Information Systems Frontiers
https://doi.org/10.1007/s10796-024-10472-3

A Multi-Criteria Decision-Making Framework to Evaluate the Impact of Industry 5.0 Technologies: Case Study, Lessons Learned, Challenges and Future Directions

Mohamed Abdel-Basset[1] · **Rehab Mohamed**[1] · **Victor Chang**[2]

Accepted: 22 January 2024

Abstract

Smart technologies have demonstrated striking outcomes regarding the early diagnosis of diseases and the delivery of the necessary healthcare in the last decade. However, by emphasizing the core fundamentals of social justice and sustainability, together with digitalization and smart technologies that predicate raising productivity and flexibility, Industry 5.0 has proven to achieve more efficient results. Industry 5.0 technologies provide more intelligent ways for human employees and higher efficiency development while also improving safety and performance in many applications. In this research, the contribution is focused on the healthcare and how Industry 5.0 technologies demonstrate several advantages for the healthcare sector, starting with automated and precise disease prediction, moving on to aiding medical personnel in continual surveillance and monitoring and concluding with successful digital automation of smart equipment. The objective of this study is to apply a hybrid multi-criteria decision-making approach under a neutrosophic environment to evaluate the advantages of industry 5.0 technologies in the healthcare sector. Industry 5.0 primary value is to reach human-centric, sustainable, and resilient industries. While Industry 5.0 technologies sub-values regarding the healthcare sector are determined and distinguished according to the 3-main values mentioned previously based on literature. The methodologies applied in this study are: The Analytical Hierarchy approach (AHP) evaluates the main values and sub-values. Subsequently, the effectiveness of industry 5.0 technologies according to their values to the healthcare sector are ranked by Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The approach is constructed under uncertainty based on a neutrosophic environment to achieve accuracy in the evaluation process. The results show that the most influential technology in healthcare are AI and cloud computing, while nano-technology, drone technology, and robots are at the end of the ranking. While validating the suggested technique, outcome comparisons were carried out to demonstrate the benefits of the methodologies. A sensitivity study indicates that adjusting the weightings of the sub-values has no significant effect on the ranking of technologies.

Keywords Industry 5.0 · Healthcare · Multi-criteria decision-making · AHP · TOPSIS

1 Introduction

The industrial revolution has changed from decade to decade; at the moment, industrial businesses compete globally. Nearly every aspect of human life has been impacted by the numerous advancements in science and technology. Industry 5.0 has added a unique perspective where, with cutting-edge technology, the industrial market has reached a level never before attained. The review reveals that Industry 4.0 is concentrated on productivity that is powered by technology (Ghobakhloo et al., 2022). Based on this, Industry 5.0 is conscious of the social and sustainability aspects that Industry 4.0 lacks. Whereas industry 5.0 competencies

✉ Victor Chang
ic.victor.chang@gmail.com; v.chang1@aston.ac.uk

Mohamed Abdel-Basset
mohamedbasset@ieee.org

Rehab Mohamed
rehmohamed@zu.edu.eg

[1] Faculty of Computers and Informatics, Zagazig University, Sharqiyah 44519, Egypt

[2] Department of Operations and Information Management, Aston Business School, Aston University, Birmingham, UK

did not just extend to manufacturing industries but also to several other sectors, including agriculture and healthcare (Sindhwani et al., 2022). Industry 5.0's emphasis on sustainability seeks to move beyond the conventional economic focus by including the social and environmental components, achieving all three dimensions of sustainability, and delivering chances and benefits to society. Through efficient collaboration between the intelligence of human labor and the superior capabilities of technology, Industry 5.0 may also enhance business relationship imbalance, altering the economic and social dimensions. In order to ensure sustainability, Industry 5.0 also prioritizes environmental protection as a strategic goal.

Industrial revolutions started with Industry 1.0 in the late 1800s in the textile industry by using mechanical tools manually. The core notion of the second revolution was electricity. In contrast, automation and digitalization was the main concept of the third revolution. Industry 4.0 originated in 2011 and advanced the idea of Cyber-Physical Production Systems (CPPS). The concept "Industry 4.0" was applied to represent the notion of CPPS, which encompasses a variety of smart technologies such as the Internet of Things (IoT), Big Data, Artificial Intelligence (AI), Cloud Computing, and others (Xu et al., 2021). As a result, Industry 5.0 offers a distinct perspective in assisting the industry in its long-term contribution to humanity within sustainability (Breque et al., 2021).

The complete transition in healthcare from traditional healthcare to relying on intelligent systems to provide health services has led to a significant shift in the technologies utilized in this field (Breque et al., 2021). Smart Healthcare is defined as the ability to integrate system components, people, and resources, send health information remotely, and effectively address the healthcare environment's demands through innovative technologies (Muhammad et al., 2021).

The healthcare sector witnessed a technological revolution, such as other industries, and has gone through generations from 1.0 to 4.0 through the aid of other industries (Aceto et al., 2020). Initially, paper-based healthcare systems were used to store patient data and track their health status, but as technology advanced, surgeries were performed utilizing nano-technology and robotics. Smart Healthcare is described as the administration of medical services using smart technologies such as robots, sensors, IoT, and others to provide superior healthcare (Bamiah et al., 2012). Emerging 5G technology, robots, IoT, big data, AI, cloud computing, and other smart techniques demonstrate significant advancement in smart healthcare. These technologies make existing healthcare systems more accessible, consistent, and sustainable. Healthcare 5.0 integrates the power of industry 5.0 to fulfill societal goals and high-efficiency healthcare in an environmentally conscious manner.

Various technologies connected to Industry 5.0 are being used in the healthcare sector to improve medical services. Each technology contributes to better health management. To evaluate the value of these technologies in healthcare, we proposed a MCDM approach in this study. These digital technologies include nano-technology, 5G, drones, blockchain, robotics, big data, IoT, AI, and cloud computing. Each of these technologies contributes significantly to the various phases of healthcare management and has a unique value. The central values of Industry 5.0 technologies are human-centric, sustainability, and resilience. However, each of the above technologies provides an outstanding value for the intelligent healthcare system.

Most studies that dealt with smart healthcare were based on industry 4.0 technology, with little attention paid to keeping up with the advancements in other industries that enable the healthcare sector to provide better services. During the previous two years, industry 5.0 technologies have shown a strong trend, yielding excellent outcomes in the COVID-19 Pandemic. The COVID-19 Pandemic posed exceptional difficulties and chances to change worldwide healthcare systems. In these situations, turning to new intelligent technologies that offer the opportunity to provide virtual health services effectively has become unavoidable. Therefore, this study focuses on industry 5.0 technologies due to integrating new smart technologies and sensors that promote resilient performance in healthcare systems with greater sustainability.

First, the values of industry 5.0 technologies in the healthcare sector are divided into 3-main values and 18 sub-value. The main values and sub-values are evaluated by the Analytical Hierarchy approach (AHP) method under a neutrosophic environment. We rely on AHP in this stage because of its adaptability and ability to detect discrepancies. Neutrosophic theory can deal with vagueness, which is deliberated as an extension of fuzzy theory (Siksnelyte et al., 2019). Second, industry 5.0 technologies will be ranked by Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) also under a neutrosophic environment to reduce the uncertainty.

Industrial change is a socio-technical process. One recent term for this trend is "industry 5.0," which is defined as a humanized vision of technological changes in the industry that balances the present and future needs of workers and society with the sustainable optimization of energy consumption, material processing, and product lifecycles. The motivation of this study is to track the profound effects of Industry 5.0 technologies in a variety of industries. The healthcare sector is among the most significant of them, since it has attracted a lot of attention following the Corona pandemic, which faces many challenges. In addition, the motivation of this research is to determine how Industry 5.0 and its new developments are assisting in resolving Industry 4.0's drawbacks. Industry 5.0 not only brought forth a number of new technology, but it also aids in addressing Industry 4.0's limitations.

In summary, there has not been much research on industry 5.0 technology's effects on the healthcare field, and the majority of studies that have addressed this topic have focused on industry 4.0 technologies. Additionally, most recent work has primarily discussed how Industry 5.0 would affect healthcare theoretically, not practically. So, in this study, a proposed hybrid MCDM framework (AHP-TOPSIS) is utilized to evaluate the values and sub-values of industry 5.0 technologies in healthcare (using AHP) and classify the technologies according to their values in the healthcare sector (using TOPSIS). Moreover, this study also has the benefit of considering ambiguity while appraising the situation by deliberating the evaluation process in a neutrosophic environment.

Overall, the contributions of this study are:

- Study industry 5.0 technologies and their benefits to the healthcare sector.
- Evaluate the principal values of Industry 5.0 and sub-values regarding healthcare and how they affect sustainability and resilience.
- Minimize the uncertainty in evaluating industry 5.0 technologies in healthcare by applying the proposed AHP-TOPSIS approach under a neutrosophic environment.

The remainder of the paper is organized as follows: an overview of previous research that studied smart healthcare and the influence of Industry 5.0 on it in Sect. 2. Section 3 deliberates industry 5.0 technologies and their value in healthcare. The proposed AHP-TOPSIS approach based on a neutrosophic environment is explained in Sect. 4. Section 5 shows the evaluation of industry 5.0 technologies and their value in the healthcare sector using the proposed approach. Section 6 compares with other MCDM techniques to check the proposed framework's efficiency. Section 7 discusses a sensitivity analysis to verify the results. Section 8 discusses the challenges and future directions, and finally, Sect. 9 concludes the work.

2 Related Works

This section has overviewed literature associated with Healthcare 4.0 and Healthcare 5.0.

2.1 Industry 4.0 Technologies and Healthcare

Based on a literature review, Tortorella et al. (2020) investigated the trends, problems, and theoretical gaps in the implementation of Healthcare 4.0. They argue that the H4.0 literature is carelessly constructed, lacking academic coherence and a grounded theory-based practical viewpoint. (Tortorella et al., 2020). The role of fog computing, cloud computing, and the Internet of Things in the healthcare sector is examined by Kumari et al. (2018). They propose a three-layer patient-driven healthcare architecture for real-time data collection, processing, and transmission. (Kumari et al., 2018). The study of Karatas et al. (2022) gives readers a survey of literature that touches on Industry 4.0, big data, and healthcare operations. According to their analysis, big data holds a significant position among the technologies Industry 4.0 offers in the healthcare sector (Karatas et al., 2022). Manogaran et al. (2017) proposed a system that employs key management security procedures to safeguard large amounts of data. They present a secure Industrial IoT framework for the enormous volumes of scalable sensor data processing and storage for medical applications. The suggested system attaches sensor medical devices to the body to gather patient clinical measurements. When the body's typical values for breathing rate, heart rate, blood pressure, body temperature, and blood sugar are exceeded, the devices use a wireless network to send a clinically significant alarm notification to the specialist (Manogaran et al., 2017). In the context of COVID-19, Sood et al. (2022) research presents a scientific examination of the literature on Industry 4.0 technologies. The findings show that China has created the most remarkable research outcomes, even though India is the nation that collaborates with other countries the most in this area (Sood et al., 2022).

2.2 Industry 5.0 Technologies and Healthcare

Much research has been overviewed associated with healthcare and industry 5.0. In order to model Healthcare 5.0, the article of Mohanta et al. (2019) enumerates all the key ideas, including AI, IoT, and 5G connectivity (Mohanta et al., 2019). At the same time, the study of Mbunge et al. (2021) examines the functions and features of sensors and industry 5.0 technologies, including blockchain, robots, big data, the IoT, AI, and cloud computing (Mbunge et al., 2021). Bhavin et al. (2021) investigated several security methods for electronic health records (EHRs) and used quantum computing (QC) to improve on the traditional encryption technique. After that, they suggested a blockchain-based architecture for Healthcare 5.0 that would let users access the database's data according to their assigned roles. Compared to state-of-the-art techniques, the results show that the proposed method is more effective in transaction throughput, resource utilization, and network traffic (Bhavin et al., 2021). For Healthcare 5.0 applications, Gupta et al. (2021) suggested a drone delivery system based on the blockchain. The proposed solution combines blockchain and the Internet of Drones (IoD) over haptic 5G Internet to enable low-latency responsive medicinal material distribution that can be tracked and overseen across several stakeholders (Gupta et al., 2021).

2.3 Industry 5.0 Technologies and the COVID-19 Pandemic

Regarding the COVID-19 Pandemic in the most recent timeframe, Javaid et al. (2020a, b) recognized and researched vital Industry 5.0 technologies that benefited the pandemic. They discussed the supportive aspects of Industry 5.0 for the COVID-19 Pandemic. Additionally, they identified serious issues with Industry 5.0 technology regarding the COVID-19 Pandemic (Javaid et al., 2020a). On the same subject, Sarfraz et al. (2021) investigated numerous Industry 4.0 and Society 5.0 technologies, such as robots and AI, to slow the spread of COVID-19 worldwide. They demonstrate how AI, big data, and IoT technology may be applied in the healthcare sector. Lastly, they reviewed the transition from Industry 4.0 to Society 5.0 in light of the COVID-19 effects and the technology approaches being considered and utilized.

2.4 MCDM Studies of Healthcare and Industrial Revolutions

Many studies dealt with this topic in different ways concerning evaluating the performance of smart healthcare systems that depend on technologies of the industrial revolution. This paper suggests a method for assessing the effectiveness of technology integration in healthcare management utilizing fuzzy decision-making. In this work, the TOPSIS of fuzzy AHP is used to assess the data protection of healthcare of the smart healthcare management system (Quasim et al., 2021). In the field of disease prediction, the study of Shynu et al. (2021) suggests effective Blockchain-based healthcare services for disease forecast in fog computing. A rigorous experiment and analysis were conducted utilizing data from the actual world of healthcare to determine how effectively this service operated. According to the experimental data, the suggested technique efficiently predicts the disease and achieves a prediction accuracy of more than 81% (Shynu et al., 2021). Yang et al. (2022) propose a hybrid three-phased MCDM model for evaluating a Smart Healthcare Management System in a resource-limited environment (Yang et al., 2022). Table 1 provides more studies of healthcare and industrial revolutions.

3 Industry 5.0 Technologies and Healthcare

3.1 Introduction to Industry 5.0 and Its Central Values

The Internet of Things (IoT), artificial intelligence (AI), augmented reality (AR), and other technologies were all introduced by Industry 4.0 into general manufacturing and other sectors. These technologies are now widely used in engineering, business, healthcare, and service-based organizations. Industry 5.0 was created as a way to address the shortcomings of Industry 4.0 by encouraging human centricity and addressing social requirements. Industry 5.0 links human intelligence with the accuracy and efficiency of machines using AI in industrial production. In other words, Industry 5.0 is an effort to bring back the use of human labor in manufacturing facilities, where man and machine would collaborate to increase productivity in processes by fully utilizing human intelligence and creativity through their integration with the current intelligent systems.

Industry 5.0 complements the present Industry 4.0 model by allowing research and innovation to steer the transition to a more sustainable, human-centric, and resilient future (Breque et al., 2021). Industry 5.0 is a result of the European Commission's determination that technical innovation must be used to advance European social and environmental concerns. Industry 4.0 is not the ideal framework, according to proponents of Industry 5.0, for attaining sustainable growth. The European Commission launched the Industry 5.0 plan for a resilient, sustainable, and human-centric European industry in 2021. This strategy contends that Industry 5.0 is an extension of Industry 4.0 that gives growing socio-environmental requirements first priority (Mazur & Walczyna, 2022). Industry 5.0 encourages the human workforce by promoting human-centric strategies for technical progress. In addition, Industry 5.0 fosters technical improvement in ecological sustainability (Ghobakhloo et al., 2022).

Three integrated fundamental values, human-centric, sustainability, and resilience, serve as the basis of Industry 5.0, as Fig. 1 shows. This figure explains that the Industry 5.0 revolution is an encouragement to action for putting sustainability principles into action, fusing technology and human values, and is viewed as a step toward accomplishing sustainable development and resilience objectives.

