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A COMMAND SUPPORT MODEL BASED ON BLOCKCHAIN AND THE METAVERSE

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Abstract: Traditional command support systems face issues such as deficiencies in decision support, data silos, and risks of forgery and tampering, which significantly hinder the enhancement of combat effectiveness and support capabilities. The metaverse, through tools like visualization, immersive platforms, and scenario simulations, aids in decision-making. However, it is threatened by data security concerns and asset ownership issues. Fortunately, blockchain technology offers a higher level of trust and security for the metaverse, serving as a foundational technology to address its shortcomings while effectively facilitating data flow and integration, thus eliminating data silos. Based on a needs analysis, this paper proposes a command support system model integrating the metaverse and blockchain. It provides a detailed description of the model's construction and briefly introduces the challenges and solutions associated with this integration. This work offers valuable insights for aligning future intelligent equipment supply support needs with the demands of modern warfare.
Keywords: Metaverse; Blockchain; Command support; Military application

1 INTRODUCTION

The rapid transformation of modern warfare necessitates that command support systems possess greater flexibility and responsiveness to adapt to increasingly complex battlefield environments. In this context, the efficiency of command support systems becomes a critical factor influencing the outcome of conflicts [1]. Traditional command support systems often employ a centralized hierarchical management model, where decision-making processes typically require multiple levels of approval, leading to cumbersome procedures and slow response times that hinder adaptability to rapidly changing battlefield demands. Additionally, centralized data storage presents a risk of single points of failure; should the system collapse, it could severely disrupt information transmission and order issuance, thereby diminishing the overall command effectiveness. Therefore, the decentralization of command support systems is not only an optimization of management structure but also a crucial means to enhance command efficiency.

The metaverse and blockchain technology, as two prominent trends in the contemporary internet and information technology landscape, are increasingly reshaping our societal structures and developmental models. Beyond their widespread applications in entertainment, finance, and the arts, both the metaverse and blockchain hold significant potential for advancing national defense and military development. As an emerging virtual interaction platform, the metaverse injects new vitality into command support systems through immersive experiences, data visualization, and augmented reality technologies [2]. By providing intuitive information displays and dynamic predictive analytics, the metaverse enables commanders to better comprehend complex battlefield situations. For instance, data visualization techniques allow commanders to monitor real-time distributions of resources, battlefield dynamics, and the comparative strengths of friendly and enemy forces, facilitating more accurate decision-making.

Moreover, the real-time feedback mechanisms and collaborative platforms within the metaverse enhance communication efficiency among teams, enabling rapid information sharing and significantly improving the scientific and effective nature of the decision-making process. The virtual nature of the metaverse also allows for the creation of various simulation scenarios, providing an ideal environment for equipment testing and personnel training. Through virtual reality technology, commanders and soldiers can conduct tactical drills and equipment operations in a safe environment, accumulating experience and enhancing professional skills. This immersive training not only reduces the costs associated with actual exercises but also effectively improves the overall quality and adaptability of military forces.

While the metaverse possesses many distinctive features, user data is at risk of privacy breaches and misuse. This concern is particularly critical in command support tasks, where data security is paramount; any information leakage could lead to irreversible consequences. In this context, the introduction of blockchain technology is essential. By employing decentralization and encrypted storage, blockchain enhances data security, effectively protects user privacy, and ensures that information within command support systems is safeguarded against unauthorized access or tampering.

This paper proposes a model for a command support system that integrates the metaverse and blockchain. The combination of these two technologies promises to provide more efficient and secure decision support in complex battlefield environments. The paper first outlines the characteristics of the metaverse and blockchain technologies, discussing the opportunities and challenges presented by their convergence, which is expected to significantly elevate the level of intelligence in command support systems and enhance operational effectiveness. Furthermore, it designs a command support system model, detailing its overall design, technical architecture, smart contracts, and application scenarios.

