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Review article

Drivers and barriers to Industrial Revolution 5.0 readiness: A comprehensive review of key factors

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ABSTRACT

As industries navigate the transition toward Industrial Revolution 5.0, understanding the key drivers and barriers to readiness becomes crucial. This study conducts a comprehensive literature review to uncover the critical factors shaping IR 5.0 adoption. The findings highlight that technological advancements, workforce upskilling, and supportive policies serve as primary drivers, accelerating the shift toward human-centric and sustainable industrial ecosystems. Conversely, resistance to change, financial constraints, and lack of awareness emerge as significant barriers, impeding progress. To bridge these gaps, this study emphasizes the need for strategic investments in advanced technologies, targeted workforce development programs, and robust policy frameworks. By offering a structured analysis of the enablers and inhibitors of IR 5.0 adoption, this research provides valuable insights for industry leaders, policymakers, and academics, fostering sustainable growth and innovation in an era of rapid technological evolution.

1. Introduction

The emergence of the Industrial Revolution 5.0 marks a significant shift in the way technology is integrated with human skills to enhance sustainability, productivity, and innovation across various sectors. This evolution of industry is not just a technological change but a human-centered movement that concerns politicians, academics, practitioners, and society at large. Unlike its predecessor, IR 4.0, which stressed automation and digitalization, IR 5.0 brings human values, empathy, and creativity back into focus, advocating for synergy between advanced technologies such as artificial intelligence (AI), robotics, and the Internet of Things (IoT) and the unique capabilities of human workers [1]. In a world where digital change is quickening and social equity and sustainability are top issues, this paradigm shift is particularly pertinent. It emphasizes the need for a more balanced industrial strategy that recognizes both human well-being and technological advancement. Therefore, industries aiming long-term resilience and social influence must not only be timely but also crucial knowledge of what motivates ready for IR 5.0 [2]

Companies all over the world are beginning to embrace the key elements of IR 5.0 readiness. One key driver is the increasing need for product and service personalization, particularly in manufacturing and logistics. Companies are providing tailored solutions via linked devices, AI-driven analytics, and smart manufacturing systems while maintaining high efficiency and low environmental impact. At the same time, Hernandez-Matias et al. [3] described that regulatory requirements and stakeholder expectations encourage sustainability, which motivates businesses to alter their corporate strategies to incorporate carbon-reduction goals and environmental policies. Technologies enabling these transformations include digital twins, machine learning, and real-time data processing, which permit data-driven decision-making. Beyond technology, human-centric concepts are gaining increasing appeal as businesses seek to create inclusive, engaging workplaces emphasizing creativity, collaboration, and well-being [4]. Human-centered design, which prioritizes user experience and worker empowerment first, is the foundation of innovation and agility in the IR 5.0 era. These elements point to a positive trend suggesting that many businesses are actively looking for preparation through technological, strategic, and cultural shifts [5]

However, this readiness journey is not without significant complexities and barriers, especially when viewed from a global and cross-sectoral lens. Shaped by economic conditions, institutional maturity, labor skills, and infrastructural development, the character of IR 5.0 preparedness differs greatly between areas. For example, Minkov [6]

