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Industry 5.0 Challenges: Analyzing with Interval-Valued Intuitionistic Fuzzy AHP

Endüstri 5.0 Zorlukları: Aralık Değerli Sezgisel Bulanık AHP ile Analiz

Damla Çevik Aka[1]

Abstract

Focusing on employee interoperability with technology, sustainability, and durability pushes traditional production processes to change and highlights Industry 5.0 (I5.0). However, businesses have significant concerns about implementing I5.0. This study aims to explore the challenges in the implementation of I5.0 and to model these challenges for manufacturers in the automotive industry hierarchically. Challenges were examined in the context of developing economies. Through a comprehensive literature review, experts identified fundamental challenges, each serving as a criterion, and subsequently examined their suitability. Five experts with extensive experience in the automotive sector conducted the evaluation processes. In the application section of the study, relevant criteria were analyzed using the interval-valued intuitionistic fuzzy AHP method. The research results provide various insights for manufacturers in the automotive sector to comprehend, manage, and take preventive measures regarding the challenges of implementing Industry 5.0. The study's main findings shed light on the significant difficulties businesses encounter in the automotive supply chain.

Anahtar Kelimeler: *Industry 5.0, Human-Robot Collaboration, Challenge, Interval-Valued İntuitionistic Fuzzy Set, F-AHP.*

Öz

Teknoloji ile çalışanların birlikte çalışabilirliğine, sürdürülebilirliğe ve dayanıklılığa odaklanılması, geleneksel üretim süreçlerini değiştirmeye zorlamakta ve Endüstri 5.0'ı öne çıkarmaktadır. Ancak işletmeler, Endüstri 5.0'ı uygulama konusunda önemli endişeler taşımaktadır. Bu çalışma, Endüstri 5.0'ın uygulanmasındaki zorlukları araştırmayı ve bu zorlukları otomotiv sektöründeki üreticiler için hiyerarşik olarak modellemeyi amaçlamaktadır. Zorluklar, gelişmekte olan ekonomiler bağlamında incelenmiştir. Kapsamlı bir literatür taramasıyla, uzmanlar temel zorlukları belirlemiş, her birini bir kriter olarak ele almış ve uygunluklarını değerlendirmiştir. Otomotiv sektöründe geniş deneyime sahip beş uzman değerlendirme süreçlerini yürütmüştür. Çalışmanın uygulama bölümünde, ilgili kriterler aralık değerli sezgisel bulanık AHP yöntemi ile analiz edilmiştir. Araştırma sonuçları, otomotiv sektöründeki üreticilere Endüstri 5.0'ın uygulanmasındaki zorlukları anlamaları, yönetmeleri ve önleyici tedbirler almaları konusunda çeşitli içgörüler sunmaktadır. Çalışmanın temel bulguları, işletmelerin otomotiv tedarik zincirinde karşılaştıkları önemli zorluklara ışık tutmaktadır.

Keywords: *Endüstri 5.0, Insan-Robot Işbirliği, Zorluk, Aralık Değerli Sezgisel Bulanık Küme, Bulanık AHP.*

JEL Codes: *M11, O31, Q01*

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[1]Dr. Öğr. Üyesi, Kırklareli Üniversitesi, İktisadi ve İdari Bilimler Fakültesi, İşletme Bölümü Öğretim Üyesi, Kırklareli, Türkiye, damlacevik@sakarya.edu.tr, ORCID: https://orcid.org/0000-0001-9622-273X.

Introduction

Industry 4.0 (I4.0), arising from a project of the German government, has led to rapid changes in production systems. Each industrial era has increasingly focused on productivity and efficiency compared to its predecessor. The fourth industrial revolution created a revolution in the industry by integrating various technologies such as artificial intelligence, the Internet of Things, and cloud computing into production systems. Industry 4.0 has contributed to the real-time exchange of large amounts of information through Internet networks by integrating cyber-physical systems (CPS) into business operations. The aim is to create a 'smart' manufacturing sector by linking machines that can control and communicate with each other from start to finish (Xu, 2020).

Industry 4.0's central theme is to enhance production efficiency through process automation. The cost of human labor, which can impact process efficiency, is carefully considered (Nahavandi, 2019). Particularly for Industry 4.0, the definition of the lights-out factory has brought forth the concept of increased mechanization by causing employees to move away from the production facility. The establishment of a complete automation system in the manufacturing facility significantly restricts the intervention of employees (Lasi et al., 2014). With the focus on reducing the number of employees, many issues have begun to be discussed. Rising employment concerns and ethical issues have reduced the impact. By affecting the potential of employment, this situation increases the resistance of unions and complicates the acceptance of this process (Demir et al., 2019). At the same time, it could significantly impact the rest of society.

Industry 4.0 faces challenges in achieving sustainability goals due to its lack of significant sensitivity to environmental and social issues. Technologies commonly used, such as additive manufacturing, may limit material usage and energy consumption. However, evaluating the entire process reveals that many environmental impacts are ignored. As a result of the inability to prevent societal problems and environmental issues, applications of Industry 4.0 have become insufficient. The emergence of themes such as sustainability, human-centricity, and environmental concerns has necessitated a new approach. Because the digital transformation resulting from technological advancements leads to socio-cultural changes.

Many companies worldwide are working towards achieving Industry 4.0 maturity, yet Industry 5.0 has gained prominence in recent years (Di Nardo & Yu, 2021). Making more investments in research and innovation to create an industry with high competitiveness and world standards is seen as a crucial necessity (Doyle-Kent & Kopacek, 2020). Researchers such as Rajesh (2023) believe that transitioning to Industry 5.0, which emphasizes human-centricity, sustainability, and resilience, is the right move. Many researchers believe that Industry 5.0 will bring back the workforce to the manufacturing industry (Nahavandi, 2019). On the other hand, the European Commission does not consider Industry 4.0 as the right approach to achieving globally accepted goals by 2030 and supports Industry 5.0 strategies for this purpose (European Commission, 2021).

Industry 5.0 aims to solve the problems in I4.0 (Huang et al., 2022; Leng et al., 2022) and gains more importance as it strives for both social and sustainability with the presence of advanced technologies. Industry 5.0's essence is a new generation production system called the Cognitive Cyber-Physical Production System. Rajesh (2023) expressed that I5.0, unlike I4.0, focuses more on human-centric processes and sustainable industries to respond to global concerns such as climate change, resource shortages, and pandemics. Industrial revolutions undoubtedly have the most significant impact on manufacturing sectors. Kumar et al. (2023) noted that existing research on Industry 5.0 predominantly concentrates on manufacturing and medical sectors, primarily remaining conceptual.

A comprehensive overview is needed to understand the latest developments (trends, strengths, etc.) in Industry 5.0 (Ben Youssef, A., & Mejri, 2023; Leng et al., 2022). Although the literature on I5.0 is still in an embryonic stage, it can be observed that it is experiencing a clear rise (Madsen & Berg, 2021; Musarat et al., 2023). Despite research conducted in recent years on this emerging paradigm, it is a fact that there are many challenges and issues associated with the process. Implementing Industry 4.0 is challenging for many manufacturers, and reaching Industry 5.0 will require significant changes (Musarat et al., 2023). In recent years, there has been little research conducted to examine the challenges of adopting I5.0 (Chauhan et al., 2021; Khanzode et al., 2021). Focusing on societal issues, supporting employees, and aiming for sustainability and resilience can be challenging for businesses (Aslam et al., 2020; Demir et al., 2019; Huang et al., 2022; Rajesh, 2023). Embracing significant innovation in the industry requires the implementation of differences in many aspects, such as new technologies, new infrastructure, and different workforce skills. In addition, the new system attaches importance to sustainability, durability, and social welfare, which may make its implementation difficult.

In the existing literature, only a few studies examine the challenges encountered while adapting to Industry 5.0 using production case studies or real-sector examples. This study was initiated to express the actual expectations associated with the challenges that businesses are expected to encounter. The study aims to reveal the challenges in implementing Industry 5.0 in developing countries' industrial systems, particularly in the automotive sector. It is one of the first applications in the literature to identify and prioritize challenges to the adaptation to I5.0 through experts' discussions. As far as it is known, the application conducted in the automotive sector is the first attempt. Conversely, this is recognized as the inaugural effort to establish a decision-making framework using a combination of Interval-Valued Intuitionistic (IVI) and Fuzzy Analytical Hierarchy Process (F-AHP). This framework was designed to help identify and prioritize the challenges related to the adoption of Industry 5.0.

In this study, answers to several research questions were sought to achieve this goal.

RQ1: What are the challenges of implementing Industry 5.0 in industries in developing countries?

RQ2: What are the challenges of implementing Industry 5.0 for businesses in the automotive sector?

RQ3: How can these challenges be hierarchically ranked?

Firstly, an in-depth review of research focused on Industry 5.0 challenges was conducted, and a list of relevant challenges was compiled. Subsequently, interviews were conducted with experts to validate these criteria, and the list was updated. An essential part of the research involves evaluating the criteria by experts. Following this step, the criteria were analyzed with the Interval-Valued Heuristic Fuzzy Analytic Hierarchy Process Method, and the weight values for each criterion were reached. These values show the importance of the criteria regarding challenges.