2 BACKGROUND

2.1 Metaverse

Metaverse is not a simple collocation of meta and universe, it is a compound word that transcends both, and is a three-dimensional virtual world that simulates participation in political, economic, and cultural activities [3]. Neal Stephenson coined the term “Metaverse” in his 1992 science fiction novel Snow Crash and conceived of a parallel virtual world. “ and conceived of a parallel virtual world. With the Metaverse being a fusion of multiple disciplines and an integrated use of existing IT technologies [4]. With the advancement and application of technologies such as virtual reality and artificial intelligence, the concept of metaverse has evolved, such as second life [5] and 3D virtual world [6]. Usually, a metaverse is an intermingled multi-user shared space that integrates the ternary physical world, the human world, and the digital world into a single, self-sustaining, inter-temporal space, which is based on the fusion of technologies that enable multi-sensory interactions with virtual environments, digital objects, and people [7]. In particular, the metaverse has multiple features and infinite possibilities such as virtual, realistic immersive experience, intermingling, socialization, and interaction [8].

Among them, realistic immersive experience is to create an environment where it is almost impossible to distinguish the difference between the virtual and the real through a high degree of realism and immersive feeling, which is one of the key elements that enable the explosion of the metaverse. With the development of a variety of technologies such as somatosensory devices, digital smell, digital taste, brain-computer combination, etc., players are able to obtain an infinitely close to the reality in which they can feel, and this realism allows users to better integrate into it and enjoy a distinctive experience, and at the same time promotes the development of social exchanges, education and training, entertainment and culture, and other fields.

Intermingling refers to combining the virtual world with the real world. In a perfect meta-universe, the virtual world is seamlessly connected to the real world, allowing users to travel freely between the two worlds.

2.2 Military Metaverse

The military applications of the Metaverse, analogous to its manifestations in fields such as fashion, libraries, and healthcare, are collectively referred to as the "military Metaverse" [9]. Scholars describe the military Metaverse as the convergence of military domains and Metaverse technologies, integrating knowledge and techniques from various disciplines, including military science, computer science, artificial intelligence, data science, intelligence studies, design, and engineering, to construct virtual battlefields and simulate combat scenarios, thereby supporting military operations [10]. The military Metaverse is not merely a singular virtual world; its complexity lies in its capacity to accurately replicate a variety of scenarios that may arise in complex real-world environments, requiring the integration of advanced artificial intelligence technologies to simulate the behaviors and reactions of both friendly and adversarial actors. To fully understand the military Metaverse, it is essential to study it from multiple perspectives.

From a technological standpoint, while the Metaverse shares many similarities with the internet, it should be viewed as an application of the internet rather than the internet itself [11]. The Metaverse relies on the internet to enhance user experiences from "2D" to "3D," allowing users to engage with virtual worlds in a more realistic and immersive manner. Its technologies, applications, and business models differ significantly from those of the internet. Therefore, the Metaverse should not be simply regarded as the next generation of the internet but rather as one of the trends and directions for its further development. A singular scenario cannot constitute the military Metaverse; instead, it is an integrated network composed of numerous simulation platforms and virtual worlds, designed to provide a comprehensive and realistic training environment through high integration and seamless connectivity [9].

From the perspective of military training and education, human involvement plays a crucial role in the development of military capabilities, which is achieved through education, training, and management, with training being the primary avenue. Over the years, military forces have utilized various isolated and cumbersome training systems [12]. Consequently, the military has sought to link training with virtual worlds. The establishment of the Simulator Networking (SIMNET) broke new ground in how the entire industry and military conduct operations, serving as the first demonstration of a widespread simulator network for collective training and mission rehearsals [13]. Following this, the emergence of Distributed Interactive Simulation (DIS) and High-Level Architecture (HLA) standards accelerated the integration of different simulation training, allowing combat personnel to experience battlefield "fog" and environments in a synthetic space [14]. Despite effective training outcomes, interoperability and collaboration remain insufficient, posing significant challenges in real battlefield scenarios. In Orson Scott Card's novel Ender's Game, soldiers engage in training within a realistic immersive world [15], reflecting a contemporary desire for virtual training and exploration of virtual worlds. While various training centers are valuable, the COVID-19 pandemic disrupted physical institutions, prompting combat personnel and commanders to seek increased opportunities for distributed learning, such as through developed wargaming and faster-than-real-time tools [16]. Due to its realistic immersive user experience and rich multimedia capabilities, the Metaverse emerges as an ideal model for educational, training, and skill development tasks [17], offering tailored training feedback for individuals.

