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THE ROLE OF ROBOTICS AND AUTOMATION IN INDUSTRY 4.0 TRANSFORMATION

PERAN ROBOTIKA DAN AUTOMASI DALAM TRANSFORMASI INDUSTRI 4.0

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ABSTRACT
Industry 4.0 transformation has driven the adoption of robotics and automation, but challenges in implementation are still a significant obstacle for many companies. This research aims to identify and analyze the main challenges faced in the application of robotics technology in the industrial sector. This study focuses on grouping technical, economic, regulatory, social and security challenges that hinder the adoption of robotics in the context of industry 4.0. This research uses a Systematic Literature Review (SLR) approach to collect and analyze data from relevant scientific articles, with strict inclusion and exclusion criteria. Analysis was carried out using the PRISMA framework to ensure transparency and validity of the results. Research findings show that the main challenges in robotics implementation include system interoperability, high implementation costs, regulatory uncertainty, social resistance to automation, and cybersecurity risks. The impact of these challenges can hinder innovation and efficiency in the industry. The results of this research provide important insights for practitioners and policy makers to design effective mitigation strategies in facing the challenges of robotics adoption. In addition, this research also contributes to the development of technology adoption theory in industry 4.0 by providing an evidence-based analysis of the obstacles faced.
Keywords: robotics, automation, industry 4.0 challenges, Systematic Literature Review, technology adoption.

ABSTRAK
Transformasi industri 4.0 telah mendorong adopsi robotika dan otomatisasi, namun tantangan dalam implementasinya masih menjadi hambatan signifikan bagi banyak perusahaan. Penelitian ini bertujuan untuk mengidentifikasi dan menganalisis tantangan utama yang dihadapi dalam penerapan teknologi robotika di sektor industri. Studi ini berfokus pada pengelompokan tantangan teknis, ekonomi, regulasi, sosial, dan keamanan yang menghambat adopsi robotika dalam konteks industri 4.0. Penelitian ini menggunakan pendekatan Systematic Literature Review (SLR) untuk mengumpulkan dan menganalisis data dari artikel ilmiah yang relevan, dengan kriteria inklusi dan eksklusi yang ketat. Analisis dilakukan menggunakan framework PRISMA untuk memastikan transparansi dan validitas hasil. Temuan penelitian menunjukkan bahwa tantangan utama dalam implementasi robotika meliputi interoperabilitas sistem, biaya implementasi yang tinggi, ketidakpastian regulasi, resistensi sosial terhadap otomatisasi, dan risiko keamanan siber. Dampak dari tantangan ini dapat menghambat inovasi dan efisiensi dalam industri. Hasil penelitian ini memberikan wawasan penting bagi praktisi dan pembuat kebijakan untuk merancang strategi mitigasi yang efektif dalam menghadapi tantangan adopsi robotika. Selain itu, penelitian ini juga berkontribusi pada pengembangan teori adopsi teknologi dalam industri 4.0 dengan memberikan analisis berbasis bukti mengenai hambatan yang dihadapi.
Kata kunci: robotika, otomatisasi, tantangan industri 4.0, Systematic Literature Review, adopsi teknologi.

1. INTRODUCTION

The advent of Industry 4.0 has profoundly transformed the industrial landscape by integrating digital technologies such as robotics, automation, Artificial Intelligence (AI), and the Internet of Things (IoT) into production processes. Central to this transformation is the deployment of robotic systems, which significantly enhance production efficiency, reduce

operational costs, and improve manufacturing flexibility. Robotics, defined as the use of machines to perform tasks traditionally undertaken by humans, enables a shift in production paradigms, as industrial robots can effectively manage a range of complex tasks, including assembly, welding, and material handling (Rao & Newe, 2021; E.A.E, 2019). The increasing intelligence of robotic systems is a consequence of advancements in AI and machine learning, enabling them to adapt to dynamic work environments (Zhao et al., 2024; Adebayo et al., 2024). For instance, modern robots are capable of employing algorithms that allow them to optimize processes in real-time, improving overall productivity (Adebayo et al., 2024).