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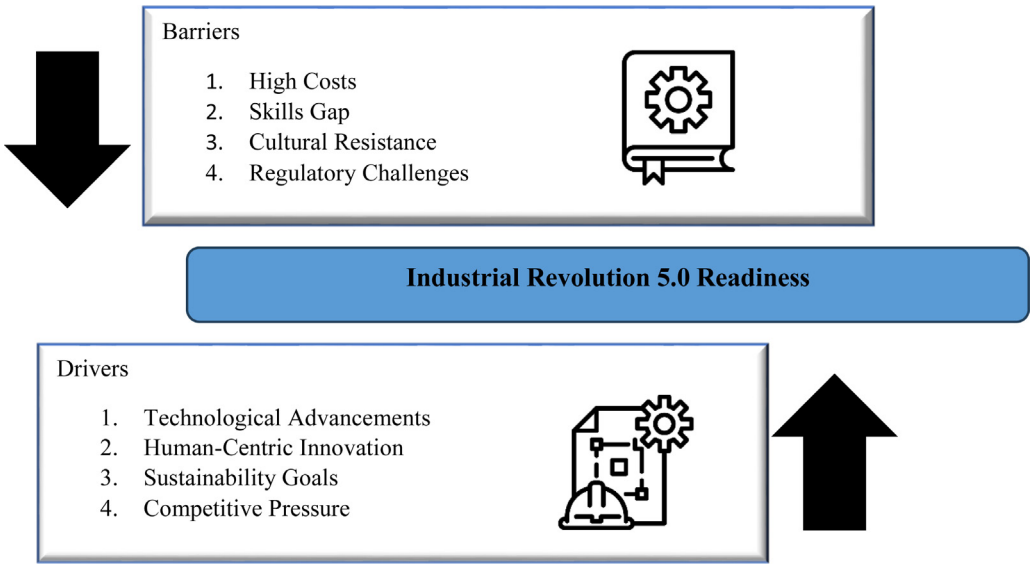

Fig. 1. Relationship between drivers and barriers for industrial 5.0.

explained that in many developing nations, issues like inadequate digital infrastructure, antiquated facilities, and lack of trained workers impede the adoption of innovative technology. Organizational culture is also very important; reluctance to change, anxiety of job loss, and conflict between technical objectives and employee values can all postpone or undermine the sustainability of IR 5.0 projects. Different regulations and broken-up policy systems add to the complexity of preparation initiatives since companies have to negotiate several certification procedures and compliance criteria. The multidisciplinary character of IR 5.0, which calls for the confluence of engineering, human sciences, environmental science, and information technology, aggravates these obstacles. Addressing these multi-dimensional issues calls for a local and flexible strategy that considers cultural sensitivities and regional limitations as well as uses worldwide technology developments [7].

Though academic interest and business attention on IR 5.0 are increasing, important knowledge gaps still exist. Although several studies have looked at the advantages and applications of technologies, few have offered a thorough synthesis of both the drivers and obstacles to IR 5.0 readiness across different industries and geographic settings. Though these factors are usually critical in deciding the success or failure of IR 5.0 implementation, there is little study combining cultural, structural, and policy aspects with technology readiness alongside one another [8]. There is also no consistent methodology in the literature to assess how human-centric values and environmental goals interact with digital transformation plans. Though the function of employee training is generally highlighted, its relationship with leadership practices and organizational change management is sometimes ignored. Lack of whole viewpoints limits the capacity of decision-makers to create well-rounded preparation plans. Thus, it is vital to chart these interrelated elements and know how they influence the readiness of sectors moving to IR 5.0 [9].

This narrative review aims to bridge these gaps by offering a thorough analysis of the enablers and constraints affecting IR 5.0 readiness. The review investigates how technology developments interact with organizational dynamics, workforce competencies, and sustainability objectives by synthesizing knowledge from academic literature and practical case studies. It seeks to find practical ideas and best practices that could help companies to overcome typical obstacles including legacy systems, employee opposition, and legal issues. By providing a whole viewpoint on what it means to be "ready" for this industrial transformation, this study helps to fill the gap in information on IR 5.0. Recognizing that the real promise of IR 5.0 is in the seamless integration of technology with empathy, ethics, and environmental responsibility, it also emphasizes the need of matching human-centered innovation with long-term sustainability goals. In the end, the article aims to educate future policy creation, direct organizational strategy, and motivate cross-disciplinary cooperation toward a more inclusive and sustainable industrial future.

2. Industrial Revolution 5.0

Industrial Revolution 5.0 represents the next stage in the evolution of industrial practices, characterized by a focus on human-centric technology and the seamless integration of artificial intelligence, robotics, and other advanced technologies into production and logistics systems. Unlike its predecessor, Industrial Revolution 4.0, which emphasized automation, efficiency, and the Internet of Things, Industry 5.0 seeks to enhance human collaboration with machines, prioritizing the role of people in the technological ecosystem [10]. One of the key features of Industry 5.0 is the concept of collaborative robots, or cobots, which are designed to work alongside human operators in a shared workspace. These robots are equipped with AI and machine learning capabilities, allowing them to learn from human actions and adapt to changing environments. This collaboration not only increases productivity but also enhances the overall workplace experience, as it allows human workers to focus on more complex and creative tasks while leaving repetitive or hazardous activities to machines [11].