From the perspective of operational simulation and rehearsal, the military Metaverse can simulate various complex combat environments and scenarios, assisting commanders in formulating scientifically effective operational plans while assessing the feasibility and risks of various strategies. Different simulation environments can interconnect,

allowing soldiers to experience diverse military actions—from ground combat to aerial strategies and naval tactics—in a coherent and unified virtual space [18], thus equipping combat personnel to respond to real-world situations and rapidly enhance combat skills, thereby improving command and control capabilities. Additionally, personalized training programs can be developed to facilitate realistic training and enhance soldiers' operational readiness and response capabilities in emergencies [18].

The Metaverse is poised to lead the future paradigm of internet development, forming a value chain for the Metaverse [19]. Brown identifies three key advantages of the Metaverse that have garnered the attention of the Department of Defense: "first, establishing tighter global connections and networks; second, creating high-fidelity environments that simulate the real world; and third, providing immersive experiences". The impact of the military Metaverse extends beyond mere simulation and modeling; it significantly influences the interactions between humans, machines, and network computing, intersecting importantly with defense cyberspace initiatives in areas such as data, digital twins, and artificial intelligence [20]. Literature reviews indicate that the military applications of the Metaverse hold substantial potential across various directions, including military education and training, command decision-making and situational awareness, logistical support and exercises, and optimization of joint operational systems.

2.3 Blockchain

Blockchain technology possesses characteristics such as decentralization, distribution, immutability, transparency, anonymity, smart contracts, and high availability, providing new solutions for secure, reliable, and efficient data exchange and value transfer [21].

Decentralization means that in a blockchain network, there is no central authority or server controlling and managing the entire network; instead, all nodes collaboratively maintain and manage all transactions and data. This characteristic eliminates the risk of single points of failure, reduces the likelihood of system attacks, and ensures a high level of transparency and openness.

Immutability refers to the inability to modify, delete, or tamper with data once it is recorded on the blockchain. This is due to the decentralized distributed ledger technology, where all transaction data is recorded across multiple nodes, each possessing a complete copy of the ledger. Any modification would be detected and rejected by other nodes. Additionally, each block in the blockchain contains the hash of the previous block; any change would alter the hash values of all subsequent blocks, thereby compromising the integrity of the entire blockchain.

Anonymity indicates that users' identities and transaction information in the blockchain network are anonymous and cannot be easily tracked or identified, providing enhanced privacy protection.

Traceability means that blockchain technology allows for the tracing and recording of the origin and destination of every historical transaction through its chain structure and storage system, ensuring the authenticity and credibility of each on-chain transaction.

3 METAVERSE AND BLOCKCHAIN CONVERGENCE DEVELOPMENT NEEDS ANALYSIS

Blockchain provides a secure and reliable infrastructure for the metaverse. Its transparency ensures that all transactions and interactions within the metaverse are recorded and publicly verifiable, enhancing user satisfaction and experience. The immutability of blockchain preserves original transaction records. Furthermore, blockchain can confirm ownership of users' virtual assets, such as virtual land, goods, and digital currencies, enabling secure transactions in a decentralized environment and enhancing property security, thereby increasing the overall safety and trustworthiness of the metaverse. The demands of the metaverse drive continuous advancements in blockchain technology. The distributed storage and encryption features of blockchain align with the metaverse's need for data security and foster innovative developments in data privacy protection. Additionally, the necessity for interoperability among multiple virtual environments and applications propels the evolution of blockchain's smart contract services and protocol configurations.

