Utilising Digital Twins for Increasing Military Supply Chain Visibility

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Abstract. The dynamic and complex nature of the military supply chain (MSC) requires effective monitoring of supplies and timely decisions to ensure success in combat operations, particularly in the face of unexpected disruptions such as inclement weather conditions and terrorist attacks. Although, existing technologies such as RFIDs, Next-Generation Wireless Communication (NGWC) and RuBees are applied MSC, they are not sufficient in ensuring end-to-end visibility across the entire SC. However, digital technologies such as the internet of things, cloud computing, Application Programming Interface (APIs), machine learning, augmented and virtual reality, big data, analytics and pervasive computing play a critical role in improving visibility to ensure effective SC management. Hence, the introduction of the concept of digital twin enabled by these technologies creates a digital replica of the whole supply chain operations, ensuring adequate end-to-end visibility through real-time data that ensures effective tracking, monitoring and reporting of all SC activities. The focus of this paper is to explore the enabling technologies of digital twin and its implementation to achieve end-to-end visibility in the military supply chain. In this paper, the authors identify the digital twin's tracking and monitoring capability, which will improve supply chain management by enabling a cycle of continuous adjustment of the SC against unexpected disruptions.

Keywords: Military supply chain, Visibility, Tracking, Monitoring, Digital twin.

1 Introduction

The complexity of the Military supply chain (MSC) requires effective monitoring of supplies and timely decisions to ensure success in combat operations, particularly in the face of unexpected disruptions such as inclement weather conditions and terrorist attacks. This challenge is forcing military logistic planners to redesign their supply networks to be more proactive in monitoring, tracking and reporting of all supply chain activities. Hence, the introduction of the concept of end-to-end SC visibility that makes supply chain more visible and transparent [1]. This is achieved through technologies such as RFIDs, Next-Generation Wireless Communication (NGWC) and RuBees [2]. These technologies have been in use in the military supply chain but have not been sufficient in ensuring efficient end-to-end visibility. This could be attributed to network security, incomplete or poorly read information and technology challenges [2, 3]. According to [4], visibility is necessary in the SC in curtailing theft or loss of freight, substitution of items transported, and building confidence in consumers.

Recently, visibility in supply chain had been enhanced with the introduction of digital twin enabled by digital technologies such as Internet of Things, cloud computing, APIs and machine learning, augmented and virtual reality. These technologies can improve visibility and provide real-time insights into the supply chain, giving full control and confidence (Sunil, 2020). According to [5, 6], a digital SC twin is a model that shows the condition of a network at any point in time enabling end-to-end SC visibility so as to enhance resilience and robust contingency plan. Hosseini, Ivanov and Dolgui (2019) mentions the possibilities of digital twin in monitoring "transportation, inventory, demand and capacity" in supply chain to enable planning and timely decisions.

In the military field, digital twin technology stands out among the emerging technologies with the advantages it offers in terms of producing cost-effective solutions and increasing efficiency and quality [7]. Since time is a critical factor in the military, digital twin technology will aid in improving systems and support decision makers to make speedy judgments where needed [7].

Therefore, the aim of the paper is to explore the benefits and implementation of the digital twin within the military supply chain. This exploration will reveal areas where the digital twin has been applied or areas that will need further attention.

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2. Existing technologies employed for military supply chain visibility

2.1. Radio Frequency Identification Device (RFID)

RFID is a tiny tag with an integrated circuit chip and an antenna that can respond to radio waves transmitted by an RFID reader in order to transfer, process and store data [2]. The first use of RFID was during World War 2 when radio waves were used to retrieve information stored in a tag by allied forces to determine allegiance of military aircraft [8-11]. Since then, the technology had been employed in other fields to either automate product authentication and tracking of merchandise, solving or at least reducing the negative effects caused by mismanagement or attacks against the weakest link in the the supply chain [12]. Visibility is enabled by RFID through radio waves, by identifying automatically tagged items at transit nodes and ensuring information is collected [13].The military uses RFIDs for locating and directing shipments and to automatically identify and locate logistic supplies [14]. For example, in the Iraq conflict in 2001 the combination of information from satellites, RFIDs and other systems assisted tremendously in asset tracking and visibility according to military officials. [15] carried out a study on ubiquitous and RFID technologies on military garrison supplies system in Iran. Results showed improved accuracy in information, speed and efficiency of process. However, the challenges of adopting RFID as mentioned by [3] is that of technical risks, barcode popularity and privacy [3]. Others challenges are technology, patency, infrastructure challenges and barcode to RFID migration challenges [2]. Military assets tracking using RFID is presented in Figure 1.