In addition to enhancing human–machine collaboration and promoting sustainability, Industry 5.0 emphasizes personalization in production processes. Advances in technology allow for customized products tailored to individual consumer preferences. This capability is especially relevant in sectors such as fashion, automotive, and electronics, where personalized products can create significant competitive advantages [12]. The leveraging data analytics and AI, companies can gain insights into consumer behavior and preferences, enabling them to design and manufacture products that meet specific demands. A description of the relationship between drivers and barriers and industrial 5.0 can be show in Fig. 1.

From the explanation of the above points, it can be interpreted that readiness toward Industrial Revolution 5.0 is influenced by various factors that act as drivers and barriers [13]. Key drivers include technological advancements such as AI, IoT, and robotics, which enable further automation and increased efficiency across various industrial sectors. Human-centric innovation also plays an important role, combining

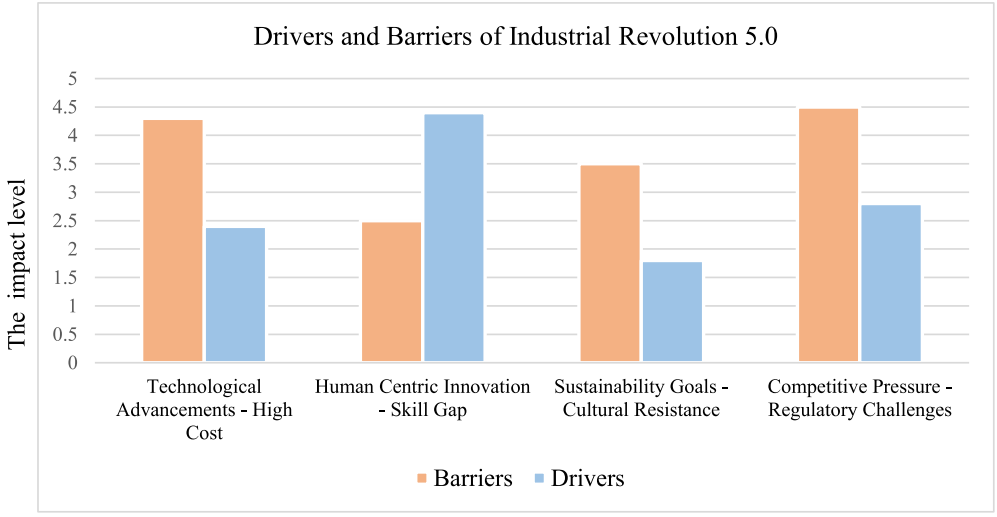

Fig. 2. Comparison of impact levels between drivers and barriers.

technology with human creativity to drive personalization of products and services and strengthen collaboration between humans and machines [2]. Increasingly important sustainability goals are driving industries to implement green practices and minimize environmental impact. In addition, competitive pressures in the global marketplace require companies to continuously innovate to stay relevant.

IR 5.0 offers great opportunities for technological improvement and sustainability, but also faces barriers that require strategic addressing, such as cost reduction, skills upgrading and cultural adjustment to change [14]. Comparison of impact levels between drivers and barriers can be show in Fig. 2. A detailed explanation will also be outlined in Table 1.