Section 2 provides conceptual content related to the concept of Industry 5.0, its fundamental foundations, impacts, and the technologies used. Section 3 provides a concise literature review of the challenges associated with Industry 5.0. Section 4 presents the intuitionistic fuzzy sets and IVIF-AHP. Section 5 includes an application carried out with managers in the automotive industry and its results. Chapter 6 concludes the paper and gives further suggestions.

1. Motivations behind the Evolution of Industry 5.0

The I5.0 concept emerged with a post by Michael Rada on LinkedIn (Rada, 2015). In the published text by Rada, the term "industrial advanced transformation" was used to denote Industry 5.0. Contrary to the definitions of Industry 4.0, Rada stressed the importance of examining industry tools and environments virtually within a physical context. He mainly assessed that people will continually contribute to production due to evolving capabilities. Some researchers have developed this idea and started relasing scientific articles on the subject.

The I5.0 concept has various interpretations. While some researchers accept the I5.0 paradigm as a process built on the I4.0 paradigm (Mourtzis et al., 2022), others accept Industry 5.0 as a complement to Industry 4.0 (Akundi et al., 2022). Tropschuh et al. (2021) define the concept of Industry 5.0 as a path toward future digitized production, built on the success of the cyber-physical systems-focused trend of the fourth industrial revolution. Katna (2022) expresses that Industry Revolution 5.0 is not a revolution on its own but a kind of support for the improvement of the fourth industrial revolution. The researcher also emphasizes that while I4.0 is more focused on connected machines and smart products, Industry 5.0 focuses on hyper-personalization and a responsive supply chain for customer satisfaction. Both perspectives can be considered correct in some aspects I5.0 complement Industry 4.0's deficiencies and leverages its technological infrastructure. Essentially, I5.0 can be described as an enhanced version of Industry 4.0, enabling the rapid digitization of many sectors. Thus, it can be said that the new industrial transformation addresses a broader context. However, the Industry 5.0 concept being accepted as a new revolution will likely remain an inadequate notion.

Despite various I5.0 definitions, it can be stated that many of them describe the same things with similar words. The I5.0 paradigm represents an advanced transformation in the manufacturing system, focusing on humanity, resilience, and sustainability. In other words, Industry 5.0 focuses on the creation of synergy by matching humans and machines and executing production processes with smart systems. To provide a clearer definition of Industry 5.0, it's essential to outline its fundamental principles. I5.0 has three basic pillars: human orientation, sustainability, and durability (Ben Youssef & Mejri, 2023).

1.1. Human Orientation

Industry 5.0 adopts Industry 4.0 technologies while integrating new advancements to enhance efficiency and effectiveness. Industry 5.0 aims to bring the workforce back to the factory, where humans and machines are paired to benefit from human brainpower along with smart systems (Nahavandi, 2019). Human involvement is pivotal in Industry 5.0, contrasting with Industry 4.0's emphasis solely on advanced technologies like IoT, AI, and additive manufacturing. Industry 5.0 harmonizes and collaborates these technologies with human input. The main distinction between Industry 4.0 and Industry 5.0 is the level of collaboration or interaction between machines and workers. Manrique (2019) suggested that people use technology to produce information and intelligence in Industry 4.0, whereas machines, through artificial intelligence, will present information to people in I5.0. Behaviors promote synergy among machines, diverse data sources, and employees.

The industry's transformation is a subject that requires social change. I5.0 prioritizes a human-centric approach, aligning societal expectations and desires with technological advancements. Due to its emphasis on social issues, the Industry 5.0 concept is often associated with Society 5.0, which is commonly used to describe a human-centred society. Society 5.0 envisions a revolution in both industries and people's living spaces by integrating information technologies (Leng et al., 2022). However, Society 5.0 is not limited to the manufacturing industry; it focuses on societal issues in various aspects. The Japanese Science, Technology and Innovation Council began implementing the idea of Society 5.0 in detail as outlined in the "Fifth Science and Technology Basic Plan" (Carayannis et al., 2021). This initiative is accepted as a development strategy. Its main basis is to increase social welfare.

Society 5.0 is depicted as a comprehensive socio-technical transformation of society driven by technological advancements. Interconnected wireless networks will streamline societal decision-making by leveraging vast data volumes generated by technology. Such synergy has the potential to guide society with greater awareness from a societal perspective. People are intimately involved in the cyber-physical interaction cycle, forming human-cyber-physical systems (HCPS). HCPS, which is the cornerstone of I5.0, can seamlessly integrate people, cyberspace, and physical entities while ensuring the well-being of all stakeholders throughout the product life cycle. Employee critical and cognitive thinking also influences decision accuracy.

1.2. Sustainability

Limiting Industry 5.0 to merely enhancing efficiency or effectiveness through advanced technologies would be inaccurate. Also, defining it exclusively as harmony between humans and technology would be inadequate. "Sustainability" is one of the main themes for Industry 5.0. Industry 5.0 strives for sustainable production, considering efficiency, effectiveness, employee well-being, and environmental impact.

Previously, sustainability issues had come to the fore with I4.0 systems. It is stated that strengthening technology can create significant differences in the economic and environmental dimensions of sustainability. However, in Industry 4.0, the focus is more on the economic dimension of sustainability. Industry 5.0 is different because it focuses more on social issues with human-centred applications. I5.0 leverages the potential of the industrial sector in the social dimension of sustainability. The processes carried out by human-machine collaboration have crucial social impacts. In Industry 5.0, the value placed on employees encourages sustainability from a social perspective by influencing their well-being (Xu et al., 2021) and quality of life. In assessing sustainability from a social standpoint, employees are viewed as indispensable in production systems, necessitating a human-centred approach for economic and productivity gains (Nahavandi, 2019).

Industry 5.0 is expected to be more effective regarding the environmental dimension of sustainability. I5.0 offers green solutions that focus more on preserving the natural environment compared to previous industrial eras (Demir et al., 2019). One of the major environmental issues in the industry is waste management. Human-robot collaboration fosters flexible business models that minimize waste and overproduction by adjusting to real-time demand (Gosselin et al., 2022). Investments aimed at environmental protection include the development of a systematic waste prevention system. Reducing industrial waste and demonstrating sensitivity to environmental issues will be crucial. To achieve sustainable production, it is essential to develop active processes that effectively reuse and recycle resources (Aslam et al., 2020).

1.3. Resilience

The third crucial focus of Industry 5.0 is "resilience." Resilience is the ability to survive potential changes in expected or unexpected situations. Durability in the industry enhances production robustness and supports its preservation against interruptions. As technology advances, the manufacturing industry is also in a constant state of change. Businesses must be able to respond to this change by both standing against their competitors and meeting customer expectations. However, being able to respond to change is not sufficient. Businesses will need to possess both the flexibility to respond and the resilience to withstand change without deviating from their goals. Making accurate decisions and implementing them is a challenging process for any business. Real-time data from cutting-edge technologies is vital for businesses to make informed decisions quickly and accurately. Using the latest advanced technologies is also effective in this process. Industry 5.0 utilizes predictive data analytics and operational intelligence to make more accurate and stable decisions (Maddikunta et al., 2022). On the other hand, leveraging skilled and knowledgeable human resources is crucial for a more resilient system.

I5.0 focuses more on mass customization and offers a structure in which people will guide robots (Maddikunta et al., 2022). For this reason, it is stated that Industry 5.0 adds more value to businesses and increases customer satisfaction (Javaid & Haleem, 2020). A key difference between Industry 4.0 and Industry 5.0 regarding product customization is that

Industry 5.0 prioritizes achieving the utmost precision in production. While Industry 4.0 focuses more on output and efficiency, Industry 5.0 also focuses on more customization and flexibility in production processes. Industry 5.0 has the flexibility to offer personalized products thanks to advanced machines and automation (Xu et al., 2021). Another major contribution is its potential to produce higher-quality products. The contribution of Industry 5.0 to the production of high-quality products is based on the combined use of smart machines and human expertise. Machines handling tasks that demand power, difficulty, and monotony can improve production quality, while humans can be entrusted with tasks requiring critical thinking (Maddikunta et al., 2022). Industry 5.0 focuses on increasing efficiency in many aspects, and it also reduces operational costs with its applications (Sharma et al., 2022).

One of the crucial fields of research in I5.0 is related to technologies. Although many of these technologies are used in current production periods, they are also used for some reasons. Robot technology comes first among these technologies. Robots, which use more advanced technologies with the development of CPS, are one of the most significant tools for Industry 5.0. Robot technology is a CPS. In previous industrial eras, robots were extensively used, particularly in tasks requiring heavy labour such as carrying loads, painting, and pressing. Robot cyber-physical system is centred around collaborating with employees and leveraging their cognitive abilities. The ability of robots to undertake physically demanding tasks is of great importance for the health and safety of workers. Due to the many opportunities, the use of collaborative robots that can work alongside operators is becoming more crucial. Robots designed with artificial intelligence for collaboration are commonly referred to as cobots. Koch et al. (2017) define Industry 5.0 as the era of socially smart factories, where cobots interact with humans. Cobots can make production processes faster and more effective. This is a crucial situation that increases productivity in production. Another crucial contribution of cobots is ensuring the flexibility of production lines.