Figure 1. Miliatry assets tracking [14]

2.2. Next-Generation Wireless Communication (NGWC)

The Next-Generation Wireless Communication (NGWC) also known as the wireless sensor network (WSN) sponsored by the U.S. Army Logistics Innovation Agency (LIA) is presently being used by the Department of Defense (DoD) in overseas logistics operations for the tracking and monitoring of military supplies and equipment [16]. Other applications in the military include; monitoring friendly forces, equipment and ammunition where commanders can constantly monitor the status of friendly troops, the condition and the availability of equipment and ammunition in a battle field [17, 18]. NGWC provides a much larger coverage area (twenty-mile radius) than other tags, greater data transmission speeds and higher levels of security. However, low energy communication network, storage space or computing power, latency, scalability are some of the constraints of this technology [19]. Military application of wireless sensor networks is presented in Figure 2.

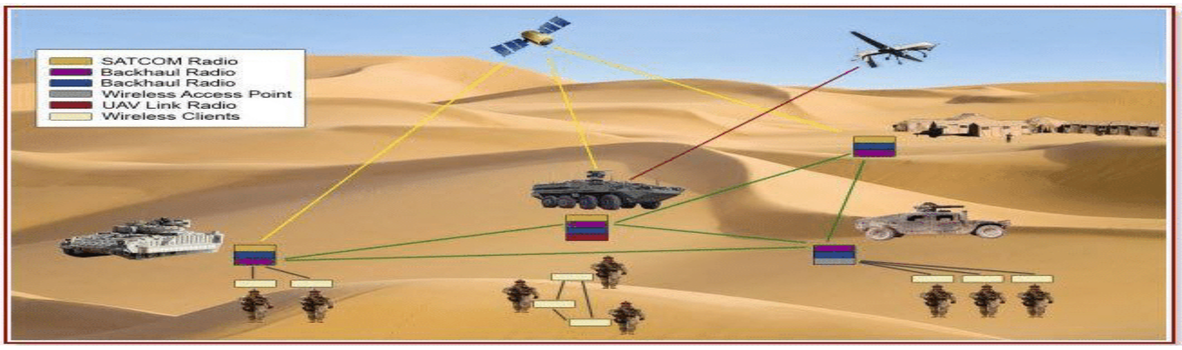

Figure 2. Images of military applications of wireless sensor networks[17, 18]

2.3. RuBee technology

RuBee is the commercial name for what is known officially as LWID (Long Wavelength ID), as defined by the Institute of Electrical and Electronic Engineers' (IEEE) [20]. RuBee technology provides visibility, thus giving more information than just tracking of products. This technology provides the ability to be read in adverse conditions (e.g water, metal), greater read range, greater read accuracy and long battery life [21]. The U.S Navy in conjunction with Lockheed Martin and visible assets inc., have developed a new weapons maintenance system that remotely manages, diagnoses and tracks weapons and munitions called the RuBee Weapon Shot Counter thus saving it millions of dollars [22]. An integrated model for asset visibility, tracking and monitoring for the supply network of the Canadian Armed Forces (CAF) was presented by [23]. However, this technology is limited by slower read rates making it unsuitable for supply chain network. Image of some RuBee tags is presented in Figure 3 while the summary of the limitations of these technologies is presented in Table 1.

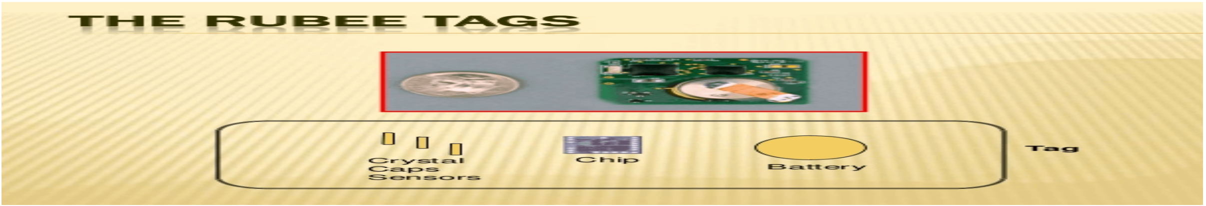

Figure 3. Image of RuBee Tags [21]