Table 1 Literature review of industry 4.0 and industry 5.0 in healthcare

	Research title	Objective of research	Reference
Industry 4.0	Industry 4.0 in Healthcare: A systematic review	a systematic review of the literature to examine the effects of Industry 4.0 on healthcare systems, manage patient records and assist in limiting the expansion of COVID-19	Ahsan and Siddique (2022)
	An edge-based architecture to support efficient applications for the healthcare industry 4.0	The paper proposes a novel architecture convenient for human-centric applications, considering the development of the healthcare industry	Pace et al. (2018)
	Status of Industry 4.0 applications in Healthcare 4.0 and Pharma 4.0	The study aimed to compare the current state of Industry 4.0-enabled applications in the pharmaceutical and healthcare industries	Inuwa et al. (2022)
	Towards a GDPR-compliant way to secure European cross-border Healthcare Industry 4.0	adoption of the architectural model for healthcare industry 4.0 and integration of various tools to provide safety and security across this model	Larrucea et al. (2020)
	A. Medical 4.0 technologies for healthcare: Features, capabilities, and applications	This study examines the demand for Medical 4.0 in the healthcare industry and different forward-thinking initiatives for Medical 4.0 implementation. The main uses of Medical 4.0 for healthcare services are explored and presented in this study	Haleem et al. (2022)
Industry 5.0	Industry 5.0 technology capabilities in Trauma and Orthopaedics	Examine the growth of the Industry 5.0 revolution in trauma and orthopedics and emphasize how the interaction of robotic technology, smart machine systems, and human intelligence leads to the creation of individualized treatment	Iyengar et al. (2022)
	B. Industry 5.0 and its applications in Orthopedics	Describe how Industry 5.0 helps provide high-quality, personalized orthopedic implants, equipment, and devices with the necessary specifications	Haleem and Javaid (2019)
	COVID-19 and hospitality 5.0: Redefining hospitality operations	This study investigates how Industry 5.0 design ideas can be applied to hospitality, resulting in Hospitality 5.0 increasing operational effectiveness	Pillai et al. (2021)

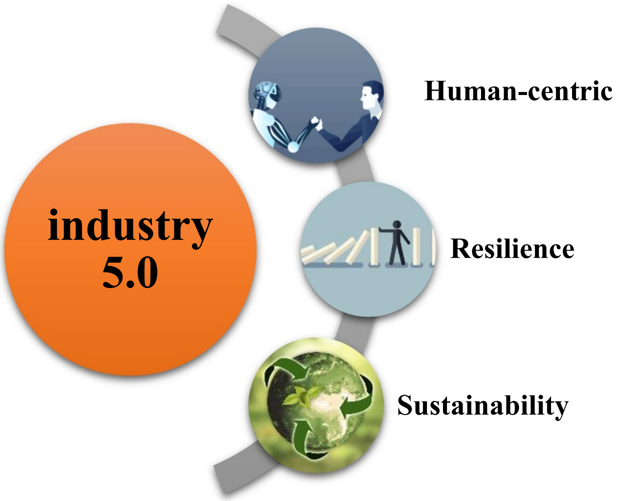


Fig. 1 Industry 5.0 main values

This revolution is centered on the ideas of sustainability, bioeconomy, and a technology-human collaboration environment, creating a resilient enterprise that includes human social values.

3.1.1 Human-centric

This principle places human needs and interests at the basis of the production process. The need to improve productivity while keeping human employees in the industrial sector places a heavy burden on the global market. This strategy conflicts with the machine-based paradigm of prior industrial revolutions, where production and business are the primary goals and environmental and human costs can be minimized (Breque et al., 2021). Industry 5.0's capacity to combine human and robot intellect and decision-making, assisted by intelligent technology, enables unprecedented personalization in a variety of industries. The human-centered value prioritizes people's overall well-being along with the improvement of production to protect their function, abilities, and rights. Robots, 5G, AI, IoT, and other disruptive technologies that allow Industry 5.0, combined with human ingenuity and intelligence, can assist companies in fulfilling demand and providing personalized and customized goods more quickly. Collaborative robots are employed in Industry 5.0 to boost production and solidify a new interaction between people and machines. By reintroducing human intelligence to the production process, industry 5.0 has strongly emphasized intelligent manufacturing, allowing robots to share and work together with people. Numerous technological researchers think Industry 5.0 will revive the human component in the industrial sector (Nahavandi, 2019).

3.1.2 Sustainability

In order to achieve a more efficient and effective manufacturing process with respect to the environment and resources, Industry 5.0 is based on recycling natural environmental resources to reduce harmful emissions and the negative impact of industrial waste on the environment.

3.1.3 Resilience

It focuses on developing more elastic, resilient, and innovative industries. It implies the requirement to strengthen manufacturing to a greater extent, protecting it better versus interruptions and ensuring it can provide and sustain crucial infrastructure during disasters.

3.2 Industry 5.0 Technologies and Their Values Associated With Healthcare

3.2.1 Cloud Computing

One of the most significant innovations that have attracted the interest of technologists worldwide is cloud computing. The Internet service provider created cloud computing to offer the most users and elastic services with a massive low cost of computing resources (Jangjou & Sohrabi, 2022). Industry 5.0 is now able to minimize network bandwidth, enhance data security and privacy generally, and facilitate transactions that are limited by connectivity problems because of improvements in cloud computing. Cloud Computing is shaping and renovating healthcare services since it eliminates complexity, allows efficient administration, and encourages collaboration across the systems in the healthcare sectors (AlTwaijiry, 2021). The benefits of cloud computing in healthcare include the ability to store, process, analyze, and manage patient health information, which may assist industry stakeholders and patients beyond obstacles (Javaid et al., 2020b). It also allows patients and medical professionals to communicate via cloud-based applications. For example, in the COVID-19 Pandemic, we see that cloud computing is crucial to effectively tackle the difficulty of working from home. It effectively detects, monitors, and monitors infected patients by integrating smart devices, intelligent applications, and synchronized applications.

3.2.2 Robotics

A significant advance for humanity is the present paradigm of robots in the field of healthcare. Industry 5.0 will undoubtedly revolutionize healthcare systems due to the incorporation of robots. For instance, it allows businesses to plan out various surgery sequences and try them out before implementing them in a real world that continuously monitors various pertinent metrics. The order of pre-planning and rehearsal for complicated procedures provides specialist surgeons executing operations with helpful recommendations (Verma et al., 2018). In addition, during the outbreak of COVID-19, the critical applications of robots and drone technology are crowd monitoring, public announcements, screening and diagnosis, and the delivery of major supplies (Firouzi et al., 2021). The use of medical robots in various procedures during the care process, including disease prevention, screening, diagnosis, treatment, and home care, has been widely adopted and has tremendous potential for further advancement (Lallo et al., 2021).

3.2.3 Blockchain

The blockchain is a series of blocks that, like a traditional public ledger, contain an exhaustive list of transaction data in a decentralized and distributed network (Zheng et al., 2018). Transactions are more secure and tamper-proof in blockchain, and its features include decentralization, stability, transparency, and audibility. Blockchain technology has recently exploded in popularity and permeated several industries, such as the healthcare sector. Blockchain technology is being utilized more often in healthcare, primarily for data exchange, keeping patient information, and access control. Data sharing and monitoring an audit trail of clinical practices are all possible with blockchain technology. It can also facilitate medicine prescriptions, supply chain management, and any risk data management (Hölbl et al., 2018).

3.2.4 5 G Technology

The fifth generation of wireless transmission technology, or 5G, greatly impacts how smart medical equipment is connected to offer a high data transfer rate. Healthcare would considerably benefit from dependable internet access for medical devices, with larger capacity, better coverage, and faster internet (Li, 2019). Monitoring patients remotely is conceivable with wearable devices enabled by powerful sensors linked to a 5G network. 5G technology is anticipated to satisfy the requirements of the intelligent information society for Industry 5.0 applications.

3.2.5 Big Data

In the healthcare sector, several big data sources include medical reports, patient history, medical assessment findings, and smart devices. It must be properly managed and analyzed to get relevant knowledge from this data. Otherwise, rapidly pursuing solutions through big data analysis becomes terrible (Dash et al., 2019). Large amounts of data have emerged to assist the healthcare industry in healthcare management, service enhancement, medication quality enhancement, and therapy integrity (Miah et al., 2022). Big data techniques in medication development, treatment improvement, and best clinical services have saved costs while improving the treatment experience. Big Data might be used to track disease outbreaks in real-time, such as the COVID-19 Pandemic. Online platforms, mobile devices, Internet of Things-enabled devices, and publicly available data in various forms are all possible sources (Haafza et al., 2021). Large volumes of data are produced and managed by manufacturers with the help of big data analytics shared with intelligent systems and data centers.

3.2.6 Drone Technology

The use of drones in healthcare has received a lot of attention. Blood, medications, vaccinations, and laboratory test samples, among other things, were recognized as medical supplies carried by drones. These drones can give healthcare assistance by distributing medicines, treatments, and vaccines to distant places promptly and effectively. On-time vaccination and medicine assistance can help reduce the frequency of diseases and save many lives. For instance, in the COVID-19 Pandemic, drone presents a great chance to deploy sophisticated robotics to provide healthcare support (Sharma, 2021). Drones have several benefits, including reduced reaction times during medical crises, which help save human lives and are ecologically benign due to lower CO2 emissions levels than traditional distribution by vehicles and cars (Nyaaba & Ayamga, 2021).

3.2.7 Artificial Intelligence

Artificial intelligence (AI) is transforming healthcare to a high level of accuracy and efficiency. Artificial Intelligence and Healthcare assist in the elimination of time-consuming patient monitoring procedures. AI can enhance disease detection precision and agility and open the door to individualized medical treatments. In addition, AI is transforming and improving modern healthcare through technology that governs surgery-assisting robots (Shaheen, 2021). Additionally, it has aided pharmaceutical corporations in expediting medication research. This can also help forecast the risk behavior of patients with chronic diseases, which can help prevent readmissions and provide individualized care.

3.2.8 Internet of Things

IoT is a rapidly growing ecosystem that combines software, hardware, physical items, and computing devices to interact, gather, and share data. Sensors, medical devices, artificial intelligence, and sophisticated imaging technology are all critical components of IoT applications in the medical area. The IoT is a developing technology that allows enhancements and improved solutions in the health sector, such as remote health data exchange, rapid diagnostics, device integration, and precise disease detection (Javaid & Khan, 2021). Through the use of sensors, this technology can instantly alert users to health-related risks, improving healthcare standards. But when used in industrial infrastructures, IoT presents a number of challenges, including centralization, privacy protection, and security. The use of IoT in Industry 5.0 presents a chance to save operational costs by removing data communication inefficiencies, lowering latency, decreasing supply chain waste, and improving manufacturing methods.

3.2.9 Nano-technology

Nano-technology has an ongoing impact on healthcare and significantly impacts its evolution. In the age of nanoscience, nano-technology advancements have revolutionized the healthcare system by constructing nanostructures that significantly improve the diagnosis and therapeutic aspects of many chronic diseases (Manzoor et al., 2022). The world has witnessed nano-technology progress, which has been expedited by substantial research in several healthcare fields. Nano-technology technologies have grown more helpful in healthcare, resulting in the development of unique nanosystems for diagnosing, imaging, and treating cancer and other diseases. It also has a lot of promise for target-specific medication delivery in treating many diseases and efficiently utilizing nanoscale surgeries (Anjum et al., 2021).

4 A Proposed Neutrosophic AHP-TOPSIS Framework

Many advantages are combined in this proposed framework. Whereas the AHP theory has gained popularity as a way for establishing weights, whether used alone or in combination with other strategies, it was utilized in the first round of evaluation since it showed its potential to address MCDM challenges. The addition that other similar studies lack is to carry out the evaluation process based on a linguistic scale and taking into account the uncertainty and accuracy of the evaluations, as this step was applied under netrosophic environment. Moreover, the second evaluation phase is also applied under neutrosophic environment to ensure a more accurate and reliable evaluation framework. There may be some approaches similar to the proposed framework, but they did not deal with the evaluation process in this way in terms of taking into account the uncertainty and the difference between decision makers' assessments. In addition, other approaches similar to our framework were not applied to assess the efficiency of industry 5.0 technologies in the field of healthcare.

This research aims to investigate the values and sub-values of industry 5.0 technologies in the healthcare sector in the context of uncertainty. The values and sub-values of industry 5.0 technologies in healthcare that will be considered in this study are compiled from the literature as discoursed in the previous section. In addition, the nine technologies of Industry 5.0 widely utilized in healthcare are deliberated in Sect. 3.2. Therefore, a MCDM framework is proposed to evaluate the industry 5.0 technologies based on their values and sub-values to healthcare. The phases of the suggested framework will be clarified in this section and summarized in Fig. 3.

4.1 Phase 1: Define the Problem Dimensions

First, the problem dimensions are constructed as a hierarchy consisting of values, sub-values, and technologies of Industry 5.0 related to healthcare, as shown in Fig. 2. A review of prior literature and research on Industry 5.0, particularly technologies associated with healthcare, was conducted to evaluate these technologies' main values and sub-values and rank them based on their benefits to healthcare services in an uncertain environment. The proposed framework of this study consists of two MCDM methods (AHP and TOPSIS) under a neutrosophic environment in order to reduce the vagueness in the evaluation process.

This suggested framework was evaluated by three experts in the smart healthcare field to provide their opinions on industry 5.0 technologies. Their input values and sub-values on the healthcare sector were gathered based on two written questionnaires. The first questionnaire is administered to assess the sub-values of industry 5.0 technologies with their primary values in healthcare services (Human-centric, sustainability, and resilience). The second questionnaire is applied to evaluate the nine technologies identified, as shown in Fig. 2, based on their sub-values to healthcare (Fig. 3).

4.2 Phase 2: Evaluation of Main Values and Sub-Values of Industry 5.0 Technologies in the Healthcare Sector Using Neutrosophic AHP

In this section, a neutrosophic AHP will be used to analyze the three primary values and their sub-values to demonstrate their priorities. The neutrosophic set theory will be utilized

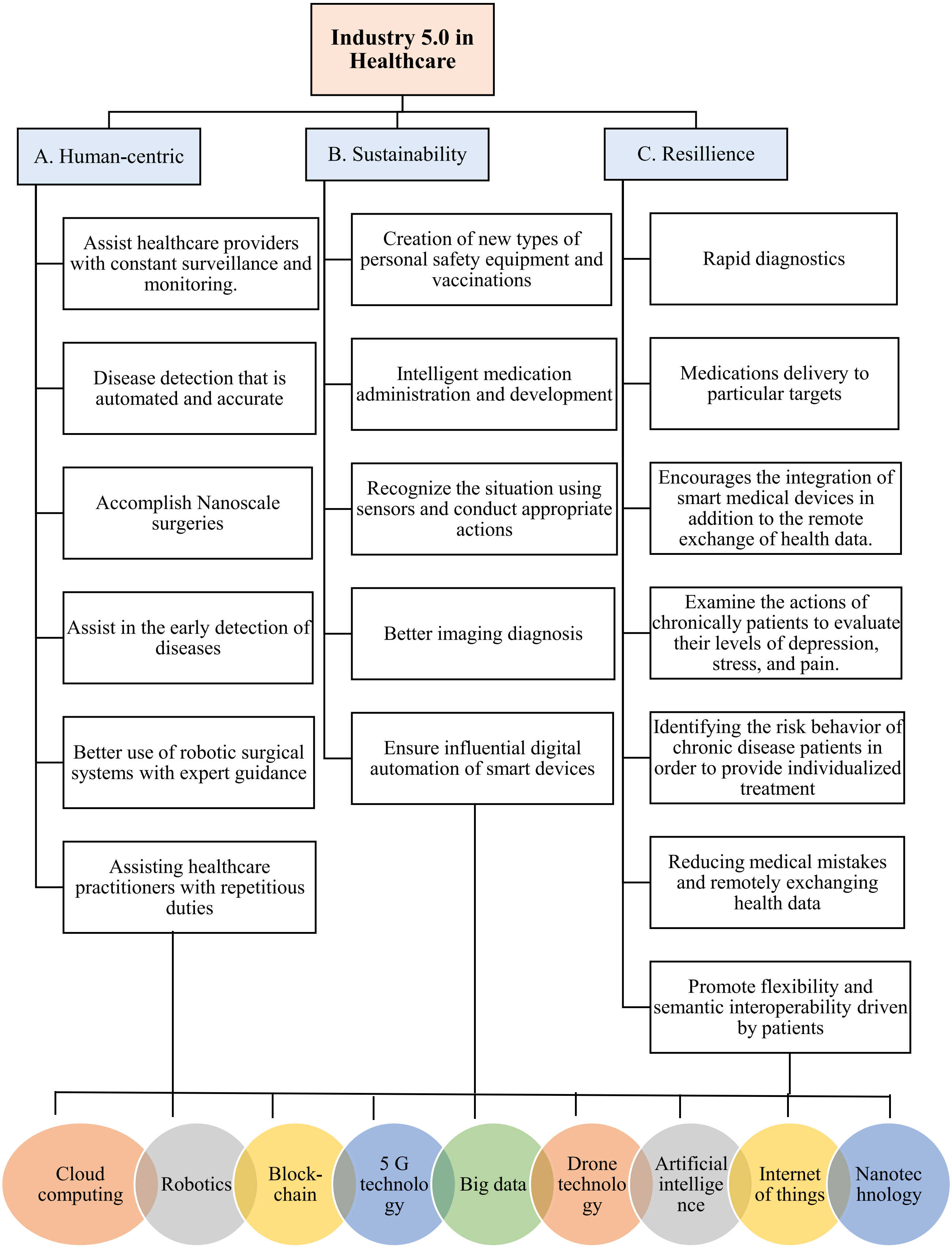
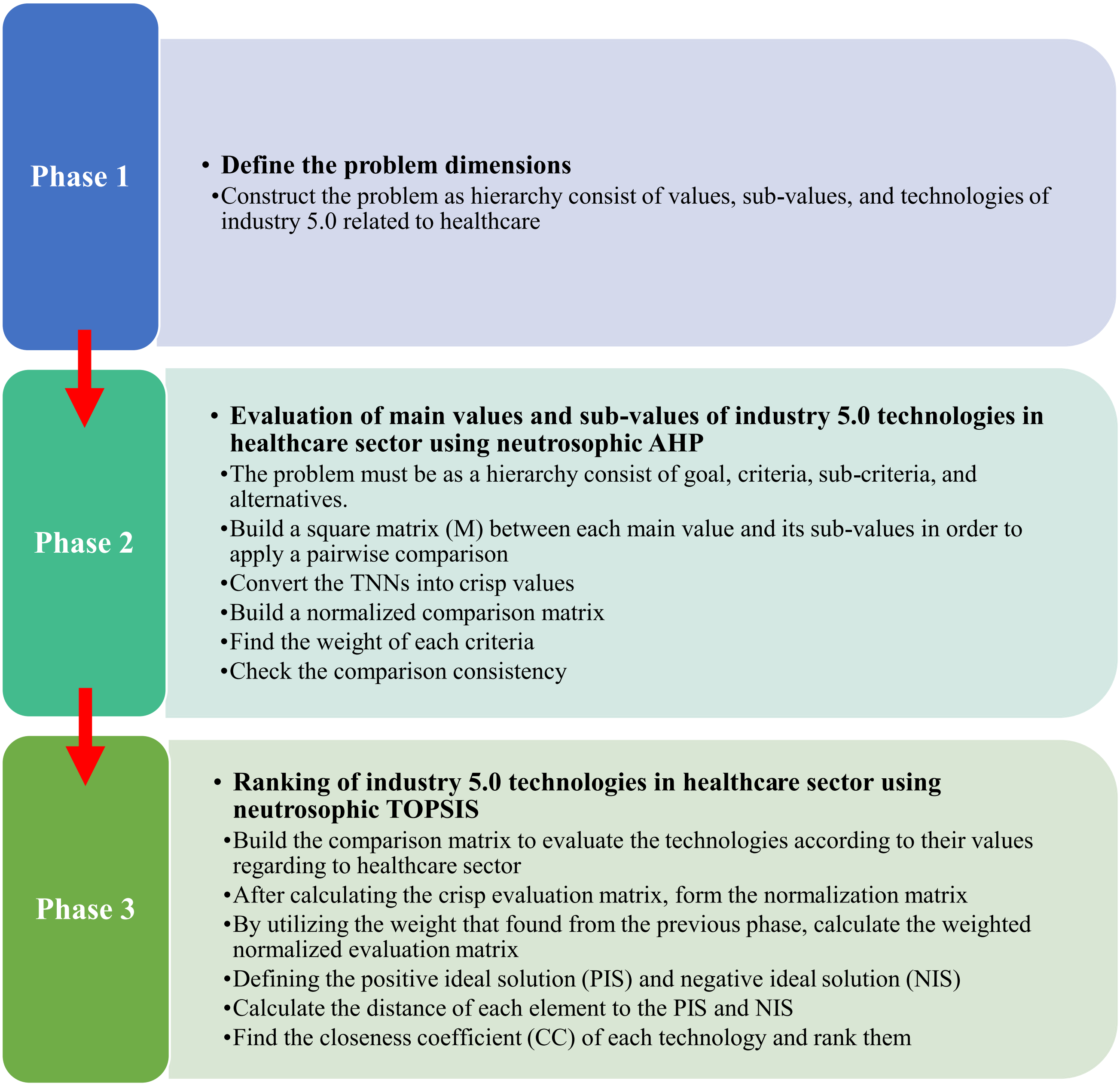


