REVIEW

Artificial intelligence in the digital twins: State of the art, challenges, and future research topics [version 1; peer review: awaiting peer review]

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Abstract
Advanced computer technologies such as big data, Artificial Intelligence (AI), cloud computing, digital twins, and edge computing have been applied in various fields as digitalization has progressed. To study the status of the application of digital twins in the combination with AI, this paper classifies the applications and prospects of AI in digital twins by studying the research results of the current published literature. We discuss the application status of digital twins in the four areas of aerospace, intelligent manufacturing in production workshops, unmanned vehicles, and smart city transportation, and we review the current challenges and topics that need to be looked forward to in the future. It was found that the integration of digital twins and AI has significant effects in aerospace flight detection simulation, failure warning, aircraft assembly, and even unmanned flight. In the virtual simulation test of automobile autonomous driving, it can save 80% of the time and cost, and the same road conditions reduce the parameter scale of the actual vehicle dynamics model and greatly improve the test accuracy. In the intelligent manufacturing of production workshops, the establishment of a virtual workplace environment can provide timely fault warning, extend the service life of the equipment, and ensure the overall workshop operational safety. In smart city traffic, the real road environment is simulated, and traffic accidents are restored, so that the traffic situation is clear and efficient, and urban traffic management can be carried out quickly and accurately. Finally, we looked forward to the future of digital twins and AI, hoping to provide a reference for future research in related fields.

Keywords
Digital twins, artificial intelligence, intelligent manufacturing, autonomous driving, smart city
**Introduction**

The most important inspiration for Digital Twins (DTs) comes from the need for feedback between real physical systems and the digital cyberspace model. People try to recreate what occurs in the material world in digital space. Only the whole life tracking using cyclic feedback is the true concept of the whole life cycle. This way, digital consistency with the material world may be truly ensured throughout the whole life. Various simulations, analysis, data accumulation, mining, and even artificial intelligence applications based on digital models can ensure that it is suitable for real physical systems. An intelligent system’s intelligence must first be observed, modeled, evaluated, and reasoned. If there is no accurate modeling description of the actual production system by the digital twins, the intelligent manufacturing system cannot be realized.

Machine Learning (ML)-based AI applications are commonly regarded as a promising technology in the manufacturing industry. Nevertheless, the ML method needs a huge number of high-quality training datasets. In the case of supervised ML, manual input is frequently necessary to label these datasets. This method is costly, error-prone, and time-consuming, particularly in a complicated and dynamic manufacturing setting. Alexopoulos, et al. (2020) pointed out that the digital twin’s model can be used to accelerate the ML training phase by generating an appropriate training data set and automatically labeling it through a simulation tool chain, thereby reducing user participation in the training process. These synthetic datasets may be expanded and cross-validated using extensive real-world data that does not require considerable use. Fan, et al. (2021) investigates and proposes a vision of a disaster city digital twins concept, which can realize the interdisciplinary integration of information and communication technology (ICT) in crisis informatics and disaster response. This involves incorporating AI algorithms and methods to enhance situation assessment, decision-making, and coordination among different stakeholders, thereby increasing visibility into the dynamics of intricate disaster response and humanitarian assistance. According to Rasheed, et al.’s (2019) study, digital twins are adaptive models of complex systems. The latest developments in computing pipelines, multiphysics solvers, AI, big data cybernetics, data processing, and management tools have brought the prospect of digital twins and their influence on society closer to reality. Digital twins are currently a significant rising trend in a wide range of applications. Also known as computing giant models, device shadows, mirroring systems, avatars, or synchronized virtual prototypes. As a result, digital twins play a transformational role not only in how we build and manage cyber-physical intelligent systems, but also in how we promote the modularization of multidisciplinary systems to solve fundamental obstacles.

This paper aims to review the application status of digital twins combined with artificial intelligence technology in various fields, as well as the current challenges and the topics that need to be studied in the future. We hope to provide a theoretical basis for the application research of digital twins in various industries and have some enlightening effects.

**Research status of artificial intelligence technology in digital twins**

**AI in digital twins**

Professor Dr. Michael Grieves of the University of Michigan suggested the concept of digital twins for the first time in 2003. It is also known as digital mirror and digital mapping. It is a system of physical-to-physical world or digital expression. It is simple and straightforward to comprehend that it is in the virtual world. Copying real things in the real world is a concept that transcends reality. It is a digital simulation process that integrates several disciplines, physical quantities, scales, and probabilities using physical models, sensor devices, and historical operating data. According to Gartner, the digital twin was one of the top ten key technology trends for 2019. It was estimated that by 2020, there would be more than 20 billion sensors and terminals connected, and the digital twin would connect billions of physical devices, trying to simulate as much as possible of the actual situation of the physical world in the virtual world. This prediction has been verified, and it is the opinion of the authors that more sensors and terminal equipment will be used in this technology in 2021. Because the advantages of digital twins are becoming more and more prominent, the research fields of digital twins are diverse, mainly in the field of computer integrated manufacturing, and the development process has gone through many stages, as shown in Figure 1 below.

Data acquisition, data modeling, and data application are three main aspects of the digital twins. Data collection refers to the full use of satellite remote sensing, tilted aerial photogrammetry, lidar measurement, cameras and other technologies to obtain three-dimensional data from a complete physical space. The function of the sensor is to obtain different kinds of real data in the real world. The technical difficulty and key of data collection is the high precision and efficiency of data collection, which determines the quality, efficiency, and cost of data collection. After obtaining a large amount of original physical world data, data modeling was carried out, and automatic modeling tools were used for further processing to generate a three-dimensional model of the actual recovery of the physical world. In addition to high-precision virtual reconstruction of the environment, digital twin data is more effective in supporting various operating processes. Data modeling can be divided into two parts: visual 3D modeling and semantic modeling. Visual 3D modeling is a 3D reproduction of the physical world. The semantic modeling of digital twins includes “structuring” the collected data and identifying objects such as vehicles, roads, people, and internal objects. The mapping concept is shown in Figure 2.

AI, as a discipline of computer science, has not only changed our lives, but also changed many industries. It seeks to comprehend the basis of intelligence in order to create a new intelligent machine capable of responding in a manner akin to human intelligence. Robotics, language recognition, image recognition, natural language processing, and expert systems are all areas of study in this discipline. Computers, robotics, economic and political decision-making, control systems, and...
Figure 1. The development history of digital twins.