Table 1. Summary of limitations of enabling technologies

Technology	Limitations
Radio Frequency Identification Devices	Technical risks, barcode popularity and privacy, patency, infrastructure challenges and barcode to RFID migration challenges
New Generation Wireless Connection	Low energy communication network, storage space or computing power, latency, scalability
RuBee technology	Slower read rates making it unsuitable for supply chain network

3. The digital twin concept

In 2003 at the University of Michigan, the concept of digital twin was presented in the product lifecycle management topic area by Grieves, 2014 [24]. Afterwards, NASA in 2011 developed the first working Digital twin by way of forecasting aircraft structural behaviours by performing analysis and simulation on them in form of digital models [9] (see Figure 4). Digital twin is the bridge between the physical and digital world and with an interface, gives an understanding of the past, present and future state of a process combining data and intelligence. The digital twin with the help of real-time data is capable of carrying out simulations, optimizations and making predictions of possible outcomes [25]. These predictions can be made in the digital environment many times than in the physical world with the ability to test scenarios by manipulating parameter values [7].

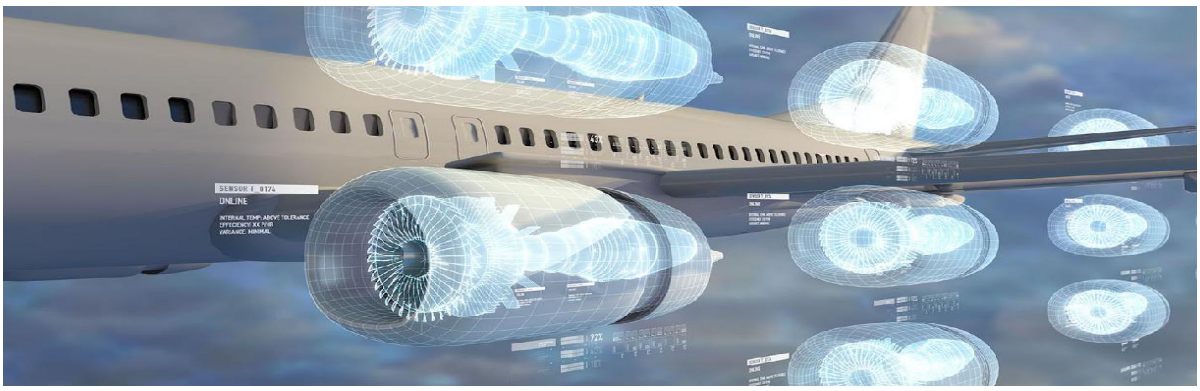

Figure 4. Visualization of digital twin in an aircraft [9]

4. Benefits of digital twin for military supply chain visibility

One of the actions military can take to secure their supply chains and improve forecasting in all conditions is to embrace better end-to-end visibility. This can be achieved by creating digital twin that will be able to visualize potential disruptions in the supply chains to improve the process of decision making. Among the upcoming technologies used within the military, the digital twin technology provides solutions that are cost effective, and improves quality and efficiency [7]. In agreement,[26] opined that the the application of the digital twin provides a sense of readiness for military operations in terms of tracking in real time personnel, equipment, weapons systems, and vital supplies (food, water and fuel). There have also been attempts by the U.S. military to secure the supply chain of their semi-conductors by using digital twin capability to validate their integrity [27].

5. Enabling technologies of digital twin for supply chain visibility

5.1. Internet of things (IOT)

Internet of Things (IoT) is the linking of objects to a network for the purpose of interaction through embedded systems for humans to communicate with device or device to device [28]. The communication can be made possible through sensors with the devices having the required data [29]. These sensors enables the digital twin to carry out analysis, and determination of the existing physical twin [25]. The IoT facilitates end-to-end asset visibility in MSC and ensures that supplies arrive at the right destination and time. This helps decision makers to have precise and up to date information on the location and conditions of critical military supplies (food, fuel, weapons, equipment, and spare parts).

5.2. Machine learning

Machine learning is a computer system with a combination of computer science and statistical elements that automatically improves its performances through experience [29]. The structure of Machine learning can create a digital twin capable using real-time data to analyse and make decisions with the aid of predictive analytics.

5.3. Cloud computing

Cloud computing allows shared network to have access to computer resources that belongs to a third party and maintained through the internet with users accessing the resources from any location. Some of these resources are data storage, databases, computing power and data analytics processing [30]. The benefit of cloud computing is that a user does not need to have large storage in their hardware but to pay for services used [30].