On an economic level, the adoption of robotics is creating significant impacts. Companies that integrate robotic systems often experience spikes in productivity and competitive strength, especially in a globalized market (Adebayo et al., 2024; Graetz & Michaels, 2018). Nevertheless, these advancements come with inherent challenges. One major concern surrounds the implications for the workforce, including job displacement and the need for new skill sets among workers. Research indicates that areas experiencing increased automation may witness a decline in employment opportunities, particularly for low-skilled labor (Stemmler, 2019; Ing & Grossman, 2022). Furthermore, the initial costs associated with implementing robotic systems can be prohibitive, posing barriers for smaller enterprises looking to adopt these technologies (Adebayo et al., 2024).

Despite the increasing adoption of robotics in Industry 4.0, several challenges still hinder its widespread implementation. Companies often face technical challenges, such as system interoperability and the reliability of hardware and software. Additionally, regulatory and policy aspects also influence the speed of technology adoption. Some countries have more supportive policies, while others are still in the process of developing regulations related to robotics and automation. Changes in the labor market also raise concerns, as automation can replace conventional jobs, potentially causing social and economic uncertainty (Adebayo et al., 2024).

Previous studies have predominantly focused on the benefits of robotics and automation in enhancing production efficiency and company profitability. However, there remains a gap in understanding the key barriers industries face in adopting these technologies. Some studies discuss technical aspects but do not sufficiently consider social, economic, and regulatory factors, which are equally crucial for the successful implementation of robotics. Additionally, limited research has applied a systematic approach to identifying and categorizing these challenges. Therefore, this study aims to fill the gap in the literature by providing a more comprehensive and evidence-based analysis of the barriers to implementing robotics and automation in Industry 4.0.

This study contributes both academically and practically in several key aspects. From a systematic analysis perspective, it identifies the major challenges in implementing robotics in Industry 4.0 through a comprehensive literature review. These findings offer insights into the technical, economic, regulatory, social, and security barriers to technology adoption. Additionally, this study has implications for practitioners and policymakers by providing insights for industries and regulators to design more effective and sustainable implementation strategies. A deep understanding of the barriers to robotics adoption can help formulate more adaptive policies and develop targeted mitigation strategies. Academically, this research fills gaps in the literature by offering a deeper understanding of the challenges that have not been widely explored in previous studies. By adopting a Systematic Literature Review (SLR) approach, this study presents an evidence-based analysis that can serve as a foundation for further exploration. Finally, these findings can serve as a basis for future research, including studies that explore solutions and mitigation strategies for the challenges of robotics implementation through empirical, conceptual, or industry-based experimental approaches.

2. METHODS

2.1 Research Design

This research uses an approach Systematic Literature Review (SLR) to identify, evaluate and synthesize relevant literature regarding challenges in implementing robotics in Industry 4.0. The SLR method was chosen because it provides a structured and transparent approach in researching and summarizing the results of existing studies. By following systematic procedures, SLR allows researchers to obtain a broader and deeper picture of the themes studied and ensures easier replication for future research. This approach follows principles that have been developed in previous studies related to SLR, including the use of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method to increase transparency guarantee of the study selection process. Thus, this study not only provides a comprehensive overview of the challenges in robotics implementation, but also strengthens the validity of the findings through an evidence-based approach.

2.2 Data Collection Methods

Data collection in this research was carried out by searching and collecting scientific articles from various sources database reputable academics, like Scopus, Web of Science, IEEE Xplore. This database was chosen because it has broad coverage of high quality scientific publications, both in the form of journals, conferences and proceedings related to robotics and Industry 4.0.

2.2.1. Inclusion and Exclusion Criteria

To maintain the relevance of the data and ensure that the studies taken are in accordance with the researcher's objectives, set inclusion criteria And exclusion criteria with as follows:

- **Inclusion Criteria:**
  - Studies that discuss technical, economic, regulatory, social and security challenges in the implementation of robotics in Industry 4.0.
  - Article published in journals or conferences indexed in the academic databases mentioned above.
  - Studies published over time last 10 years to ensure relevance with the latest technological developments.
  - Articles in languages English And Indonesia to expand the scope of research.