Simulation systems all employ AI. As shown in Figure 3, it is quietly changing our way of life. We can use map software to avoid congestion while out for a drive; the smart watches we wear can help us monitor and predict health risks; the robots in our home can use the voices of parents to tell stories to our babies; our sweeping robot can clean a large duplex house easily. Combining artificial intelligence with digital twins will produce unimaginable changes in all aspects of our lives.

Application status of AI technology based on digital twins

Artificial intelligence in digital twins is a universally applicable theoretical and technical system, with many applications, such as product design, equipment manufacturing, medical analysis, aerospace and other fields. At present, the most in-depth application in China is in the field of engineering construction, and intelligent manufacturing has gained the most attraction in the research field. The classification diagram of application areas is shown in Figure 4.

The use of digital twins in the aerospace field. The notion of digital twins was originally presented for use in the aerospace field. For example, digital twins are used in the maintenance and quality assurance process of flight simulation and aerospace flight machines. The real aircraft model is established in the digital space, and then the sensors are used to integrate the digital space. The status of the aircraft is...
synchronized with the status of the flying aircraft in reality. In this way, the process of each aircraft taking off and landing is simulated and stored in the digital space. Through the data analysis of the digital space, it is possible to clearly understand whether the aircraft needs maintenance and whether it can proceed to the next flight.

The purpose of the research by Yurkevich, et al. (2021) is to develop a neural model for digital air traffic control. This method adopts the concept of a physical self-organizing social network of a distributed organization and technical system, and its components are connected to wireless 4G and 5G networks. The advantage of this method is that the principle of analysis and management is very promising, and it has complex integration with hybrid artificial intelligence. Dai, et al. (2021) showed that the autopilot Unmanned Aerial Vehicle (UAV) system, as a safety-critical system, requires continuous improvement in its reliability and safety. Testing a complicated automatic pilot control system, on the other hand, is a time and money-intensive project that necessitates several outside flight tests during the project growth period. Therefore, an internal automated testing system for automatic driving platform is presented as a way to increase the efficiency and safety of UAV development. With the development of unmanned aircraft technology, unmanned aircraft are being employed in an increasing number of applications and are regarded as an essential component of the future smart city infrastructure. Simultaneously, the security and privacy threats connected with drone-based applications require proper testing and surveillance techniques. For a platform that facilitates the administration and performance of drone-based applications on a common drone architecture, Grigoropoulos, et al. (2020) supplied an analog environment and digital twins support. First, the simulation environment can perform in-depth testing of the platform itself and the functions of the applications running on the platform, and it can then be deployed to the actual world. After deployment, the digital twin is used to discover gaps and expected behaviors between applications, which in turn can be used as an error indicator when the simulation test is executed or malfunctions have not been found. Maintenance has evolved from “post-incident maintenance” and “preventive maintenance” to “predictive maintenance,” making it one of the most critical components of aviation. Precision maintenance is the future development path, with the purpose of ensuring operational safety and lowering the collaborative optimization goal and operating cost. To improve the effect of engine predictive maintenance, Xiong, et al. (2020) studied a digital twin-driven aircraft engine predictive maintenance framework, and discovered an implicit digital twin IDT model. The model’s validity is determined by evaluating the concordance of virtual and actual data assets. The usefulness of the approach is demonstrated by integrating the data-driven
deep learning (DL) method\textsuperscript{45} with the LSTM (Long Short-Term Memory) model\textsuperscript{46} and using an aviation engine as an example.

As shown in Figure 5, Compared with other industries, aircraft assembly has the characteristics of complex structure, a huge number of parts and extremely strict requirements on the aerodynamic shape of the product\textsuperscript{47}. Therefore, a professional assembly frame must be used to ensure that the parts will not be affected by human factors during the installation process, causing the problem of deformation and assembly errors\textsuperscript{48}. It is difficult to ensure strict precision requirements only by using traditional engineering drawings for process design and production and assembly basis. The emergence of digital twin technology provides the possibility for timely and effective interaction between the aircraft assembly process and on-site information feedback control\textsuperscript{44}. Liang, et al. (2020)\textsuperscript{49} pointed out that the full-field displacement perception of aircraft core components and digital twins play a vital role in precision production (such as aviation manufacturing). In their research, a real-time full-field displacement sensing method combining online multi-point displacement monitoring and matrix complete theory is also proposed, and a conceptual model of full-field displacement sensing based on multi-point observation information is established. HPP (High Precision Products)\textsuperscript{48}, a multidisciplinary coupled high-precision product, is frequently employed in aerospace, marine, chemical and other industries. It is precisely because the inner core of HPP is complicated and compacted, and the assembly process, which incorporates interdisciplinary coupling, demands great accuracy. Traditional assembly methods relying on hand experience are inefficient and inconsistent in quality. In light of the aforementioned issues, Sun, et al. (2020)\textsuperscript{47} researched and proposed a digital twin-driven HPP assembly and debugging method. It provides the theoretical architecture for digital twin-driven assembly and debugging, as well as the method for building an assembly and debugging full-element information model based on digital twins technology.

With regards to the problems of the civil aircraft quality deviation control system, the quality deviation control data is dispersed across numerous management systems, making it impossible to gather quality data-related information from the complete life
Figure 4. Classification of artificial intelligence application fields in digital twins.

Figure 5. Flight life prediction based on digital twin.
cycle of the aircraft concerned; there is a lack of closed-loop cyber physics for quality data analysis and quality deviation control Fusion System\textsuperscript{48}. Therefore, locating the quality deviation problems is tough, and dealing with these issues takes a long time. Cai, et al. (2021)\textsuperscript{43} researched and proposed a quality deviation control model based on digital twins. Multi-source heterogeneous qualitative deviation data may be retrieved and merged using digital twins modeling based on asset management technology, and a quality deviation system can be constructed. The FP-growth association rule algorithm is used in this system to evaluate aircraft quality deviation data, and the system may deliver findings to assist the assembly site and maximize the performance and correctness of correcting quality problems in the real world\textsuperscript{49}.

According to these discussions above, the digital twin offers a wide spectrum of uses in the aerospace industry, including digital simulation of aircraft flight routes, timely reporting of faults and repairs, and testing of the performance of unmanned aerial vehicles. Major breakthroughs and progress have been made in these areas.

