International Journal of Aeronautical and Space Sciences (2024) 25:593–604
https://doi.org/10.1007/s42405-023-00675-4

ORIGINAL PAPER

Level and Program Analytics of MUM-T System

Byung Woon Kim[1] · Ga Eun Choi[1]

Received: 25 June 2023 / Revised: 7 September 2023 / Accepted: 2 October 2023 / Published online: 23 November 2023

Abstract

This study establishes the concept and classification system of MUM-T for the operation and development of AI-based complex combat systems. We analyze the core aspects of this system: autonomy, interoperability, and program level. AI MUM-T can improve the survivability of manned systems, expand their operational range, and increase combat effectiveness. We analyze technical challenges and program levels using data from the USA and UK, which are building the AI MUM-T integrated combat system. Currently, MUM-T is at the level of complex operation of a manned platform and an unmanned aerial vehicle platform. In the mid to long term, interoperable communication between heterogeneous platforms such as unmanned ground vehicles, unmanned surface vehicles, and unmanned underwater vehicles is possible. Depending on the level of development of the common architecture and standard protocols for interoperability between AI MUM-T systems, MUM-T can evolve from the "1 to N" concept to various combinations of operating concepts from "N to N." The difference of this study from existing studies is that the core technologies of the fourth industrial revolution, such as AI, autonomy, and data interoperability, are reflected in the MUM-T system. In addition, an AI-enabled autonomous MUM-T operation and facility classification system was established by reflecting AI and autonomy in the existing unmanned system taxonomy, and the level and program were analyzed taking this into consideration.

Keywords MUM-T · Autonomous vehicle · Unmanned ground vehicle · Unmanned aerial vehicle

1 Introduction

This study establishes the concept of manned-unmanned teaming (MUM-T) for the purpose of operation, development, and utilization of intelligent combined combat system. In addition, it analyzes interoperability, autonomy, challenges, and program levels. AI-enabled autonomous unmanned MUM-T improves the survivability of manned systems, expands operational range, and dramatically improves combat efficiency. Unlike before, the concept of MUM-T is expanding along with the evolution of artificial intelligence, and interoperability and autonomy are also being advanced accordingly. The USA and North Atlantic Treaty Organization (NATO) countries are presenting challenges in the field of future defense and conducting programs to solve them at the unmanned system (UMS) and MUM-T levels. This study analyzes the technical challenges and program levels for the operation and utilization of the autonomous MUM-T combined combat system and presents essential element technologies. The research method establishes the MUM-T concept based on the existing definition and the fourth industrial revolution. And the level of interoperability, autonomy, challenges, and programs in terms of technology and utilization are analyzed with data from NATO, USA, and UK.

2 MUM-T System, Taxonomy and Interoperability

2.1 Complex Combat System

MUM-T definitions vary around the Department of Defense (DoD). US The Army UAS Center of Excellence (UAUCE) views manned platforms and unmanned aerial vehicles (UAV) as a single system. The integration of manned and unmanned systems such as robotics, sensors, unmanned