- **Exclusion Criteria:**
  - Articles that only focus on the technical aspects of robotics development without discussing the challenges of implementing them in an industrial context.
  - Studies that do not have a clear methodology or are not based on empirical research.
  - Articles are editorials, comments, or opinions that do not present evidence-based data or analysis.

All articles found will be screened in stages, starting from selection based on title and abstract, to in-depth evaluation of the complete contents of articles that meet the inclusion criteria.

2.3 Analysis Approach

To ensure systematic analysis, this research uses a framework PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) in the literature selection process. PRISMA is used to organize a transparent search, selection and data synthesis flow, which consists of four main stages:

1. Identification: Determine search sources, keywords, and search strategies in relevant databases.
2. Filtering: Review search results based on inclusion and exclusion criteria to eliminate irrelevant articles.
3. Qualifications: Evaluate the full text of articles that have passed the screening stage to ensure suitability for research objectives.
4. Data Synthesis: Conduct thematic analysis of the results of selected studies to identify main patterns in the literature.

After the PRISMA stage, the data obtained will be analyzed using thematic analysis, which aims to identify key patterns and themes in the literature reviewed. This analysis was carried out using an approach coding, where each article will be classified based on the category of challenges faced in implementation of robotics in Industry 4.0. Thus, this research can reveal trends, relationships, and gaps in existing research.

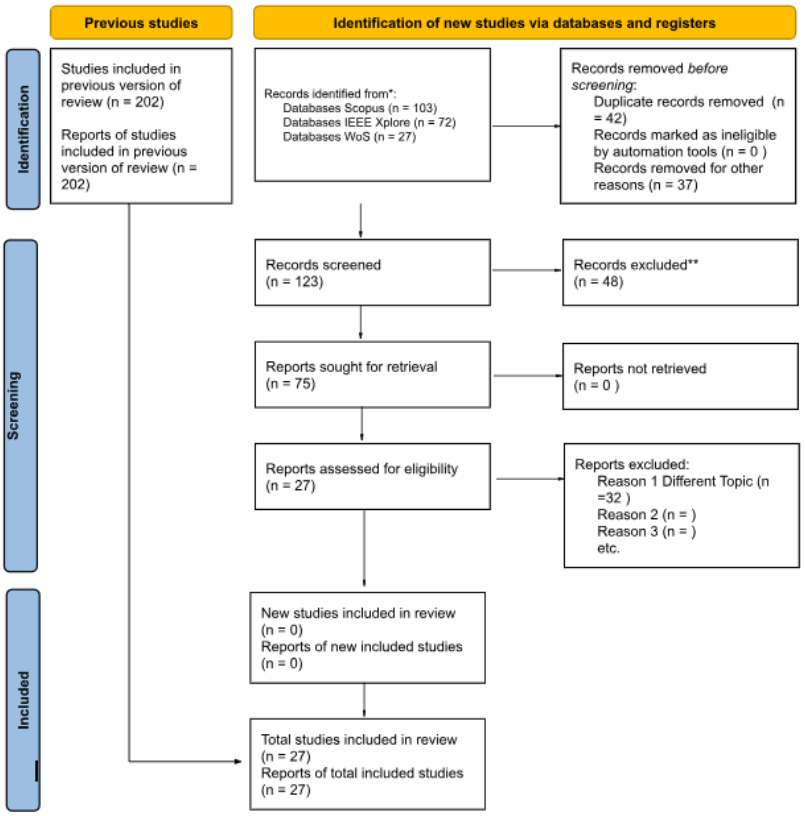
2.4 Justification of Methodology

Method selection Systematic Literature Review (SLR) in this research is based on several academic and practical considerations. SLR allows research to:

1. Guarantee Comprehensiveness – By using systematic procedures, this research can review and summarize various research that has been carried out, thus providing a broader picture regarding the challenges of implementing robotics.
2. Increase Validity and Reliability – A rigorous literature selection process based on the PRISMA framework ensures that the results obtained are more objective and can be replicated in future research.
3. Avoiding Individual Selection Bias – By applying clear inclusion and exclusion criteria, this research minimizes subjectivity in study selection, thereby reducing the possibility of bias.
4. Providing a Solid Foundation for Future Research – By identifying gaps in existing research, this study can become a reference for further research, especially in developing solutions to overcome the challenges of implementing robotics in Industry 4.0.