Below is a comparison graph of the impact levels between *drivers* and *barriers* on long-term sustainability in two key categories: operational efficiency and environmental sustainability. The graph illustrates that operational efficiency is more strongly influenced through *drivers*, such as the adoption of technologies that boost productivity, while *barriers* like initial costs and cultural resistance have a smaller impact. Similarly, environmental sustainability is largely driven through *drivers*, such as eco-friendly technologies, with *barriers* like high initial investment playing a lesser role. Maximizing the influence of *drivers* and addressing *barriers* helps organizations significantly support both operational and environmental sustainability [15]. The transition to Industrial Revolution 5.0 signifies a profound shift in the industrial landscape, characterized by the integration of advanced technologies and an enhanced focus on human-centric values. This new era unfolds against a backdrop of rapid technological evolution, where innovations such as artificial intelligence, robotics, and the Internet of Things promise to redefine operational efficiency and productivity across various sectors. Organizations increasingly recognize the necessity of adapting to these technological advancements to maintain competitiveness in a constantly evolving marketplace [16]. However, alongside these drivers exist significant barriers that organizations must navigate. These barriers include outdated infrastructure, insufficient workforce training, cultural resistance to change, and regulatory constraints that may hinder the implementation of new technologies. The emphasis on human-centric innovation within the framework of IR 5.0 cannot be overstated [1]. Organizations must recognize the importance of aligning technological initiatives with the needs and values of their workforce. Human-centered design principles, prioritizing user experience and engagement, are essential in fostering a culture of collaboration and creativity. Additionally, incorporating sustainability goals into organizational strategies reflects a growing recognition of the need for responsible industrial practices. Balancing the pursuit of technological advancement with sustainable practices not only contributes to environmental stewardship but also enhances an organization's reputation and long-term viability [17]. Similarly, environmental sustainability is largely driven through eco-friendly technologies, with barriers such as high initial investments playing a lesser role. Maximizing the influence of drivers and addressing barriers helps organizations significantly support both operational and environmental sustainability. This narrative review aims to provide a thorough analysis of the drivers and barriers affecting readiness for Industrial Revolution 5.0 [18]. Exploring the interplay between technological advancements and organizational dynamics sheds light on the factors influencing successful implementation. Furthermore, the global nature of today's economy complicates the readiness landscape. Organizations must consider varying regulatory environments, cultural differences, and technological infrastructures across different regions. Addressing these challenges requires a nuanced understanding of local contexts and a willingness to adapt strategies to align with diverse needs [2]. Embracing this complexity offers opportunities for organizations to differentiate themselves in a competitive market, ultimately enhancing their readiness for the demands of IR 5.0. A very significant impact can be seen in the Fig. 3.

Industrial Revolution 5.0 is characterized by the integration of advanced technologies with a human-centered approach, focusing on sustainability and wellbeing [19]. The drivers of IR 5.0 include technological advancements such as artificial intelligence, the Internet of Things, and robotics, which enhance productivity and innovation while fostering collaboration between humans and machines. Additionally, the growing demand for sustainable practices and the need to address climate change act as significant motivators for businesses to adopt these new paradigms. However, barriers to implementation persist, including a lack of skilled workforce, resistance to change within organizations, high initial investment costs, and concerns about data privacy and security [13]. Overcoming these challenges is crucial for realizing the full potential of IR 5.0 and ensuring a balanced approach to economic growth, environmental stewardship, and social equity.

3. Drivers and barriers

Industrial Revolution 5.0 readiness is driven by technological advancements like AI, robotics, and IoT, which enhance automation and sustainability. Market competition and regulatory incentives push companies to adopt these innovations, while workforce development programs equip employees with necessary skills [20]. However, barriers such as high implementation costs, skill shortages, and cultural resistance slow adoption. Integration challenges with legacy systems