4 CONSTRUCTING THE MODEL OF COMMAND SUPPORT SYSTEM

4.1 System Architecture

The command support system model based on blockchain and the metaverse utilizes decentralized and tamper-proof blockchain technology to record operational and logistical data, ensuring information security and transparency. Additionally, it leverages the virtual environment of the metaverse for simulations and exercises to enhance the operational capabilities of individuals and teams. This system model facilitates real-time data sharing and dynamic adjustments, contributing to the optimization of operational strategies while reducing resource consumption and casualty rates, ultimately establishing an efficient and reliable military support system. As shown in Figure 1, the architecture of this model consists of six layers, arranged from bottom to top as follows: foundational layer, data integration layer, network layer, consensus layer, contract layer, and application layer. This model combines the security features of blockchain with the immersive training capabilities of the metaverse, creating a comprehensive and efficient support platform that significantly improves resource utilization and operational effectiveness.

The foundational layer includes the blockchain platform and the metaverse platform. The blockchain platform provides decentralized, tamper-proof, and transparent management of data, ensuring the secure recording and storage of military information. Notably, important data is only uploaded as hashed values without including metadata on-chain.

Additionally, logistics allocation and equipment management operations are recorded in logs to ensure data integrity, facilitating traceability and auditing. Meanwhile, the metaverse platform establishes military simulation systems and data connectivity networks, enabling seamless integration of various intelligence, sensor data, and real-time imagery. This allows for global observation and real-time monitoring in a virtual environment, where troops can simulate various tactical scenarios and conduct live drills to better assess outcomes and make optimal decisions [22]. Furthermore, the metaverse provides a real-time collaborative platform for command teams, enabling close coordination between commanders and operational personnel through technologies such as voice, visual aids, and virtual AI assistants.

The data integration layer is responsible for consolidating data from both the blockchain and the metaverse to support command decision-making. It collects real-time data, including training performance, simulation results, and group competition outcomes, and standardizes this data to enhance its usability and shareability. Additionally, data analysis and visualization are conducted to facilitate intuitive access for commanders, enabling rapid responses.

The network layer employs standardized communication protocols to ensure interoperability and data sharing with the blockchain platform, metaverse platform, and other systems. Security measures such as firewalls and encrypted transmissions are implemented, along with an authentication mechanism to ensure that only authorized users can access the system.

The consensus layer utilizes the Practical Byzantine Fault Tolerance (PBFT) consensus algorithm, allowing the network to function normally and maintain data consistency even in the presence of malicious nodes. Smart contracts are deployed in the contract layer, where code defines the rules and logic for core operations, automating the execution of protocols related to military support. The automated execution of smart contracts enhances system efficiency and reliability, reducing operational costs.

The application layer, or user interface layer, supports multi-device access (computers, tablets, and other mobile devices) to meet operational needs across various scenarios. Its user-friendly interface facilitates information retrieval, allowing users to quickly grasp the current situation. The layer features multifunctional modules for command scheduling, task allocation, supply support, and training communication, enabling users to select relevant modules based on their needs and improve work efficiency. Additionally, it supports real-time feedback on operations, provides data analysis insights, and offers recommendations and guidance to assist decision-making.