With this methodology, this research can make a significant contribution to academic understanding of barriers to robotics adoption and provide valuable insights for practitioners and policy makers in designing more effective implementation strategies.

Table 1. Prism Diagram



Sumber: Data Processed, 2025

The PRISMA diagram above illustrates the process of identifying, screening, and inclusion of studies in a systematic review. This process began with two main sources, namely studies that had been included in the previous version of the review totaling 202 studies, as well as new studies identified through searches in three main databases, namely Scopus (103 studies), IEEE Xplore (72 studies), and Web of Science (27 studies). Of the total of 202 new studies identified, there were 42 duplicate records removed, as well as 37 records removed for other reasons, such as non-compliance with selection or relevance criteria. After this process, the remaining 123 studies entered the further screening stage.

At the screening stage, of the 123 records examined, 48 studies were excluded, leaving only 75 reports remaining for further evaluation. All reports were successfully obtained, and 27 reports were then assessed for suitability. In this process, several reports were excluded for the primary reason of topic inappropriateness (32 reports).

After going through all these stages, no new studies met the criteria for inclusion in the final review. Therefore, the total number of studies included in the review remained at 27 studies, which were reports of previously existing studies. These results indicate that after systematic searching and screening, no additional new studies were found that met the inclusion criteria in this review.

3. RESULTS

3.1 Main Findings

The results of this research reveal various challenges faced in implementing robotics and automation in Industry 4.0. Based on the literature analysis carried out, the main challenges identified include technical, economic, regulatory, social and security aspects. The adoption of robotics technology in industrial contexts is fraught with numerous technical, economic, regulatory, social, and security challenges that need to be critically addressed for successful implementation.

1. Technical Challenges

The interoperability of automation systems poses significant technical challenges, especially when integrating with legacy infrastructure. Many organizations still heavily depend on outdated technologies that exhibit compatibility issues with modern automation solutions (Azadeh et al., 2019). For instance, Fager et al. highlight the scarcity of empirical studies analyzing the challenges of implementing robotic picking applications, emphasizing the need for robust interoperability frameworks that can link old and new systems effectively (Fager et al., 2020). Additionally, limitations in robot adaptability and flexibility in dynamic production environments represent considerable obstacles. This adaptability issue is compounded by the current rigidity in robotic manufacturing systems that are not designed for seamless integration in rapidly changing scenarios (Gharbi, 2021). Thus, innovative control strategies and flexible robotic systems are essential to tackle these challenges and foster more dynamic operations (Wang et al., 2018).

2. Economic Challenges

From an economic perspective, the high implementation costs associated with robotics can deter small and medium enterprises (SMEs) from making investments in automation technologies. Naik emphasizes that a thorough understanding of cost analysis, ROI, and market dynamics is crucial for assessing the economic sustainability of robotics (Rise, 2023). The initial capital required for robotics hardware and software, compounded by uncertainty regarding ROI and payback periods, further exacerbates this reluctance (Chuah et al., 2022). Organizations also express concerns about potential financial implications and the long-term viability of the technology, which often leads to hesitation in adopting such transformative solutions (Rise, 2023).

3. Regulatory Challenges

Regulatory challenges present another substantial barrier to robotics adoption, marked by a lack of cohesive policies and standards across different regions. Without consistent regulatory frameworks to govern robotics technologies, companies may face significant compliance risks that slow the implementation of these systems (Hindel et al., 2020). Moreover, liability issues related to accidents involving robots remain unresolved, leading to legal ambiguity that can further hinder reticent businesses from adopting automation technologies (Hindel et al., 2020).