Fig. 2 Industry 5.0 technologies and their main values and sub-values related to healthcare



Phase 1

- **Define the problem dimensions**
  - Construct the problem as hierarchy consist of values, sub-values, and technologies of industry 5.0 related to healthcare

Phase 2

- **Evaluation of main values and sub-values of industry 5.0 technologies in healthcare sector using neutrosophic AHP**
  - The problem must be as a hierarchy consist of goal, criteria, sub-criteria, and alternatives.
  - Build a square matrix (M) between each main value and its sub-values in order to apply a pairwise comparison
  - Convert the TNNs into crisp values
  - Build a normalized comparison matrix
  - Find the weight of each criteria
  - Check the comparison consistency

Phase 3

- **Ranking of industry 5.0 technologies in healthcare sector using neutrosophic TOPSIS**
  - Build the comparison matrix to evaluate the technologies according to their values regarding to healthcare sector
  - After calculating the crisp evaluation matrix, form the normalization matrix
  - By utilizing the weight that found from the previous phase, calculate the weighted normalized evaluation matrix
  - Defining the positive ideal solution (PIS) and negative ideal solution (NIS)
  - Calculate the distance of each element to the PIS and NIS
  - Find the closeness coefficient (CC) of each technology and rank them

Fig. 3 Proposed framework

to handle ambiguity and uncertainty in the decision-making process. As AHP is utilized in collective management, it delivers a choice based on the decision-aims makers rather than offering a proper alternative. While there are various categorization methods, we use AHP because of its versatility and ability to detect errors. Furthermore, AHP is capable of dissecting an issue into elements to construct problem hierarchies. We also looked into AHP for subjective and objective evaluation metrics to help decision-making. To apply AHP under neutrosophic theory, we perform the following steps:

Table 2 Qualitative scale and equivalent of TNNs utilized for evaluating main values and their sub-values

Qualitative Scale (QS)	Triangular neutrosophic number (TNN)
Very weakly significant (VWS)	$\langle(0.10, 0.25, 0.3);0.1, 0.3, 0.1\rangle$
Weakly significant (WS)	$\langle(0.2, 0.3, 0.5);0.6, 0.2, 0.3\rangle$
Partially significant (PS)	$\langle(0.45, 0.3, 0.5);0.6, 0.1, 0.2\rangle$
Equal significant (ES)	$\langle(0.5, 0.5, 0.5);0.9, 0.1, 0.1\rangle$
Strongly significant (SS)	$\langle(0.7, 0.75, 0.8);0.9, 0.2, 0.2\rangle$
Very strongly significant (VSS)	$\langle(0.85, 0.8, 0.95);0.8, 0.1, 0.2\rangle$
Absolutely significant (AS)	$\langle(0.95, 0.90, 0.95);0.9, 0.10, 0.10\rangle$

- Step 1: the problem must be as a hierarchy consisting of goals, criteria, sub-criteria, and alternatives. In our study, the goal is to develop Industry 5.0 technologies and their value to the healthcare sector. In comparison, the criteria and sub-criteria are industry 5.0 technologies values and sub-values, respectively. And alternatives are the industry 5.0 technologies related to the healthcare sector.
- Step 2: Build a square matrix (M) between each main value and other criteria to apply a pairwise comparison. The comparison matrix elements are based on a qualitative scale that means triangular neutrosophic numbers (TNNs), as shown in Table 2, based on the expertise questionnaire results. This step is the foremost step that reduces the uncertainty of the evaluation process. The diagonal elements of the comparison matrix are always Equal significant (ES) since the criteria compared to itself have the same importance as shown in Eq. 1. Then, substitute each qualitative scale value with a corresponding TNN to form a neutrosophic comparison matrix, as Eq. 2 shows.

$$M = \begin{array}{c|cccc} & C_1 & C_2 & \dots & C_n \\ \hline C_1 & ES & QS_{12} & \dots & QS_{1x} \\ C_2 & \dots & ES & \dots & QS_{2x} \\ \vdots & QS_{31} & \dots & ES & \dots \\ C_n & QS_{y1} & QS_{y2} & \dots & ES \end{array} \tag{1}$$

$$M = \begin{bmatrix} \langle(0.5,0.5,0.5);0.9,0.1,0.1\rangle & \langle(a_1,a_2,a_3);T,I,F\rangle_{12} & \dots & \langle(a_1,a_2,a_3);T,I,F\rangle_{1x} \\ \langle(a_1,a_2,a_3);T,I,F\rangle_{21} & \langle(0.5,0.5,0.5);0.9,0.1,0.1\rangle & \dots & \langle(a_1,a_2,a_3);T,I,F\rangle_{2x} \\ \dots & \dots & \langle(0.5,0.5,0.5);0.9,0.1,0.1\rangle & \dots \\ \langle(a_1,a_2,a_3);T,I,F\rangle_{y1} & \langle(a_1,a_2,a_3);T,I,F\rangle_{y2} & \dots & \langle(0.5,0.5,0.5);0.9,0.1,0.1\rangle \end{bmatrix} \tag{2}$$

where $\langle(a_1,a_2,a_3);T,I,F\rangle$ is a single-valued triangular neutrosophic set, with truth membership $T_a(x)$, indeterminate membership $I_a(x)$, and falsity membership function $F_a(x)$ (Hezam et al., 2017).

- Step 3: Convert the TNNs into crisp values by using Eq. 3.λ_{max} The mean of the weighted sum vector is divided by the corresponding criteria, and n is the number of criteria. Then, to check the matrix consistency, calculate the consistency ratio (CR) using Eq. 5. The value of the random index (RI) may be checked from the AHP table. If the CR is less than 0.1, then the matrix is consistent. Otherwise, the comparison must be made again.

$$S(a) = \frac{1}{8} \times (a_1 + a_2 + a_3) \times (2 + T - I - F) \tag{3}$$

- Step 4: build a normalized comparison matrix by calculating the sum of the columns and then divide each column element by the corresponding sum. The sum of each column of the normalized matrix must equal 1.λ_{max} The mean of the weighted sum vector is divided by the corresponding criteria, and n is the number of criteria. Then, to check the matrix consistency, calculate the consistency ratio (CR) using Eq. 5. The value of the random index (RI) may be checked from the AHP table. If the CR is less than 0.1, then the matrix is consistent. Otherwise, the comparison must be made again.
- Step 5: find the weight of each criterion by finding the average of the rows of the normalized matrix.λ_{max} The mean of the weighted sum vector is divided by the corresponding criteria, and n is the number of criteria. Then, to check the matrix consistency, calculate the consistency ratio (CR) using Eq. 5. The value of the random index (RI) may be checked from the AHP table. If the CR is less than 0.1, then the matrix is consistent. Otherwise, the comparison must be made again.
- Step 6: Check the comparison consistency. Calculate the consistency index (CI) using Eq. 4. If CI is 0, then the comparison is consistent. Otherwise, the consistency ratio must be checked.λ_{max} The mean of the weighted sum vector is divided by the corresponding criteria, and n is the number of criteria. Then, to check the matrix consistency, calculate the consistency ratio (CR) using Eq. 5. The value of the random index (RI) may be checked from the AHP table. If the CR is less than 0.1, then the matrix is consistent. Otherwise, the comparison must be made again.

$$CI = \frac{\lambda_{\max - n}}{n - 1} \tag{4}$$

$$CR = \frac{CI}{RI} \tag{5}$$

Table 3 Linguistic variables and the equivalent of TNNs utilized for rating industry 5.0 technologies related to the healthcare sector

Importance linguistic variable	Triangular neutrosophic number
Very low influence (VLI)	$\langle(0.10, 0.30, 0.35); 0.1, 0.2, 0.15\rangle$
Low influence (LI)	$\langle(0.15, 0.25, 0.10); 0.6, 0.2, 0.3\rangle$
Partially influence (PI)	$\langle(0.40, 0.35, 0.50); 0.6, 0.1, 0.2\rangle$
Medium important (MI)	$\langle(0.65, 0.60, 0.70); 0.8, 0.1, 0.1\rangle$
High influence (HI)	$\langle(0.70, 0.65, 0.80); 0.9, 0.2, 0.1\rangle$
Very high influence (VHI)	$\langle(0.90, 0.85, 0.90); 0.7, 0.2, 0.2\rangle$
Absolute influence (AI)	$\langle(0.95, 0.90, 0.95); 0.9, 0.10, 0.10\rangle$

4.3 Phase 3: Ranking of Industry 5.0 Technologies in the Healthcare Sector Using Neutrosophic TOPSIS

This phase concentrates on the evaluation of industry 5.0 technologies concerning the healthcare sector based on the weight of its main values and sub-values determined in Phase 2, as discussed previously. The evaluation of the nine technologies (cloud computing, robotics, blockchain, 5G technology, big data, drone technology, artificial intelligence, internet of things, and nano-technology) is applied under a neutrosophic environment. The steps of this phase are as follows:

- Step 7: Build the decision matrix to evaluate the technologies according to their values in the healthcare sector. The comparison matrix elements are based on important linguistic variables, meaning triangular neutrosophic numbers (TNNs) and substitute each important linguistic variable with a corresponding TNN, as shown in Table 3 based on the expertise questionnaire results.

- Step 8: After calculating the crisp evaluation matrix using Eq. 3, form the normalization matrix by dividing each element in the matrix by the sum of the corresponding row, as Eq. 6 shows.

$$R = (r_{ij})_{m\times n} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^{2}}} \tag{6}$$

- Step 9: by utilizing the weight found from the previous phase, calculate the weighted normalized evaluation matrix. This matrix consists of the multiplication of each element by the corresponding weight

$$V = (v_{ij})_{m\times n} = w_j \times r_{ij} \tag{7}$$

where w_j is the weight of each technology value found in Phase 2 using AHP.

- Step 10: defining the positive ideal solution (PIS) and negative ideal solution (NIS), which is the main idea of TOPSIS, is to find the optimal decision by measuring the distance of each alternative to these two vectors. The positive ideal solution is the maximum element of each row in the weighted normalized matrix, while the negative ideal solution is the minimum value, as Eqs. (8-11) show.

$$A^{+} = \left\{v_1^{+}, v_2^{+}, \ldots, v_n^{+}\right\} \tag{8}$$

$$v^{+} = \left\{\left(max_i v_{ij} \middle| j \in J_b\right), \left(min_i v_{ij} \middle| J \in J_{nb}\right)| \in [1 \ldots m]\right\}. \tag{9}$$

$$A^{-} = \left\{v_1^{-}, v_2^{-}, \ldots, v_n^{-}\right\} \tag{10}$$

$$v^{-} = \left\{\left(min_i v_{ij} \middle| j \in J_b\right), \left(max_i v_{ij} \middle| J \in J_{nb}\right)| \in [1 \ldots m]\right\}. \tag{11}$$

- Step 11: Calculate each element's distance to the PIS and NIS using Eqs. 12 and 13.

$$D_i^{+} = \left[\sum_{j=1}^{m} (V_i - V_j^{+})^2\right]^{0.5} \tag{12}$$

$$D_i^{-} = \left[\sum_{j=1}^{m} (V_i - V_j^{-})^2\right]^{0.5} \tag{13}$$

- Step 12: using Eq. 14, find each technology's closeness coefficient (CC) and rank them.

$$cc_i = \frac{S_i^{-}}{S_i^{+} - S_i^{-}} \tag{14}$$

5 Evaluation of Industry 5.0 Technologies and Their Value to the Healthcare Sector Utilizing the Proposed Framework

The relevance of industry 5.0 technologies was explored in this research section, which has shown significant leverage in numerous industries in the latest years, the most important of which is the healthcare sector, particularly the healthcare supply chain. In Sect. 3, the nine technologies of Industry 5.0 that will be considered in this research were clearly explained with their impact on the healthcare service. Furthermore, Fig. 2 shows the main values that characterized Industry 5.0 rather than other industrial revolutions. In addition, the three main values and the 18 sub-values that are classified according to these main values are clearly shown in Fig. 2.

This study may be classified into three main parts: Firstly, we will study each of the main values of Industry 5.0 and its sub-values separately to be the first level of AHP evaluation. Secondly, the second level of AHP evaluation will be to weigh the 18 sub-values to each other. Finally, the evaluation of Industry 5.0 nine technologies according to their sub-values in regard to healthcare will be discussed based on TOPSIS.

5.1 Phase 2: Evaluation of Three Main Values and 18 Sub-Values Using AHP

We will now apply AHP to evaluate each main value of Industry 5.0 to its sub-value. First, the following steps are followed to evaluate the human-centric sub-values.

- Step 1: This value has six sub-values.
- Step 2: Apply a pairwise comparison based on a qualitative scale shown in Table 2. In this step, the evaluation will be constructed based on the questionnaire conducted by the three experts. The three expert's questionnaire result is shown in Table 12 (see Appendix) as a pairwise comparison matrix. The equivalent neutrosophic evaluation matrix is shown in Table 13 (see Appendix).
- Step 3: Calculate the crisp evaluation matrix of each expert comparison matrix.
- Steps 4 and 5: Normalized evaluation matrix of the first expert.
- Step 6: The average consistency is 6. By calculating the Consistency Index, We find CI as 0, indicating that the pairwise comparison is consistent. Furthermore, the consistency ratio is zero, meaning that the matrix is consistent.