The use of digital twins in the intelligentization of automated driving. AI applications are quickly developing as deep learning and big data analysis technologies advance. Among them, it is imperative to use artificial intelligence algorithms to develop autonomous driving systems. In real life, autonomous driving technology can reduce traffic accidents, realize the efficiency of time and space and other resource utilization, and even provide great convenience for the driving process of the disabled. However, due to the high technical requirements of autonomous driving, the need for digital twins to simulate driving in a virtual simulation environment has become an indispensable step\textsuperscript{50}.

Before self-driving cars actually enter the road, they must go through rigorous virtual simulation tests to ensure safety\textsuperscript{51}. In the traditional virtual simulation test environment, HTL (High Threshold Logic) equipment\textsuperscript{52} is often used for safety and proactive performance testing. But in this kind of test, only the controller is real, and other factors like the driver, gearbox, power, road environment, and other controller-related content are simulated in a virtual environment. Due to the limited computer level at present, the simulation environment cannot be set too complicated, so the performance of the tested car object is not so accurate, and the test accuracy has a certain deviation. Of course, testing in a real environment is undoubtedly the best choice, but due to various limitations of physical conditions, it is impossible to maintain a uniform test scenario every time. Therefore, a test evaluation system combining automatic driving simulation testing based on digital twin technology and actual road environment should be implemented\textsuperscript{53}. The digital twin test architecture diagram is shown in Figure 6.

Larin, et al. (2019)\textsuperscript{54} pointed out that the goal of self-driving automobiles based on Internet of Things (IoT) technology is to integrate linked cars and make them into “objects” that can move automatically. One of the important challenges that this technology has is ensuring the compatibility of various components and IoT systems, such as delivering services for vehicle and road equipment and sensors. The solution adopted is to use the joint Internet of Things platform and the oneM2M interoperability platform of the International Organization for Standardization in the Internet of Things field to ensure that there is no obstacle to communication between all components. Almeaibed, et al. (2021)\textsuperscript{55} pointed out that the new industrial revolution brought about by the digital transformation era makes it possible to use more and more AI and automation technologies in the manufacturing and transportation process. The application of the concept of digital twins to self-driving cars has benefited from the results driven by the digital age. Moreover, ensuring the safety of auto-driving cars can effectively reduce the occurrence of traffic accidents. There are also significant advantages in maintaining a safe distance between the driver and pedestrians during driving. In order to enable the intelligent manufacturing safety transportation system and realize the end-to-end transportation mode, the study proposes to adopt a new safety design to enhance the flexibility and security of the entire autonomous driving system. The study of Yun, et al. (2021)\textsuperscript{56} pointed out that computer simulation based on digital twins is an indispensable step in the design of autonomous vehicles. However, it takes a lot of effort to design a simulation environment that is exactly the same as the real road conditions, and the cost-effectiveness is very low, because many things must be implemented. In the study, a method was proposed to use the online game “GTA5” (Grand Theft Auto V) as the basis for the simulation of autonomous vehicles. The GTA5 online game may be utilized as an appropriate simulation tool since it has a range of ideal items, pedestrians, and highways. Through capturing the GTA5 game screen using OpenCV\textsuperscript{57} and analyzing it with Python’s YOLO (You Only Live Once)\textsuperscript{58} and TensorFlow\textsuperscript{59}, a highly accurate object recognition system can be established by designing algorithms to avoid object collisions and different lane recognition.

Applying digital twins to the field of autonomous driving, city or city-level digital twin data can be used as high-precision maps, that is, basic environmental data for car operation. It is the opinion of the authors that automobile manufacturers, auto-pilot equipment manufacturers and comprehensive solution providers all need the popularization of this technology. On the one hand, because the test environment for autonomous driving is very limited and costly, the digital twin can provide customers with an autonomous driving simulation system as a solution. The automated driving system using virtual simulation can verify the sensor performance and the reliability of the vehicle algorithm. On the other hand, it can be used as one of the mapping data in the actual autonomous driving environment. Automobile manufacturers can use the digital test field to perform virtual tests on vehicle performance, such as vehicle dynamics, comfort, and durability. The virtual test track is the road for performing tests on the ground. The virtual environment and real-world scenes are required to be as realistic as possible, including fixed vehicles, road signs, pedestrians, zebra crossings, obstacles, moving vehicles, and the number of road lanes in the
scene. Of course, with the continuous enhancement of technology in the field of autonomous driving, the requirements for the technical complexity of virtual test scenarios are getting higher and higher, so we need to develop a more complete architecture. Therefore, at least 80% of the time cost can be saved through the digital twin automatic driving test, and the same road conditions can be tested repeatedly, reducing the parameter scale of the actual vehicle dynamics model, and greatly improving the accuracy of the test results. It is the opinion of the authors that the process of operating in the virtual scene can avoid the probability of accidents that may occur in real traffic conditions, and can also reduce unnecessary material loss, thereby reducing enterprise costs. Therefore, the use of digital twins in the realm of autonomous driving opens up new ideas for automobile manufacturing and performance testing.

The use of digital twins in intelligent manufacturing. With the continuous development of intelligent manufacturing technology in various countries around the world, the informatization level of the manufacturing industry is gradually improving. In order to enhance product production rates and deal with emergencies in the production process in a timely manner, enterprises must strengthen the management and control measures of each module in the production workshop to improve the company’s ability to control the production process. Moreover, consumers’ higher individual requirements for products have caused companies to face a large amount of data, data requirements and data structures in the production process, which has made it difficult for companies to manage and analyze data. Therefore, in the manufacturing process, how to effectively and timely feedback the use status of the equipment in the production workshop and early warning of failures has become a major problem in the current intelligent manufacturing industry.

The development of modern and advance information technology, such as big data, AI, IoT, edge computing, etc. have promoted the transformation of traditional manufacturing to intelligent manufacturing. The most crucial feature of intelligent manufacturing is its autonomy and active self-optimization.
Zhou, et al. (2020) researched and proposed a knowledge-driven system framework for the transformation of digital twin manufacturing units for intelligent manufacturing, which can intelligently sense, simulate, understand, predict, optimize and control. Not only can it maximize product quality, but it can also reduce production costs. Smart manufacturing is not so much a challenge faced by traditional manufacturing, as it is an opportunity. The sustainability characteristics of smart manufacturing are more obvious. Li, et al. (2020) studied how to build a sustainable development evaluation digital twin driving system for smart manufacturing projects, and developed a digital twin driving system based on the classic digital double mapping system. Information architecture is a crucial solution for the sustainable growth of smart manufacturing projects. With the advancement of sensor technology and data processing, intelligent manufacturing based on cyber-physical systems has become the main trend in the development of the manufacturing industry. Given the variety and volatility of discrete production workshops, controlling the carbon emissions in the manufacturing workplace presents certain issues. Zhang, et al. (2019) researched and proposed a smart manufacturing workshop digital twin driven carbon emission predictive control model, which combines the latest computer technology and low-carbon control technology to verify and optimize the model in the virtual workshop.