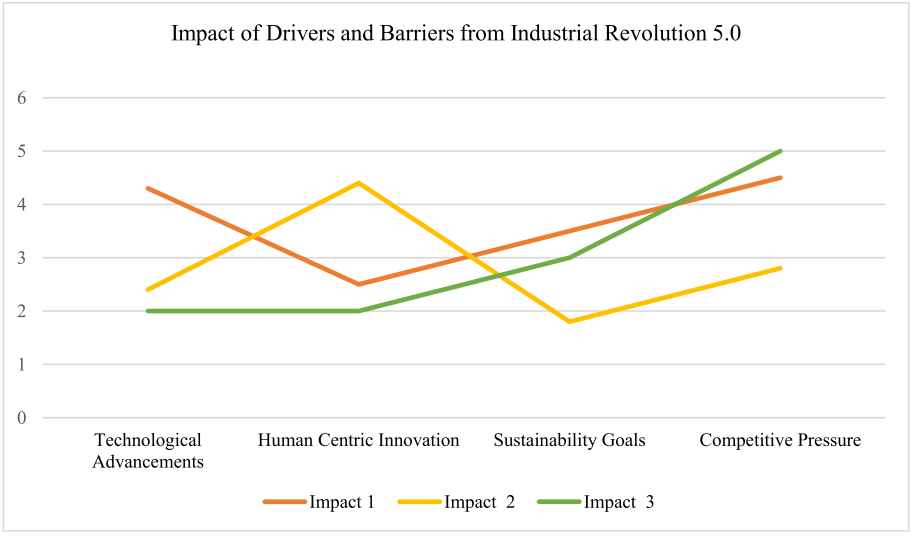

Fig. 3. Impact of Drivers and Barriers from Industrial Revolution 5.0.

Table 1
Category of drivers.

Category	Details
Technological Advancements	Emerging technologies (AI, IoT, robotics) drive IR 5.0 readiness [21].
Manufacturing Impact	Automation, 3D printing, and smart factories enhance efficiency [22].
Logistics Role	IoT, warehouse automation, and supply chain systems optimize operations [23].
Industry 5.0 Integration	Supports human-centric and sustainable production [24].
Key Challenges	Resistance to change, skill gaps, and financial constraints [25].
Future Trends	AI, blockchain, and sustainability innovations [26].

Table 2
Category of barriers.

Category	Details
High Implementation Costs	Significant financial investment required for new technologies [27].
Cost Components	Initial investment (hardware, software), training, maintenance [18].
Financial Implications	Budget constraints for SMEs, need for ROI assessment [28].
Barriers to Adoption	Risk aversion, resistance to change, limited knowledge [29].

and cybersecurity risks add complexity. Overcoming these hurdles requires strategic investment, workforce training, and strong cybersecurity measures to ensure a smooth transition to IR 5.0. Details will be explained in the Tables 1 and 2.

Cultural factors, such as uncertainty avoidance, can be significant barriers to IR 5.0 adoption. In societies or organizations where there is a strong preference for traditional working methods, the integration of new technologies may be met with skepticism or resistance [30]. This resistance can slow down the adoption of IR 5.0 practices and hinder organizations from reaping the full benefits of technological advancements. The drivers and barriers of IR 5.0 readiness represent a complex balance between the benefits of adopting cutting-edge technologies and the challenges that industries face in integrating these innovations into their operations. While technological advancements, sustainability goals, and competitive pressures push companies toward readiness, high costs, skill shortages, and cultural resistance can slow down progress [7]. Despite its insights, this review's narrative approach has limitations, emphasizing the need for broader empirical research across industries. Future studies should explore sector-specific readiness factors to provide more targeted strategies. A holistic approach aligning technology, skills development, and cultural adaptation will be essential for organizations to remain competitive and drive sustainable growth in the IR 5.0 era. The detail explanation of drivers and barriers is described in Table 3.

Infrastructure barriers significantly affect a company's ability to adapt to Industrial 5.0. In many regions, both physical and digital infrastructure are insufficient to support new technologies. For example, a company seeking to utilize automated systems may find that its facilities are not designed to accommodate modern machinery. Additionally, poor internet connectivity can hinder the use of cloud-based technologies needed for data analytics and supply chain management. Without robust infrastructure, organizations will struggle to fully leverage the potential of Industrial 5.0. Understanding and addressing these barriers is essential for companies looking to transition to Industrial 5.0 and achieve their sustainability objectives.