Cobots are equipped with various sensors from a technical perspective. Designing cobots with new hardware compared to traditional robot technology ensures a more advanced CPS in many ways. Cobots are also more reliable compared to classic robots (Simões et al., 2020). Human-robot collaboration requires the cobot to handle and understand human requests with precision and reliability (Jabrane & Bousmah, 2021). Cobots are generally easily programmable and can operate the system with faster adjustments. Therefore, they are considered user-friendly CPS. Additionally, cobots can foresee and intervene in any problems. This impact is crucial for ensuring the safety of workers and eliminating disruptions in the production system.

2. Industry 5.0 Compatibility Obstacles

2.1. Theoretical Background on Obstacles in the Industry 5.0 Process

Due to digitalization, factories' use of advanced technologies has become a crucial force for competitiveness. However, while these changes may bring new opportunities, there may also be many difficulties in adapting to this process. Industry 5.0 faces challenges in human-machine collaboration, technology integration, and sustainability (Adel, 2022; Javaid et al., 2020; Leng et al., 2022). Over the past few years, Industry 5.0 has become increasingly popular. In recent years, several studies have explored the challenges of adopting Industry 5.0 (Chauhan et al., 2021; Karmaker et al., 2023; Khanzode et al., 2021; Rajesh, 2023). Although there are some studies, it can be stated that these studies are quite minimal. The studies focused more on the difficulties in technologies than the difficulties encountered in Industry 5.0. Limited research directly addresses I5.0 challenges in production.

Obstacles in Risk Management 5.0, Industry 5.0, and Society 5.0 were examined in terms of technologies such as blockchain, the Internet of Things (IoT), and artificial intelligence (Carayannis et al., 2021). Researchers have focused on the obstacles to these technologies rather than directly discussing the obstacles to Industry 5.0. The obstacles in artificial intelligence technology were determined as "neural network opacity, ensuring data quality, and data security," and the obstacles in blockchain technology were determined as "scalability, energy consumption, transaction costs, and transaction speed." The obstacles in the IoT were determined to be "data security and privacy, energy consumption, massive connectivity of billions of devices, interoperability, and over-the-air firmware updates." Jabrane and Bousmah (2021) conducted a study on training cobots with small data for big data, which they see as a problem in Industry 5.0. The study also discussed challenges in AI for human-robot collaboration. The obstacles were created for deep learning, human-robot interaction, and artificial intelligence technology. Coronado et al. (2022) proposed a framework for human-centred smart environment design, addressing I5.0 challenges. The study focused on quality measurement problems in human-robot interaction applications. The first hurdle was the implementation of accurate, invasive, and offline ergonomic assessment tools that require extensive preparation. The second obstacle was the lack of specialized "human-robot interaction." The third obstacle was the opaque robotic system, and the fourth was poor flow management. Flow obstruction occurs when actions or collaborative activities cannot synchronize with efficiency. Mondal and Wong (2022) focused on several obstacles related to the collaboration of humans and robots. Increasing interest in human-machine collaborations may bring various challenges in terms of ensuring social participation. Although interacting with robots is expected to be easy, non-verbal communication such as body language, gestures, and nuances in voice and language can be difficult to read easily. Another obstacle was designing mechanisms to integrate robots into societies and work environments without causing competition.

Kaasinen et al. (2022) conducted a study in which they identified the challenges in I5.0 production systems. These barriers were classified as overly shallow or unclear analyses, misuse of technology, misinterpretation of data, failure to allocate appropriate resources, failure to define the clear responsibilities of actors, and resistance from stakeholders. The obstacles were examined only from a conceptual perspective, and no practical implementation was carried out. Battini et al. (2022) studied a flexible workplace model to overcome the challenges of the new technological transformation. Adel (2022) focused on challenges in organizations where robots and humans work together. The study was examined theoretically in line with the relevant subject, and no practical implementation was conducted. Adel mentioned four main difficulties in the study. First, employees need diverse social and technical skills. Programming robots and managing the process may require a high skill level in I5.0. The second obstacle was shown as the fact that customized software in collaborative robots could strain businesses in terms of both time and effort. The third obstacle was the investment requirement. High investments were deemed necessary for both the technologies and the employee training program.

Leng et al. (2022) discussed the challenges of the I5.0 discovery. They examined the relevant topic only theoretically and did not conduct any practical implementation. In the study, system heterogeneity and value-oriented technology transformation were considered as technological obstacles. Research included value orientation, socio-ecological systems (productivity and high investment problems), social value (policies, ethical issues, and moral issues), and social control systems (large amounts of data, compliance with industry standards) in the realm of social challenges. Karmaker et al. (2023) evaluated the obstacles to implementing Industry 5.0 in developing economies. The researchers examined the impacts on the supply chain after the COVID-19 pandemic. Also, they discussed a total of fifteen challenges for this purpose. Some of these were "concern about environmental protection and sustainability", "lack of in-house talent and qualified employees," "insufficient information about disruptive technologies," and "lack of active participation of senior managers,".

Alojaiman (2023) mainly categorized the obstacles in the I5.0 process into four classes. The first was the need for technical skills for employees. Employees take an active role in tasks such as programming and controlling new technologies. Secondly, there was a lack of knowledge about new technologies and many other applications that enable real-time data transfer. Alojaiman stated that this requires both time and dedication. The third obstacle was the need for high investment in technologies and employee training. The final obstacle was the transformation speed. One of the most crucial recent studies is Rajesh's research (2023), which examines the challenges, relationships among these challenges, and their impacts on I5.0. The researcher used Gray Impact Analysis for experts' evaluations to show relationships between criteria. Rajesh implemented the application in the Indian manufacturing industry. There were nine obstacles in the study. They were “social heterogeneity in value,” “measurement of environmental and social values,” “integration with existing systems,” “gaps with skill levels,” “data security and privacy,” “cost of integration,” “regulatory challenges,” “ethical challenges,” and “managing system complexity.”

Musarat et al. (2023) made a general evaluation of published studies on I5.0. Researchers also aimed to draw a path for the advancement of Industry 5.0, especially in the construction industry. They highlighted employees requiring more time and effort with new technologies, the necessity of investing in advanced technologies, and authentication challenges due to device communication. Kumar et al. (2023) conducted a comprehensive study on I5.0 applications, technologies, and challenges. They performed a comprehensive review of the literature on challenges in Industry 5.0. The prominent obstacles were security concerns, privacy issues, scalability, regulatory issues, social issues, a qualified workforce, and technical problems (such as collaborative work and lack of information). Kazancoglu et al. (2023) examined the challenges in the textile. They used a fuzzy decision-making experiment and evaluation laboratory approach to uncover causal interactions between challenges. Five experts evaluated the criteria. They identified fifteen challenges for this change in the textile industry. They were “standardization and legalization of technologies,” “interoperability,” “digitization of processes,” “ineffective change management and resistance to change,” “ethics issues,” “legislation and certification,” “green efforts,” “security,” “profitability and scalability,” “heterogeneity of the system,” “transformation of human-centric value-driven technology,” “worker training and social values.”

2.2. Industry 5.0 Process Key Challenges

Technology alone is not sufficient to strengthen a knowledge-driven culture (Cillo et al., 2022). There are various challenges for human-robot collaboration, artificial intelligence, and subfields of this technology (Jabrane & Bousmah, 2021). Industry 5.0, which relies on human-machine collaboration, may pose various challenges.

2.2.1. Technical and Social Ability of Employees

I4.0's fully automated systems faced challenges due to the need for skilled workers (Longo et al., 2020). Similarly, a crucial problem with the I5.0 systems is having a qualified workforce. It is a big problem that employees do not have certain skills in terms of technical and social aspects (Liu et al., 2020). The workforce's skill gap poses significant challenges to business operations. Workforce cognitive abilities are essential. Industry 5.0 combines human and robot intelligence, simplifying production tasks. A qualified workforce is vital for this transformation process that emphasizes people's abilities.

The employees' experience, working efficiency, cognitive ability, and daily workload are crucial for workforce selection in production systems. In developing countries, recruiting employees adept at utilizing new technologies and engaging in informed decision-making can be challenging. Internal training is crucial for enhancing skills and judgment. Employees need to improve their skills in many aspects of collaborating with robots (Narvaez Rojas et al., 2021).

2.2.2. Transformation Speed

The industrial transformation is a significant phenomenon that affects production systems both technically and socially. It is essential to be capable of responding to change and keep up with it quickly. In today's highly competitive business environment, businesses need to respond rapidly and effectively to changing conditions (Nahavandi, 2019). Completing a rapid and effective change process affects the efficiency and effectiveness of businesses in many ways. Multiple parameters affect the transformation speed of businesses. Kumar et al. (2023) emphasized the importance of insufficient investment hindering the transition to automation for companies in developing countries. Specifically, the limited technology budget emerges as a factor prolonging this process's completion. Additionally, the prolonged duration of training programs aimed at enhancing employees' skills, as mentioned in Section 2.2.1, can also slow down this process.