Digital twin workshops are the core component of intelligent manufacturing. They are composed of a physical workshop, a virtual workshop, a workshop service system and workshop twin data, among which virtual workshop is the most important component. The construction of a virtual workshop starts from three directions and consists of several elements: using virtual digital geometric models to represent the environmental elements of the workshop, including workshop staff, machines, products, etc. Behavior elements include production elements such as the speed trajectory of the equipment in the workshop and different production instructions, simulation of the operation status of the equipment in the workshop. Rule elements use the existing physical environment of the workshop to evaluate, analyze, predict, and optimize the production process to realize the establishment of a virtual workshop. As shown in Figure 7. In the actual production process, equipment failures occur from time to time, which affects the production schedule and costs. If repairs are carried out after the fault occurs, it is often difficult and requires a lot of manpower and material resources to perform fault screening. Therefore, it is particularly important to carry out early warning of the failure of the equipment and the service life of the equipment.

The research of Zhao, et al. (2019) aimed at the real-time visual monitoring of digital twins workshops, and presented a 3D
visual monitoring method based on real-time data of the workshop. The interaction between the workplace of digital twins and 3D visualization real-time monitoring is investigated. A multi-level 3D visualization monitoring mode and a real-time data-driven virtual workshop operation mode are proposed. This paper explained workshop geometric modeling, workshop real-time data management, workshop multi-level 3D visualization monitoring, and workshop status board construction methods in detail. The effectiveness of the presented method is verified through actual case studies. The research of Wu, et al. (2019) pointed out that the workshop production line combines the use of key digital technologies on the basis of intelligent workshop equipment. It mainly adopts virtual-real data synchronous communication and virtual-real mapping technology to realize surreal virtual real-time of physical entity digital simulation. The items in the workshop can be developed according to actual applications, and a virtual model of the intelligent workshop can be built internally. Job shop scheduling is always vital in the production process and is one of the most critical elements influencing manufacturing efficiency. There are some unknown occurrences, information asymmetry, anomalous disturbances, and so on in the real production scheduling process that will create execution deviations and impair the efficiency and quality of scheduling execution. Traditional scheduling strategies are insufficient to address these issues effectively. Fang, et al. (2019) proposed that due to the rise of digital twins, which have the characteristics of virtual reality interaction as well as real-time mapping and symbiotic evolution, a new job shop scheduling method based on digital twins is proposed to reduce scheduling deviation.

Based on the above research, it can be shown that digital twins have made breakthroughs in the field of intelligent manufacturing, especially the use of virtual workshops, which can greatly reduce the probability of equipment failures, and also help staff to adjust the overall scheduling of the workshop in time and improve equipment production efficiency. Digital twin technology can realize virtual simulation of products, manufacturing processes and even the entire factory in the field of intelligent manufacturing, thereby improving the production efficiency of product development and manufacturing of manufacturing enterprises. In addition, it can also create products in a virtual three-dimensional space. By modifying the components and products of various sizes and assembly relationships, it can greatly simplify product geometry verification work, assembly feasibility verification work, and process implementation. At the same time, the manufacturing times, time and cost of physical prototype in the iterative process are greatly reduced.

The use of digital twins in smart cities. The concept of digital twins is simply to map people, objects, relationships, and processes in real-world to virtual-world, and realize the research and control of real objects by observing and analyzing the digital twin in virtual space. Applying this concept to the field of urban transportation is undoubtedly a boon to the construction of smart cities, this is reflected in Figure 8. The major functional region management of an urban area is a spatial organization and strategy that promotes urban and regional development with space control as the main goal. The research of Gao, et al. (2017) shows that: the construction program of urban functional areas is optimized and analyzed according to big data and GIS.
Digital twins improve the efficiency of unmanned driving training. At present, intelligent research centers are conducting research on intelligent unmanned driving virtual training systems to provide an open virtual test and training platform for the road driving safety and intelligent driving capabilities of unmanned car driving algorithms. The goal of this type of project is to reproduce real traffic scenarios in the digital space, create extreme environments and critical high-risk scenarios for unmanned vehicles through generalized derivative technologies, and greatly increase the effectiveness of unmanned driving training.

Based on the perception of static and dynamic data, we can create a digital twin model, realize the scene reproduction based on twin data, and help unmanned vehicles conduct virtual testing and training. However, it is not enough to provide digital twins with high-fidelity scenarios. What is more important is to derive and generalize the twin scenarios to continuously enrich the test scenarios of unmanned vehicles. The research of Mavromatis et al. (2020) shows that in a world where artificial intelligence has completely changed the tasks of reasoning, forecasting and judgment, digital twins have become a tool that affects game balance. A typical example is the creation and improvement of the CITS (Cooperative Intelligent Transportation System), which is the integration of cyber-physical digital infrastructure and (semi) automated mobility. Derivative generalization is the key to digital twin technology. It must be derived from reality, but must also be higher than reality and make some changes to the reality. Bhatti et al. (2020) pointed out that the popularization of smart electric vehicles can reduce carbon dioxide emissions by up to 43%. Nevertheless, in order to mainstream these automobiles, some support infrastructure is required to enhance them in a long-term manner. As a new emerging architecture, the related method of digital twins is based on a virtual map principle, which can be used as a basis for expansion, and it can further help the study of the life cycle of multi-system subjects in the virtual environment. In the system development, generalization simulations of various cases are also carried out based on the twin scenarios, such as increasing the generalization of weather changes, human driving behaviors, and scenario cases. As an example of the generalization of a scenario case, it is assumed that the accident scenario of a large truck rolling over a person is simulated, but after the model is completed, it is a fixed scenario. That is, the vehicle arrives at a fixed position at a fixed time, lacking information on the cause and consequence of the actual accident scene. At this time, you need to do some intelligent processing, such as increasing the speed of the car, or increasing traffic participants, etc., so that the scenario case is similar to the real scenario but is different. Here, similarity refers to the reappearance of real accident scenes, while the difference is reflected in the more dynamic process reappearance in the virtual scene.