4. Discussion

The shift toward Industrial Revolution 5.0 is transforming industries worldwide, driven by the convergence of advanced technologies, human-centric design, and sustainability principles. Understanding the elements that facilitate this shift, known as drivers, and those that pose challenges, termed barriers, is crucial for organizations aiming to be well-prepared for this new industrial age [41]. A primary driver of IR 5.0 readiness is the rapid technological advancement. Innovations such as artificial intelligence (AI), the Internet of Things (IoT), and robotics play a pivotal role in enhancing productivity and operational efficiency. For example, AI can conduct data analysis at unprecedented speeds, providing insights that enhance decision-making processes [42]. The IoT supports real-time monitoring of equipment and systems, enabling organizations to quickly respond to operational changes. These technologies collectively mark a significant step forward, paving the way for more efficient and adaptable industrial operations [43].

The increasing focus on sustainability is another strong driver propelling organizations toward IR 5.0 readiness. Companies are increasingly aware that sustainable practices not only support environmental well-being but also bolster their competitive edge. The investing in green technologies and sustainable production processes, businesses can reduce their carbon emissions and attract environmentally

Table 3
Explanation is outlined drivers and barriers.

Category	Subcategory	Description
Drivers		
1. Advanced Technology	(a) Definition and Scope	Innovative tools, systems, and methods enhancing productivity in industries such as IT, automation, AI, and advanced manufacturing [31].
	(b) Impact on Manufacturing	Transition from manual processes to automated systems [32].
	(c) Robotics	Automation improves precision and speed in production, reducing human error [3].
	(d) Additive Manufacturing	3D printing enables rapid prototyping and complex design creation [8].
	(e) Smart Factories	IoT integration allows machines to optimize performance in real-time [33].
	(f) Role in Logistics	Technology enhances efficiency through real-time tracking and automated supply chain management [34].
	(g) Future Trends	(1) AI for predictive analytics; (2) Blockchain for supply chain transparency; (3) Sustainability innovations as a key focus.
	(h) Integration with Industry 5.0	Essential for human-centric and sustainable production principles.
2. Human-Centered Innovation	(a) Definition and Importance	Focuses on designing products and services prioritizing user needs and experiences.
	(b) Principles	(1) Empathy: Understanding user needs; (2) Co-Creation: Involving users in the innovation process; (3) Iterative Design: Continuous feedback.
	(c) Applications in Industry	(1) Product Development: Emphasizing user experience; (2) Service Design: Improving customer interactions;
	(d) Role of Technology	Data analytics aids in understanding user behavior, and UX tools support design processes.
		(1) Organizational Resistance; (2) Resource Limitations; (3) Balancing Stakeholder.
	(f) Future Directions	Merging advanced technology with human-centered innovation while considering sustainability [35].
3. Sustainability Goals		Global sustainability needs drive the adoption of practices aligned with environmental standards [36].
Barriers		
1. Technological Barriers	(a) Discuss limitations in adopting new technologies and innovations.	Lack of adequate infrastructure, outdated systems, cybersecurity issues [37].
2. Human Resource Barriers	(a) Explore challenges related to workforce skills and knowledge.	Insufficient training programs, resistance to learning new technologies, talent shortages [7].
3. Organizational Culture Barriers	(a) Analyze the impact of organizational culture on innovation and change.	Resistance to change, hierarchical structures, lack of collaboration [38].
4. Regulatory and Policy Barriers	(a) Examine how government policies and regulations can impede progress.	Strict regulations, lack of incentives for sustainable practices, bureaucratic hurdles [3].
5. Financial Barriers	(a) Discuss the financial challenges associated with implementing new technologies and practices.	High initial investment costs, limited access to funding, cost–benefit analysis challenges [39] .
6. Awareness and Understanding Barriers	(a) Evaluate the level of awareness and understanding of sustainability benefits among stakeholders.	Misconceptions about sustainability, lack of knowledge dissemination, insufficient stakeholder engagement [40].

conscious consumers [44]. For instance, adopting renewable energy sources can help companies lower operational costs while positioning themselves advantageously in a market that increasingly prioritizes sustainability. Aligning with environmental objectives is no longer

Table 4
Factors and Concerns Readiness.