✉ Ga Eun Choi
choi_ge@etri.re.kr

Byung Woon Kim
bukim@etri.re.kr

1 ETRI School, University of Science and Technology, 218, Gajeong-ro, Yuseong-gu, Daejeon, Republic of Korea

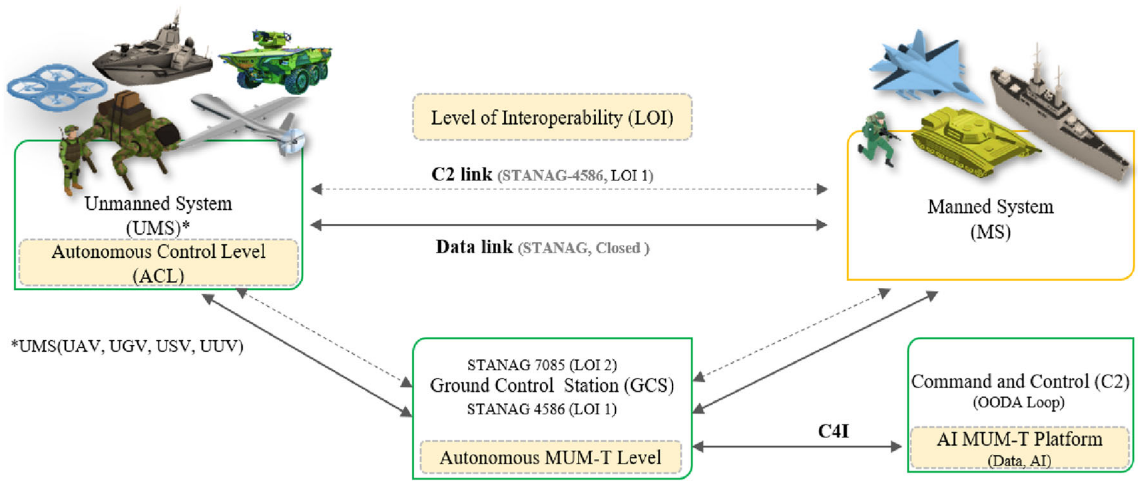

Fig. 1 MUM-T system

aerial vehicles, and combatants enhances situational awareness, lethality, and ability to survive [1]. DoD sees the relationship as an integrated team performing a common mission, and the US The Army Aviation Center of Excellence (UAACE) defines it as simultaneously operating soldiers, UAV, and unmanned ground vehicles (UGV) to improve situational understanding and survivability [2]. It approached a standardized system architecture and communication protocol that allowed accurate image data from sensors to be shared across the entire force. It is most widely used in national defense today. Army Aeroflightdynamics Directorate (AFDD 2015) defines it as providing special functions to each system so that existing manned platforms and unmanned assets can cooperate for the same mission. This is a risk avoidance approach by improving the situational awareness of individual combatants by transmitting real-time information to manned assets from air, land, and sea unmanned systems [3]. Figure 1 is a schematic diagram of the level of MUM-T system on the battlefield.

In January 2016, intelligent, interconnected, distributed, and digital (I2D2) were presented as a core technology after the Fourth Industrial Revolution (Fourth IR) of the World Economic Forum (WEF) Agenda. These technologies have the characteristics of autonomy, analytics, communications, and edge computing in future science. The combination of characteristics of this technology constitutes autonomous systems and agents (intelligent + distributed), expanding domains (interconnected + distributed), battle networks (interconnected + digital), and precision warfare domains (intelligent + digital). Intelligent AI will change the landscape of warfare, while the availability of digital data will allow distributed and interconnected (autonomous) systems to analyze, adapt, and respond. These changes will, in turn, potentially support better decision-making through predictive analytics.

NATO (2020) approaches a complex combat system with the core technology characteristics of the Fourth Industrial Revolution and their combination [4–6]. Agency for Defense Development (ADD 2018), MUM-T complex system is an unmanned combat system that can supplement or replace the capabilities of combatants in order to maximize combat efficiency and minimize human casualties in battlefield situations. It has been defined as a combat system that operates a manned combat system including combatants in a complex way [7]. Considering the definitions of DoD (2010), NATO (2020), and ADD (2018), AI-enabled autonomous MUM-T complex combat system (hereinafter referred to as "Autonomous MUM-T") and OODA loop are expressed as in Table 1 [1, 5, 7]. This study refers to the MUM-T complex combat system, which provides observation, analysis, and control in all areas of air, ground, sea, space, cyber, and warfare through joint command and control that can be operated by integrating/connecting manned and unmanned systems of all military forces. It is defined as "a combat system that performs joint operations based on decisions and actions."