In the analysis of traffic accidents, a truck traffic accident is taken as an example. Once the accident scene environment and the trajectory of traffic participants are tracked and restored, the process of the accident can be observed from multiple angles. Rudskoy et al. (2020) indicate that transportation regulation issues in all cities at the emergence stage are very serious. Originally, the control center was responsible for resolving this issue. At present, these centers have gradually introduced some intelligent traffic management methods to help solve the key issues of the transportation network. With the help of digital twins and AI, they can realize the optimized development of modern traffic control. Through the freeze-frame processing, it can be found from the perspective of the vehicle that the truck driver cannot actually see anyone passing by on a bicycle. The road digital twin is an important step to realize the smart city of the future, and for this, ElMarai et al. (2020) deployed the Digital Twin Box on a road with a 360° camera and a collection of IoT devices linked to a sole hub on-board computer. Digital twins box transforms a physical road into a digital replica asset by continuously transmitting real-time data (including 360° real-time streaming, GPS (Global Positioning System) location, and temperature and humidity measurements) to the edge or cloud. The live stream is displayed via a head-mounted device or using a 360° web-based player. The data will be utilized as real-time supervision of traffic conditions and other assignment such as historical traffic data query. It is also possible to monitor the occurrence of traffic accidents by installing smart cameras in cars. As for the fast-paced growth of smart cars and driver assistive technologies, in the traffic system, there is a varied degree of human driver engagement. In this case, Liu et al. (2020) pointed out that the driver’s visual guidance is essential to avert possible dangers. To encourage the advancement of visual directing mechanisms, an innovative sensor merging technique was introduced to integrate camera images from the cloud and digital twin knowledge. Combining the findings of the target detector operating on the vehicle and the position information from the cloud, the bounding box of the target vehicle is drawn and matched. Therefore, digital twins have great application value in traffic accident analysis scenarios, which can help trace and analyze the specific causes of the accident and find the person responsible.

In the direction of overall traffic control, digital twin technology is used to simulate urban traffic conditions, and then to
optimize traffic control strategies through evaluation and deduction. This is an important application scenario for digital twins to empower smart transportation. It mainly involves three levels of functions:

The first is monitoring and discovery. Through the digital twin system, a closed loop of information acquisition and control can be created, and the whole process can be controlled. More importantly, in a very large and complex scene, some key issues can be discovered and dealt with in time. For example, in the autumn and winter season, a certain section of high-speed section of the fog frequently occurs. The fog has the characteristics of low visibility, strong suddenness, and difficulty in weather forecasting, and it is easy to cause traffic accidents. Using the digital twin technology, real-time detection of dynamic perception data can detect the occurrence of cluster fog in time and give warnings. For instance, airport traffic control can also use digital twins. Sainudinov, et al. (2020) studied and made a digital twin experiment in the area of concentrated transportation management at airports. A specific simulation model was used to mimic the data flow of vehicle spatial features. The model may be used to explain and simulate certain circumstances in the transmission network that necessitate the involvement of a centralized control system. Assuming that, in the early phases of employing digital twins, users with appropriate traffic management abilities can execute the function of the control system, and that user’s decisions are saved in the digital twin’s memory, which may be used to teach the control system using machine learning. The design and integration of the ship traffic service system and the implementation of the new VTS (Vandenber Tracking Station) software development is a difficult endeavor with many obstacles in terms of interface and time. The research of ÜZUMCÜ, et al. (2019) pointed out that the personal instructions of the command operation center and the participation of information from the captain as a participant, as well as the automatic identification system, radar system, electro-optical system, and physical security outside the traffic service system and the participation of different systems makes the overall system design difficult to manage. The use of MBSE (Model Based System Engineering) technology systems and tools designed using digital twin technology help simplify the system design overview and check before the execution and combination phase begins, the interface definitions on the left side of the model.

The second level of functions is deduction and prediction. After mastering the data, it is possible to create micro-behavior models for some participants, and then through simulation calculations for a large number of traffic participants, macro-simulation results can be obtained, the development of the situation can be deduced, and the prediction function can be realized. The rapid development of the national highway transportation system is not only based on the intelligent construction of the city, but also the result of continuous innovation in contemporary information technology, and GIS technology has effectively promoted the development of country’s highway transportation informatization. GIS technology, as a significant geographic data process system, has apparent technological benefits in traffic data collecting, analysis, and processing, and encourages the growth of road traffic in the direction of informatization. In order to hasten the maturation of the road traffic system, Wang, et al. (2021) pointed out that from the aid of GIS technology, road traffic digital twins can gradually be built. Digital technology fosters the growth of road transportation in a green, open, and shared direction as a revolutionary technology in the development of road transportation, creating a firm basis for the quality of road building. Owing to the complexity of cities, smart cities are a complicated process. The city is not a computerized system that is easy to understand and predict, but rather a living system. Although the research on urban digital twins is still in its initial stages, the progress of digital twins is developing rapidly and has made feasible contributions to enhancing the development of smart cities. Shahat, et al. (2021) determine the current and future potential and obstacles of digital twin cities, and put forward a research agenda to guide future research on urban digital twins in order to approach the pinnacle of comprehensiveness and completeness of urban digital twins.

The third level of functions is to evaluate and optimize countermeasures. Through massively parallel computing, the simulation results of many parallel worlds can be evaluated at the same time. Then, through intensive learning and other technologies, we will continuously improve the traffic control plan, and make historical retrospective and review research. When an incident occurs, we can use the digital twin system to restore the entire process of the traffic accident, and explore whether each step of the response was done well enough and whether there is room for improvement. A digital replica of the infrastructure may be used to perform simulations throughout its life cycle, allowing for better asset creation, management, and maintenance. These digital twins (defined as integrated multiphysics, multi-scale and probabilistic simulations of complex products) reflect the behavior and environmental response of their corresponding twins. Steyn, et al. (2021) use optical sensor technology, and at the same time use a contact-mobile sensor platform as a support, through digital reconstruction technology to provide a feasible low-cost alternative to the digital twin of innovative physical infrastructure through digital reconstruction technology. Brunner, et al. (2019) point out that the range of potential safety-critical situations of autonomous driving functions in urban traffic is too wide to be fully tested by natural driving alone or in a controlled laboratory environment. Technology and traffic road conditions are constrained. These and similar issues can be solved by the use of extensive and validated random simulations in a virtual, randomized controlled trial design. The virtual test can create a large database and provide the statistical capabilities needed to detect the high-dimensional traffic scene space needed for safety evaluation and “stress testing.” Ingolstadt has created a “digital twin” of the city’s road network. Germany is a key requirement for virtual testing. Gao, et al. (2017) concluded through research that the small-distance arterial road has the advantage of adaptable network framework, which is friendly to land development and transportation development. When traffic demand is high and it does not
fulfill the standards of traditional road infrastructure layout, it should be combined with actual conditions, in-depth study, and the road network plan should be prepared to optimize the road network’s traffic efficiency based on regional circumstances.

