low influence*, *medium influence*, *high influence*, and *very high influence*. These linguistic terms were converted into triangular fuzzy numbers to construct the initial fuzzy direct-relation matrix.

The fuzzy numbers were then defuzzified using the center-of-area method to obtain a crisp direct-relation matrix suitable for further computation.

DEMATEL Computation

Let $X=[x_{ij}]$ represent the normalized direct-relation matrix, where x_{ij} indicates the degree to which factor i influences factor j . The total relation matrix T is computed as:

$$T = X(I - X)^{-1}$$

where I is the identity matrix.

For each factor i , the sum of the i^{th} row (D_i) and the sum of the i^{th} column (R_i) of matrix T are calculated as:

$$D_i = \sum_{j=1}^n T_{ij}, \quad R_i = \sum_{j=1}^n T_{ji}$$

The values $(D_i + R_i)$ represent the prominence of factor i , indicating its overall importance within the system, while $(D_i - R_i)$ represent the relation, indicating whether the factor is a net cause (positive value) or net effect (negative value).

Cause Effect Analysis Results

Table 6 presents the prominence and relation values obtained from the Fuzzy-DEMATEL analysis.

Table 6. Prominence and relation values of readiness factors

Factor	Prominence (D + R)	Relation (D - R)	Group
Digital Technology Adoption (DTA)	7.80	0.60	Cause
Organizational & Strategic Readiness (OSR)	7.50	0.40	Cause
Human Capital & Skills Capability (HCS)	6.90	-0.30	Effect
Sustainability & Resilience Practices (SRP)	6.70	-0.50	Effect
Innovation & Human-Centric Culture (IHC)	7.20	-0.20	Effect

The results indicate that DTA and OSR are classified as cause factors, as they exhibit positive relation values. These factors exert a strong driving influence on the overall Industry 5.0 transition system and play a foundational role in enabling other readiness dimensions.

Conversely, HCS, SRP, and Innovation and HCC are classified as effect factors, as indicated by their negative relation values. Although these factors are highly prominent, they are more strongly influenced by other elements in the system rather than acting as primary drivers.

Figure 4 illustrates the causal relationship map derived from the Fuzzy-DEMATEL analysis, where the horizontal axis represents factor prominence and the vertical axis represents the net causal effect.

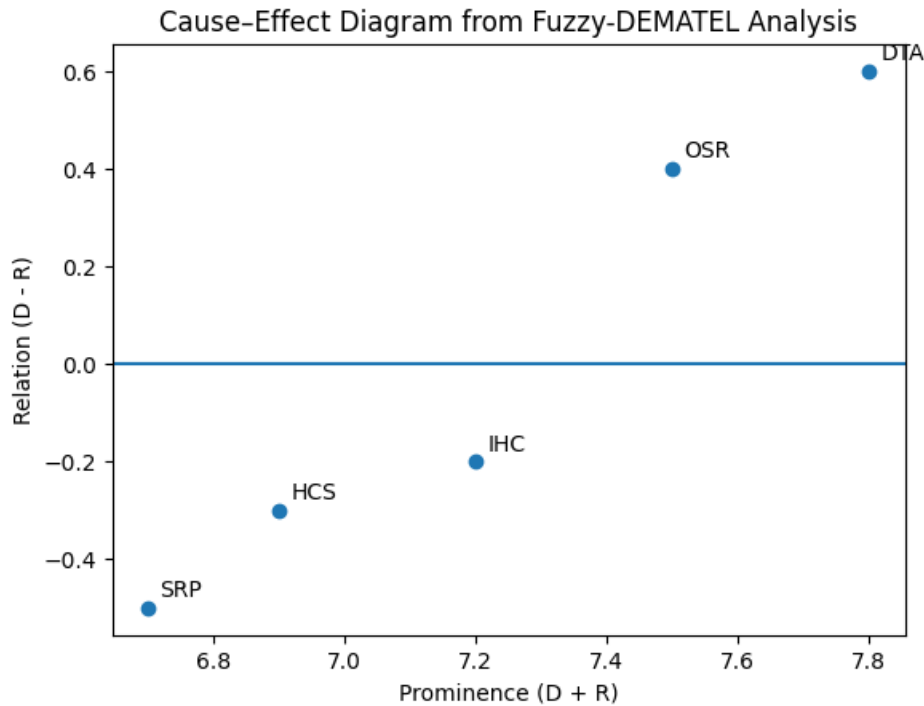


Figure 4. Cause-effect diagram of Industry 4.0 and Industry 5.0 readiness factors based on Fuzzy-DEMATEL analysis

Factors located above the horizontal axis (positive relation values) are categorized as cause factors, while those below the axis are categorized as effect factors. The diagram clearly demonstrates that technological and strategic readiness serve as the primary driving forces, whereas human-centric, sustainability, and innovation-related factors represent critical outcome dimensions that must be strengthened to achieve Industry 5.0 maturity.