4. Social Challenges

Social resistance to automation due to job displacement fears is another critical socio-economic challenge. Workers and labor unions often oppose the adoption of robotics, expressing concerns about job losses and the necessity for upskilling existing employees to adapt to new technologies (Yang et al., 2018). Effective communication and training programs are essential to alleviate fears and facilitate smoother transitions towards automation (Zheng et al., 2019). Addressing these social dynamics is crucial for stakeholders aiming to harmonize

human and robotic workforce interactions, thus ensuring a more sustainable adoption of technology (Kunduru, 2023).

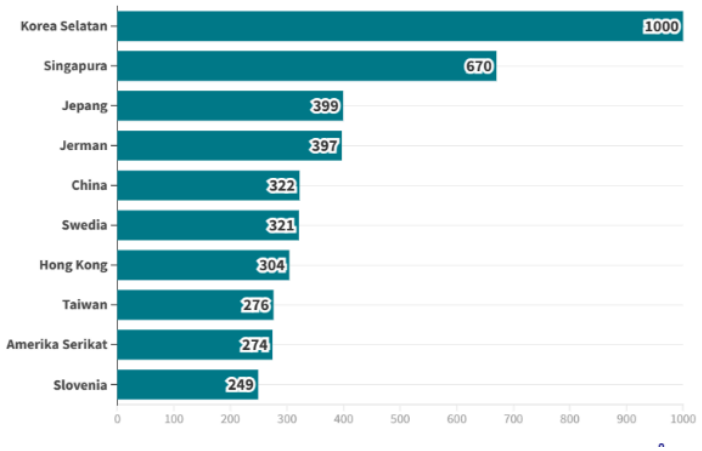
5. Security Challenges

Finally, the vulnerability of IoT and AI-based automation systems to cyber threats poses significant security challenges. As highlighted by Kunduru, the integration of increased automation within existing systems raises critical concerns related to data security and system resilience against cyber-attacks (Kunduru, 2023). The threat landscape necessitates robust security measures that not only protect the integrity of data but also ensure the seamless operation of robotics in industrial settings (Wang et al., 2024). Additionally, the incorporation of blockchain technology as a potential mitigative strategy against data breaches represents a forward-thinking approach to safeguard sensitive information in robotic systems (Wang et al., 2024).

In conclusion, addressing the multifaceted challenges in adopting robotics—ranging from technical interoperability and economic viability to regulatory coherence, social acceptance, and security resilience—is paramount for its successful implementation across industries.

3.2 Data Presentation

To support understanding of research findings, various methods of presenting data in use:



Picture 1. Countries with the Most Use of Robots in the World
Source: Goodstats, 2025

The data above shows the density of industrial robots per 10,000 employees in various countries, based on data from the International Federation of Robotics (IFR). South Korea occupies the highest position with 1,000 robots per 10,000 workers, followed by Singapore (670), Japan (399), and Germany (397). China, known as a global manufacturing hub, has a robot density of 322, while other countries such as Sweden, Hong Kong, Taiwan, the United States and Slovenia show relatively lower figures.

In the context of this research on the challenges of implementing robotics in Industry 4.0, this data illustrates how the adoption of robotics is uneven across countries. Countries with high robot densities, such as South Korea and Japan, generally have industrial policies that support automation, government incentives, and mature technology ecosystems. Meanwhile, lower density countries may face challenges such as high investment costs, a lack of a workforce skilled in robotics, or regulations that do not yet support the adoption of this technology.

This research can use this data to further analyze the factors that influence robotics adoption, including economic aspects, industrial policy, technology readiness, and its impact on the workforce. In addition, differences in robot density in various countries show that there are specific factors that influence the success or failure of robotics implementation in Industry 4.0, which need to be studied in more depth to provide appropriate policy recommendations.

4. DISCUSSION

4.1 Interpretation of Findings

The implementation of robotics within the framework of Industry 4.0 indeed faces multifaceted challenges, which can be categorized into technical, economic, regulatory, social, and security aspects.