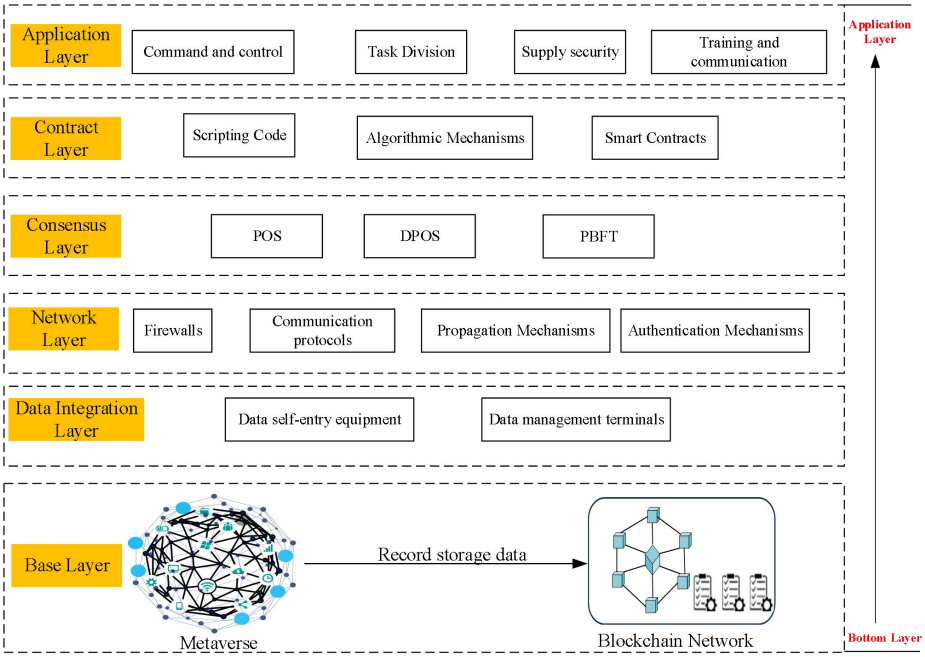

Figure 1 The Architecture of Command Support Model Based on Blockchain and Metaverse

4.2 Alliance Chain Design

Based on an analysis of command support requirements, the blockchain is designed with reference to the characteristics of the body of the information source (logistics department). For intuitive understanding, the business process of equipment supplies is simplified in Figure 2. The supply chain for equipment utilizes a consortium blockchain, with the logistics department serving as the administrator. Nodes in the blockchain network include material producers, transporters, suppliers, quality inspection units, storage units, end-users, and maintenance units, all collaboratively managing and maintaining a traceable system throughout the entire lifecycle of equipment supplies, from production to transmission, distribution, usage, and maintenance.

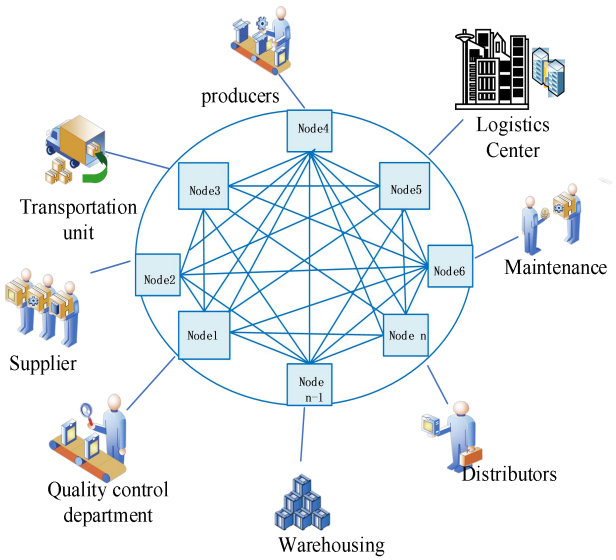

Figure 2 Blockchain-Based Equipment Material Flowchart

As shown in Figure 3, each block consists of a block header and a block body. The block header is the core component, containing elements such as timestamps, hash values, and version numbers. Additionally, the block body contains numerous transactions. This paper describes the changes in transaction data within the block, using equipment supplies as an example to illustrate the formation of a traceable supply chain.