On the other hand, the transformation speed may slow down due to the environmental impacts of some technologies and concerns among stakeholders (Chauhan et al., 2021). Stakeholders' expectations of producers may extend these processes in unexpected ways. Therefore, it is crucial to reach a common consensus among stakeholders in a production system. One of the factors that slows down the transformation speed is resistance to change. This may be due to the attitude of both top management and employees. Coronado et al. (2022) and Karmaker et al. (2023) stated that this transformation will slow down if businesses extend the preparation time for a new process. The integration of technologies such as deep learning and artificial intelligence may extend trial-and-error times. The prolongation of trial-and-error periods is a significant obstacle to the implementation of Industry 5.0 (Jabrane & Bousmah, 2021).

2.2.3. High Investment Requirements

Industry 5.0 is about integrating new technologies into existing digital technologies. It is anticipated that investment amounts may increase due to the focus on themes such as continuity and durability in this integration process. Businesses perceive investment as a significant problem during transitioning from Industry 4.0 to Industry 5.0 (Paschek et al., 2019). Because using new technologies is crucial to enhancing production and efficiency (George & George, 2020), this often requires substantial investments. Moreover, the training necessary for utilizing new technologies is also linked to significant costs (George & George, 2020; Rajesh, 2023). A significant cost factor is research and development activities. It is known that allocating a larger budget to research and innovation can also enhance the competitiveness of businesses (Doyle-Kent & Kopacek, 2020).

2.2.4. Required Knowledge and Awareness

The difficulty encountered by businesses in developing countries regarding automation is the lack of reliable information (Raj et al., 2020). This situation can be distinctly felt, especially during the acceptance phase of a new technology or system. Understanding the new technologies in real-time data transfer, their usage, and the effects of the technologies is crucial for undergoing an effective adaptation process. Many businesses in developing countries do not have sufficient knowledge about automation and technologies (Stentoft et al., 2021). Limited information on new technologies seriously hinders businesses. Limited information can affect businesses' initiatives to experiment with new systems. On the other hand, a lack of awareness about innovations makes it challenging to adapt to Industry 5.0 (Kumar et al., 2023). Therefore, businesses with sufficient knowledge and awareness will facilitate the implementation.

2.2.5. Integration

In Industry 5.0, integration is the effective incorporation of human-centric technologies and systems into existing manufacturing facilities. Adapting to Industry 5.0 requires having a pre-existing technological infrastructure established in Industry 4.0. An effective integration process is required for businesses to incorporate new technologies into their systems and make them durable and sustainable. The Industry 5.0 production paradigm will require the coordinated operation of the entire system as it focuses on mass customization (Leng, 2022). Hence, Industry 5.0 technologies must harmonize seamlessly with one another. However, it is challenging for businesses to adopt a human-centric approach and ensure sustainability and resilience (Sanchez et al., 2020).

2.2.6. Integration

The shift from machine-to-machine integration in I4.0 to human-to-machine integration in I5.0 is changing how people work and interact (Musarat et al., 2023). The focus on production has turned to reducing the workforce in recent years. Nowadays, the focus is shifting to human-centredness. This transformation is challenging for industries. Adapting to task changes in systems based on human-robot cooperation is necessary for efficient and effective production management. In Industry 5.0, coordinated cooperation between humans and machines is very significant. Businesses promoting collaboration and adaptability demonstrate a greater likelihood of success, as they can more effectively utilize the skills and knowledge of their workforce (Müller, 2020). Businesses that encourage collaboration appear to have a higher probability of success because they can better utilize the talents of their employees (Müller, 2020). If robots cannot be adapted to work together with humans, complexity may occur in the facility, and this may create risks (Leng, 2022).

Design challenges related to mutual dependence and teamwork arise in human-robot collaboration (Ma et al., 2018). When teamwork is considered, each unit in the team will need to act synchronously in situations such as communication and coordination. Therefore, when teams encounter unexpected obstacles, they must collaborate at a high level to reach the same goal (Musarat et al., 2023). It does not seem easy to demonstrate this effect in new intelligent systems. Employees may struggle to predict robot behavior, while robots may find it difficult to understand employee emotions and intentions (Kaasinen et al., 2022).

2.2.7. Big Data Management

In today's use of technology, manufacturers have difficulty managing big data sets. Many I5.0 applications are knowledge-based, and integrating new technologies into existing systems generates large amounts of data. For example, deep learning used to learn a task in an organization requires big data. In deep learning, digital representations must closely mirror reality to ensure consistent understanding across individuals and systems. Data collection, along with the exponentially growing learning curve due to problem complexity, is crucial (Jabrane & Bousmah, 2021). Specialized algorithms support data generation and information exchange for technologies requiring different technical assistance (Rajesh, 2023).

2.2.8. System Security and Privacy

Data security, network security, and system security are crucial factors for the effective implementation of Industry 5.0. They are critical elements for the sustainability and resilience of businesses as well as the effective adaptation of I5.0. Since the fourth industrial revolution, the increased use of digital technologies has made storage and data management more difficult. Big data generation and sharing can increase data security threats. Data resulting from interactions with human robots can become a potential target of cyberattacks. Enterprises that use information-based technology should have robust security systems. If data stores are not fortified, cyberattacks can easily capture system data. Therefore, the system must be resilient to all threats.

2.2.9. Social (Value and Ethical) Concerns

In the human-centred design of smart factories, the values and ethical issues of technology engineering should be prioritized (Longo et al., 2020). In the human-centred design of smart factories, it is essential for technology engineering to prioritize values and ethical issues. Due to the direct relevance of these issues to social sustainability, steps in this direction are expected from I5.0. Businesses must identify bottlenecks both socially and ethically (Kumar et al., 2023). However, measuring social value production creates pressure on businesses (Leng, 2022b). In Industry 5.0, it is crucial to arrange the workplace ergonomically.

One of the social issues is protecting the health of both employees and society. While robots perform physically demanding tasks, employees can work in more ergonomic conditions, improving quality of life. On the other hand, it is crucial for social value that production does not hurt public health. A concern about changing production roles is societal employment. The uncertainty on this issue is putting pressure on employees. At the same time, the need for a skilled workforce in Industry 5.0 raises ethical considerations for others (Narvaez Rojas et al., 2021). Due to the need for a qualified workforce, some remedial work should be undertaken to ensure that employees can work comfortably and safely. Job rotations and cross-training may be supportive, depending on the employees' capabilities. A concern about changing production roles is societal employment (Leng et al., 2022).

2.2.10. Environmental Concerns

In developing countries, there may be a need to strike a balance between economic growth and environmental well-being. The ecological impacts of production should not be overlooked alongside economically driven factors. Industry

5.0's sustainability expectations require businesses to prioritize environmental issues. Measuring environmental values is perceived as highly complex and challenging, much like the difficulty in measuring social values in these systems. Despite the increase in sustainability-related research in recent times, numerous systems have been developed. However, establishing a universal standard for measuring environmental values is challenging (Rajesh, 2023). This situation has the potential to pressure businesses into adopting sustainable production methods.

The environmental concerns of businesses may vary depending on the technologies. A major concern in implementing I5.0 is the increased energy load from IoT technologies (Taneja et al., 2023). Wireless networks, human-robot collaboration, and advanced automation in smart manufacturing directly impact energy consumption. On the other hand, balancing workloads (Zaplana et al., 2020) and optimizing movements also affect energy consumption. Therefore, routing should be planned to minimize unit movement within the production facility.

3. Research Method: IVIF-AHP

Many decision-making situations involve uncertainty, where the exact knowledge of factors such as decisions, objectives, constraints, and possible actions is not known (Bellman & Zadeh, 1970). Zadeh (1965) initially developed a fuzzy set theory to tackle this uncertainty problem. The fuzzy set theory provides a mathematical way to handle uncertainty. In particular, converting linguistic terms into fuzzy numbers can be beneficial in overcoming uncertainties involved in the linguistic prediction process (Wu & Lee, 2007). The values of linguistic variables are not numeric but involve linguistic terms (Zadeh, 1975). In this study, the presence of various uncertainties necessitated the use of fuzzy sets to address the problem.

To achieve this goal, interval-valued intuitionistic fuzzy (IVIF) sets were utilized for linguistic expressions gathered from expert interviews. Certainly, here's a revised version. Atanassov developed the concept of IVIF in 1986. The method proves to be an effective tool for managing uncertain situations. Intuitionistic fuzzy sets consider membership and non-membership values to define any x in X, ensuring that the sum of membership and non-membership is ≤ 1. In the continuation of the study, IVIF sets were amalgamated with the Analytic Hierarchy Process (AHP) to determine the final weight values of the criteria. Because AHP alone cannot offer effective solutions to address uncertainties in the subjective judgments of experts, the use of fuzzy set theory can alleviate this disadvantage.

IVIF-AHP Method Steps:

Stage 1: Each decision-maker compares the decision criteria pairwise according to the linguistic terms in Table 1.