Table 4 Concluding weight of the 18 sub-values of industry 5.0 technologies regarding the healthcare sector

	Expert 1	Expert 2	Expert 3	Concluding weight	Rank
A1	0.0848	0.0872	0.0854	0.0858	1
A2	0.0860	0.0836	0.0858	0.0851	2
A3	0.0466	0.0423	0.0427	0.0439	10
A4	0.0428	0.0431	0.0430	0.0430	12
A5	0.0689	0.0706	0.0686	0.0694	6
A6	0.0621	0.0613	0.0628	0.0621	8
B1	0.0802	0.0801	0.0781	0.0795	4
B2	0.0565	0.0571	0.0585	0.0574	9
B3	0.0297	0.0310	0.0284	0.0297	17
B4	0.0385	0.0360	0.0379	0.0375	14
B5	0.0706	0.0751	0.0750	0.0736	5
C1	0.0437	0.0431	0.0438	0.0435	11
C2	0.0659	0.0640	0.0669	0.0656	7
C3	0.0824	0.0820	0.0828	0.0824	3
C4	0.0440	0.0429	0.0417	0.0429	13
C5	0.0287	0.0287	0.0287	0.0287	18
C6	0.0324	0.0344	0.0335	0.0334	16
C7	0.0363	0.0374	0.0364	0.0367	15

The pairwise comparison of the second and third experts is illustrated in Table 14 (see Appendix). Finally, the aggregated weight of human-centric sub-values is shown in Table 9 (see Appendix). The same previous steps will be applied in order to evaluate the sustainability and resilience sub-values based on the three experts under neutrosophic theory. The concluding weight and the rank of sub-values corresponding to sustainability and resilience are shown in Tables 10 and 11 (see Appendix). Figure 4 shows the weight of human-centric, sustainability, and resilience and their corresponding sub-values.

Secondly, the second level of AHP evaluation will be to weigh the 18 sub-values to each other based on the three healthcare experts. The same steps of AHP will be applied, but the evaluation matrix will be constructed based on the qualitative scale, as shown in Table 2. The comparison matrix in the form of linguistic variables, neutrosophic numbers, normalized matrix, and weight are shown in

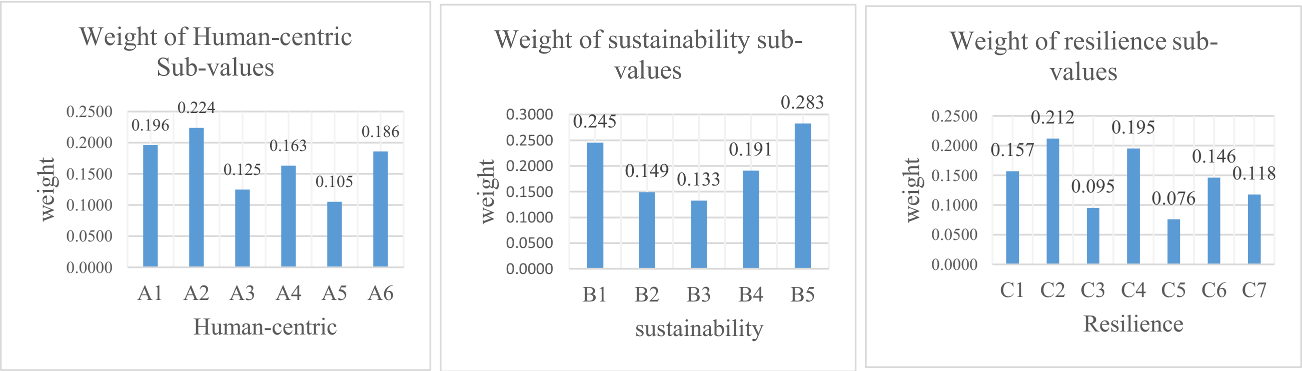


Fig. 4 The weight of industry 5.0 main values and their corresponding sub-values using neutrosophic AHP

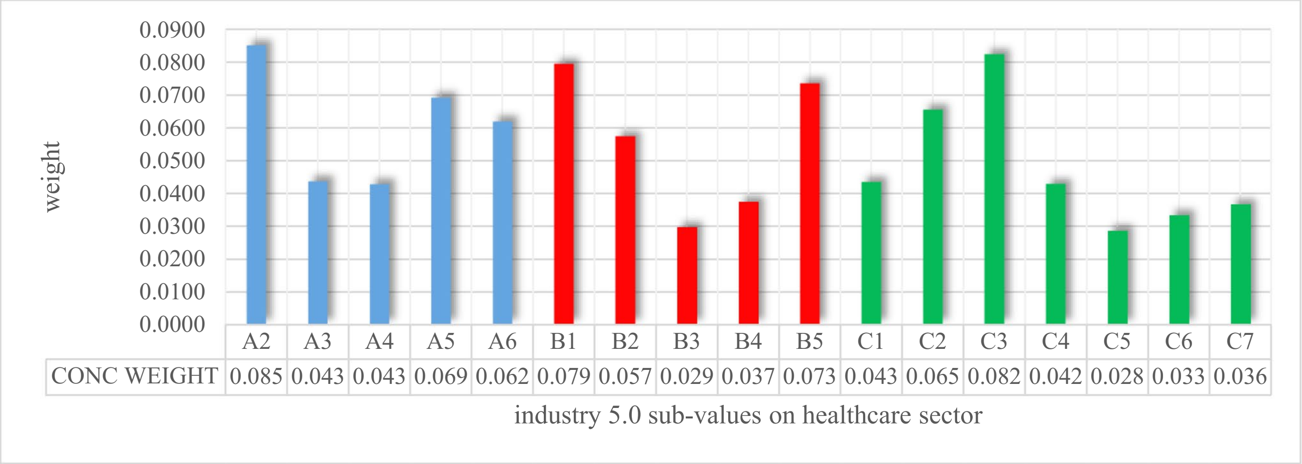


Fig. 5 The weight of industry 5.0 sub-values using neutrosophic AHP

Table 5 The closeness coefficient and ranking of the nine technologies using TOPSIS

Technologies	PIS	NIS	CC	Rank
Nano-technology	0.0601	0.0570	0.4868	7
5G technology	0.0358	0.0721	0.6684	4
Drone technology	0.0626	0.0513	0.4506	8
Blockchain	0.0414	0.0654	0.6123	6
Robots	0.0655	0.0522	0.4439	9
Big data	0.0372	0.0666	0.6414	5
IoT	0.0208	0.0720	0.7757	3
AI	0.0179	0.0734	0.8041	1
Cloud computing	0.0197	0.0737	0.7889	2

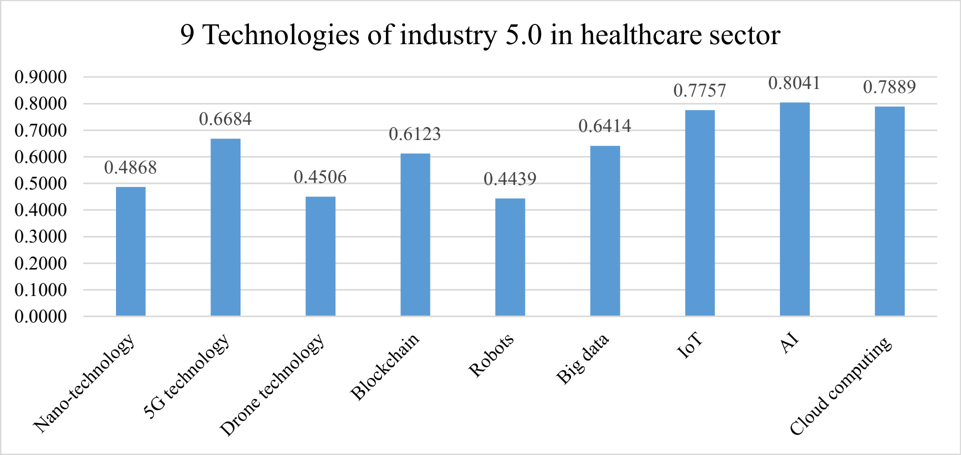
Tables 15, 16, 17, 18, and 19 (see Appendix). The concluding weight of the three experts' evaluation of the sub-values is shown in Table 4 using AHP under a neutrosophic environment. Figure 5 summarizes the weight of the 18 sub-values.

5.2 Phase 3: Evaluation of Nine Technologies of Industry 5.0 Related to Healthcare and 18 Sub-Values Using TOPSIS

The third phase of the proposed framework will be applied in this subsection. This phase examines the nine healthcare-related technologies specified in Sect. 3.2. The assessment procedure will be implemented based on the 18 sub-values of these technologies.

- Step 7: the comparison matrix of the nine technologies is conducted based on the importance of linguistic variables, as shown in Table 3. The evaluation matrix is shown in Table 20 (see Appendix). Hence, the equivalent

Fig. 6 The ranking of the nine technologies related to the healthcare sector based on their sub-values using TOPSIS



neutrosophic evaluation matrix is shown in Table 21 (see Appendix).

- Step 8: in this step, the crisp evaluation matrix is calculated using Eq. 3. While the normalized evaluation matrix is calculated using Eq. 6. This step's results are shown in Tables 22 and 23 (see Appendix).
- Steps 9 and 10: Calculate the weighted normalized matrix using Eq. 7. Here, we will utilize the weight of the sub-values found from Phase 2, as shown in Table 24 (see Appendix). In addition, the PIS and NIS were determined, as represented in Table 5.
- Step 11: the distance from PIS and NIS was calculated according to Eqs. 12 and 13.
- Step 12: the ranking of the nine technologies of Industry 5.0 related to the healthcare sector is represented in Table 5 and Fig. 6 based on the closeness coefficient as a result of Eq. 14.

5.3 Results Discussion and Managerial Implications

In this sub-section, we will discuss the application of the proposed framework and clarify the results of each phase. The application of AHP in this framework considered the evaluation of Industry 5.0 main values (human-centric, sustainability, and resilience) and its corresponding sub-values on healthcare service.

Firstly, we apply the AHP to each one of the main values, six sub-values related to human-centric values. By applying the AHP, we found that A2, which is "Disease detection that is automated and accurate," is the most important sub-value as a result of the first healthcare expert evaluation with a weight of 0.2241. Followed by A1, "Assist healthcare providers with constant surveillance and monitoring" with a weight of 0.1963, then A6, "Assisting healthcare practitioners with repetitious duties, "with a weight of 0.1860. The last three sub-values of human-centric are ranked as follows: A4, "Assist the early detection of diseases" with a weight of 0.1634, then A3, "Accomplishment Nanoscale surgeries" with a weight of 0.1247, and in the last rank, A5 "Better use of robotic surgical systems with expert guidance" with weight 0.1055.

Secondly, the result of neutrosophic AHP that was applied to sustainability sub-values shows that B5 is the most touching sub-value of sustainability with a weight of 0.2826, as Table 10 (see Appendix) shows. The remaining sub-values of sustainability are ranked as follows: B1 with a weight of 0.2450, B4 with a weight of 0.1908, B2 with a weight of 0.1488, and the final rank is B3 with a weight of 0.1328.

Third, the ranking of resilience sub-values as a result of neutrosophic AHP is as follows. C2 with a weight of 0.2121, C4 with a weight of 0.1951, C1 with a weight of 0.1572, C6 with a weight of 0.1464, C7 with a weight of 0.1178, C3 with a weight of 0.0955, C5 with weight 0.0759.

The second level of neutrosophic AHP is applied to weigh the 18 sub-values of industry 5.0 technologies regarding the healthcare sector. Table 4 and Fig. 5 show that the top three sub-values are A2, A1, and C3; their weights are 0.0860, 0.0848, and 0.0824, respectively. On the other hand, the last three sub-values are C6, B3, and C5; their weights are 0.0324, 0.0297, and 0.0287, respectively. As we can see, the most successful sub-values of industry 5.0 technologies in healthcare services are thinking about how to employ smart devices to deliver the best diagnostic with the help of healthcare experts. However, all the sub-values that were previously determined play an important role in providing a distinguished health service by relying on Industry 5.0 technologies rather than traditional smart healthcare services.

The second phase of the proposed framework considers the evaluation of industry 5.0 nine technologies regarding the healthcare sector using neutrosophic TOPSIS. This phase is based on the weights of the 18 sub-values found from the previous phase (AHP). Table 5 and Fig. 6 show that the most influential technology is AI and Cloud computing, with closeness coefficients of 0.8041 and 0.7889, respectively. As observed, IoT and AI almost have the same closeness coefficient, which implies that they play a significant role in healthcare systems based on industry 5.0 technologies, especially in the management of smart medical devices utilized in the phases of diagnosis and follow-up treatment, as well as in the procedures of recording medical data for patients. If we classify the nine technologies into three levels, 5G IoT, big data, and blockchain are coming in the second level affects the healthcare sector. In contrast, the third level will have nano-technology, drones, and robots.

This framework has the ability to assist managers in identifying service quality gaps for smart healthcare services, as well as to offer healthcare management insights for creating and implementing a service quality improvement program. Moreover, the outcome of neutrosophic AHP-TOPSIS directs the attention of smart healthcare management to industry 5.0 technologies that primarily address human intelligence to deliver more resilient and sustainable service. Particular focus is directed to technologies that assist emotional prediction, which is absent in traditional healthcare solutions that depend solely on technical aspects. The application of the neutrosophic theory can accommodate vagueness and ambiguity compared with other approaches. Furthermore, the neutrosophic theory makes it easier for healthcare professionals to react to service quality measurement standards utilizing linguistic expression. This implies that when decision-makers and stakeholders focus on the ultimate goal of selecting a technology that assists the healthcare professionals in providing the best service in the healthcare sector.

The findings of this study have a wide range of theoretical implications for the researchers. The current work has first explored the list of benefits of Industry 5.0 that must be taken into account while building a smart healthcare system in the post-COVID-19 future. This study has brought attention to the relationship between industrial 5.0 technologies and smart healthcare services, which could aid researchers in developing more durable solutions in the future. This study has provided a new and integrated framework for modeling Industry 5.0's smart technologies to develop resilient and sustainable smart healthcare systems. This framework combines neutrosophic AHP with TOPSIS, which may give future researchers a new perspective on how to use such a combination with other approaches to find the relevant interest aspects. The results of using the suggested framework also have a number of managerial implications. The current COVID-19 epidemic has created an uncertain business climate, forcing healthcare providers to reconsider the efforts and strategies they need to implement in order to provide smart, resilient, and sustainable healthcare services. The recommended solutions, such as AI, cloud computing, and IoT in the development of the healthcare industry, could be useful in helping operations managers and service providers come up with the best strategies to create a resilient healthcare system.

6 Comparative Analysis

The same AHP data are utilized in this comparison study to assess the efficacy of various ranking methods. The first methodology is AHP-CODAS (Büyüközkan & Mukul, 2020), utilized to evaluate smart healthcare technologies. They evaluate different healthcare technologies (Cloud computing, IoT, big data, 3D Printers, AI, robotics) under different criteria. The criteria and alternatives are identified based on academic research and expert opinions. While checking the validity of these results, the same alternatives are tested against a variety of current techniques from the literature to prove the methodology's efficiency and performance when compared to those approaches.

According to the weights in Table 4 found from AHP, we rank the nine technologies using the AHP-CODAS technique, as Table 6 and Fig. 7 show. The result of the comparison shows that there are similar rankings for both techniques. For instance, the top three technologies using TOPSIS are AI, cloud computing, and IoT, while using CODAS are cloud computing, AI, and 5G. On the other side, the last three technologies using TOSIS are nano-technology, drone technology, and robots, while using CODAS are nano-technology, robots, and drone. However, the proposed neutrosophic AHP-TOPSIS is more highly considering the uncertainty than

Table 6 Assessment score of nine technologies using the AHP-CODAS technique

Technologies	Cloud computing	Drone Technology	AI	IoT	Robots	Blockchain	Big data	Nano-technology	5G technology	AS
Cloud computing	0.0000	−0.0151	0.0057	−0.0084	0.0047	−0.0096	−0.0150	−0.0164	−0.0167	−0.0708
Drone Technology	0.0151	0.0000	0.0208	0.0066	0.0199	0.0054	0.0001	−0.0014	−0.0016	0.0649
AI	−0.0057	−0.0207	0.0000	−0.0141	−0.0009	−0.0153	−0.0206	−0.0220	−0.0223	−0.1216
IoT	0.0084	−0.0066	0.0141	0.0000	0.0132	−0.0012	−0.0066	−0.0080	−0.0083	0.0050
Robots	−0.0047	−0.0198	0.0009	−0.0131	0.0000	−0.0144	−0.0197	−0.0211	−0.0214	−0.1133
Blockchain	0.0097	−0.0054	0.0153	0.0012	0.0144	0.0000	−0.0053	−0.0068	−0.0070	0.0161
Big data	0.0150	−0.0001	0.0207	0.0066	0.0198	0.0054	0.0000	−0.0015	−0.0017	0.0643
Nano-technology	0.0165	0.0014	0.0222	0.0080	0.0213	0.0068	0.0015	0.0000	−0.0003	0.0774
5G technology	0.0168	0.0016	0.0224	0.0083	0.0215	0.0071	0.0017	0.0003	0.0000	0.0796