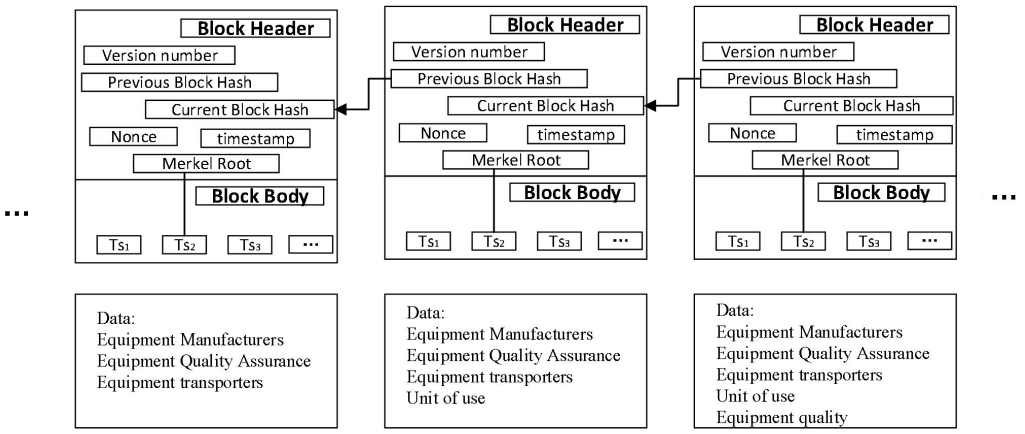

Figure 3 Structure of the Block

4.3 Smart Contracts

In the smart contract code, the necessary protocols and operations are defined. For instance, the automated execution of predefined contracts and rules allows for the allocation of supplies, equipment, and resources to various units, effectively reducing human error, enhancing efficiency, and promoting fairness. Additionally, access control policies are stipulated within the smart contract execution protocols.

Furthermore, when equipment malfunctions or operational errors occur, a device diagnostic request can be sent through the blockchain network. The smart contract then automatically executes the fault diagnosis and report generation process, while also receiving diagnostic responses from suppliers or other non-original supplier nodes. The diagnostic results are updated in real time to reflect the support requirements, and supply and maintenance requests are generated automatically. This automated processing ensures accurate delivery of support needs, thereby improving the efficiency of logistical support and the speed of response.

4.4 Application Scenarios

With the rapid advancement of technology, unmanned combat platforms are playing an increasingly important role in modern warfare [23]. However, these platforms heavily rely on network transmission for information exchange, which can lead to challenges such as information latency, limitations in human-machine interaction, and difficulties in real-time decision-making due to complex environments and network congestion. In this context, metaverse technology offers a more intelligent and efficient solution for unmanned combat operations. By establishing a virtual network

environment in cyberspace and utilizing high-speed internet for data transmission, it enables real-time, efficient information flow. This allows unmanned combat platforms to accurately acquire and process the necessary information, particularly when quick decisions and responses are required during operations. Additionally, metaverse technology enhances operator perception, understanding, and control of unmanned combat platforms through virtual reality devices and intelligent interaction systems, thereby improving combat effectiveness. Furthermore, by integrating data from various sensors and smart devices and conducting real-time analysis, it provides decision-makers with accurate and timely guidance. The decentralized and tamper-proof characteristics of blockchain ensure that all interactions and data are recorded securely. Any information tampering can be immediately detected, resulting in greater security and reliability for unmanned combat platforms. Moreover, the redundancy of data across nodes enhances the platform's robustness and resilience to attacks. The integration of blockchain and metaverse technology offers heightened security to ensure seamless command and realistic virtual environments with intelligent equipment. As both metaverse and blockchain technologies continue to evolve, they are expected to bring further innovations and breakthroughs to unmanned combat operations in the future.

Robust logistical support capabilities are essential for securing victory in warfare. In recent years, the U.S. military has studied the role of big data in the logistics of equipment management [24], while some Chinese scholars have explored the characteristics of logistical support under information conditions and its impact on logistics enhancement. However, issues with data statistics have faced criticism from personnel, highlighting challenges such as poor integration of information systems and lack of standardized protocols [25]. Emerging frontier technologies, such as military metaverse technology and artificial intelligence, empower logistics commanders to obtain real-time supply demands from various units in combat zones. This enables timely adjustments to support plans and facilitates scientific, rapid allocation based on need. By leveraging the extensive metaverse network, information can be rapidly integrated, supply routes can be planned, and logistical efficiency can be optimized [26]. Additionally, within the metaverse, the establishment of military simulation systems and data connectivity networks allows for the seamless integration of various intelligence, sensor data, and real-time imagery. This enables global observation and real-time monitoring in a virtual environment. Troops can simulate various tactical scenarios and conduct real-time drills in the metaverse, leading to better evaluation of outcomes and optimal decision-making [27]. Furthermore, the metaverse provides a real-time collaborative platform for combat command teams, enhancing coordination between commanders and operational personnel. Through technologies such as voice, visual aids, and virtual AI assistants, remote command support can be effectively executed.