2.2 Taxonomy

In the MUM-T taxonomy, the Ministry of National Defense (MND 2022) directive of the Ministry of Defense Power Development (Defense Business Act and the Defense Innovation Act) classifies weapon systems into main, middle, and sub-categories [8]. Main taxonomy is classified into air weapon system, moving weapon system, and ship weapon system. Middle taxonomy includes fixed wing aircraft, rotorcraft, tanks, armored cars, individual combat, surface ships, UAV, UGV, and unmanned surface vehicles (USV). The classification system of MND (2022) does not reflect intelligent, interconnected, distributed, or digital (see Table 2).

Table 1 Definition of MUM-T complex combat system by ADD, DoD, and NATO data analysis

Fourth IR technologies (I2D2)	Characteristics of future S&T landscape	Characteristics combination	Complex combat system	OODA
Intelligent (AI)	Autonomy, humanistic intelligence, knowledge analytics	Intelligent, distributed	Autonomous, systems and agents	Observe (O)
Interconnected (autonomous)	Trusted communications, synergistic systems	Interconnected, distributed	Expanding domains	Orient (O)
Distributed (data)	Edge computing, ubiquitous sensing, decentralized production, democratized S&T	Interconnected, digital	Battle networks	Decide (D)
Digital (data)	Digital twin, synthetic realties	Intelligent, digital	Precision warfare	Act (A)

Table 2 MUM-T weapon classification system with the MND defense business act

Main	Middle		Subcategory
Air weapon system	Manned	Fixed wing aircraft	F-4, (K)F-16, FA-50, T-50, TA-50, P-3C/CK
		Rotorcraft	500MD(TOW), LYNX, AH-64E
	Unmanned	UAV	145/2
Moving weapon system	Manned	Tank	K-1, K1A1, T-80U, K-2
		Armored car	K281(A1), K21
		Individual combat	
	Unmanned	UGV	Combat (unmanned combat vehicles) Combat support (explosive detection/ removal robots)
Ship weapon system	Manned	Surface ship	Combat ships Landing ships
		Submarine	Submarine (submarine, small submarine)
	Unmanned	USV	Unmanned surface systems Unmanned surface vessels for mines only Unmanned surface vessels for combat) Unmanned underwater systems

UAV, UGV, and USV (unmanned system, UMS) in Table 2 mean that "manded" is excluded from MUM-T. The National Institute of Standards and Technology (NIST, 2003) considers UMS as a powered physical system with unmanned principal components operating in the physical world to achieve assigned missions [2, 9, 10]. The UMS taxonomy has been expanded to include UAV, UGV, USV, unmanned underwater vehicles (UUV), unattended munitions (UM), and unattended ground control sensors (UGCS) [11, 12].

NATO (2021) classified autonomous military systems (AMS) into UAV, UGV, and UUV. Autonomous vehicles in the defense sector are operating using AI instead of relying on pre-determined paths (automation). The difference between NIST (2003) and NATO (2021) is whether it is AI-autonomous (see Fig. 2). The former focuses on device and equipment, while the latter focuses on operation and facilities. The future F-35 will use AI (autonomy) to control the "Wingman," an unmanned aerial vehicle (drone).

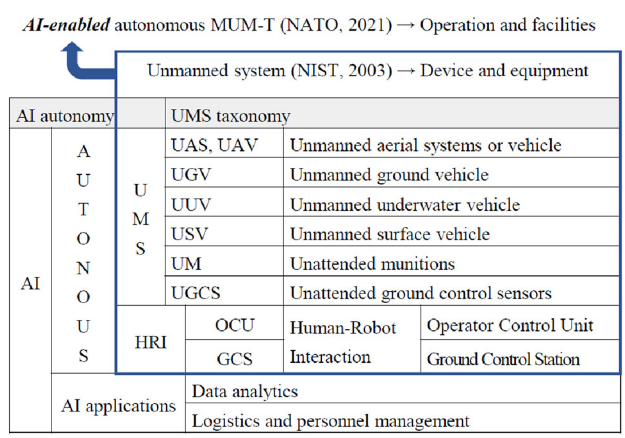

Fig. 2 Analysis of AI-enabled Autonomous MUM-T system based on NIST and NATO taxonomy