5.4. Application programming interface(API)

APIs allows for interaction between applications like databases, networks and IoT sensors. As a result, data can be effectively transferred between clouds, devices and other systems. However, public API connections have security concerns as seen in the compromise of facebook accounts that were linked with individual's phone numbers in 2015 [31].

5.5. Augmented and virtual reality

Virtual reality is a technology that creates a virtual world mimicking the real world while augmented reality provides information layer to the real world. These technologies can provide a platform for visualizing and inspecting the digital twin through the use of either a 2D screen or a 3D. The data provided and processed by IoT, cloud computing, APIs and machine learning for creating a digital twin can be visualised in augmented and virtual reality [32, 33]. Enabling technologies of the digital twin are presented in Figure 5.

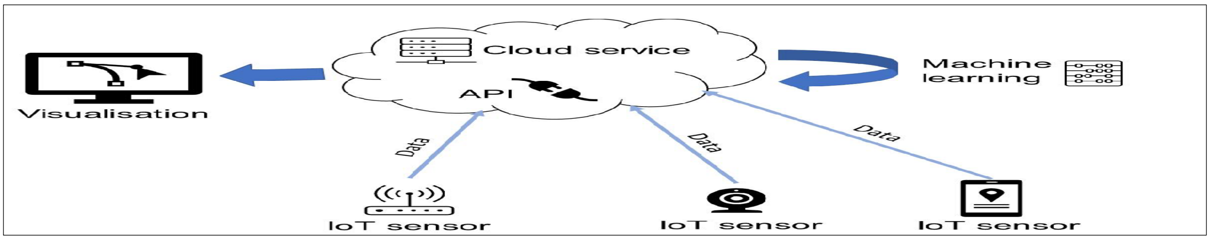

Figure 5. Enabling technologies of the digital twin [32]

6. Implementation and application of the digital twin for visibility in the military supply chain

A digital SC twin can support decision-making about the physical SC on the basis of data. At each point of time, the digital twin mirrors the physical SC: the actual transportation, inventory, demand, and capacity data and can be used for planning and real-time control [6]. The combination of simulation, optimization, and data analytics constitutes a full stack of technologies which can be used to create an SC digital twin—a model that always represents the state of the network in real time as represented in Figure 6. The application of the digital twin in the military can be seen in the area testing new models during production of aircrafts, predicting equipment failures, reducing time to manufacture weapons and aircrafts, hardware maintenance, and assisting in emergency decision making. Table 2 is the summary of the various application areas of digital twin in the military [34-38].

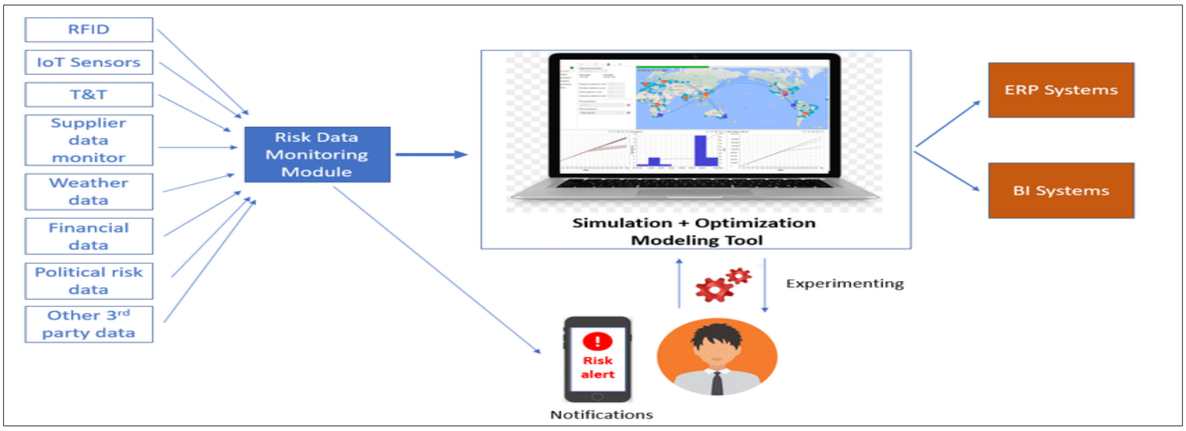

Figure 6. Digital twin of supply chain [6]

Table 2. Summary of the application areas of digital twin in the military

Authors	Field applied	Specific Application area
(Mendi Erol and Dogan 2021)	Aviation	Testing new models during aircraft production, predicting engine failures.
(Ji et al., 2021)	Airforce	Building the architecture of individual combat quadrotor UAV.
(Kraft, 2016)	Airforce	Engineering analysis capabilities and support to decision making in lifecycle of air vehicles.
(Wang et al., 2021)	Aviation	Drone maintenance, operation, testing and production using cloud computing
(Li et al; 2020)	Military hardware (equipment)	1) Maintenance and management of air-conditioners, power systems, and water supply using historical and real-time data. 2) Prediction of future state of equipment using artificial intelligence.