In summary, digital twins are widely used in urban smart transportation. The digital twin technology underpins the construction of urban information model, and includes elements of architectural information, geographic information, new street scenes, and real three-dimensional scenes. Its core revolves around end-to-end management and operation of global data, including data collection, access, governance, integration, lightweight, visualization, and application. The visual model of the urban environment contributes to a clearer, more efficient, rapid and accurate urban traffic management.

**Challenges for artificial intelligence in digital twins**

Challenges faced by digital twins in the field of automotive autonomous driving

Due to the rapid development of the global intelligent internet automotive industry, research on automotive internet related technologies is of great significance to promote the development of automotive Internet. The parameterization and generalization technology of traffic scene simulation shows that the test process and working conditions of autonomous driving simulation can be said to have no boundaries. Whether the car is running normally or not, it can be tested repeatedly to facilitate the discovery and location of problems. However, in the process of vehicle dynamic simulation test, the simulation sensor and sensing system enter the automatic driving control and decide to form a closed-loop test and system verification test equipment by pure software, which is also an important challenge for the current automatic driving hardware equipment.

The main function of automatic driving is to control the simulation car corresponding to the real car in the simulation system by receiving the real-time position, speed, acceleration, heading angle and other information of the real car sent by the data collection visualization system. Realize the real vehicle control and the simulation vehicle runs in the virtual scene, so that the motion states of the two are synchronized, and realize the basic function of the real vehicle in the loop. Although the current stage of research has formed a highly open digital twin autonomous driving test capability, a friendly and open test and verification environment has also been established to support a variety of autonomous driving algorithm experiments and provide open testing services for research companies related to autonomous driving. However, there are still challenges to solve the test solution:

**Testing cost issues.** The current test system for autonomous driving is not complete yet, but it has already produced high test costs. This is a very big challenge for automobile manufacturers. The most important issue for automobile manufacturers is how to maximize benefits and minimize costs. Therefore, the establishment of an efficient and low-cost test environment, a structured test process, and a strong test standard are all key issues in reducing test costs;

**Smooth advancement of the test system.** Autonomous driving technology solutions for automobiles will definitely face tremendous changes and reforms in the future. First of all, the test system needs to smoothly adapt to technological advancement. During the test, the vehicles, pedestrians, road conditions, traffic signs, etc. in the system must be kept stable and orderly. Of course, it also needs to be tested according to the test. The number of objects grows and the types of cars undergo system upgrades from time to time.

Challenges faced by digital twins in the aerospace sector

Although the artificial intelligence application of digital twins has a wide range of research in the aerospace field, there are still some technical challenges. Take the aero-engine gas path system as an example. Based on the advancement of cognition processing innovations and industrial level, the data analysis of aero-engines is shifting towards all-round, multi-level, and visualization. The analysis of engine parameters ranges from engine components to the overall engine, from engine condition monitoring to overall health management. Data analysis has also gone from traditional integration to a digital twin process that combines large amounts of data, methods, and models. At present, the detection of engine condition monitoring and authorization digital electronic control system, fault detection and location can basically be completed, but the method of analyzing the overall health of the engine is limited, which has also become a major challenge for scholars around the world.

The concept of digital R&D strategy seems to be a cliché. With the efforts of industrial software manufacturers in the past 10 years, various industries in China, including the aerospace industry, are already “quite” familiar with the concept of digital twins, but we are familiar with digital R&D applications. What is the depth, breadth, and value of the harvest, we still have considerable room for improvement. The life cycle of an aircraft can reaches several decades, so recording and analyzing the data of the entire life cycle is not only valuable, but necessary. The document-based departmental collaboration model must shift to a model-based, digital twin-digital collaboration model. This also brings great challenges to related industries.

Regarding the use of digital twins, the best generalization is to build and maintain a large number of surreal models and data.
They are best able to predict the product behavior throughout the life cycle through real-time simulation. These models are constructed in several proportions and examples according to different application situations, integrating multiple aspects, including the best and physical descriptions, and mirroring the real product life. When the digital twin is deployed to the full range, it will track all parameter information that affects the operation of the product. It includes the initial design and further improvements, manufacturing-related deviations, modifications, uncertainties, updates, as well as all the historical data and aviation data that can be obtained from the sensor data of the airborne combine traffic wellness supervisory system, manage former records, and realize data mining.

Therefore, only by utilizing the complete digital twins technology to establish a large number of surreal models and data, including digital product models, digital manufacturing models, and digital performance models, real-time, two-way, transparent, and systematic consideration of design, manufacturing, and performance. It is possible to control and reduce the development cycle, otherwise as the difficulty of research and development increases, the risk of delayed delivery will become greater and greater. In addition, only full digitalization can break through the bottleneck of performance design.

Challenges faced by digital twins in the field of smart manufacturing
As many intelligent production and construction technology becomes more and more mature, intelligent manufacturing technology is becoming more and more popular, and the realization of efficient and intelligent real-time monitoring of the production process of workshop equipment is still the focus of research. At present, industrial production has developed to a stage of high automation and informationization, but there are still many problems that need to be improved and optimized. For example, many factories have different levels of construction of information systems, the channels between the systems are not fully opened up, there are a large number of information islands, and there are issues like incomplete data management and inconsistent data standards. Specifically, the products produced by the factory are diversified, highly personalized, and poor in versatility. This directly leads to frequent product design and process changes, and brings great challenges to production, procurement, warehouses, and quality.

Besides, the factory also has problems to be solved for the small batch production of multiple varieties of products: for example, some discrete production models of multiple varieties and small batches limit the pace of large-scale production and intelligent transformation of the workshop production line. Factory equipment is obsolete and difficult to rebuild, and many links are still dominated by manual operations. However, if the factory relies too much on manual operations, it will lead to a reduction in automation and intelligence. The digital twin platform plays a very important role in industrial product design and industrial product production. In the current highly informatized and integrated industrial production model, when an unexpected failure occurs on the production line, it is easy to cause the entire production line to stop and stop production. For example, a highly refined automobile production line can cause millions of losses every day. For some special process production lines, such as chemical production lines under high temperature and pressure, they even face serious safety risks and derivative disasters. Therefore, the industrial production process must rely on the help of large-scale data, such as equipment diagnosis, chemical production process simulation, and simulation prediction of current equipment status and production process results in a virtual digital space, so as to prevent field failures and production abnormalities to cause serious consequences.