The European Sixth Generation Future Combat Air System (FCAS) and BAE Tempest will be equipped with an AI-enabled autonomous aviation system [13]. Korea's MND

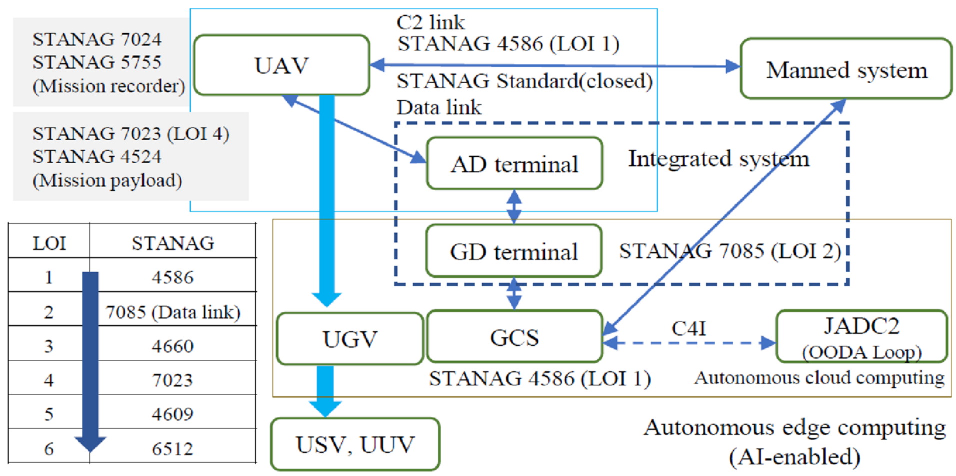

Fig. 3 NATO STANAG LOI 5 and autonomous edge-computing MUM-T interoperability level design

(2022) applies the NIST (2003) taxonomy. The UMS system is differentiated from NATO (2021), where AI, autonomy, and data analytics are reflected in UAV, UGV, and USV.

2.3 Interoperability

The interoperability standards of Autonomous MUM-T have been reviewed focusing on UAVs. A sophisticated data link is used to connect the manned platform to various unmanned aerial systems (UAS) at the level of interoperability (LOI) of STANAG 4586, a North Atlantic Treaty Organization (NATO 2011) standard. It is a concept that improves decision-making and mission efficiency by providing new tactical opportunities through information sharing between manned aircraft and ground control system (GCS) (see Fig. 3). As of December 2022, STANAG 4586 (LOI 1) is centered on text, and STANAG 7085 (LOI 2), a meta data link standard, is undisclosed. Moreover, the interoperability standards for UGV and USV are in the early stages of research and development, and Autonomous MUM-T including UGV and USV is not reflected.

3 Autonomous Level Analytics of MUM-T System

3.1 ACL and HAT

Parasuraman (2000) presented Human-Autonomy Teaming (HAT) as 10 levels of automation (LOA) in which people and autonomous agents cooperate to achieve a common goal at the Institute of Electrical and Electronics Engineers (IEEE 2000) [14, 15]. Autonomous agent means a machine with a certain level of decision-making ability and information exchange ability with humans. The ability to make decisions and exchange information will enable more flexible team composition as automated capabilities that perform predefined actions based on conditions evolve to autonomy using artificial intelligence (AI). With continued advances in AI, autonomous agents (machines) expand the scope of teaming to include coordination and assignment of tasks, and continuous interaction with humans and other autonomous agents. Automated agents have the weakness of not working properly for unintended tasks, but autonomous agents using AI can secure ad hoc capabilities equal to or superior to humans.