Table 1. Linguistic Scale and its Corresponding IVIF

Linguistic Terms	Membership and non-membership values
Certainly Low (CL)	([0.10, 0.25], [0.65, 0.75])
Very Low (VL)	([0.15, 0.30], [0.60, 0.70])
Low (L)	([0.20, 0.35], [0.55, 0.65])
Below Medium (BM)	([0.25, 0.40], [0.50, 0.60])
Exactly Equal (EE)	([0.50, 0.50], [0.50, 0.50])
Above Medium (AM)	([0.50, 0.60], [0.25, 0.40])
High (H)	[0.55, 0.65], [0.20, 0.35])
Very High (VH)	([0.60, 0.70], [0.15, 0.30])
Certainly High (CH)	([0.65, 0.75], [0.10, 0.25])

Stage 2: Linguistic evaluations regarding the criteria are transformed into IVIFS using the scale in Table 1.

Stage 3: At this stage, the consistency of experts' assessments should be checked (Kahraman et al., 2018).

Λ_{max} is the maximum eigenvalue of the matrix, and n is the number of criteria. Its calculation is as follows:

$$\Lambda_{max} = \frac{1}{\mathrm{n}} \sum_{\mathrm{i}=1}^{\mathrm{n}} \frac{\sum_{j}^{n} aj*wj}{wi} \quad (1)$$

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (2)$$

Table 2. Random Index (RI) Values

1	2	3	4	5	6	7	8	9	10
0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty (1994)

Then, the RI value is decided by looking at Table 2 and CR is calculated (Solangi et al. 2019):

$$CR = \frac{CI}{RI} \tag{3}$$

Stage 4: The pairwise comparison matrices obtained separately for decision-makers are combined (Ayyildiz, 2023, Dogan et al., 2020). Thus, the "aggregated pairwise comparison matrix" is obtained. At this point, the importance of experts is also recognized. If no weights are assigned, each expert is considered to have equal importance.

Let $\widetilde{a_j} = ([a_j, b_j], [c_j, d_j])\ j = (1,2, \dots, n)$ be a collection of IVIFNs.

Interval-valued intuitionistic fuzzy weighted averaging is that: (Xu, 2010)

$$IIFWA_w\ (\widetilde{a_1}, \widetilde{a_2}, \dots, \widetilde{a_n}) = \text{w1} * \widetilde{a_1} \otimes \text{w2} * \widetilde{a_2} \otimes \text{w3} * \widetilde{a_3} \otimes \dots \otimes \text{wn} * \widetilde{a_n} \quad w_j > 0,$$
$$\sum_{j=1}^{n} w_j = 1 \tag{4}$$

$$IIFWA_w\ (\widetilde{a_1, . a_n}) = ([1 - \prod_{i=1}^{n}(1 - a_i)^{wi}, 1 - \prod_{i=1}^{n}(1 - b_i)^{wi}], [(\prod_{i=1}^{n}(c_i)^{wi}), (\prod_{i=1}^{n}(d_i)^{wi})]) \tag{5}$$

These combined decision matrices (R̃g) are obtained after the application of these equalities (Ayyildiz, 2023; Dogan et al., 2020; Kahraman et al., 2018).

$$\tilde{R}\text{g} = \begin{pmatrix} [\mu_{g11}{}^{-}, \mu_{g11}{}^{+}], [v_{g11}{}^{-}, v_{g11}{}^{+}] & \cdots & [\mu_{g1n}{}^{-}, \mu_{g1n}{}^{+}], [v_{g1n}{}^{-}, v_{g1n}{}^{+}] \\ \vdots & \ddots & \vdots \\ [\mu_{gn1}{}^{-}, \mu_{gn1}{}^{+}], [v_{gn1}{}^{-}, v_{gn1}{}^{+}] & \cdots & [\mu_{gnn}{}^{-}, \mu_{gnn}{}^{+}], [v_{gnn}{}^{-}, v_{gnn}{}^{+}] \end{pmatrix}$$
(6)

Stage 5: The score judgment matrix ($\tilde{S}$) is formed using Equation (7).

$$\tilde{S} = \begin{pmatrix} [\mu_{g11}{}^{-} - v_{g11}{}^{+}], [\mu_{g11}{}^{+} - v_{g11}{}^{-}] & \cdots & [\mu_{g1n}{}^{-} - v_{g1n}{}^{+}], [\mu_{g1n}{}^{+} - v_{g1n}{}^{-}] \\ \vdots & \ddots & \vdots \\ [\mu_{gn1}{}^{-} - v_{gn1}{}^{+}], [\mu_{gn1}{}^{+} - v_{gn1}{}^{-}] & \cdots & [\mu_{gnn}{}^{-} - v_{gnn}{}^{+}], [\mu_{gnn}{}^{+} - v_{gnn}{}^{-}] \end{pmatrix} \tag{7}$$

Stage 6: The interval exponential matrix (Ã) is calculated as Equation (8).

$$\tilde{A} = \begin{pmatrix} [e^{(\mu_{g11}{}^{-} - v_{g11}{}^{+})}], [e^{(\mu_{g11}{}^{+} - v_{g11}{}^{-})}] & \cdots & [e^{(\mu_{g1n}{}^{-} - v_{g1n}{}^{+})}], [e^{(\mu_{g1n}{}^{+} - v_{g1n}{}^{-})}] \\ \vdots & \ddots & \vdots \\ [e^{(\mu_{gn1}{}^{-} - v_{gn1}{}^{+})}], [e^{(\mu_{gn1}{}^{+} - v_{gn1}{}^{-})}] & \cdots & [e^{(\mu_{gnn}{}^{-} - v_{gnn}{}^{+})}], [e^{(\mu_{gnn}{}^{+} - v_{gnn}{}^{-})}] \end{pmatrix}$$

$$\tilde{A} = \begin{matrix} [a_{11}{}^{-},\ a_{11}{}^{+}] & \cdots & [a_{1n}{}^{-},\ a_{1n}{}^{+}] \\ \vdots & \ddots & \vdots \\ [a_{n1}{}^{-},\ a_{n1}{}^{+}] & \cdots & [a_{nn}{}^{-},\ a_{nn}{}^{+}] \end{matrix} \tag{8}$$

Stage 7: The priority vector ($\widetilde{\text{w}}$) is calculated for each criterion using Equation (9).

$$\widetilde{w}_i = \left[\frac{\sum_{j=1}^{n} a_{ij}{}^{-}}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}{}^{+}}, \frac{\sum_{j=1}^{n} a_{ij}{}^{+}}{\sum_{i=1}^{n}\sum_{j=1}^{n} a_{ij}{}^{-}} \right] = [w_j^{-}, w_j^{+}], i = 1,2, \dots, n \tag{9}$$

Stage 8: Possibility degree matrices are obtained using Equations (10) and (11):

$$\boldsymbol{P}(\widetilde{\boldsymbol{w}}_i > \widetilde{\boldsymbol{w}}_j) = \boldsymbol{p}_{ij} = \frac{\max(0,\ w_i^{+} - w_j^{-}) - \max(0, w_i^{-} - w_j^{+})}{(w_i^{+} - w_i^{-}) + (w_j^{+} - w_j^{-})} \tag{10}$$

$$\boldsymbol{P}(\widetilde{\boldsymbol{w}}_j > \widetilde{\boldsymbol{w}}_i) = \boldsymbol{p}_{ij} = \frac{\max(0,\ w_j^{+} - w_i^{-}) - \max(0, w_j^{-} - w_i^{+})}{(w_i^{+} - w_i^{-}) + (w_j^{+} - w_j^{-})} \tag{11}$$

Stage 9: Possibility degrees of criteria are prioritized using Equation (12).

$$\boldsymbol{w_i} = \frac{\sum_{j=1}^{n} \boldsymbol{p_{ij}} - \mathbf{1}}{\boldsymbol{n}} + 0.5 \quad (12)$$

Stage 10: The weights of each criterion are normalized using Equation (13).

$$\boldsymbol{w_i^T} = \frac{w_i}{\sum_{j=1}^{n} w_i} \quad (13)$$

4. Real-World Application

This section aims to analyze the potential challenges that an actual manufacturing operation may encounter. The goal is to identify obstacles and assess their respective impact levels on the adaptation process. This case study occurred in the automotive sector. Because this sector is one of the most crucial economies in many developing countries.

4.1. Selection of Criteria

Criteria selection began with a comprehensive literature review to identify the most used criteria. Based on these criteria, the criteria that should be included in the study were determined. Subsequently, one-on-one interviews were conducted with five experts from the automotive sector to evaluate these criteria. However, after their assessments, the experts revised some of the criteria, and the study commenced with a total of ten criteria.

These criteria are used in the study: “technical and social ability of employees,” ”transformation speed,” “high investment requirement,” “required knowledge and awareness,” “integration,” “human-robot interoperability,” “big data management,” “system security and privacy,” “social (value and ethical) concerns,” and “environmental concerns.” Each of these criteria is detailed in Section 3.2. Table 3 lists obstacles identified from literature reviews and expert opinions, along with studies referencing all criteria. Researchers prepared the referenced studies on Industry 5.0 or its obstacles.