7. Conclusion and future work

The digital twin has great potentials to ensuring end-end visibility in the whole supply chain process. With the use of real-time data, the digital twin is always up to date which is a reflection of the present condition or state of the physical process. The digital twin enabled by technologies like IOT, cloud computing, machine learning, API and augmented and virtual reality can help in the visualization and analysis of processes. The military can secure their supply chains by creating digital twin to improve forecasting through end-to-end visibility thus ensuring timely decision making in the face of disruption. Even though digital twin shows great potential, there is still a dearth in literature of the actual implementation of digital twin to achieve end-to-end visibility in military supply chain. Hence, we suggest future research on implementing digital twin in the military supply chain to achieve end-to-end visibility to manage unexpected disruptions.

References

[1] Ivanov, D. and A. Dolgui, *A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0.* Production Planning & Control, 2021. 32(9): p. 775-788.

[2] Wu, N.-C., et al., *Challenges to global RFID adoption.* Technovation, 2006. 26(12): p. 1317-1323.

[3] Tajima, M., *Strategic value of RFID in supply chain mgt.* Journal of purchasing and supply management, 2007. 13(4): p. 261-273.

[4] Pundir, A.K., J.D. Jagannath, and L. Ganapathy. *Improving supply chain visibility using IoT-internet of things*. in *2019 ieee 9th annual computing and communication workshop and conference (ccwc)*. 2019. IEEE.

[5] Ivanov, D. and A. Dolgui, *A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0.* Production Planning & Control, 2020: p. 1-14.

[6] Ivanov, D., et al., *Digital Supply Chain Twins: Managing the Ripple Effect, Resilience, and Disruption Risks by Data-Driven Optimization, Simulation, and Visibility*, in *Handbook of Ripple Effects in the Supply Chain*, D. Ivanov, A. Dolgui, and B. Sokolov, Editors. 2019. p. 309-332.

[7] Mendi, A.F., T. Erol, and D. Dogan, *Digital twin in the military field.* IEEE Internet Computing, 2021.

[8] Landt, J. and B. Catlin, *Shrouds of Time: The history of RFID.* AIM inc, 2001.

[9] Lu, Y., et al., *Digital Twin-driven smart manufacturing: Connotation, reference model, applications and research issues.* Robotics and Computer-Integrated Manufacturing, 2020. 61: p. 101837.

[10] Slettemeås, D., *RFID—The "next step" in consumer–product relations or Orwellian nightmare? Challenges for research and policy.* Journal of Consumer Policy, 2009. 32(3): p. 219-244.

[11] Lehpamer, H., *RFID design principles*. 2012: Artech House.

[12] Caballero-Gil, P., C. Caballero-Gil, and F.M. Fernandez, *Ubiquitous Computing Technologies to Manage a Transport Monitoring System.* IEICE Proceedings Series, 2015**.** 22(SESSION5-1).

[13] Lee, I., *RFID Technology in Business and Valuation Methods*, in *RFID Technology Integration for Business Performance Improvement*. 2015, IGI Global. p. 260-278.

[14] Caterinicchia, D., *Military Logistics Boosts Asset Visibility.* Excerpt from unpublished article, n. pg.[On-line], Available: http://www. fcw. com/fcw/articles/2003/0616/tec-log-06-16-03. asp. Accessed: June, 2003. 16: p. 2003.

[15] Jafari, P. and A. Sadeghi-Niaraki, *Use of ubiquitous technologies in military logistic system in Iran.* International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2013. 1: p. W3.

[16] Offor, P., *Exploring Broadband Enabled Smart eEnvironment: Wireless Sensor (Mesh) Network.* 2013.

[17] Gupta, S.K. and P. Sinha, *Overview of wireless sensor network: a survey.* Telos, 2014. 3(15μW): p. 38mW.