3.2 ACL for UAV

Bluce T. Clough, technical director of Air Force Research Laboratory (AFRL, 2002), based on the concept of human dynamist, divided autonomous control levels (ACL) into 11 levels (from 0 to 10) through intense discussions with government research institutes and industries, and observe, orient, decide, and act (OODA) were presented [16]. Levels 0 to 4 are classified as automation levels, levels 5–9 are semi-autonomous levels, and levels 10 are classified as complete autonomy levels. These ACL metrics were applied to the autonomous UAV control R&D program in AFRL (2002) [17]. As of 2022, the UAV MUM-T is an autonomous level of ACL 5–6, and the practical autonomous system is ACL 7–8.

3.3 ALFUS for UMS

National Institute of Standards and Technology (NIST, 2003) defines autonomy as the ability of UMS to sense, recognize, analyze, communicate, make decisions, and execute to achieve goals assigned by human operators through human–robot interaction (HRI) [9, 17]. Autonomy levels for unmanned systems (ALFUS) are considered "a series of progressive indices (typically given by number and/or name) that identify the ability of UMS to perform assigned autonomous

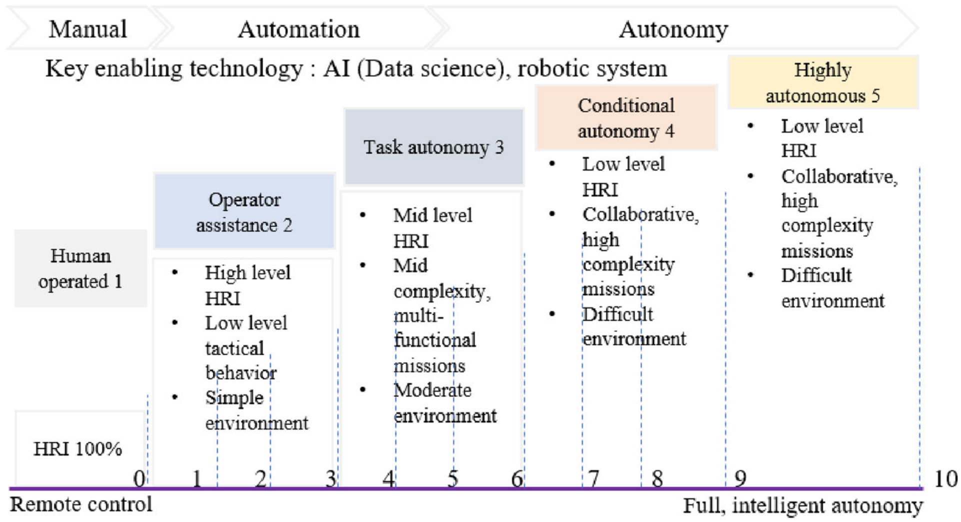

Fig. 4 Autonomous level evolution analysis on AI-enabled UMS and robotic systems

missions." This index shows the complexity of the mission, the difficulty of the environment, and the change in HRI level. The level of autonomy increases as the robot independently or cooperatively improves the OODA loop possibilities to achieve assigned complexity missions in difficult environments.

3.4 LOC for MUS

The Ministry of Defense (MoD 2022) in UK considered AI data science as a core technology of autonomy and divided autonomy level in the manned-unmanned system (MUS) into five levels. The core of autonomous evolution is AI, data science, robot system, and automation technology. The AI-assisted autonomy level is upgraded to human operated, operator assistance, task autonomy, conditional autonomy, and highly autonomy according to the level of control (LOC) of the AI MUS (see Fig. 4). MoD (2022) is meaningful in that it announced for the first time at the national level that AI is a technology that advances the level of Autonomous MUS. Like NIST (2007), Robot UGV is targeted, and the level of autonomy is simple with 5 levels, and its core technology is AI [13, 17].