Table 3. Industry 5.0 Challenges and Their Resources

Code	Criteria	References
C_1	Technical and Social Ability of Employees	Adel (2022), Battini et al. (2022), Cillo et al. (2022), Grabowska et al. (2022), Karmaker et al. (2023), Kumar et al. (2023), Musarat et al. (2023), Narvaez Rojas et al. (2021), Rajesh (2023); Kazancoglu et al. (2023)
C_2	Transformation Speed	Adel (2022), Alojaiman (2023), Coronado et al. (2022), Jabrane & Bousmah (2021), Karmaker et al. (2023), Mondal & Wong (2022), Kazancoglu et al. (2023)
C_3	High Investment Requirement	Adel (2022), Alojaiman (2023), Karmaker et al. (2023), Musarat et al. (2023), Rajesh (2023), Sharma et al. (2022)
C_4	Required Knowledge and Awareness	Alojaiman (2023), Karmaker et al. (2023), Kumar et al. (2023), Leng, (2022)
C_5	Integration	Aslam et al. (2020), Rajesh (2023)
C_6	Human-Robot Interoperability	Carayannis et al., (2021), Cillo et al. (2022), Coronado et al. (2022), Karmaker et al. (2023), Kazancoglu et al. (2023), Kumar et al. (2023), Mondal and Wong, (2022), Rajesh (2023), Sharma et al. (2022)
C_7	Big Data Management	Coronado et al. (2022), Kaasinen et al. (2022), Karmaker et al. (2023)
C_8	System Security and Privacy	Adel (2022), Coronado et al. (2022), Karmaker et al. (2023), Kazancoglu et al. (2023), Kumar et al. (2023), Leng et al. (2022), Musarat et al. (2023), Rajesh (2023)
C_9	Social (Value and Ethics) Concerns	Kazancoglu et al. (2023), Longo et al. (2020), Leng et al. (2022), Musarat et al. (2023), Rajesh (2023)
C_{10}	Environmental Concerns	Carayannis et al. (2021), Taneja et al. (2023), Rajesh (2023)

4.2. Decision-Makers' Choice

The selection of decision-makers can be described as purposive sampling due to the collection of qualitative data. These experts, with over ten years of professional experience, are actively involved in Turkey's automotive industry. Mixed expertise was preferred to achieve unbiased results regarding the research. Therefore, a careful approach was adopted in the selection of experts. These experts took on roles in projects related to new technological initiatives, depending on the adoption of Industry 4.0 applications in the factories. Furthermore, they are interested in sustainability, the circular economy, and new production technologies. Table 4 includes the job descriptions and experiences of the participants.

Table 4. Profiles of Experts

Expert's Code	Job Description	Total Experience
E_1	Production Manager	11 years
E_2	Business Analyst	14 years
E_3	Project Manager	12 years
E_4	Research and Development Manager	10 years
E_5	General Manager	17 years

4.3. Determination of Criteria Weights Using the IVIF-AHP Method

In this study, the IVIF-AHP method was used to determine the weights of the ten criteria. To compute the weights of the criteria through the IVIF-AHP method, the following steps were pursued:

Stage 1: Each decision-maker compared the criteria pairwise using the linguistic variables in Table 5.

Table 5. Pairwise Comparisons of the Criteria

E_1	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
C_1	EE	BM	BM	AM	BM	AM	H	VH	H	VH
C_2	-	EE	BM	H	BM	AM	VH	VH	H	CH
C_3	-	-	EE	H	EE	H	VH	CH	VH	CH
C_4	-	-	-	EE	L	AM	AM	H	AM	VH
C_5	-	-	-	-	EE	H	VH	CH	VH	CH
C_6	-	-	-	-	-	EE	H	H	AM	VH
C_7	-	-	-	-	-	-	EE	AM	BM	H
C_8	-	-	-	-	-	-	-	EE	BM	AM
C_9	-	-	-	-	-	-	-	-	EE	H
C_{10}	-	-	-	-	-	-	-	-	-	EE

E_2	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
C_1	EE	BM	L	AM	BM	AM	H	VH	H	VH
C_2	-	EE	BM	H	EE	AM	H	CH	VM	CH
C_3	-	-	EE	VH	AM	H	H	CH	VH	CH
C_4	-	-	-	EE	L	BM	AM	H	AM	VH
C_5	-	-	-	-	EE	AM	H	CH	VH	CH
C_6	-	-	-	-	-	EE	AM	H	H	VH
C_7	-	-	-	-	-	-	EE	AM	AM	H
C_8	-	-	-	-	-	-	-	EE	BM	AM
C_9	-	-	-	-	-	-	-	-	EE	AM
C_{10}	-	-	-	-	-	-	-	-	-	EE

E_3	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
C_1	EE	BM	L	AM	BM	EE	H	AM	AM	VH
C_2	-	EE	BM	H	AM	AM	VH	H	H	CH
C_3	-	-	EE	VH	AM	H	CH	VH	VH	CH
C_4	-	-	-	EE	L	BM	H	AM	AM	VH
C_5	-	-	-	-	EE	AM	VH	H	H	VH
C_6	-	-	-	-	-	EE	H	AM	AM	VH
C_7	-	-	-	-	-	-	EE	BM	BM	AM
C_8	-	-	-	-	-	-	-	EE	EE	H
C_9	-	-	-	-	-	-	-	-	EE	H
C_{10}	-	-	-	-	-	-	-	-	-	EE

E_4	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
C_1	EE	AM	BM	H	BM	AM	H	H	AM	VH
C_2	-	EE	L	H	BM	AM	H	H	AM	VH
C_3	-	-	EE	VH	AM	H	VH	VH	H	CH
C_4	-	-	-	EE	VL	BM	AM	AM	BM	H
C_5	-	-	-	-	EE	H	VH	VH	H	CH

C6	-	-	-	-	-	EE	AM	AM	EE	H
C7	-	-	-	-	-	-	EE	EE	BM	AM
C8	-	-	-	-	-	-	-	EE	BM	AM
C9	-	-	-	-	-	-	-	-	EE	H
C10	-	-	-	-	-	-	-	-	-	EE

E5	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	EE	BM	L	AM	BM	AM	H	H	AM	VH
C2	-	EE	BM	H	EE	AM	VH	H	AM	CH
C3	-	-	EE	VH	AM	H	CH	VH	H	CH
C4	-	-	-	EE	L	BM	AM	AM	BM	H
C5	-	-	-	-	EE	AM	VH	H	AM	CH
C6	-	-	-	-	-	EE	H	H	AM	VH
C7	-	-	-	-	-	-	EE	BM	L	AM
C8	-	-	-	-	-	-	-	EE	BM	H
C9	-	-	-	-	-	-	-	-	EE	H
C10	-	-	-	-	-	-	-	-	-	EE

Stages 2 & 3: Firstly, in this stage, the scale and linguistic expressions in Table 1 were transformed into IVIF sets. Subsequently, a consistency analysis was conducted to ensure the reliability of the obtained results. For this purpose, Equality (1), (2), and (3) were applied. Table 6 presents consistency ratios for each expert's evaluations.

Table 6. Consistency Ratios

	CI	CR
E_1	0.125	0.083
E_2	0.146	0.098
E_3	0.146	0.098
E_4	0.133	0.089
E_5	0.132	0.088

The consistency ratios of the assessments made by the five decision-makers regarding the criteria are below the upper limit of 0.1. Therefore, the evaluations are considered consistent.

Stage 4: The pairwise comparison matrices, separately created for each of the five decision-makers, were combined. The experts' weight was the same. The aggregated pairwise matrix (see Table 7) was formed using Equation 4, Equation 5, and Equation 6.

Table 7. Aggregated Pairwise Comparison Matrix

0	**C1**	**C2**	**C3**	**C4**	**C5**
C1	([0.50,0.50],[0.50,0.50])	**([0.31,0.45],[0.44,0.55])**	([0.22,0.37],[0.53,0.63])	([0.51,0.61],[0.24,0.39])	([0.25,0.40],[0.50,0.60])
C2	([0.46,0.57],[0.31,0.43])	([0.50,0.50],[0.50,0.50])	([0.24,0.39],[0.51,0.61])	([0.55,0.65],[0.20,0.35])	([0.41,0.49],[0.44,0.51])
C3	([0.53,0.63],[0.22,0.37])	([0.51,0.61],[0.24,0.39])	([0.50,0.50],[0.50,0.50])	([0.59,0.69],[0.16,0.31])	([0.50,0.58],[0.29,0.42])
C4	([0.24,0.39],[0.51,0.61])	([0.20,0.35],[0.55,0.65])	([0.16,0.31],[0.59,0.69])	([0.50,0.50],[0.50,0.50])	([0.19,0.34],[0.56,0.66])
C5	([0.50,0.60],[0.25,0.40])	([0.46,0.52],[0.38,0.47])	([0.31,0.48],[0.50,0.52])	([0.56,0.66],[0.19,0.34])	([0.50,0.50],[0.50,0.50])
C6	([0.31,0.42],[0.52,0.58])	([0.25,0.40],[0.50,0.60])	([0.20,0.35],[0.55,0.65])	([0.46,0.57],[0.29,0.43])	([0.23,0.38],[0.52,0.62])
C7	([0.20,0.35],[0.55,0.65])	([0.17,0.32],[0.58,0.68])	([0.14,0.29],[0.61,0.71])	([0.24,0.39],[0.51,0.61])	([0.16,0.31],[0.59,0.69])
C8	([0.19,0.34],[0.54,0.66])	([0.17,0.32],[0.57,0.68])	([0.13,0.28],[0.62,0.72])	([0.23,0.38],[0.52,0.62])	([0.15,0.30],[0.60,0.70])
C9	([0.23,0.38],[0.52,0.62])	([0.21,0.36],[0.54,0.64])	([0.17,0.32],[0.58,0.68])	([0.36,0.49],[0.38,0.51])	([0.19,0.34],[0.56,0.66])
C10	([0.15,0.30],[0.60,0.70])	([0.11,0.26],[0.64,0.74])	([0.10,0.25],[0.65,0.75])	([0.17,0.32],[0.58,0.68])	([0.11,0.26],[0.64,0.74])
	C6	C7	C8	C9	C10
C1	([0.50,0.58],[0.29,0.42])	([0.55,0.65],[0.20,0.35])	([0.56,0.66],[0.19,0.34])	([0.52,0.62],[0.23,0.38])	([0.60,0.70],[0.15,0.30])
C2	([0.50,0.60],[0.25,0.40])	([0.58,0.68],[0.17,0.32])	([0.58,0.68],[0.16,0.32])	([0.54,0.64],[0.21,0.36])	([0.64,0.74],[0.11,0.26])