In the process of industrial product design, if there is no digital help, designing a product will have to go through many iterations, which consumes resources and affects the delivery time. In the design of a highly integrated industrial production line, it is necessary to optimize and coordinate various equipment, materials, quality inspection, manual assembly and other links based on precise beats to improve overall efficiency. The traditional planning process can only rely on manual simulation or verification in a real production line.

Challenges faced by digital twins in the field of smart city transportation
The digital twins city is a brand-new technology path for the construction of a new type of smart city under the background that the accumulated data of the city changes from quantitative to qualitative change, and in the context of major breakthroughs in information technology such as perception modeling and artificial intelligence. It is an emerging technology path and advanced mode for urban intelligence and sustainable operation. However, in the face of many challenges in current urban management, how to break through the shackles of traditional smart cities and gradually transform and upgrade to a “digital twin city” is a question worth considering. The kernel of the digital twins city is the model and data, and the establishment of a complete digital model is a crucial beginning point. From the perspective of the current application of traditional smart city construction, there are still data fragmentation in various fields. Generally, there are at least three base maps in general cities, namely, the urban information model platform promoted by the housing and urban-rural construction system, the spatiotemporal big data platform led by natural resources and land planning, and the city base map for urban security and comprehensive governance based on the line of public security politics and law. Each base map forms its own system, and generally only supports the applications in the system. It cannot be used by other departments on demand and at any time. The number has already been accumulated in quite some time, and it is tough to give up and integrate. This makes it difficult and challenging to implement the urban traffic simulation process.

In fact, in terms of the construction of digital twin tools and platforms, most of the current tools and platforms focus on certain specific aspects and lack systematic considerations.
However, to create a visualization of the entire process of urban planning, construction and management, collect urban “pulse” data, reflect the in-time operating situations of the city, and provide root solutions for information resource sharing, integration, effective utilization, and cross-departmental business collaboration. Digital twin technology has great potential.

Future prospects of artificial intelligence in digital twins

Future prospects of digital twins in the field of automotive autonomous driving

In the future promotion of the digital twin automobile autonomous driving virtual environment test system, the use of open analog interfaces to control code-based traffic scenarios is a major trend in the future. Future research topics will be carried out around the promotion of the test platform. After all, the current utilization rate of the autonomous driving test environment is not so high. In the future, a large amount of comprehensive market research is needed to accurately grasp market needs, formulate a reasonable market promotion plan, including scientific research results transformation methods, product promotion and application methods, product pricing, etc., formulate a reasonable product development plan, and establish software and hardware integration digital twin autonomous driving test platform.

The promotion can be achieved through the establishment of a digital twin autopilot test system through joint auto manufacturing companies, auto suppliers, scientific research institutions, etc., to jointly overcome its technical difficulties, gradually form a consensus on the autopilot test system, and promote the development of the autopilot test industry. On the other hand, it launched a digital twin autonomous driving test platform for auto companies, auto suppliers, and scientific research institutions. It adopts a joint unit membership system for low-cost use and joint development; for non-joint units, two methods are used: fee-per-time for testing services, annual fee for platform establishment, or perpetual authorization fee. Establish a complete pre-sales consulting-platform establishment-testing service-after-sales maintenance team and system, and carry out the adaptability adjustment of the test platform and the collection and resolution of after-sales problems.

Of course, tracking and recording the process is also very important. Continuously track and record the external use of the digital twin autonomous driving test platform, establish a database of use information, and compare various aspects on the bases of use data. The modularization and platformization effect evaluation of the digital twin automatic driving test system is carried out, so as to realize the targeted improvement of the digital twin automatic driving test system, and realize the closed-loop development mode of “platform establishment-tracking return visit-iterative upgrade”.

Future research topics of digital twins in the aerospace field

In the aerospace field, the use of digital twins has already shown impressive benefits. With the help of the construction of physical entity model and the application of related data, it can not only reduce the number and duration of aircraft certification tests, eliminate accidental cracks and failures, but also reduce the number of maintenance inspections for the overall structure of the aircraft and frequency to achieve unprecedented economic safety and reliability. However, the digital twin technology currently lacks a systematic and universal reference model for guidance, and in the future, there is still a long way to go in related research on the optimization of digital twin models. In addition, digital twins will gradually develop in the direction of simulation and integration. These two are also the subject of future research. Virtualization- the integrity of object digital twins is critical to the success of their application in the industrial area. Each physical model has a particular model, commonly used models such as fluid mechanics, structural mechanics, thermodynamic, applied mechanics, fatigue damage, material state evolution model, etc., in the future, associating different models together and reflecting them in the twin model in real time is the key to the implementation of digital twin technology. Integration-the realization of the two-way interaction of models and key data at all stages of the product and twin life cycle determines whether the digital twin technology can be successfully applied. The realization of this breakthrough requires other technical support, and the vision of the digital twin needs to be integrated with other advanced technologies to be realized.

Future prospects of digital twins in the direction of smart manufacturing

In the coming years, digital twins development trend will keep increasing. More and more manufacturers are beginning to utilize digital twin technology to improve procedures, generate real-time database judgments, and begin to look for opportunities to revise innovative services, products, and business methods. The manufacturing industry will slowly become a pioneer in the application of digital twin technology. If early practitioners show first-mover advantages in various industries, other manufacturing companies will follow their pace. In the long run, to realize the full potential of digital twin technology, it may be necessary to integrate systems and data across all parts of ecosystem. Establish a complete digital imitation of the client life cycle or supply chain, and provide an insightful macro-operation view, including first-tier suppliers and their own suppliers, but still need to integrate exterior substances into the interior digital ecosystem. Now, most manufacturers are still dissatisfied with outside connection that extends beyond point-to-point connectivity. To overcome this hesitancy may be a long-term battle, but in the end all the effort is worth it. In the future, companies hope to use block chains to break information silos, verify information and enter digital twins. This will release a large amount of previously inaccessible data, make the simulation more detailed and dynamic, and create immeasurable potential value.