From a technical standpoint, a significant barrier is the lack of interoperability between advanced automation systems and established legacy infrastructures. This problem is amplified by the findings of Rodriguez-Guerra et al. (Rodriguez-Guerra et al., 2021), indicating that modern industrial environments are often hindered by incompatibility issues with existing technology. This aligns with research conducted by (Jabeen et al., 2021), who highlighted that many robotics applications struggle to integrate due to outdated foundational systems.

Economically, the high initial investment costs present substantial hurdles, particularly for small and medium-sized enterprises (SMEs). These organizations often grapple with uncertainty surrounding the return on investment (ROI) when implementing such technologies. This situation is corroborated by Jabeen et al. (Jabeen et al., 2021), who noted that larger companies are generally better positioned to manage these costs, while SMEs often confront significant financial constraints that deter technology adoption. Consequently, without appropriate financial strategies or support mechanisms, the adoption of robotics in these smaller enterprises is likely to remain inconsistent.

On the regulatory front, the absence of robust policies supporting industrial automation emerges as a critical challenge. Guenat et al. Guenat et al. (2022) pointed out that regulatory frameworks in many regions are ill-prepared to foster a robotics-based industrial ecosystem, particularly concerning labor rights and job security, leading to inaction among companies hesitant to adopt new technologies. This regulatory hesitation is further complicated by the slow pace of regulation contrasted with the rapid advancement of robotics.

Socially, the fear of job loss owing to automation continues to be a significant roadblock. Zhu and Deng Zhu & Deng (2021) emphasized that although robotics enhances production efficiency, it simultaneously evokes anxiety among workers regarding job security, leading to resistance against further automation in workplaces. Such sentiments are crucial in understanding the human factors that influence the readiness for adopting robotics, as expressed by Turja et al. (Turja et al., 2019), highlighting that psychological readiness is influenced by socio-demographic factors affecting individuals' acceptance of robotic technologies.

Finally, security issues, particularly cybersecurity threats associated with IoT and AI systems used in robotics, are paramount concerns. Marchang and Nuovo Marchang & New (2022) illustrated that potential cyber attacks could lead to substantial operational disruptions, significantly affecting businesses both financially and in terms of reputation. This aligns with the suggested need for robust security measures to safeguard these advanced technological integrations from malicious threats.

In conclusion, the integration of robotics within the framework of Industry 4.0 is impeded by a confluence of technical, economic, regulatory, social, and security challenges that must be carefully addressed to foster widespread adoption.

4.2 Contribution to the Literature

This research contributes to enriching the literature by providing a systematic, evidence-based analysis of the challenges in implementing robotics in Industry 4.0. Meanwhile, previous research has highlighted the benefits of robotics in increasing production efficiency, this study highlights barriers that have not been systematically discussed in the literature. Apart from that, this research also provides a new perspective by elaborating on how each challenge interacts with each other. For example, economic barriers in implementing robotics are not only related to high costs but are also influenced by the lack of incentive policies from the government. Thus, this research can help academics develop a more comprehensive theoretical framework regarding industrial technology adoption.

4.3 Practical Implications

4.3.1. For Industry

The results of this research provide insight for companies in identifying the main challenges they may face when adopting robotics. Companies can use these results to design mitigation strategies such as investments in system interoperability, long-term financial planning, and workforce training to minimize resistance to new technologies.

4.3.2. For Policy Makers

Regulators can use these findings to design policies that support the adoption of robotics in industry, such as providing tax incentives for companies that invest in automation or developing labor regulations that ensure a just workforce transition.

4.3.3. For Academics

This research opens up space for further exploration regarding how each challenge can be resolved effectively. Case-based empirical studies could be the next step in understanding how specific industries face these barriers.

4.4 Research Limitations

Although this research provides important insights into the challenges of implementing robotics in the Industry 4.0 era, there are several limitations that need to be considered. First, limitations in the number of studies analyzed may affect the scope of the findings, because although the Systematic Literature Review (SLR) approach ensures rigorous selection of studies, research results remain dependent on the articles available in the databases used. Second, this research only focuses on identifying challenges without specifically discussing mitigation strategies that have been implemented in various industries. While mapping barriers is an important first step, further analysis of effective solutions will provide greater added value for academics and practitioners. Third, this research has not specifically analyzed the geographical and sectoral context, so the findings produced are still general in nature without distinguishing between different industries or policy differences in various countries. Therefore, further research that considers these aspects is needed to provide a more comprehensive picture of the implementation of robotics in various sectors and regions.