Factors Influencing Readiness	Readiness Concerns
Technological Advancement	**Resistance to Change**
Innovations like AI, IoT, and big data are crucial for transitioning to Industrial 5.0 [46].	Uncertainty and resistance from employees and management can hinder implementation [47].
Workforce Skills	**Cybersecurity Risks**
The readiness of the workforce in digital skills and adaptability is key; retraining is essential [48].	Increasing technology use raises concerns about cyber threats that must be managed [49].
Organizational Culture	**Integration Challenges**
An organizational culture that supports innovation and collaboration accelerates the adoption of Industrial 5.0 practices [50].	Difficulties in integrating new technologies with existing systems can impede progress [51].
Investment in Infrastructure	**Resource Allocation**
Investment in digital and physical infrastructure is vital to support the implementation of new technologies [52].	Proper allocation of resources, including time and funds, is challenging when preparing for this transition [24].
Regulatory Environment	**Cultural Barriers**
Supportive government policies and regulations can facilitate technology adoption and enhance industrial readiness [53].	Cultural differences and existing values within the organization can affect readiness to adapt to new Industrial 5.0 concepts [54].

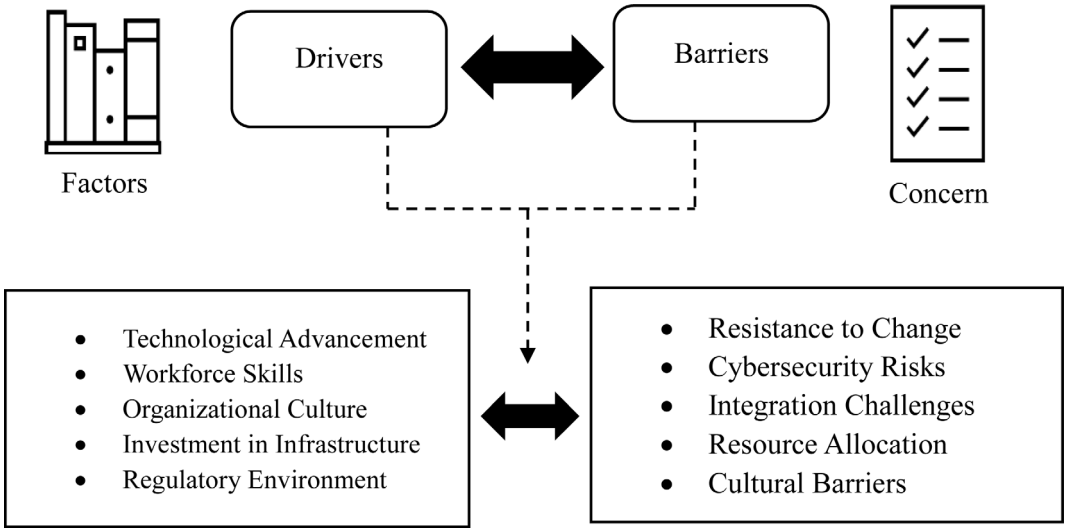

Fig. 4. Framework Factors and Concern Readiness.

just a trend; it is becoming essential for success in today's industrial landscape [14].

Despite these drivers, barriers exist that organizations must address. For example, an organization may plan to implement IoT solutions for real-time analytics but face challenges due to inadequate network infrastructure for such advanced applications. Additionally, cybersecurity concerns can act as deterrents for adopting new technologies. The fear of potential data breaches and the significant costs associated with securing new systems can cause hesitation among organizations when considering technological adoption [45]. Can create hesitance among companies, ultimately slowing down their transition to IR 5.0. For a detailed description of the explanation can be show in the following Table 4.

From the explanation of the table above are identifying and understanding these factors and concerns related to readiness will assist organizations in planning and implementing strategic steps toward Industrial 5.0. A thorough analysis of these aspects can help mitigate barriers and maximize the potential benefits of this transition. In the description of the factors and concerns regarding technological readiness above, it can be summarized in a framework that can integrate a decision on drivers and barriers in determining industry 5.0 readiness. The framework image can be seen in Fig. 4.