[18] Srivastava, S., M. Singh, and S. Gupta. *Wireless sensor network: a survey*. in *2018 International Conference on Automation and Computational Engineering (ICACE)*. 2018. IEEE.

[19] Bhattacharyya, D., T.-h. Kim, and S. Pal, *A comparative study of wireless sensor networks and their routing protocols.* sensors, 2010. 10(12): p. 10506-10523.

[20] O'Connor, M.C., *Visible assets promotes RuBee tags for tough-to-track goods.* RF Journal, 2006. 19.

[21] Wyld, D.C., *RuBee: applying low-frequency technology for retail and medical uses.* Management Research News, 2008.

[22] MarketScreener (2015). Lockheed Martin and visible assets inc. develop new RuBee Weapon Shot Counter. Available at: https://www.marketscreener.com/quote/stock/LOCKHEED-MARTIN-CORPORATI-13406/news/Lockheed-Martin-and-Visible-Assets-Inc-Develop-New-RuBee-Weapon-Shot-Counter-System-38465429/ (Accessed 12/04/22)

[23] Boukhtouta, A. and J. Berger. *Improving in-transit and in-theatre asset visibility of the Canadian Armed Forces supply chain network*. in *2014 International Conference on Advanced Logistics and Transport (ICALT)*. 2014. IEEE.

[24] Grieves, M., *Digital twin: manufacturing excellence through virtual factory replication.* White paper, 2014. 1: p. 1-7.

[25] Haße, H., et al. *Digital twin for real-time data processing in logistics*. in *Artificial Intelligence and Digital Transformation in Supply Chain Management: Innovative Approaches for Supply Chains. Proceedings of the Hamburg International Conference of Logistics (HICL), Vol. 27*. 2019. Berlin: epubli GmbH.

[26] Accenture (2021) Digital vision for defence is a mirroed world. Available at: https://www.accenture.com/gb-en/blogs/voices-public-service/digital-vision-for-defence-its-a-mirrored-world-2 (Accessed 11/04/22).

[27] EE Times. News(2020) Military enlists digital twin technology to secure chips. Available at: https://www.eetimes.com/military-enlists-digital-twin-technology-to-secure-chips/ (Accessed 12/04/22).

[28] Xia, F., et al., *Internet of things.* International journal of communication systems, 2012. 25(9): p. 1101.

[29] BLOMKVIST, Y. and L. Ullemar Loenbom, *Improving supply chain visibility within logistics by implementing a Digital Twin: A case study at Scania Logistics*. 2020.

[30] Arora, R., A. Parashar, and C.C.I. Transforming, *Secure user data in cloud computing using encryption algorithms.* International journal of engineering research and applications, 2013. 3(4): p. 1922-1926.

[31] Conrad, E., S. Misenar, and J. Feldman, *Domain 8: Software Development Security (Understanding, Applying, and Enforcing Software Security).* CISSP Study Guide, 3rd ed.; Syngress: Boston, MA, USA, 2016: p. 429-477.

[32] Yang, C.-S., *Maritime shipping digitalization: Blockchain-based technology applications, future improvements, and intention to use.* Transportation Research Part E: Logistics and Transportation Review, 2019. 131: p. 108-117.

[33] Omollo, C.A., *Disruptive Technologies in the Logistics And Supply Chain Industry: A Study on Blockchain*. 2019, United States International University-Africa.

[34] Mendi, A.F., Erol, T. and Dogan, D., 2021. Digital twin in the military field. *IEEE Internet Computing.*

[35] Wang, Y.C., Zhang, N., Li, H. and Cao, J., 2021. Research on digital twin framework of military large-scale UAV based on cloud computing. In *Journal of Physics: Conference Series*(Vol. 1738, No. 1, p. 012052). IOP Publishing.

[36] Li, S., Yang, Q., Xing, J. and Yuan, S., 2020, November. Preliminary study on the application of digital twin in military engineering and equipment. In *2020 Chinese Automation Congress (CAC)* (pp. 7249-7255). IEEE.

[37] Kraft, E.M., 2016. The air force digital thread/digital twin-life cycle integration and use of computational and experimental knowledge. In *54th AIAA aerospace sciences meeting* (p. 0897).

[38] Ji, G., Hao, J.G., Gao, J.L. and Lu, C.Z., 2021, July. Digital Twin Modeling Method for Individual Combat Quadrotor UAV. In *2021 IEEE 1st International Conference on Digital Twins and Parallel Intelligence (DTPI)* (pp. 1-4). IEEE.