C3	([0.55,0.65],[0.20,0.35])	([0.61,0.71],[0.14,0.29])	([0.62,0.72],[0.13,0.28])	([0.58,0.68],[0.17,0.32])	([0.65,0.75],[0.10,0.25])
C4	([0.31,0.45],[0.44,0.55])	([0.51,0.61],[0.24,0.39])	([0.52,0.62],[0.23,0.38])	([0.41,0.53],[0.33,0.47])	([0.58,0.68],[0.17,0.32])
C5	([0.52,0.62],[0.23,0.38])	([0.62,0.69],[0.16,0.31])	([0.60,0.70],[0.14,0.30])	([0.56,0.66],[0.19,0.34])	([0.64,0.74],[0.11,0.26])
C6	([0.50,0.50],[0.50,0.50])	([0.53,0.63],[0.22,0.37])	([0.53,0.63],[0.22,0.37])	([0.51,0.59],[0.27,0.41])	([0.59,0.69],[0.16,0.31])
C7	([0.22,0.37],[0.53,0.63])	([0.50,0.50],[0.50,0.50])	([0.41,0.51],[0.38,0.49])	([0.30,0.44],[0.44,0.56])	([0.52,0.62],[0.23,0.38])
C8	([0.22,0.37],[0.53,0.63])	([0.41,0.51],[0.38,0.49])	([0.50,0.50],[0.50,0.50])	([0.31,0.42],[0.50,0.58])	([0.53,0.63],[0.22,0.37])
C9	([0.30,0.41],[0.51,0.59])	([0.47,0.58],[0.27,0.42])	([0.50,0.58],[0.29,0.42])	([0.50,0.50],[0.50,0.50])	([0.54,0.64],[0.21,0.36])
C10	([0.16,0.31],[0.59,0.69])	([0.23,0.38],[0.52,0.62])	([0.23,0.38],[0.52,0.62])	([0.21,0.36],[0.54,0.64])	([0.50,0.50],[0.50,0.50])

For example, the value of ([0.31,0.45],[0.44,0.55]) that is remarked in bold numbers in Table 4 illustrates the importance of C_1 (Technical and Social Ability of Employees) according to C_2 (Transformation Speed).

$$1-\left(\sqrt[5]{(1-0.25)*(1-0.25)*(1-0.25)*(1-0.50)*(1-0.25)}\right) = 0.31$$

$$1-\left(\sqrt[5]{(1-0.40)*(1-0.40)*(1-0.40)*(1-0.60)*(1-0.40)}\right) = 0.45$$

$$\sqrt[5]{(0.60)*(0.60)*(0.60)*(0.40)*(0.60)} = 0.44$$

$$\sqrt[5]{(0.50)*(0.50)*(0.50)*(0.25)*(0.50)} = 0.55$$

Stage 5 & 6: Score judgment matrice ($\tilde{S}$) was formed using Equation (7), and then interval exponential matrice ($\tilde{A}$) was calculated as Equation (8). $\tilde{A}$ was formed as given in Table 8.

Table 8. Interval Exponential Matrix

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
C1	[1,1]	[0.79,1.01]	[0.66,0.85]	[1.13,1.45]	[0.70,0.90]	[1.08,1.34]	[1.22,1.57]	[1.25,1.60]	[1.15,1.48]	[1.35,1.73]
C2	[1.03,1.30]	[1,1]	[0.69,0.89]	[1.22,1.57]	[0.90,1.05]	[1.11,1.42]	[1.30,1.67]	[1.30,1.68]	[1.20,1.54]	[1.46,1.88]
C3	[1.17,1.51]	[1.13,1.45]	[1,1]	[1.32,1.70]	[1.08,1.34]	[1.22,1.57]	[1.38,1.77]	[1.40,1.80]	[1.30,1.67]	[1.49,1.92]
C4	[0.69,0.89]	[0.64,0.82]	[0.59,0.76]	[1,1]	[0.63,0.80]	[0.79,1.01]	[1.13,1.45]	[1.15,1.48]	[0.94,1.22]	[1.30,1.67]
C5	[1.11,1.42]	[0.99,1.15]	[0.81,0.98]	[1.25,1.60]	[1,1]	[1.15,1.48]	[1.36,1.70]	[1.35,1.75]	[1.25,1.60]	[1.46,1.88]
C6	[0.76,0.90]	[0.70,0.90]	[0.64,0.82]	[1.03,1.32]	[0.68,0.87]	[1,1]	[1.17,1.51]	[1.17,1.51]	[1.11,1.38]	[1.32,1.70]
C7	[0.64,0.82]	[0.60,0.70]	[0.57,0.73]	[0.69,0.89]	[0.59,0.76]	[0.66,0.85]	[1,1]	[0.92,1.14]	[0.77,1.00]	[1.15,1.48]
C8	[0.63,0.82]	[0.60,0.70]	[0.55,0.71]	[0.68,0.87]	[0.58,0.74]	[0.66,0.85]	[0.92,1.14]	[1,1]	[0.76,0.92]	[1.17,1.51]
C9	[0.68,0.87]	[0.72,0.84]	[0.60,0.77]	[0.86,1.12]	[0.63,0.80]	[0.75,0.90]	[1.05,1.36]	[1.08,1.34]	[1,1]	[1.20,1.54]
C10	[0.58,0.74]	[0.53,0.68]	[0.52,0.67]	[0.60,0.77]	[0.53,0.68]	[0.59,0.76]	[0.68,0.87]	[0.68,0.87]	[0.65,0.84]	[1,1]

For example, the interval exponential value of C_1 according to C_2 is [0.79, 1.01]. This value was calculated using Equation (8) as [$\boldsymbol{e}^{(0.31-0.55)}$, $\boldsymbol{e}^{(0.45-0.44)}$].

Stage 7: Priority vectors ($\tilde{w}$) were calculated for each criterion using Equation (9). The calculated priority vectors $(\widetilde{w})$ of the ten criteria are in Table 9.

Table 9. Priority Vectors

Criteria	Priority
C1	[0.088,0.139]
C2	[0.096,0.150]
C3	[0.106,0.200]
C4	[0.076,0.119]
C5	[0.100,0.156]
C6	[0.082,0.128]
C7	[0.065,0.100]
C8	[0.064,0.099]
C9	[0.073,0.113]
C10	[0.054,0.084]

For example, the priority vector of C_1 is [0.088,0.139]. This value was calculated using Equation (9) as [$\frac{\mathbf{10.33}}{\mathbf{117.28}}$, $\frac{\mathbf{12.93}}{\mathbf{93.26}}$].

Stage 8, 9, and 10: Firstly, possibility degree matrices were obtained using Equation (10) or (11). Secondly, the unnormalized weights were calculated using Equation (12), and then the weights were normalized using Equation (13). Weight values for all criteria are in Table 10.

Table 10. Global Weights of the Criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	w_i	W_i^T
C_1	0.5	0.41	0.23	0.67	0.36	0.59	0.86	0.87	0.73	1.0	1.022	0.113
C_2	0.59	0.5	0.30	0.76	0.45	0.68	0.96	0.97	0.82	1.0	1.103	0.122
C_3	0.77	0.70	0.5	0.91	0.67	0.84	1.0	1.0	0.95	1.0	1.234	0.137
C_4	0.33	0.24	0.09	0.5	0.19	0.42	0.69	1.0	0.55	0.89	0.890	0.099
C_5	0.64	0.55	0.33	0.81	0.5	0.73	1.0	1.0	0.86	1.0	1.142	0.127
C_6	0.41	0.32	0.16	0.58	0.27	0.5	0.78	0.79	0.64	0.97	0.942	0.105
C_7	0.14	0.04	0	0.31	0	0.22	0.5	0.01	0.36	0.71	0.629	0.070
C_8	0.13	0.03	0	0	0	0.21	0.99	0.5	0.35	0.69	0.690	0.077
C_9	0.27	0.18	0.05	0.45	0.14	0.36	0.64	0.65	0.5	0.84	0.808	0.090
C_{10}	0	0	0	0.11	0	0.03	0.29	0.31	0.16	0.5	0.540	0.060

Following the steps of the proposed method, the weights of the criteria were calculated as 0.113, 0.122, 0.137, 0.099, 0.127, 0.105, 0.070, 0.077, 0.090, and 0.160 (see Table 10).