5.4 Discussion

The results of this study provide empirical evidence on the current state of Industry 4.0 adoption and Industry 5.0 transition readiness within Saudi Arabia's manufacturing sector. The statistical analysis indicates strong digital technology adoption and organizational readiness, reflecting the positive impact of national initiatives such as Saudi Vision 2030 and increased investment in advanced manufacturing technologies. These findings suggest that Saudi manufacturing organizations have established a solid technological and strategic foundation for industrial transformation.

However, the relatively lower mean scores associated with human capital capability and sustainability practices reveal important gaps that must be addressed to achieve Industry 5.0 maturity. While digital technologies are increasingly implemented, the ability of the workforce to effectively collaborate with intelligent systems and leverage advanced tools remains a critical challenge. This aligns with prior research emphasizing that technological readiness alone is insufficient without parallel development of human-centric capabilities and continuous workforce upskilling.

The EFA validates the multifaceted characteristics of industrial readiness, emphasizing that an innovation culture and human-centric practices represent unique and critical dimensions in the transition to Industry 5.0. These dimensions highlight employee engagement, ethical technology utilization, and organizational adaptability, which are increasingly acknowledged as critical factors influencing long-term industrial resilience and competitiveness.

The Fuzzy-DEMATEL results help us understand even more by showing how readiness factors are related to each other. The adoption of digital technology and the readiness of the organization were identified as key driving factors that had a big impact on other parts of the system. On the other hand, human capital capability, sustainability and resilience practices, and an innovation culture were found to be effect factors. This means that their growth depends a lot on strategic leadership and technology-driven projects. This causal insight indicates that investments in advanced manufacturing technologies should be complemented by intentional initiatives to convert technological capabilities into human and sustainability outcomes.

In practical terms, the results suggest that Saudi manufacturing companies should take a balanced approach to change that includes using technology, training employees, making systems more sustainable, and putting people at the center of system design. The results show that at the policy level, there is a need for coordinated industrial policies that connect digital transformation efforts with frameworks for education, training, and sustainability. For Industry 4.0 investments to effectively support the human-centered, resilient, and sustainable manufacturing systems envisioned in Industry 5.0, they must be aligned in this way.

6. Conclusion

This study evaluated the extent of Industry 4.0 adoption and the preparedness of Saudi manufacturing entities for the transition to Industry 5.0 through a survey-based quantitative methodology. We used reliability analysis, exploratory factor analysis, and Fuzzy-DEMATEL to check the measurement constructs and look at the causal links between the main readiness factors.

The results show that Saudi manufacturing sectors are quickly adopting digital technologies and getting ready for strategic changes. This shows that the country is still working towards industrial digitalization. Nevertheless, the maturity of human capital capability, sustainability and resilience practices, as well as innovation and a human-centric culture, was found to be comparatively lower. The Fuzzy-DEMATEL results showed that technological and strategic readiness are the main driving factors, while human, sustainability, and innovation-related dimensions are dependent but important outcome factors.

The primary contribution of this research is the provision of an integrated analytical framework that amalgamates statistical validation with causal modelling to facilitate Industry 5.0 transition planning. The findings provide actionable insights for policymakers and industry leaders aiming to harmonize technological progress with workforce development, sustainability goals, and human-centered manufacturing principles in alignment with Saudi Vision 2030. Subsequent research may build upon this study via longitudinal or sector-specific analyses.

AI Tool Usage Declaration

The author declare that AI tool is used for language improvement and the author reviewed and edited the content as needed and takes full responsibility for the content of the published article.

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Biographies

Hisham Alkhalefah received the master's and Ph.D. degrees from the Industrial Engineering Department, King Saud University. He is an associate professor at the Advanced Manufacturing Institute, King Saud University. Moreover, he served as a supervisor at the Advanced Manufacturing Institute, King Saud University. His research interests include advanced manufacturing technologies, particularly Industry 4.0, additive manufacturing, digital manufacturing, manufacturing systems, and non-conventional machining, among others. He has published several research articles in reputable international journals and conferences.