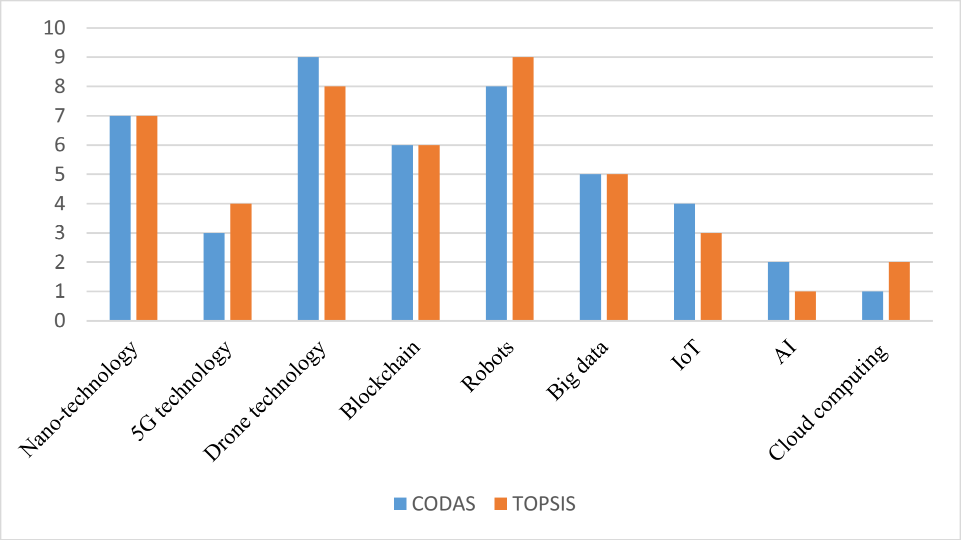


Fig. 7 Comparison of ranking results using CODAS and TOPSIS

Table 7 Comparison between AHP-CODAS and AHP-TOPSIS

Comparison sided	AHP-CODAS	AHP-TOPSIS
The evaluation environment	Fuzzy	Neutrosophic
Type of modification	Hybridization	Hybridization
Technologies to be evaluated	Cloud computing, IoT, big data, 3D Printers, AI, robotics	Industry 5.0 technologies (cloud computing, robotics, blockchain, 5 G technology, big data, drone technology, artificial intelligence, internet of things, and nano-technology)
Evaluation Attributes/criteria	Technology-based, Human-based, system-based, organization-based	Human-centric, sustainability, resilience
Ranking of nine technologies	Cloud computing – AI – 5G –IoT – Big data –Block chain – Nano-technology –Robots – Drone	AI – Cloud computing – IoT – 5G – Big data –Block chain – Nano-technology – Drone – Robots
Correlation coefficient	0.95	–

other techniques. These differences may be used to assess the presented approach's success, efficiency, reliability, applicability, and superiority. In order to check the correspondence between these two techniques, we used the Spearman correlation coefficient, which must be more than 0.800 to have correspondence between them. As shown in Table 7, we find that the correlation coefficient is 0.95, which shows no similarity between them in the ranking result. That means the proposed neutrosophic AHP-TOPSIS has priority over fuzzy AHP-CODAS with higher consideration of uncertainty.

7 Sensitivity Analysis

We conducted a sensitivity analysis to ensure the veracity of our findings. To check the sensitivity of the results, we change the weight of the 18 sub-values according to the qualitative scale, as Table 2 shows. In this work, we employed TNNs. Hence, the possibilities of instability are lower, yet, we conducted a sensitivity analysis to corroborate our results. Since sub-value weights have a major impact on rank, any modifications in weight value should be carefully addressed. Figure 8 depicts the results, which indicate stability as weight is changed. The change in closeness coefficient in sub-values is lower or equal to the change in weight, indicating that the model and findings are stable. We note that the first seven scenarios have the same values if all sub-values have the same qualitative scale evaluation. Moreover, as Table 8 shows, other scenarios show that when the sub-values evaluation weight increased, the evaluation of the technologies slightly increased as a result. Obviously, changing the weights of the sub-values does not change the rank significantly.

8 Challenges and Future Directions

8.1 Industry 5.0 Challenges

Future-focused is the main literary stream in Industry 5.0. In contrast to Industry 4.0, which appears to have a specific

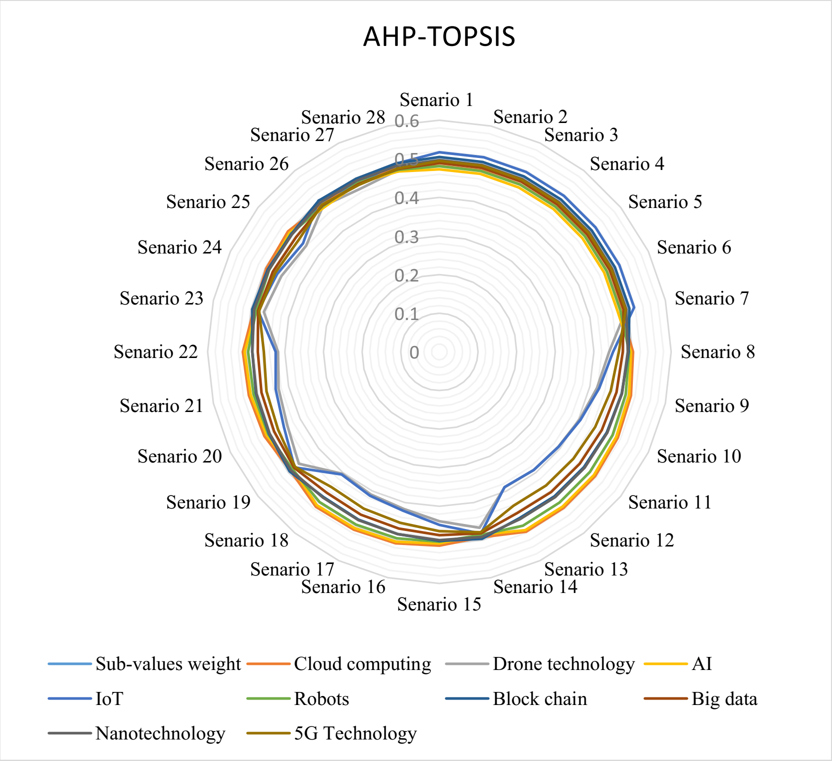


Fig. 8 Sensitivity analysis of AHP-TOPSIS using differing sub-value weights

technology-oriented goal, i.e., the use of digital technologies to solve specific production issues and improve productivity, Industry 5.0 follows a more comprehensive goal with a more customer-centric as well as a more human-centric view in general. Therefore, one may contend that Industry 5.0 is value-driven rather than technology-driven from two points. First, Industry 5.0 regards humans as consumers who demand highly customized products. Second, workers with the necessary skills can work alongside robots to make this happen. For instance, transferring patients from their homes to hospitals for standard checkups is very challenging in the modern era. Waiting time, transportation duration, and the risk of patients catching different infections while passing through this unsafe environment are just a few of the difficulties. The healthcare sector is now concentrating on in-home healthcare services, which let patients conduct physicals in the convenience of their own homes. Industry 5.0 technology can accomplish this easily, quickly, and accurately.

The effective and efficient delivery of healthcare services is critical to combating emerging diseases and promoting healthy lives and population well-being. Achieving full benefit from the advantages of the technologies that characterize the fifth generation of industry in the healthcare field is an interesting matter in light of the spread of epidemics and pandemics that the world is witnessing in recent times. Even though Industry 5.0 has the potential to transform a diverse range of industries completely, several obstacles have to be overcome, such as how to handle large datasets and manage resources. However, many challenges prevent the optimal realization of these advantages that serve the best provision of health service. One of the most important of these challenges is security. Security issues must be checked when managing massive data and employing cloud computing for industrial data management. The use of automation and AI in Industry 5.0 presents threats to the business, whereby it should enable reliable security. Maintaining patient data privacy, especially in the healthcare industry, is one of the most crucial considerations that must be made to provide patients with successful healthcare and prevent ethical problems.

The reorganization of work led by humans and their collaboration with the robot, which necessitates coordination of work between them, is one of the challenges facing the application of industry 5.0 technologies. People should acquire competent abilities to work with sophisticated robots and learn about cooperating with robots and innovative machine manufacturers. Scalability in Industry 5.0 refers to a system's performance in various working situations, regardless of whether there are more or less hyper-connected systems available in the network. Scalability becomes a more severe obstacle when creating a companionship between humans and machines or robots by sharing their tasks.

Table 8 The sensitivity analysis of TNNs based AHP-TOPSIS technique

Scenario #	Sub-values weight	Cloud computing	Drone technology	AI	IoT	Robots	Blockchain	Big data	Nano-technology	5G Technology
1	All sub-values VWS	0.4818	0.4966	0.4729	0.5168	0.4808	0.5046	0.4893	0.4962	0.4945
2	All sub-values WS	0.4818	0.4966	0.4729	0.5168	0.4808	0.5046	0.4893	0.4962	0.4945
3	All sub-values PS	0.4818	0.4966	0.4729	0.5168	0.4808	0.5046	0.4893	0.4962	0.4945
4	All sub-values ES	0.4818	0.4966	0.4729	0.5168	0.4808	0.5046	0.4893	0.4962	0.4945
5	All sub-values SS	0.4818	0.4966	0.4729	0.5168	0.4808	0.5046	0.4893	0.4962	0.4945
6	All sub-values VSS	0.4818	0.4966	0.4729	0.5168	0.4808	0.5046	0.4893	0.4962	0.4945
7	All sub-values AS	0.4818	0.4966	0.4729	0.5168	0.4808	0.5046	0.4893	0.4962	0.4945
8	half sub-values VWS, half sub-values WS	0.5016	0.4394	0.4961	0.4493	0.4912	0.4896	0.4749	0.4875	0.4647
9	half sub-values VWS, half sub-values PS	0.5083	0.4184	0.5034	0.4241	0.4947	0.4844	0.4700	0.4845	0.4547
10	half sub-values VWS, half sub-values ES	0.5129	0.4029	0.5084	0.4053	0.4972	0.4809	0.4665	0.4825	0.4477
11	half sub-values VWS, half sub-values SS	0.5155	0.3940	0.5111	0.3945	0.4986	0.4789	0.4646	0.4814	0.4439
12	half sub-values VWS, half sub-values VSS	0.5162	0.3914	0.5119	0.3913	0.4990	0.4783	0.4640	0.4810	0.4428
13	half sub-values VWS, half sub-values AS	0.5168	0.3894	0.5125	0.3888	0.4993	0.4779	0.4636	0.4808	0.4419
14	half sub-values WS, half sub-values PS	0.4921	0.4675	0.4853	0.4825	0.4862	0.4968	0.4818	0.4917	0.4789
15	half sub-values WS, half sub-values ES	0.5020	0.4383	0.4965	0.4479	0.4914	0.4893	0.4746	0.4873	0.4642
16	half sub-values WS, half sub-values SS	0.5087	0.4168	0.5039	0.4221	0.4950	0.4841	0.4696	0.4843	0.4540
17	half sub-values WS, half sub-values VSS	0.5109	0.4096	0.5063	0.4135	0.4962	0.4824	0.4680	0.4834	0.4507
18	half sub-values WS, half sub-values AS	0.5127	0.4035	0.5082	0.4061	0.4971	0.4810	0.4666	0.4826	0.4480
19	half sub-values PS, half sub-values ES	0.4930	0.4649	0.4864	0.4795	0.4867	0.4961	0.4811	0.4913	0.4776
20	half sub-values PS, half sub-values SS	0.5023	0.4372	0.4969	0.4466	0.4916	0.4890	0.4744	0.4872	0.4636
21	half sub-values PS, half sub-values VSS	0.5056	0.4270	0.5005	0.4344	0.4933	0.4865	0.4719	0.4857	0.4587
22	half sub-values PS, half sub-values AS	0.5084	0.4178	0.5036	0.4234	0.4948	0.4843	0.4698	0.4845	0.4544
23	half sub-values ES, half sub-values SS	0.4926	0.4662	0.4858	0.4810	0.4864	0.4964	0.4815	0.4915	0.4782
24	half sub-values ES, half sub-values VSS	0.4970	0.4533	0.4909	0.4657	0.4888	0.4931	0.4783	0.4895	0.4716
25	half sub-values ES, half sub-values AS	0.5011	0.4408	0.4956	0.4509	0.4910	0.4899	0.4752	0.4877	0.4654
26	half sub-values SS, half sub-values VSS	0.4866	0.4833	0.4788	0.5011	0.4833	0.5010	0.4858	0.4941	0.4873
27	half sub-values SS, half sub-values AS	0.4916	0.4692	0.4846	0.4845	0.4859	0.4972	0.4822	0.4919	0.4798
28	half sub-values VSS, half sub-values AS	0.4868	0.4827	0.4790	0.5004	0.4834	0.5008	0.4856	0.4940	0.4870

Data management is a significant challenge in the application of industry 5.0 technologies. Manufacturers need to ensure that their data management systems are capable of managing the vast volumes, types, and speeds of data produced by the Industry 5.0 environment. Additionally, this data needs to be protected from unauthorized access, which might risk the accuracy of the manufacturing process. In addition, One of the issues that need to be resolved in addition to technical ones. The necessity to understand complicated cybersecurity and data privacy laws is one such difficulty. It is crucial to maintain data privacy and that systems are safe from cyber attacks as more data is created and exchanged across various technologies and systems. Industry 5.0 also poses security and privacy issues with data. Sensitive and private data may become less secure due to the growing usage of data-driven decision-making processes and sophisticated technologies. Legislators must create strong data protection laws and guidelines to guarantee that personal data is utilized ethically and legally.

8.2 Future Directions: How Industry 5.0 Technologies Affect Healthcare Business Supply Chains

Healthcare is regarded as a basic requirement for survival; hence, examining the characteristics of an intelligent and sustainable supply chain may assist a nation in developing solutions to battle the healthcare issue. Industry 5.0 implies a digital revolution that has changed company models, processes, goods, and services in favor of a more efficient and customer-focused approach to managing businesses and their supply chains. As mass customization is a core idea in Industry 5.0, this aids supply chain management (SCM) in incorporating it into their manufacturing processes. With the introduction of new technologies, industry 5.0 research is expanding and offers lucrative potential for future developments.

By saving costs, minimizing unnecessary deviations, and improving patient care and engagement, the integration of industry 5.0 technologies into supply chains offers another category to healthcare systems. IoT, cloud computing, robots, blockchain, and 5 G technologies are some of Industry 5.0 technologies that can improve the level of service through real-time information exchange, visibility, traceability, agility, and connection throughout the supply chain phases (Ali & Kannan, 2022).

Healthcare supply chains have seen several challenges and significant changes over the past two years as a result of efforts to adapt to global health pandemics. As a result, business owners in the healthcare industry are more focused on the resilience of the healthcare supply chains and their ability to deal with these pandemics. Supply chain resilience refers to a supply chain's capacity to manage inevitable threats and bounce back quickly from disruptions, either to their pre-disrupted condition or to a new, more desired one. Creating supply chains that are flexible and sensitive to changes in demand by introducing new items, altering volume, controlling transactions in manufacturing and delivery, or customizing product and service characteristics to match consumer demands is a typical response to these disturbances (Gatenholm & Halldórsson, 2023). Higher degrees of interconnection and automation throughout the healthcare supply chain stages are made possible by the incorporation of industry 5.0 technologies, including IoT, AI, and big data, producing greater resilience outcomes. This is accomplished by transferring real-time data across a 5G network between supply chain stages, accommodating rapid responses to unexpected distribution and enhancing resilience (Tortorella et al., 2022). Rapid response and high-quality service will be our recommendation and value creation for the healthcare system and supply chains.

The influence of robotics, AI, and big data approaches on diagnostic, maintenance, and prediction tools in healthcare supply chains can also be studied in future research. We recommend more studies on preserving credibility, harmonies, and effective human–machine interactions and increasing the cooperation of workers and automated machines in the healthcare supply chain processes. We also draw attention to the need for more study on how industry 5.0 technologies might be used to provide a sustainable supply chain for healthcare.

9 Conclusion

Industry 5.0 is an initiative to bring back human labor in the workplace, where man and machine would collaborate to improve process efficiency by fully utilizing human intelligence and creativity through the way they interact with the current intelligent technologies. Growing digital technologies continue to advance, presenting previously unanticipated potential in global health systems to improve healthcare service delivery. However, traditional smart healthcare systems fail to recognize emotions due to their focus on the purely technical aspect and their inability to link these devices and technologies to the critical role of humans. Industry 5.0 technologies presented many technologies that move towards human-centric, sustainability, and flexibility in society and industry in many sectors, especially healthcare. Particularly in the last two years, it has been evident how critical new technologies in the healthcare field are in combating the COVID-19 epidemic worldwide, and they provide excellent results. As a result, this research proposes an integrated AHP-TOPSIS framework. The study was performed under neutrosophic conditions since the evaluation process by experts is subject to uncertainty.

This research aims to investigate and study the influence of industry 5.0 technologies on the healthcare sector. Nine technologies are considered in this study that is related to healthcare systems and healthcare supply chains—they are cloud computing, robotics, blockchain, 5G technology, big data, drone technology, artificial intelligence, the internet of things, and nano-technology. The evaluation process is based on the three main values of Industry 5.0: human-centric, sustainability, and resilience. Each value has sub-values that influence the healthcare service.