5 METAVERSE AND BLOCKCHAIN CONVERGENCE CHALLENGES

5.1 Face Challenges

5.1.1 Immature technologies and key equipment

At the current stage, although blockchain and metaverse technologies exhibit certain potential and advantages in the military domain, further enhancement and development are necessary. For instance, military blockchain encounters scalability and performance issues when facing large-scale transactions. Additionally, in high-real-time scenarios, such as military command and control systems, the characteristics of blockchain, including its consensus mechanism and data transaction confirmation time, impose limitations on real-time and high-frequency trading. Meanwhile, metaverse technology still faces bottlenecks in network bandwidth and computing power, which hinders its ability to meet the demands of large-scale, high-concurrency military applications. Furthermore, military virtual training requires a high level of realism and immersion, yet current technical support for simulating complex environments and interactive objects in the metaverse is insufficient. There remains considerable room for improvement in providing precise and reliable data support for physical simulation and human behavior modeling in complex environments.

5.1.2 Security issues

The integration of military metaverse and blockchain technology also introduces a series of security challenges. Firstly, military data is sensitive, making the assurance of data privacy and security a top priority. This integration involves storing and transmitting a significant amount of sensitive information, including personal identification details, operational plans, and strategic intelligence. Without appropriate measures to protect this sensitive data, user privacy may inadvertently be exposed to anyone accessing blockchain information. Moreover, in the military metaverse environment, a considerable amount of personal behavior data is collected and analyzed to provide customized experiences, which can be easily intercepted by malicious actors. Therefore, it is crucial to safeguard this data from unauthorized access and tampering. Additionally, the confidentiality requirements of military networks and terminals have become a focal point, as the information involved pertains to national security and military secrets, necessitating extremely high security standards. There is also a need to address potential risks of attacks and breaches.

5.1.3 Standardization issues

The integration of military metaverse and blockchain is complex. During integrated joint operations, multiple military blockchain units, networks, and terminals must collaborate. Therefore, it is essential to consider standardization and cross-platform compatibility during the integration process. This approach will facilitate the construction of a new integrated combat platform, creating a highly flexible and configurable simulation environment for future warfare. Such an environment will allow military training and actual combat to align more closely with real-world scenarios, thereby enhancing overall combat capabilities. Establishing unified standards can resolve issues related to the integration of existing equipment with blockchain technology and inconsistencies in data formats. This is vital for ensuring the normal

operation of command control systems, communication systems, and for defending against various network attacks.

5.2 Solution

In advancing the integration and development of military metaverse and blockchain technologies, nations and armed forces can adopt a multifaceted strategy. First, they should enhance talent cultivation by establishing relevant academic programs in higher education institutions that focus on virtual reality, augmented reality, and blockchain. This will strengthen theoretical education and practical training for students. Additionally, military organizations should promote internal professional training to improve personnel's understanding and operational skills regarding these new technologies. Collaborations with enterprises and organizing competitions can also attract more talented individuals to the military metaverse and blockchain sectors. Second, there should be strong support for equipment research and development to encourage technological innovation. Third, enhancing civil-military integration is essential. Lastly, it is crucial to refine the legal and regulatory framework. Through these measures, a powerful and intelligent future military force can be established, ensuring national security while remaining at the forefront of technological advancement.

6 CONCLUSION

This paper designs a military operations support model based on metaverse and blockchain technologies, detailing its architecture, blockchain design, smart contracts, and application scenarios. It then discusses the challenges faced by the integration of military metaverse and blockchain, along with potential solutions. Furthermore, the application potential of blockchain in equipment maintenance is significant, with future research objectives including the reduction of communication and computational overhead, as well as the enhancement of scalability.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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