Future research topics of digital twins in intelligent urban transportation

With the continuous iteration of information technology, the gradual improvement of 5G standards and the establishment
of commercial networks, the network performance of large bandwidth, high speed, and low latency will further empower the upgrade of the digital twin intelligent transportation system. On the one hand, the 5G ultra-high-speed network performance makes it possible for vehicles to communicate safely and reliably in high-speed movement, ensuring the realization of functions such as vehicle-road collaborative automatic driving, vehicle formation automatic driving, and remote automatic driving. On the other hand, the accelerated development of 5G has coordinated the IOT and AI to enable the transportation system to have the ability to "connect all things", allowing digital twins to "migrate" the four elements of "human-vehicle-road-environment" transportation from the physical world. In the digital world, traffic data has been greatly enriched, allowing the "digital, networked, and intelligent" of smart transportation to be truly implemented. Although digital twins are the frontier trend of smart transportation, there is still a certain gap between the real global management, synchronous visualization, and virtual-real interaction digital twin transportation system. However, driven by 5G technological changes and demand upgrades, digital twins generate novel thoughts, new approaches, and new concepts for smart transportation, which will continue to develop in the future and eventually form a complete technical operation system.

With the advancement of 5G, 6G and other cutting-edge communication technologies, coupled with end-side-cloud collaborative computing, the real-time performance of digital twins can be improved, and it is even possible to model unknown areas in real time without relying on high-precision maps. Secondly, by improving behavior simulation and prediction algorithms, the deduction of behavior prediction can be made more accurate, and with stronger computing power, even more parallel worlds can be deduced at once. Furthermore, with the development of V2X (vehicle to everything) technology, there will be more types of traffic participants and more complex scenarios. How to make simulation better is also a direction that is worth studying. Finally, in terms of real-time decision-making and remote control of individuals, the requirements for the entire twin system will be higher. For example, whether data can be transported to the cloud and backend instantaneously and safely, and through situational awareness, the control commands can be transmitted back to the physical world. This process must be done fast enough, and the data transmission process needs to be safe and stable. Incorporating related technologies such as blockchain is an exploratory solution to make this information closed-loop process safe and stable.

The digital twin city is also a product of the continuous development of urban informatization construction and a high-level stage of urban informatization development. The digital twin city corresponding to the physical city makes full use of the city-wide big data formed in the early stage to provide platforms, tools and means for city comprehensive decision-making, intelligent management, and global optimization.

**Discussion of the use of digital twins in related fields**

According to research conducted by researchers, it can be found that the application of digital twins in different fields has become mature, and there are good application prospects in the future. This has also been confirmed in some current studies. Wan, et al. (2021) reviewed the performance of semi-supervised support vector machines (SVM) in brain picture fusion digital twins in terms of feature detection, diagnosis, and prediction. Aiming at the large amount of unlabeled data in brain images, using both unlabeled and labeled data, a semi-supervised SVM is proposed. At the same time, the research also describes how AlexNet model is enhanced, and the digital twin model is used to map the brain image in the actual space to the virtual space. It is not difficult to find that although brain tumor images have complex edge structures, artifacts, offset fields and additional flaws affecting image segmentation, the application of digital twins in the medical field realizes the key steps for precise treatment of brain tumors, which truly meets clinical needs. It is extremely important in the follow-up clinical diagnosis and treatment of brain tumors.

Lv, et al. (2021) discussed the consequences of application and limits of UAV (Unmanned Aerial Vehicle) in 5G/B5G (Beyond 5G) mobile and wireless communications. According to 5G communication, DL algorithms are proposed to develop a UAV digital twin messaging pathways model on the basis of DL. Coordinated multi-point transmission technology uses unmanned aerial vehicles for research on interference suppression. The essential algorithm in physical layer safety is employed to assure information transmission security. Finally, one can simulate and analyze the constructed model. The algorithm has outstanding advantages in convergence speed and convergence effect, and shows strong robustness. The research further verified that internet technology plays an irreplaceable role in the development of aerospace industry.

Tao, et al. (2021) showed that digital twins-exact virtual copies of machines or systems-are revolutionizing the industry. Driven by real-time data collected from sensors, these complex computer models reflect almost every aspect of items, procedures, or service. Many large companies have used digital twins to find problems and improve efficiency. An analyst predicts that by 2021, half of companies may use them. Nevertheless, there is still a lot of work to be done to actualize the potential of the digital twin. Still facing the difficulty of collecting data types, such as missing or wrong data will distort the results and conceal failures. For example, if the vibration sensor fails, the oscillation of the wind turbine will be ignored. The establishment of algorithms and models also faces great challenges. For example, when software written for different purposes is manually patched together, other errors may occur. Without standards and guidelines, it is difficult to validate the generated model ’s accurateness. Many digital twins may need to be combined. For example, a virtual plane may combine a 3D model of the airframe with one of a fault diagnosis system and an air conditioning and pressurization monitoring system.

**Conclusion**

With the fast growth of big data, IoT, industrial internet and intelligent control technology, digital twins are extensively employed as a novel form of technology in many aspects of life. Digital twins have emerged as the ideal connection between the real world of manufacturing and the digital virtual world,
as well as an effective technological way of realizing the interaction and cooperation of the real and information worlds. A digital twin is a virtual entity that creates a real entity in a digital way, and uses historical data, real-time data, and algorithm models to simulate, verify, predict, and control the entire life cycle of a real entity. As a key technology and an important tool for improving efficiency, digital twins can effectively play their roles in model design, data collection, analysis, forecasting, and simulation to help boost digital industrialization and industrial digitization, as well as the incorporation of digital and actual economy development. Digital twins rely on knowledge mechanisms, digitization and other technologies to build digital models, use IoT and other technologies to convert data and information in the physical world into general data, and combine AR/VR/MR/GIS (Augmented Reality/Virtual Reality/Mediated Reality/Geographic Information System) and other technologies completely to reproduce physical entities in the digital world. On this basis, common applications such as the description of digital twins, diagnosis pre-adjustment/prediction, and intelligent decision-making using technologies such as AI, big data, and cloud computing are empowered to various vertical industries. It can be seen that artificial intelligence is one of the underlying core technologies of the digital twin ecosystem. Its necessity is mainly reflected in the massive data processing and system self-optimization in the digital twin ecosystem, so that the digital twin ecosystem is orderly and intelligent cloud travel, and it is the central brain of the digital twin ecosystem. The combination of the two is critical for the current state of research, and future research will bring varying degrees of intelligent transformation to various industries.

Data availability
No data are associated with this article.

References