The proposed framework is divided into two main phases. The first is the evaluation of industry 5.0 technologies' main values and their sub-values using neutrosophic AHP. This phase is divided into two steps, and the first is the evaluation of each main value and its corresponding sub-values. The second part is to weigh the 18 sub-value of the nine technologies regarding healthcare services. The results show that "Disease detection that is automated and accurate", "Assist healthcare providers with constant surveillance and monitoring", and "Encourages the integration of smart medical devices in addition to the remote exchange of health data" are the most significant sub-values that affect the healthcare sector. The second main phase is ranking the nine technology based on the 18 sub-value using TOPSIS under a neutrosophic environment. The result of this phase shows that IoT and cloud computing are the two main influential technologies.

One of the essential aspects of this study is its application to various sectors that rely on industry 5.0 technologies due to the differences between these technologies and their influence on the performance of this industry. Although this study addressed many aspects and technologies that influence healthcare service performance, it should have considered the consequences of using these technologies, such as data security and privacy, technological infrastructure, a lack of e-health regulatory laws, a lack of funding, and other consequences. Moreover, future research can be done to identify the difficulties Industry 5.0 technologies encounter and come up with a workable solution. Also, Future studies can be done to enhance intelligent control by enhancing the existing pattern recognition algorithms as human–machine contact increases.

Appendix

Table 9 Concluding weight of the sub-values of human-centric

	Expert 1	Expert 2	Expert 3	Concluding weight	Rank
A1	0.1927	0.2014	0.1950	0.1963	2
A2	0.2042	0.2355	0.2327	0.2241	1
A3	0.1274	0.1344	0.1123	0.1247	5
A4	0.1780	0.1513	0.1608	0.1634	4
A5	0.1096	0.0957	0.1112	0.1055	6
A6	0.1882	0.1818	0.1880	0.1860	3

Table 10 Concluding weight of the sub-values of sustainability

	Expert 1	Expert 2	Expert 3	Concluding weight	Rank
B1	0.2351	0.2604	0.2396	0.2450	2
B2	0.1630	0.1367	0.1468	0.1488	4
B3	0.1417	0.1338	0.1229	0.1328	5
B4	0.1867	0.1936	0.1921	0.1908	3
B5	0.2735	0.2756	0.2987	0.2826	1

Table 11 Concluding weight of the sub-values of resilience

	Expert 1	Expert 2	Expert 3	Concluding weight	Rank
C1	0.1487	0.1738	0.1491	0.1572	3
C2	0.2083	0.2219	0.2060	0.2121	1
C3	0.0975	0.0887	0.1002	0.0955	6
C4	0.2044	0.1888	0.1921	0.1951	2
C5	0.0783	0.0729	0.0767	0.0759	7
C6	0.1458	0.1344	0.1592	0.1464	4
C7	0.1171	0.1195	0.1168	0.1178	5

Table 12 Pairwise comparison of three expertise on human-centric values based on qualitative scale

	Human-centric					
	A1	A2	A3	A4	A5	A6
Expert 1						
A1	ES	ES	VSS	ES	SS	ES
A2	ES	ES	VSS	ES	SS	SS
A3	WS	PS	ES	PS	ES	PS
A4	PS	ES	SS	ES	SS	ES
A5	WS	WS	ES	WS	ES	WS
A6	ES	ES	SS	ES	SS	ES
Expert 2						
A1	ES	PS	VSS	SS	SS	ES
A2	SS	ES	SS	SS	SS	SS
A3	WS	WS	ES	ES	ES	PS
A4	WS	WS	ES	ES	SS	ES
A5	VWS	VWS	ES	WS	ES	WS
A6	ES	WS	SS	ES	VSS	ES
Expert 3						
A1	ES	ES	SS	ES	VSS	PS
A2	ES	ES	AS	ES	AS	SS
A3	VWS	WS	ES	PS	ES	WS
A4	PS	WS	ES	ES	SS	PS
A5	WS	VWS	ES	PS	ES	WS
A6	ES	PS	SS	ES	SS	ES

Table 13 Pairwise comparison of three expertise on human-centric values based on triangular neutrosophic numbers

Human-centric				
	A1	A2	…	A6
Expert 1				
A1	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	…	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩
A2	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	…	⟨(0.7, 0.75, 0.8);0.9, 0.2, 0.2⟩
A3	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	⟨(0.45, 0.3, 0.5);0.6, 0.1, 0.2⟩	…	⟨(0.45, 0.3, 0.5);0.6, 0.1, 0.2⟩
A4	⟨(0.45, 0.3, 0.5);0.6, 0.1, 0.2⟩	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	…	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩
A5	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	…	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩
A6	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	…	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩
Expert 2				
A1	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.45, 0.3, 0.5);0.6, 0.1, 0.2⟩	…	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩
A2	⟨(0.7, 0.75, 0.8);0.9, 0.2, 0.2⟩	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	…	⟨(0.7, 0.75, 0.8);0.9, 0.2, 0.2⟩
A3	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	…	⟨(0.45, 0.3, 0.5);0.6, 0.1, 0.2⟩
A4	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	…	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩
A5	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	…	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩
A6	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	…	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩
Expert 3				
A1	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	…	⟨(0.45, 0.3, 0.5);0.6, 0.1, 0.2⟩
A2	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	…	⟨(0.7, 0.75, 0.8);0.9, 0.2, 0.2⟩
A3	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	…	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩
A4	⟨(0.45, 0.3, 0.5);0.6, 0.1, 0.2⟩	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	…	⟨(0.45, 0.3, 0.5);0.6, 0.1, 0.2⟩
A5	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	…	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩
A6	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.45, 0.3, 0.5);0.6, 0.1, 0.2⟩	…	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩

Table 14 Normalization, weight, weighted sums, and for the human-centric sub-values by the second and third expert

Human-centric									
	A1	A2	A3	A4	A5	A6	Weight	WS	Rank
Expert 2									
A1	0.2128	0.2006	0.2174	0.2206	0.1787	0.1780	0.2014	1.2082	2
A2	0.2956	0.2826	0.1881	0.2206	0.1787	0.2473	0.2355	1.4129	1
A3	0.1104	0.1465	0.1355	0.1588	0.1287	0.1264	0.1344	0.8062	5
A4	0.1104	0.1465	0.1355	0.1588	0.1787	0.1780	0.1513	0.9079	4
A5	0.0581	0.0771	0.1355	0.0824	0.1287	0.0923	0.0957	0.5740	6
A6	0.2128	0.1465	0.1881	0.1588	0.2065	0.1780	0.1818	1.0909	3
Expert 3									
A1	0.2222	0.2488	0.1817	0.1845	0.1946	0.1382	0.1950	1.1699	2
A2	0.2222	0.2488	0.2442	0.1845	0.2263	0.2704	0.2327	1.3963	1
A3	0.0606	0.1290	0.1308	0.1310	0.1212	0.1010	0.1123	0.6736	5
A4	0.1577	0.1290	0.1308	0.1845	0.1684	0.1947	0.1608	0.9651	4
A5	0.1152	0.0679	0.1308	0.1310	0.1212	0.1010	0.1112	0.6670	6
A6	0.2222	0.1766	0.1817	0.1845	0.1684	0.1947	0.1880	1.1280	3

Table 15 Evaluation matrix of industry 5.0 sub-values in regard to healthcare sector based on importance linguistic variables

Expert 1	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	C6	C7
A1	ES	ES	VSS	VSS	SS	SS	ES	VSS	AS	VSS	ES	VSS	SS	ES	VSS	AS	AS	VSS
A2	ES	ES	VSS	VSS	SS	SS	ES	VSS	AS	AS	ES	VSS	SS	ES	VSS	AS	AS	AS
A3	WS	WS	ES	ES	WS	ES	VWS	WS	SS	ES	WS	ES	PS	VWS	ES	SS	SS	SS
A4	VWS	VWS	ES	ES	WS	ES	VWS	WS	SS	ES	WS	ES	PS	VWS	PS	SS	SS	SS
A5	WS	WS	VSS	SS	ES	ES	ES	SS	VSS	VSS	ES	SS	ES	PS	SS	VSS	VSS	VSS
A6	WS	WS	SS	ES	ES	ES	PS	ES	SS	SS	PS	ES	ES	ES	SS	VSS	VSS	SS
B1	ES	ES	VSS	SS	ES	SS	ES	SS	AS	VSS	ES	SS	SS	ES	VSS	AS	SS	VSS
B2	VWS	VWS	SS	ES	ES	ES	PS	ES	SS	SS	PS	ES	ES	WS	SS	VSS	VSS	SS
B3	VWS	VWS	WS	WS	VWS	WS	VWS	WS	ES	PS	VWS	WS	WS	VWS	PS	ES	ES	PS
B4	VWS	VWS	ES	ES	VWS	WS	VWS	PS	SS	ES	VWS	PS	WS	WS	ES	SS	ES	ES
B5	WS	WS	VSS	VSS	ES	ES	ES	SS	AS	VSS	ES	SS	ES	PS	SS	AS	VSS	VSS
C1	VWS	VWS	ES	ES	WS	ES	VWS	WS	SS	ES	PS	ES	PS	VWS	PS	SS	SS	SS
C2	WS	VWS	VSS	SS	ES	ES	ES	SS	VSS	VSS	ES	SS	ES	WS	SS	SS	VSS	VSS
C3	ES	ES	VSS	SS	SS	SS	ES	SS	AS	VSS	ES	VSS	SS	ES	VSS	AS	SS	VSS
C4	WS	VWS	ES	ES	VWS	ES	VWS	WS	SS	ES	WS	ES	PS	VWS	ES	SS	SS	SS
C5	VWS	VWS	WS	WS	VWS	WS	VWS	WS	ES	WS	VWS	WS	WS	VWS	WS	ES	ES	PS
C6	VWS	VWS	WS	WS	VWS	VWS	VWS	WS	SS	ES	VWS	PS	WS	VWS	PS	SS	ES	ES
C7	VWS	VWS	ES	ES	VWS	VWS	VWS	WS	SS	ES	VWS	PS	WS	WS	PS	SS	ES	ES

Table 16 Evaluation matrix of industry 5.0 sub-values in regard to healthcare sector based on neutrosophic numbers

Expert 1	A1	A2	…	C6	C7
A1	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	…	⟨(0.95, 0.90, 0.95);0.9, 0.10, 0.10⟩	⟨(0.85, 0.8, 0.95);0.8, 0.1, 0.2⟩
A2	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	…	⟨(0.95, 0.90, 0.95);0.9, 0.10, 0.10⟩	⟨(0.95, 0.90, 0.95);0.9, 0.10, 0.10⟩
A3	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	…	⟨(0.7, 0.75, 0.8);0.9, 0.2, 0.2⟩	⟨(0.7, 0.75, 0.8);0.9, 0.2, 0.2⟩
A4	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	…	⟨(0.7, 0.75, 0.8);0.9, 0.2, 0.2⟩	⟨(0.7, 0.75, 0.8);0.9, 0.2, 0.2⟩
A5	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	…	⟨(0.85, 0.8, 0.95);0.8, 0.1, 0.2⟩	⟨(0.85, 0.8, 0.95);0.8, 0.1, 0.2⟩
A6	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	…	⟨(0.85, 0.8, 0.95);0.8, 0.1, 0.2⟩	⟨(0.7, 0.75, 0.8);0.9, 0.2, 0.2⟩
B1	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	…	⟨(0.7, 0.75, 0.8);0.9, 0.2, 0.2⟩	⟨(0.85, 0.8, 0.95);0.8, 0.1, 0.2⟩
B2	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	…	⟨(0.85, 0.8, 0.95);0.8, 0.1, 0.2⟩	⟨(0.7, 0.75, 0.8);0.9, 0.2, 0.2⟩
B3	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	…	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.45, 0.3, 0.5);0.6, 0.1, 0.2⟩
B4	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	…	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩
B5	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	…	⟨(0.85, 0.8, 0.95);0.8, 0.1, 0.2⟩	⟨(0.85, 0.8, 0.95);0.8, 0.1, 0.2⟩
C1	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	…	⟨(0.7, 0.75, 0.8);0.9, 0.2, 0.2⟩	⟨(0.7, 0.75, 0.8);0.9, 0.2, 0.2⟩
C2	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	…	⟨(0.85, 0.8, 0.95);0.8, 0.1, 0.2⟩	⟨(0.85, 0.8, 0.95);0.8, 0.1, 0.2⟩
C3	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	…	⟨(0.7, 0.75, 0.8);0.9, 0.2, 0.2⟩	⟨(0.85, 0.8, 0.95);0.8, 0.1, 0.2⟩
C4	⟨(0.2, 0.3, 0.5);0.6, 0.2, 0.3⟩	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	…	⟨(0.7, 0.75, 0.8);0.9, 0.2, 0.2⟩	⟨(0.7, 0.75, 0.8);0.9, 0.2, 0.2⟩
C5	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	…	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.45, 0.3, 0.5);0.6, 0.1, 0.2⟩
C6	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	…	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩
C7	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	⟨(0.10, 0.25, 0.3);0.1, 0.3, 0.1⟩	…	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩	⟨(0.5, 0.5, 0.5);0.9, 0.1, 0.1⟩

Table 17 Crisp evaluation matrix of industry 5.0 sub-values in regard to healthcare sector based on Expert 1 opinion

Expert 1	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	C6	C7
A1	0.5063	0.5063	0.8125	0.8125	0.7031	0.7031	0.5063	0.8125	0.9450	0.8125	0.5063	0.8125	0.7031	0.5063	0.8125	0.9450	0.9450	0.8125
A2	0.5063	0.5063	0.8125	0.8125	0.7031	0.7031	0.5063	0.8125	0.9450	0.9450	0.5063	0.8125	0.7031	0.5063	0.8125	0.9450	0.9450	0.9450
A3	0.2625	0.2625	0.5063	0.5063	0.2625	0.5063	0.1381	0.2625	0.7031	0.5063	0.2625	0.5063	0.3594	0.1381	0.5063	0.7031	0.7031	0.7031
A4	0.1381	0.1381	0.5063	0.5063	0.2625	0.5063	0.1381	0.2625	0.7031	0.5063	0.2625	0.5063	0.3594	0.1381	0.3594	0.7031	0.7031	0.7031
A5	0.2625	0.2625	0.8125	0.7031	0.5063	0.5063	0.5063	0.7031	0.8125	0.8125	0.5063	0.7031	0.5063	0.3594	0.7031	0.8125	0.8125	0.8125
A6	0.2625	0.2625	0.7031	0.5063	0.5063	0.5063	0.3594	0.5063	0.7031	0.7031	0.3594	0.5063	0.5063	0.5063	0.7031	0.8125	0.8125	0.7031
B1	0.5063	0.5063	0.8125	0.7031	0.5063	0.7031	0.5063	0.7031	0.9450	0.8125	0.5063	0.7031	0.7031	0.5063	0.8125	0.9450	0.7031	0.8125
B2	0.1381	0.1381	0.7031	0.5063	0.5063	0.5063	0.3594	0.5063	0.7031	0.7031	0.3594	0.5063	0.5063	0.2625	0.7031	0.8125	0.8125	0.7031
B3	0.1381	0.1381	0.2625	0.2625	0.1381	0.2625	0.1381	0.2625	0.5063	0.3594	0.1381	0.2625	0.2625	0.1381	0.3594	0.5063	0.5063	0.3594
B4	0.1381	0.1381	0.5063	0.5063	0.1381	0.2625	0.1381	0.3594	0.7031	0.5063	0.1381	0.3594	0.2625	0.2625	0.5063	0.7031	0.5063	0.5063
B5	0.2625	0.2625	0.8125	0.8125	0.5063	0.5063	0.5063	0.7031	0.9450	0.8125	0.5063	0.7031	0.5063	0.3594	0.7031	0.9450	0.8125	0.8125
C1	0.1381	0.1381	0.5063	0.5063	0.2625	0.5063	0.1381	0.2625	0.7031	0.5063	0.3594	0.5063	0.3594	0.1381	0.3594	0.7031	0.7031	0.7031
C2	0.2625	0.1381	0.8125	0.7031	0.5063	0.5063	0.5063	0.7031	0.8125	0.8125	0.5063	0.7031	0.5063	0.2625	0.7031	0.7031	0.8125	0.8125
C3	0.5063	0.5063	0.8125	0.7031	0.7031	0.7031	0.5063	0.7031	0.9450	0.8125	0.5063	0.8125	0.7031	0.5063	0.8125	0.9450	0.7031	0.8125
C4	0.2625	0.1381	0.5063	0.5063	0.1381	0.5063	0.1381	0.2625	0.7031	0.5063	0.2625	0.5063	0.3594	0.1381	0.5063	0.7031	0.7031	0.7031
C5	0.1381	0.1381	0.2625	0.2625	0.1381	0.2625	0.1381	0.2625	0.5063	0.2625	0.1381	0.2625	0.2625	0.1381	0.2625	0.5063	0.5063	0.3594
C6	0.1381	0.1381	0.2625	0.2625	0.1381	0.1381	0.1381	0.2625	0.7031	0.5063	0.1381	0.3594	0.2625	0.1381	0.3594	0.7031	0.5063	0.5063
C7	0.1381	0.1381	0.5063	0.5063	0.1381	0.1381	0.1381	0.2625	0.7031	0.5063	0.1381	0.3594	0.2625	0.2625	0.3594	0.7031	0.5063	0.5063