4.5 Future Research Recommendations

To complement the findings in this study, several future research directions can be considered. First, further investigation into strategies for mitigating challenges in robotics implementation is important, where future studies could focus on practical approaches that have been used by companies to overcome technical, economic, regulatory, social, and safety barriers. Second, empirical studies based on interviews or surveys can be conducted to collect primary data from companies that have adopted robotics, so as to provide deeper insight into the obstacles and solutions that have been implemented in real contexts. Third, the use of

mixed-methods can be an effective approach, by combining qualitative methods such as interviews with industry experts and quantitative methods such as statistical analysis of robotics adoption trends. This approach not only increases the validity of the findings, but also provides a more comprehensive understanding of the phenomenon under study. By considering this research direction, it is hoped that future studies can make a more substantial contribution to the development and implementation of robotics technology in various industrial sectors.

5. CONCLUSION

5.1 Summary of Findings

This research identifies various main challenges in implementing robotics and automation in the context of Industry 4.0. From the systematic analysis carried out, five main categories of challenges were found that needed attention. First, technical challenges include a lack of interoperability between new automation systems and the legacy infrastructure that many companies still use. Second, economic challenges are related to high implementation costs and uncertainty of Return on Investment (ROI), which are the main obstacles, especially for small and medium enterprises (SMEs). Third, regulatory challenges include limited policies that support the adoption of robotics as well as employment regulations that are not yet fully in line with technological developments. Fourth, social challenges arise due to changes in the structure of the workforce as well as worker resistance to the adoption of new technology. Lastly, security challenges are increasing along with higher cyber risks in Internet of Things (IoT) and Artificial Intelligence (AI) based automation systems. These findings provide a comprehensive picture of the obstacles faced by various sectors in implementing robotics, and highlight the complexity of the transition process towards a more technology-based industry.

5.2 Academic and Practical Contributions

5.2.1. Academic Contribution

This research fills a gap in the literature by providing an evidence-based analysis of barriers to the implementation of robotics in Industry 4.0. The findings obtained not only strengthen but can also challenge previous theories regarding technology adoption, especially in identifying emerging challenges at the technical, economic, regulatory, social, and security levels. Additionally, this research provides a strong foundation for future studies that can focus on mitigation strategies to overcome these barriers, thereby encouraging more effective adoption of robotics in various industrial sectors.

5.2.2. Practical Contribution

This research provides insight for industry regarding the main challenges that need to be anticipated in the adoption of robotics and automation, so that companies can design more appropriate strategies in integrating these technologies. In addition, these findings also provide guidance for policy makers in designing more supportive regulations, such as incentive policies for companies and workforce training programs to reduce resistance to automation. From an academic perspective, this research offers a foundation for academics and researchers to develop new conceptual models or approaches that can support the adoption of robotics in various industrial sectors more effectively.

5.3 Final Recommendations

Based on the findings of this research, several main recommendations that can be implemented to overcome challenges in the implementation of robotics are as follows. Multi-stakeholder collaboration between industry, academia and government needs to be strengthened to develop policies, research and workforce training that support the adoption of robotics technology. Apart from that, synergy between technology and manufacturing

companies must also be improved to create interoperable solutions for automation systems. Developing policies and regulations that are more responsive to technological developments is crucial, including providing incentives for companies, especially SMEs, who want to invest in robotics but face limited resources. Empirical studies and further research are also needed to test and develop mitigation strategies for the challenges of robotics implementation, for example through case studies in specific industries to understand success factors in the adoption of this technology. A mixed-methods approach, which combines quantitative and qualitative methods, can be used to explore the factors that influence the application of robotics more comprehensively. With the right strategies and policies in place, challenges in implementing robotics can be managed effectively, enabling companies to maximize the benefits of technology in the Industry 4.0 era.

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