According to the results in Table 7, criterion C_3 (high investment requirement) has the highest weight with a value of 0.137. This indicates that the most prioritized criterion for businesses implementing Industry 5.0 is to have the necessary investment. The second priority criterion is C_5 with a value of 0.127, and the criterion ranked as the third priority is C_2 with a value of 0.122. This result indicates that in the process of adapting to I5.0, the most significant constraints after having the necessary investment are integration and the speed of change. On the other hand, the criterion with the lowest weight is C_{10} with a value of 0.06. Environmental concerns are identified as the least emphasized issue for manufacturers within the framework of the specified ten criteria.

Conclusions and Discussion

The advancement of CPS and other technologies, global environmental concerns, and economic pressures prompt businesses to adopt Industry 5.0, prioritizing human-centricity, sustainability, and resilience. The lack of focus on social and environmental issues in the fourth industrial revolution is addressed. While these studies have begun to emerge, Industry 4.0 principles have not been fully realized across many sectors and businesses. This transition requires the assessment of different situations in I5.0. Since issues related to I5.0 are newly studied, applications addressing obstacles are scarce. To contribute to the field, this study explored challenges experienced by automotive manufacturers.

The challenges in this direction required special focus. For this reason, it was necessary to work with people with different expertise during the research process. After both a literature review and experts' opinions, ten main challenges were identified, and the application was carried out in the automotive sector in Turkey. The interval-valued intuitionistic fuzzy AHP was used to evaluate the criteria. As far as is known, the interval-valued intuitionistic fuzzy AHP is an approach used for the first time to weigh obstacles in I5.0. This study can contribute to what challenges the automotive supply chain should focus on to successfully adapt to Industry 5.0. It is expected that the study results will assist managers in making strategic decisions by elucidating the hierarchical nature of the challenges. The study's findings can help managers make strategic decisions by explaining the hierarchical status of challenges. Additionally, this study may inform the development of investment strategies and government policies supporting human-centred digitalization of the economy.

The result of the study shows that the high investment requirement (C_3) is the most frequently influential challenge among all criteria. Kumar's study (2023) similarly finds that businesses struggle to adopt human-robot collaboration mechanisms due to financial burdens. Making significant investments in innovation emerges as a crucial necessity to create a globally competitive industry (Doyle-Kent & Kopacek, 2020). It is a fact that businesses need high investments both to provide infrastructure and to carry out research and development. Cobots and other innovative technologies are quite costly. Significant investment is required for collaborative robots equipped with human-machine interfaces that understand human intentions (Sharma et al., 2022). Productivity in production is expected to be maintained or increased with the increase in investment (Adel, 2022; Chauhan et al., 2021). In this respect, businesses need high investments to achieve their goals.

The second of the key challenges of I5.0 is integration (C_5). It is expected that businesses intending to implement Industry 5.0 have already reached a sufficient level in terms of technology and are using Industry 4.0 technologies. However, Industry 5.0's focus on human-machine collaboration, sustainability, and resilience transformation necessitates specific adaptations. Manufacturers perceive integrating new innovative applications seamlessly into the existing system as a challenge in this regard. According to the study, businesses have major concerns about integrating new technologies into their systems, despite having the required investment for technical infrastructure. Effective planning is a primary requirement for businesses to seamlessly integrate technologies, such as blockchain and cobots, into their existing production operations. Companies facing hurdles in adopting new technologies should prioritize efficient utilization of Industry 4.0 technologies. In addition, they must demonstrate an agile approach to addressing these challenges.

The third major challenge is transformation speed (C_2). Because the difficulty in the transformation speed is not an independent criterion, it was recognized as one of the major problems of the process in many studies (Adel, 2022; Alojaiman, 2023; Coronado et al., 2022). The transformation speed for businesses in the face of innovation is a critical factor because this change affects the entire system. For a smooth supply chain operation, employees must be open to change, the technical infrastructure must be established, and they must have sufficient technical knowledge. To transition effectively to I5.0, businesses must embrace change, receive senior management support, and implement it seamlessly without disrupting production. Additionally, the fact that many technologies can lead to significant and fundamental changes may cause apprehension among stakeholders and employees. This uncertainty can slow down change. Kazancoglu et al. (2023) emphasized that businesses should align the value offered by I5.0 with their specific needs and adopt an agile approach to this challenge. Simultaneously, focusing on collaboration among all stakeholders may be necessary for the smooth implementation of a new process.

According to the study findings, the fourth major obstacle is the "technical and social ability of employees." As seen in this study, the lack of a qualified workforce is a major challenge in modern manufacturing systems, as in many other studies (Kazancoglu et al., 2023; Narvaez Rojas et al., 2021). A skilled workforce is essential for utilizing advanced technologies driven by digitalization in Industry 4.0. At the same time, employees must have certain skills and competencies in Industry 5.0 systems based on cooperation between robots and employees. Qualified labour is always a problem in smart production systems. For this reason, workforce training is crucial in addressing the technical and social challenges faced by employees. However, the development of lifelong learning and training programs is one of the challenges encountered by many businesses ((Kazancoglu et al., 2023). In Industry 5.0, it is necessary to apply virtual education to technologies such as artificial intelligence (Leng et al., 2022). The streamlined implementation of virtual training can enhance training activities in numerous aspects. It is necessary to provide comprehensive training to employees in many aspects, such as using technologies, analyzing data, managing processes, and production control. It should be considered crucial in terms of lowering virtual education costs and making education safe (Adel, 2022).

Moreover, “human-robot interoperability” (C_6) is another substantial challenge. Kumar et al. (2023) and Rajesh (2023) reported a similar finding. According to the study’s findings, businesses have relatively difficulty adopting the mechanism based on human-robot cooperation in cyber-physical systems. Human-robot interoperability can involve both physical and cognitive interactions, aiming for robots to work with humans in a safe, effective, and efficient manner. As it focuses on strengthening human-machine interaction in the processes, a high level of interoperability is essential. Experts should evaluate all situations related to human-robot collaboration, and the necessary production environment should be set up to ensure responsible operations. In this system based on human-machine cooperation, employees should be provided with advanced technological skills. This harmonious unity affects the competitiveness, sustainability, and economic power of businesses.

Although studies talk about focusing more on the hierarchically most critical challenges, other potential obstacles should also be eliminated. Businesses must have the necessary accurate information about the technologies and processes in this transformation, focus on social ethics and value, ensure system security, manage big data, and consider environmental and social issues. Since Industry 5.0 proposes a human-centred production paradigm, big data management is an effective tool for ensuring the efficient execution of this human-technology-focused process. Considering the possibilities where big data can make production systems more flexible and sustainable, there is a need to investigate the issues related to achieving the human-centred and innovative goals of Industry 5.0. The intense use of technologies such as digitalization, artificial intelligence, and big data in production requires considering certain obstacles in terms of system security. It is recommended that many programs and machines in Industry 5.0 be continuously monitored and updated. Experts need to detect and address potential security vulnerabilities early on. On the other hand, security protocols need to be sufficient. Many security-related issues related to Industry 5.0 should be thoroughly detailed and developed by experts in the field. This is an important field that both academic researchers and industry experts should focus on.

Furthermore, it is significant to consider social and environmental concerns as part of the process, as sustainability is one of the main pillars of Industry 5.0. Social issues, particularly in studies related to sustainability, are often considered less than the other two dimensions. However, since Industry 5.0 adopts a human-centered approach and aims to use technology in collaboration with humans, sustainability is a key foundation. To successfully implement Industry 5.0, it is crucial to provide solutions that, alongside environmental impacts, enhance the quality of life for the workforce, support communities, and address workforce losses. Therefore, additional research in this area is essential to fully realize the potential of Industry 5.0.

Finally, this study has several limitations. Based on these limitations, it may be crucial to offer some suggestions for researchers and practitioners working in the relevant field. In this study, experts from automotive manufacturers played a key role in determining the challenges and collecting data on this subject. The challenges in the process can vary significantly for other sectors, depending on the sector's specific requirements. Therefore, although the findings do not reflect the complete picture of industries around the world, they can provide insight in many ways. The results may be generalizable, especially for similar economies and sectors. However, conducting the application in developing Turkey implies that the findings may not apply to developed countries. For this reason, the results for businesses in different sectors or automotive manufacturers in developed countries are questioned. Another issue is that the criteria in the study are generally related to in-factory management. The study does not include criteria regarding external stakeholders. Future research is recommended to explore how manufacturers engaged in cross-border business will adapt to this transformation and ensure global unity. Finally, other researchers may use various forms of "Multi-Criteria Decision-Making" approaches in terms of method.

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