Table 18 Normalized evaluation matrix of industry 5.0 sub-values in regard to healthcare sector based on Expert 1 opinion

Expert 1	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	C6	C7
A1	0.1076	0.1136	0.0744	0.0805	0.1040	0.0834	0.0920	0.0943	0.0690	0.0713	0.0830	0.0821	0.0869	0.0961	0.0785	0.0685	0.0744	0.0662
A2	0.1076	0.1136	0.0744	0.0805	0.1040	0.0834	0.0920	0.0943	0.0690	0.0830	0.0830	0.0821	0.0869	0.0961	0.0785	0.0685	0.0744	0.0770
A3	0.0558	0.0589	0.0464	0.0502	0.0388	0.0600	0.0251	0.0305	0.0514	0.0444	0.0430	0.0512	0.0444	0.0262	0.0489	0.0510	0.0554	0.0573
A4	0.0294	0.0310	0.0464	0.0502	0.0388	0.0600	0.0251	0.0305	0.0514	0.0444	0.0430	0.0512	0.0444	0.0262	0.0347	0.0510	0.0554	0.0573
A5	0.0558	0.0589	0.0744	0.0697	0.0749	0.0600	0.0920	0.0816	0.0593	0.0713	0.0830	0.0711	0.0625	0.0682	0.0680	0.0589	0.0640	0.0662
A6	0.0558	0.0589	0.0644	0.0502	0.0749	0.0600	0.0653	0.0588	0.0514	0.0617	0.0589	0.0512	0.0625	0.0961	0.0680	0.0589	0.0640	0.0573
B1	0.1076	0.1136	0.0744	0.0697	0.0749	0.0834	0.0920	0.0816	0.0690	0.0713	0.0830	0.0711	0.0869	0.0961	0.0785	0.0685	0.0554	0.0662
B2	0.0294	0.0310	0.0644	0.0502	0.0749	0.0600	0.0653	0.0588	0.0514	0.0617	0.0589	0.0512	0.0625	0.0498	0.0680	0.0589	0.0640	0.0573
B3	0.0294	0.0310	0.0240	0.0260	0.0204	0.0311	0.0251	0.0305	0.0370	0.0315	0.0226	0.0265	0.0324	0.0262	0.0347	0.0367	0.0399	0.0293
B4	0.0294	0.0310	0.0464	0.0502	0.0204	0.0311	0.0251	0.0417	0.0514	0.0444	0.0226	0.0363	0.0324	0.0498	0.0489	0.0510	0.0399	0.0412
B5	0.0558	0.0589	0.0744	0.0805	0.0749	0.0600	0.0920	0.0816	0.0690	0.0713	0.0830	0.0711	0.0625	0.0682	0.0680	0.0685	0.0640	0.0662
C1	0.0294	0.0310	0.0464	0.0502	0.0388	0.0600	0.0251	0.0305	0.0514	0.0444	0.0589	0.0512	0.0444	0.0262	0.0347	0.0510	0.0554	0.0573
C2	0.0558	0.0310	0.0744	0.0697	0.0749	0.0600	0.0920	0.0816	0.0593	0.0713	0.0830	0.0711	0.0625	0.0498	0.0680	0.0510	0.0640	0.0662
C3	0.1076	0.1136	0.0744	0.0697	0.1040	0.0834	0.0920	0.0816	0.0690	0.0713	0.0830	0.0821	0.0869	0.0961	0.0785	0.0685	0.0554	0.0662
C4	0.0558	0.0310	0.0464	0.0502	0.0204	0.0600	0.0251	0.0305	0.0514	0.0444	0.0430	0.0512	0.0444	0.0262	0.0489	0.0510	0.0554	0.0573
C5	0.0294	0.0310	0.0240	0.0260	0.0204	0.0311	0.0251	0.0305	0.0370	0.0230	0.0226	0.0265	0.0324	0.0262	0.0254	0.0367	0.0399	0.0293
C6	0.0294	0.0310	0.0240	0.0260	0.0204	0.0164	0.0251	0.0305	0.0514	0.0444	0.0226	0.0363	0.0324	0.0262	0.0347	0.0510	0.0399	0.0412
C7	0.0294	0.0310	0.0464	0.0502	0.0204	0.0164	0.0251	0.0305	0.0514	0.0444	0.0226	0.0363	0.0324	0.0498	0.0347	0.0510	0.0399	0.0412

Table 19 Weight, weighted sum, and rank of industry 5.0 sub-values in regard to the healthcare sector based on three expert opinion

	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	C6	C7
Expert 1																		
Weight	0.0848	0.0860	0.0466	0.0428	0.0689	0.0621	0.0802	0.0565	0.0297	0.0385	0.0706	0.0437	0.0659	0.0824	0.0440	0.0287	0.0324	0.0363
WS	1.5259	1.5483	0.8388	0.7703	1.2398	1.1182	1.4431	1.0175	0.5345	0.6933	1.2700	0.7862	1.1856	1.4833	0.7925	0.5166	0.5830	0.6531
Rank	2	1	10	13	6	8	4	9	17	14	5	12	7	3	11	18	16	15
Expert 2																		
Weight	0.0872	0.0836	0.0423	0.0431	0.0706	0.0613	0.0801	0.0571	0.0310	0.0360	0.0751	0.0431	0.0640	0.0820	0.0429	0.0287	0.0344	0.0374
WS	1.5700	1.5050	0.7618	0.7764	1.2707	1.1041	1.4418	1.0285	0.5585	0.6487	1.3520	0.7752	1.1518	1.4754	0.7718	0.5160	0.6199	0.6725
Rank	1	2	13	10	6	8	4	9	17	15	5	11	7	3	12	18	16	14
Expert 3																		
Weight	0.0854	0.0858	0.0427	0.0430	0.0686	0.0628	0.0781	0.0585	0.0284	0.0379	0.0750	0.0438	0.0669	0.0828	0.0417	0.0287	0.0335	0.0364
WS	1.5367	1.5444	0.7687	0.7732	1.2356	1.1308	1.4063	1.0534	0.5115	0.6818	1.3505	0.7877	1.2049	1.4900	0.7501	0.5174	0.6023	0.6548
Rank	2	1	12	11	6	8	4	9	18	14	5	10	7	3	13	17	16	15

Table 20 Evaluation matrix of 9 technologies based on importance linguistic variables

Expert 1	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	C6	C7
Cloud computing	VHI	MI	AI	VHI	LI	LI	HI	VHI	LI	MI	VLI	AI	VHI	VLI	VLI	VLI	LI	LI
Drone technology	HI	VHI	MI	HI	HI	LI	LI	MI	AI	MI	VHI	MI	AI	AI	HI	HI	VHI	MI
AI	LI	VLI	MI	LI	VHI	HI	HI	HI	HI	MI	VHI	LI	VHI	LI	LI	LI	MI	LI
IoT	HI	HI	LI	MI	LI	HI	MI	VHI	LI	LI	HI	HI	VHI	VHI	HI	HI	VHI	HI
Robots	LI	VLI	LI	LI	AI	HI	HI	HI	HI	LI	VHI	LI	HI	LI	LI	LI	HI	MI
Blockchain	HI	HI	LI	VHI	HI	VHI	MI	MI	HI	MI	HI	HI	LI	HI	HI	HI	VHI	MI
Big Data	VHI	VHI	MI	VHI	VHI	HI	MI	HI	VHI	HI	HI	VHI	HI	MI	HI	HI	HI	HI
Nano-technology	HI	HI	HI	HI	VHI	HI	HI	AI	AI	VHI	VHI	HI	HI	HI	VHI	VHI	MI	HI
5G Technology	VHI	HI	MI	HI	MI	HI	MI	HI	VHI	MI	MI	VHI	MI	AI	HI	HI	AI	MI

Table 21 Evaluation matrix of 9 technologies based on neutrosophic number

Expert 1	A1	A2	…	C6	C7
Cloud computing	⟨(0.90, 0.85, 0.90);0.7, 0.2, 0.2⟩	⟨(0.65, 0.60, 0.70);0.8, 0.1, 0.1⟩	…	⟨(0.15, 0.25, 0.10);0.6, 0.2, 0.3⟩	⟨(0.15, 0.25, 0.10);0.6, 0.2, 0.3⟩
Drone technology	⟨(0.70, 0.65, 0.80);0.9, 0.2, 0.1⟩	⟨(0.90, 0.85, 0.90);0.7, 0.2, 0.2⟩	…	⟨(0.90, 0.85, 0.90);0.7, 0.2, 0.2⟩	⟨(0.65, 0.60, 0.70);0.8, 0.1, 0.1⟩
AI	⟨(0.15, 0.25, 0.10);0.6, 0.2, 0.3⟩	⟨(0.10, 0.30, 0.35);0.1, 0.2, 0.15⟩	.	⟨(0.65, 0.60, 0.70);0.8, 0.1, 0.1⟩	⟨(0.15, 0.25, 0.10);0.6, 0.2, 0.3⟩
IoT	⟨(0.70, 0.65, 0.80);0.9, 0.2, 0.1⟩	⟨(0.70, 0.65, 0.80);0.9, 0.2, 0.1⟩	…	⟨(0.90, 0.85, 0.90);0.7, 0.2, 0.2⟩	⟨(0.70, 0.65, 0.80);0.9, 0.2, 0.1⟩
Robots	⟨(0.15, 0.25, 0.10);0.6, 0.2, 0.3⟩	⟨(0.10, 0.30, 0.35);0.1, 0.2, 0.15⟩	.	⟨(0.70, 0.65, 0.80);0.9, 0.2, 0.1⟩	⟨(0.65, 0.60, 0.70);0.8, 0.1, 0.1⟩
Blockchain	⟨(0.70, 0.65, 0.80);0.9, 0.2, 0.1⟩	⟨(0.70, 0.65, 0.80);0.9, 0.2, 0.1⟩	…	⟨(0.90, 0.85, 0.90);0.7, 0.2, 0.2⟩	⟨(0.65, 0.60, 0.70);0.8, 0.1, 0.1⟩
Big Data	⟨(0.90, 0.85, 0.90);0.7, 0.2, 0.2⟩	⟨(0.90, 0.85, 0.90);0.7, 0.2, 0.2⟩	…	⟨(0.70, 0.65, 0.80);0.9, 0.2, 0.1⟩	⟨(0.70, 0.65, 0.80);0.9, 0.2, 0.1⟩
Nano-technology	⟨(0.70, 0.65, 0.80);0.9, 0.2, 0.1⟩	⟨(0.70, 0.65, 0.80);0.9, 0.2, 0.1⟩	…	⟨(0.65, 0.60, 0.70);0.8, 0.1, 0.1⟩	⟨(0.70, 0.65, 0.80);0.9, 0.2, 0.1⟩
5G Technology	⟨(0.90, 0.85, 0.90);0.7, 0.2, 0.2⟩	⟨(0.70, 0.65, 0.80);0.9, 0.2, 0.1⟩	…	⟨(0.95, 0.90, 0.95);0.9, 0.10, 0.10⟩	⟨(0.65, 0.60, 0.70);0.8, 0.1, 0.1⟩

Table 22 Crisp evaluation matrix of the nine technologies

Expert 1	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	C6	C7
Cloud computing	0.7619	0.6338	0.9450	0.7619	0.1313	0.1313	0.6988	0.7619	0.1313	0.6338	0.1641	0.9450	0.7619	0.1641	0.1641	0.1641	0.1313	0.1313
Drone technology	0.6988	0.7619	0.6338	0.6988	0.6988	0.1313	0.1313	0.6338	0.9450	0.6338	0.7619	0.6338	0.9450	0.9450	0.6988	0.6988	0.7619	0.6338
AI	0.1313	0.1641	0.6338	0.1313	0.7619	0.6988	0.6988	0.6988	0.6988	0.6338	0.7619	0.1313	0.7619	0.1313	0.1313	0.1313	0.6338	0.1313
IoT	0.6988	0.6988	0.1313	0.6338	0.1313	0.6988	0.6338	0.7619	0.1313	0.1313	0.6988	0.6988	0.7619	0.7619	0.6988	0.6988	0.7619	0.6988
Robots	0.1313	0.1641	0.1313	0.1313	0.9450	0.6988	0.6988	0.6988	0.6988	0.1313	0.7619	0.1313	0.6988	0.1313	0.1313	0.1313	0.6988	0.6338
Blockchain	0.6988	0.6988	0.1313	0.7619	0.6988	0.7619	0.6338	0.6338	0.6988	0.6338	0.6988	0.6988	0.1313	0.6988	0.6988	0.6988	0.7619	0.6338
Big Data	0.7619	0.7619	0.6338	0.7619	0.7619	0.6988	0.6338	0.6988	0.7619	0.6988	0.6988	0.7619	0.6988	0.6338	0.6988	0.6988	0.6988	0.6988
Nano-technology	0.6988	0.6988	0.6988	0.6988	0.7619	0.6988	0.6988	0.9450	0.9450	0.7619	0.7619	0.6988	0.6988	0.6988	0.7619	0.7619	0.6338	0.6988
5G Technology	0.7619	0.6988	0.6338	0.6988	0.6338	0.6988	0.6338	0.6988	0.7619	0.6338	0.6338	0.7619	0.6338	0.9450	0.6988	0.6988	0.9450	0.6338

Table 23 Normalized evaluation matrix

Expert 1	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	C6	C7
Cloud computing	0.3945	0.3354	0.5420	0.3992	0.0652	0.0697	0.3695	0.3474	0.0622	0.3593	0.0799	0.4752	0.3584	0.0841	0.0934	0.0934	0.0623	0.0745
Drone technology	0.3619	0.4033	0.3635	0.3661	0.3473	0.0697	0.0694	0.2890	0.4482	0.3593	0.3711	0.3187	0.4446	0.4844	0.3980	0.3980	0.3619	0.3596
AI	0.0680	0.0868	0.3635	0.0688	0.3787	0.3712	0.3695	0.3186	0.3314	0.3593	0.3711	0.0660	0.3584	0.0673	0.0747	0.0747	0.3011	0.0745
IoT	0.3619	0.3698	0.0753	0.3321	0.0652	0.3712	0.3351	0.3474	0.0622	0.0744	0.3403	0.3514	0.3584	0.3905	0.3980	0.3980	0.3619	0.3965
Robots	0.0680	0.0868	0.0753	0.0688	0.4697	0.3712	0.3695	0.3186	0.3314	0.0744	0.3711	0.0660	0.3287	0.0673	0.0747	0.0747	0.3319	0.3596
Blockchain	0.3619	0.3698	0.0753	0.3992	0.3473	0.4047	0.3351	0.2890	0.3314	0.3593	0.3403	0.3514	0.0617	0.3582	0.3980	0.3980	0.3619	0.3596
Big Data	0.3945	0.4033	0.3635	0.3992	0.3787	0.3712	0.3351	0.3186	0.3613	0.3961	0.3403	0.3831	0.3287	0.3248	0.3980	0.3980	0.3319	0.3965
Nano-technology	0.3619	0.3698	0.4008	0.3661	0.3787	0.3712	0.3695	0.4309	0.4482	0.4319	0.3711	0.3514	0.3287	0.3582	0.4339	0.4339	0.3011	0.3965
5G Technology	0.3945	0.3698	0.3635	0.3661	0.3150	0.3712	0.3351	0.3186	0.3613	0.3593	0.3087	0.3831	0.2982	0.4844	0.3980	0.3980	0.4489	0.3596

Table 24 Weighted normalized matrix

Expert 1	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	C6	C7
Cloud computing	0.0338	0.0286	0.0238	0.0171	0.0045	0.0043	0.0294	0.0199	0.0018	0.0135	0.0059	0.0207	0.0235	0.0069	0.0040	0.0027	0.0021	0.0027
Drone technology	0.0310	0.0343	0.0159	0.0157	0.0241	0.0043	0.0055	0.0166	0.0133	0.0135	0.0273	0.0139	0.0292	0.0399	0.0171	0.0114	0.0121	0.0132
AI	0.0058	0.0074	0.0159	0.0030	0.0263	0.0230	0.0294	0.0183	0.0098	0.0135	0.0273	0.0029	0.0235	0.0055	0.0032	0.0021	0.0101	0.0027
IoT	0.0310	0.0315	0.0033	0.0143	0.0045	0.0230	0.0266	0.0199	0.0018	0.0028	0.0250	0.0153	0.0235	0.0322	0.0171	0.0114	0.0121	0.0145
Robots	0.0058	0.0074	0.0033	0.0030	0.0326	0.0230	0.0294	0.0183	0.0098	0.0028	0.0273	0.0029	0.0216	0.0055	0.0032	0.0021	0.0111	0.0132
Blockchain	0.0310	0.0315	0.0033	0.0171	0.0241	0.0251	0.0266	0.0166	0.0098	0.0135	0.0250	0.0153	0.0041	0.0295	0.0171	0.0114	0.0121	0.0132
Big Data	0.0338	0.0343	0.0159	0.0171	0.0263	0.0230	0.0266	0.0183	0.0107	0.0148	0.0250	0.0167	0.0216	0.0268	0.0171	0.0114	0.0111	0.0145
Nano-technology	0.0310	0.0315	0.0176	0.0157	0.0263	0.0230	0.0294	0.0247	0.0133	0.0162	0.0273	0.0153	0.0216	0.0295	0.0186	0.0125	0.0101	0.0145
5G Technology	0.0338	0.0315	0.0159	0.0157	0.0219	0.0230	0.0266	0.0183	0.0107	0.0135	0.0227	0.0167	0.0196	0.0399	0.0171	0.0114	0.0150	0.0132
A^+	0.0338	0.0343	0.0238	0.0171	0.0326	0.0251	0.0294	0.0247	0.0133	0.0162	0.0273	0.0207	0.0292	0.0399	0.0186	0.0125	0.0150	0.0145
A^-	0.0058	0.0074	0.0033	0.0030	0.0045	0.0043	0.0055	0.0166	0.0018	0.0028	0.0059	0.0029	0.0041	0.0055	0.0032	0.0021	0.0021	0.0027

Acknowledgements We thank all the reviewers, guest editors and editors for their feedback.