The link between drivers and barriers is seen in how drivers can help overcome barriers. For example, technological innovation (as a driver) can lower costs and increase efficiency, thereby reducing implementation cost barriers.

In addition, government policies that support innovation can also provide the necessary resources and support to overcome the challenges faced by companies [55]. The understanding these linkages, organizations can develop more effective strategies to improve their readiness for the Industrial Revolution 5.0, maximize the potential of the drivers, and minimize the barriers. The following is an explanation of the discussion points, can be shown in the Table 5.

Therefore the explanation is a table above, Industrial Revolution 5.0 represents a significant evolution in industrial practices, focusing on the integration of advanced technologies with human-centered approaches to enhance productivity and sustainability. Unlike its predecessors, which primarily emphasized mechanization and automation, IR 5.0 seeks to create collaborative environments where humans and machines work together seamlessly [62]. This transition presents organizations with unique opportunities to innovate and optimize their processes, but it also poses challenges that must be addressed to ensure successful implementation.

Table 5
Explanation of The Discussion.

Discussion Points	Drivers	Barriers
1. Definition and Scope	Innovative tools and systems in IT, automation, AI, and manufacturing enhance productivity [2].	Lack of adequate infrastructure and outdated systems hinder adoption of new technologies [8].
2. Impact on Manufacturing	Transition from manual processes to automated systems leads to increased efficiency [56].	Resistance to change among employees can impede implementation of new processes [57].
3. Role of Technology	Automation and robotics improve production speed and precision, reducing human error [58].	Cybersecurity concerns create hesitation in adopting advanced technologies [59].
3. Role of Technology	Automation and robotics improve production speed and precision, reducing human error [60].	Cybersecurity concerns create hesitation in adopting advanced technologies [61].
4. Applications of Additive Manufacturing	3D printing allows for rapid prototyping and complex design creation, fostering innovation [43].	Insufficient training programs lead to workforce skill gaps in using new technologies [62].

5. Conclusion

A synergistic mix of sophisticated technology, workforce development, and cultural flexibility drives readiness for Industrial Revolution 5.0 (IR 5.0). Across several industrial sectors, technologies like artificial intelligence (AI), robotics, and the Internet of Things (IoT) have great promises to change productivity, efficiency, and sustainability. The successful integration of these technologies, therefore, depends much on human elements, especially the availability of competent, flexible staff and encouraging leaders. Many businesses find the fast speed of technology development difficult to educate their workers for, hence the growing digital skills gap is still a major obstacle. This emphasizes the pressing need for focused training courses, lifetime learning policies, and leadership development investments to support a society of ongoing creativity. Technological developments by themselves will not provide the full advantages of IR 5.0 without intentional initiatives to empower the labor.

Apart from issues connected to the personnel, organizational culture greatly affects the performance of IR 5.0 implementation. While stiff institutions and opposition to change might compromise development, adaptive, inclusive, and innovative-friendly settings speed digital transformation. Key components in forming a strong and future-ready company are cross-functional cooperation and harmonizing technical projects with staff values and experiences. Although this study has included important motivations and obstacles, its narrative range limits it. Future research should thus aim for empirical studies across industries and geographic areas to produce more profound, data-driven conclusions. Longitudinal studies examining how preparation changes over time and comparison studies between sectors or countries could identify important success elements and context-specific approaches. Studies on the psychological and behavioral aspects of employee involvement in IR 5.0 projects as well as how cultural values influence technology acceptance will also help to augment the present corpus of knowledge. Building a strong, durable route toward effective IR 5.0 transformation will depend on a multidimensional approach combining technological, organizational, and human-centric viewpoints.

CRediT authorship contribution statement

Tia Tanjung: Formal analysis, Data curation, Conceptualization. **Ihwan Ghazali:** Supervision, Resources, Project administration. **Wan Hasrulnizzam Wan Mahmood:** Writing – review & editing, Supervision. **Safarudin Gazali Herawan:** Data curation, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.grets.2025.100217.

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