Authors' contributions Conceptualization, MA.., R.M, V. C.; methodology, M.A., R. M, V. C.; software, M.A.., R.M, V. C.; validation, M.A., R.M, V. C.; formal analysis, M.A.., R.M, V. C..; investigation, M.A., V. C.; resources, M.A., R.M, V. C.; data curation, M.A., R.M., V. C.; writing—original draft preparation, M.A., R.M, V. C.; writing—review and editing M.A., R.M, V. C.; visualization, M.A., V. C; supervision M. A., R.M, V. C.; project administration,V. C; funding acquisition, V. C..

Funding This project is partly funded by VC Research (VCR0000195) for Prof Chang.

Availability of data and material All the data have been presented in this paper.

Declarations

Ethics approval and consent to participate We have the ethical approval in place and the three expert interviewees agreed to participate.

Consent for publication All authors have read and agreed to the published version of the manuscript.

Competing interests The authors confirm that there is no conflict of interest with anyone for this research.

References

Aceto, G., Persico, V., & Pescapé, A. (2020). Industry 4.0 and health: internet of things, big data, and cloud computing for healthcare 4.0. *Journal of Industrial Information Integration, 18*, 100129.

Ahsan, M. M., & Siddique, Z. (2022). Industry 4.0 in healthcare: a systematic review. *International Journal of Information Management Data Insights, 2*(1), 100079.

Ali, I., & Kannan, D. (2022). Mapping research on healthcare operations and supply chain management: a topic modelling-based literature review. *Annals of Operations Research*, 1

AlTwaijiry, A. (2021). The determinants of cloud computing adoption in healthcare. *ResearchBerg Review of Science and Technology, 3*(1), 9–20.

Anjum, S., Ishaque, S., Fatima, H., Farooq, W., Hano, C., Abbasi, B. H., & Anjum, I. (2021). Emerging applications of nano-technology in healthcare systems: grand challenges and perspectives. *Pharmaceuticals, 14*(8), 707.

Bamiah, M., Brohi, S., & Chuprat, S. (2012). A study on significance of adopting cloud computing paradigm in healthcare sector. In *2012 International Conference on Cloud Computing Technologies, Applications and Management (ICCCTAM)* (pp. 65–68). IEEE.

Bhavin, M., Tanwar, S., Sharma, N., Tyagi, S., & Kumar, N. (2021). Blockchain and quantum blind signature-based hybrid scheme for healthcare 5.0 applications. *Journal of Information Security and Applications, 56*, 102673.

Breque, M., De Nul, L., & Petridis, A. (2021). *Industry 5.0: towards a sustainable, human-centric and resilient European industry*. European Commission, Directorate-General for Research and Innovation.

Büyüközkan, G., & Mukul, E. (2020). Evaluation of smart health technologies with hesitant fuzzy linguistic MCDM methods. *Journal of Intelligent & Fuzzy Systems, 39*(5), 6363–6375.

Dash, S., Shakyawar, S. K., Sharma, M., & Kaushik, S. (2019). Big data in healthcare: management, analysis and future prospects. *Journal of Big Data, 6*(1), 1–25.

Di Lallo, A., Murphy, R., Krieger, A., Zhu, J., Taylor, R. H., & Su, H. (2021). Medical robots for infectious diseases: lessons and challenges from the COVID-19 pandemic. *IEEE Robotics & Automation Magazine, 28*(1), 18–27.

Firouzi, F., Farahani, B., Daneshmand, M., Grise, K., Song, J., Saracco, R., ... & Luo, A. (2021). Harnessing the power of smart and connected health to tackle covid-19: Iot, ai, robotics, and blockchain for a better world. *IEEE Internet of Things Journal*, *8*(16), 12826–12846.

Gatenholm, G., & Halldórsson, Á. (2023). Responding to discontinuities in product-based service supply chains in the COVID-19 pandemic: Towards transilience. *European Management Journal, 41*(3), 425–436.

Ghobakhloo, M., Iranmanesh, M., Mubarak, M. F., Mubarik, M., Rejeb, A., & Nilashi, M. (2022). Identifying industry 5.0 contributions to sustainable development: A strategy roadmap for delivering sustainability values. *Sustainable Production and Consumption, 33*, 716–737.

Gupta, R., Bhattacharya, P., Tanwar, S., Kumar, N., & Zeadally, S. (2021). GaRuDa: a blockchain-based delivery scheme using drones for healthcare 5.0 applications. *IEEE Internet of Things Magazine, 4*(4), 60–66.

Haafza, L. A., Awan, M. J., Abid, A., Yasin, A., Nobanee, H., & Farooq, M. S. (2021). Big data COVID-19 systematic literature review: pandemic crisis. *Electronics, 10*(24), 3125.

Haleem, A., & Javaid, M. (2019). Industry 5.0 and its applications in orthopaedics. *Journal of Clinical Orthopaedics & Trauma, 10*(4), 807–808.

Haleem, A., Javaid, M., Singh, R. P., & Suman, R. (2022). Medical 4.0 technologies for healthcare: Features, capabilities, and applications. *Internet of Things and Cyber-Physical Systems, 2*, 12–30.

Hezam, I. M., Abdel-Baset, M., & Smarandache, F. (2017). *Neutrosophic goal programming*. Infinite Study.

Hölbl, M., Kompara, M., Kamišalić, A., & Nemec Zlatolas, L. (2018). A systematic review of the use of blockchain in healthcare. *Symmetry, 10*(10), 470.

Inuwa, H. M., Raja, A. R., Kumar, A., Singh, B., & Singh, S. (2022). Status of Industry 4.0 applications in healthcare 4.0 and Pharma 4.0. *Materials Today: Proceedings, 62*, 3593–3598.

Iyengar, K. P., Pe, E. Z., Jalli, J., Shashidhara, M. K., Jain, V. K., Vaish, A., & Vaishya, R. (2022). Industry 5.0 technology capabilities in Trauma and Orthopaedics. *Journal of Orthopaedics, 32*, 125–132.

Jangjou, M., & Sohrabi, M. K. (2022). A comprehensive survey on security challenges in different network layers in cloud computing. *Archives of Computational Methods in Engineering, 29*(6), 3587–3608.

Javaid, M., & Khan, I. H. (2021). Internet of things (IoT) enabled healthcare helps to take the challenges of COVID-19 pandemic. *Journal of Oral Biology and Craniofacial Research, 11*(2), 209–214.

Javaid, M., Haleem, A., Singh, R. P., Haq, M. I. U., Raina, A., & Suman, R. (2020a). Industry 5.0: potential applications in COVID-19. *Journal of Industrial Integration and Management, 5*(04), 507–530.

Javaid, M., Haleem, A., Vaishya, R., Bahl, S., Suman, R., & Vaish, A. (2020b). Industry 4.0 technologies and their applications in fighting COVID-19 pandemic. *Diabetes & Metabolic Syndrome: Clinical Research & Reviews, 14*(4), 419–422.

Karatas, M., Eriskin, L., Deveci, M., Pamucar, D., & Garg, H. (2022). Big Data for Healthcare Industry 4.0: Applications, challenges and future perspectives. *Expert Systems with Applications, 200*, 116912.

Kumari, A., Tanwar, S., Tyagi, S., & Kumar, N. (2018). Fog computing for healthcare 4.0 environment: opportunities and challenges. *Computers & Electrical Engineering, 72*, 1–13.

Larrucea, X., Moffie, M., Asaf, S., & Santamaria, I. (2020). Towards a GDPR compliant way to secure european cross border healthcare industry 4.0. *Computer Standards & Interfaces, 69*, 103408.

Li, D. (2019). 5G and intelligence medicine—how the next generation of wireless technology will reconstruct healthcare? *Precision Clinical Medicine, 2*(4), 205–208.

Manogaran, G., Thota, C., Lopez, D., & Sundarasekar, R. (2017). Big data security intelligence for healthcare industry 4.0. In *Cybersecurity for industry 4.0* (pp. 103–126). Springer.

Manzoor, I., Rather, M. A., Sajood, S., Bashir, S. M., Hassan, S., & Hamid, R. (2022). Nano-technology in Healthcare Management. In *Diverse Applications of Nano-technology in the Biological Sciences* (pp. 139–172). Apple Academic Press.

Mazur, B., & Walczyna, A. (2022). Sustainable development competences of engineering students in light of the industry 5.0 concept. *Sustainability, 14*(12), 7233.

Mbunge, E., Muchemwa, B., & Batani, J. (2021). Sensors and healthcare 5.0: transformative shift in virtual care through emerging digital health technologies. *Global Health Journal, 5*(4), 169–177.

Miah, S. J., Camilleri, E., & Vu, H. Q. (2022). Big data in healthcare research: a survey study. *Journal of Computer Information Systems, 62*(3), 480–492.

Mohanta, B., Das, P., & Patnaik, S. (2019). Healthcare 5.0: a paradigm shift in digital healthcare system using artificial intelligence, IOT and 5G Communication. In *2019 International conference on applied machine learning (ICAML)* (pp. 191–196). IEEE.

Muhammad, G., Alshehri, F., Karray, F., El Saddik, A., Alsulaiman, M., & Falk, T. H. (2021). A comprehensive survey on multimodal medical signals fusion for smart healthcare systems. *Information Fusion, 76*, 355–375.

Nahavandi, S. (2019). Industry 5.0—A human-centric solution. *Sustainability, 11*(16), 4371.

Nyaaba, A. A., & Ayamga, M. (2021). Intricacies of medical drones in healthcare delivery: implications for Africa. *Technology in Society, 66*, 101624.

Pace, P., Aloi, G., Gravina, R., Caliciuri, G., Fortino, G., & Liotta, A. (2018). An edge-based architecture to support efficient applications for healthcare industry 4.0. *IEEE Transactions on Industrial Informatics, 15*(1), 481–489.

Pillai, S. G., Haldorai, K., Seo, W. S., & Kim, W. G. (2021). COVID-19 and hospitality 5.0: redefining hospitality operations. *International Journal of Hospitality Management, 94*, 102869.

Quasim, M. T., Shaikh, A., Shuaib, M., Sulaiman, A., Alam, S., & Asiri, Y. (2021). Smart healthcare management evaluation using fuzzy decision making method.

Sarfraz, Z., Sarfraz, A., Iftikar, H. M., & Akhund, R. (2021). Is COVID-19 pushing us to the fifth industrial revolution (society 5.0)? *Pakistan Journal of Medical Sciences, 37*(2), 591.

Shaheen, M. Y. (2021). AI in Healthcare: medical and socio-economic benefits and challenges. *ScienceOpen Preprints*.

Sharma, M. (2021). Drone technology for assisting COVID-19 victims in remote areas: opportunity and challenges. *Journal of Medical Systems, 45*(9), 1–2.

Shynu, P. G., Menon, V. G., Kumar, R. L., Kadry, S., & Nam, Y. (2021). Blockchain-based secure healthcare application for diabetic-cardio disease prediction in fog computing. *IEEE Access, 9*, 45706–45720.

Siksnelyte, I., Zavadskas, E. K., Bausys, R., & Streimikiene, D. (2019). Implementation of EU energy policy priorities in the Baltic Sea region countries: sustainability assessment based on neutrosophic MULTIMOORA method. *Energy Policy, 125*, 90–102.

Sindhwani, R., Afridi, S., Kumar, A., Banaitis, A., Luthra, S., & Singh, P. L. (2022). Caindustry 5.0 revolutionize the wave of resilience and social value creation? a multi-criteria framework to analyze enablers. *Technology in Society, 68*, 101887.

Sood, S. K., Rawat, K. S., & Kumar, D. (2022). A visual review of artificial intelligence and industry 4.0 in healthcare. *Computers and Electrical Engineering, 101*, 107948.

Tortorella, G. L., Fogliatto, F. S., Mac CawleyVergara, A., Vassolo, R., & Sawhney, R. (2020). Healthcare 4.0: trends, challenges and research directions. *Production Planning & Control, 31*(15), 1245–1260.

Tortorella, G. L., Fogliatto, F. S., Saurin, T. A., Tonetto, L. M., & McFarlane, D. (2022). Contributions of healthcare 4.0 digital applications to the resilience of healthcare organizations during the COVID-19 outbreak. *Technovation, 111*, 102379.

Verma, V., Chowdary, V., Gupta, M. K., & Mondal, A. K. (2018). IoT and robotics in healthcare. In *Medical big data and internet of medical things* (pp. 245–269). CRC Press.

Xu, X., Lu, Y., Vogel-Heuser, B., & Wang, L. (2021). Industry 4.0 and industry 5.0—Inception, conception and perception. *Journal of Manufacturing Systems, 61*, 530–535.

Yang, C. H., Hsu, W., & Wu, Y. L. (2022). A hybrid multiple-criteria decision portfolio with the resource constraints model of a smart healthcare management system for public medical centers. *Socio-Economic Planning Sciences, 80*, 101073.

Zheng, Z., Xie, S., Dai, H. N., Chen, X., & Wang, H. (2018). Blockchain challenges and opportunities: a survey. *International Journal of Web and Grid Services, 14*(4), 352–375.

Mohamed Abdel-Basset received his B.Sc. and M.Sc. from Faculty of Computers and Informatics, Zagazig University, Egypt. Received his Ph.D. from Faculty of Computers and Informatics, Menoufia University, Egypt. Currently, Mohamed is A Head of computer science department at Faculty of Computers and Informatics, Zagazig University, Egypt. His current research interests are Optimization, Operations Research, Data Mining, Computational Intelligence, Applied Statistics, Decision support systems, Robust Optimization, Engineering Optimization, Multi-objective Optimization, Swarm Intelligence, Evolutionary Algorithms, and Artificial Neural Networks. He is working on the application of multi-objective and robust meta-heuristic optimization techniques. He is also an/a Editor/reviewer in different international journals and conferences. He holds the program chair in many conferences in the fields of decision-making analysis, big data, optimization, complexity, and internet of things, as well as editorial collaboration.

Rehab Mohamed received her B.Sc., MSc. and PhD degree from Zagazig University, faculty of computers and informatics, department of decision support, Egypt. Currently, Rehab is a lecturer at Faculty of Computers and Informatics, Zagazig University, Egypt. Her research interests include Optimization, Deep learning algorithms, Swarm Intelligence, Evolutionary Algorithms, and Artificial Neural Networks. She is also a reviewer in different international journals and conferences.

Victor Chang is currently a Professor of Business Analytics at Aston Business School, Aston University, UK. He was a Professor of Data Science and Information Systems at SCEDT, Teesside University, Middlesbrough, UK, between September 2019 and May 2022. He was a Senior Associate Professor, Director of Ph.D. (June 2016- May 2018) and Director of MRes (Sep 2017—Feb 2019) at International Business School Suzhou (IBSS), Xi'an Jiaotong-Liverpool University (XJTLU), Suzhou, China, between June 2016 and August 2019. He was an Honorary Associate Professor at University of Liverpool. Previously he was a Senior Lecturer at Leeds Beckett University, UK, between Sep 2012 and May 2016. Within 4 years, he completed Ph.D. (CS, Southampton) and PGCert (Higher Education, Fellow, Greenwich) while working for several projects at the same time. Before becoming an academic, he has achieved 97% on average in 27 IT certifications. He won a European Award on Cloud Migration in 2011, IEEE Outstanding Service Award in 2015, best papers in 2012, 2015 and 2018, the 2016 European special award and Outstanding Young Scientist 2017. He is a visiting scholar/Ph.D. examiner at several universities, an Editor-in-Chief of IJOCI & OJBD journals, former Editor of FGCS, Associate Editor of IEEE TII, JGIM, IJBSR, IJEBM & Cyber Security & Apps. He's also an Editor of Information Fusion, IDD and Scientific Reports journal, a founding chair of two international workshops and founding Conference Chair of IoTBDS and COMPLEXIS since Year 2016. He is the founding Conference Chair for FEMIB since Year 2019. He published 3 books as sole authors and the editor of 2 books on Cloud Computing and related technologies. He gave 48 keynotes at international conferences. He is widely regarded as one of the most active and influential young scientists and experts in IoT/Data Science/Cloud/security/AI/IS, as he has experience developing 10 different services for multiple disciplines.