3.5 OODA and AWS

North Atlantic Treaty Organization (NATO 2022) suggests the need to maintain the competitive advantage of AI and autonomous systems as AI is being widely used in the defense industry due to the development of sensors, rapid development of algorithm models, and improvement in computing. Autonomous systems are considered one of the seven core areas of AI: recognition, conversation, and human interaction, predictive analysis and decisions, goal-driven systems, patterns and anomalies, hyper-personalization, and autonomous systems [18]. Autonomous level is divided into human in the loop (HIL), human on the loop (HOL), and human out of loop (HO2L) according to the degree of human control. ALFUS (NIST 2003) 0 is HIL where almost 100% of the mission is performed by humans, ALFUS 10 is HO2L where almost 100% of the mission is performed by the autonomous weapon system (AWS), and HOL corresponds to ALFUS 1–9 levels, between 6 and 95% of the tasks are performed by humans (see Table 3).

4 Autonomous MUM-T Challenges and Program

4.1 Autonomous MUM-T Challenges

4.1.1 Technical Efficiency Area

US Army (2017) suggested autonomy, interoperability, and Human–Machine Collaboration as technological fields for efficient use of UMS, and presented a roadmap to be challenged by 2029 (mid-term) and 2042 (long-term) (see Table 4). The roadmap defines autonomy as an entity's ability to independently develop and select measures among several measures to achieve a goal based on the entity's knowledge and understanding of the battlefield situation [19]. Autonomy has a wide impact on future UMS, from remote control automation systems to almost fully autonomous systems. Autonomous cyber defense, agile spectrum, and strong electronic defense enhancement are technology efficiency areas (TEA) in the medium to long term. Future warfare depends on efficient interaction between weapon systems. Interoperability is a basic technology that establishes and enables

Table 3 Analysis of Autonomous MUM-T levels

Country	Levels	Classification level (high → low)	Tech
USA (2000 ~ 2003)	10 (LOA/HAT, Parasuraman)	High autonomy (6–10), partial autonomy (5), no autonomy manual control (1–4)	Autonomy
	11 (ACL/UAV, AFRL)	Full autonomy, battlefield community awareness, battlefield awareness, battlefield knowledge, real-time multi-aircraft cooperation, real-time multi-aircraft coordination, fault/incident adaptive machine, robust response to real-time fault/incident, changeable mission, predefined mission performance, remote control gas	Autonomous control
	11 (ALFUS/UMS, NIST)	Low HRI (7–10), medium HRI (4–6), high HRI (1–3), HRI 100% (0)	Interoperability
UK (2022)	5 (LOC/MUS, DoM)	Highly autonomous, conditional autonomy, task autonomy, operator assistance, human operated	AI, data science, robotics
NATO (2022)	3 (LOOP/AWS)	HIL, HOL, HO2L	AI

Table 4 Technology efficiency areas (TEA) for UMS by US Army roadmap

UMS	TEA	Year 2029	Year 2042
Interoperability	Artificial intelligence and machine learning, Increasing efficiency and effectiveness, trust, weaponization	Standardized command and control and reference, mounted on the existing system, modularization plan for new system	Uninterrupted, agile and autonomous human–machine cooperation, support for machine-to-machine cooperation, rapidly update and configure
Autonomy	Common open architecture, modularization and parts compatibility, conformity test, evaluation, inspection and validation, data strategy, data rights	Augmented reality, virtual reality, unmanned, tasks, operations, leader follower	Continuous detection, high degree of autonomy, swarm attack
Human–machine collaboration	Human–machine interface, man–machine team operation	Human–machine dialog, handling "what-if" scenarios, task division task management	Human intention inference, deep learning machine
		Deep neural networks, autonomously adjust data strategy, fully integrated robotics team members	

service, data, and communication networks between combat system units. In future operational environments, units or systems will communicate and share information in real time between different units at different levels of command.

4.1.2 Technical Focus Area

NATO Science & Technology Organization (STO 2020) broadly classifies emerging and disruptive technologies (EDT) for defense into autonomy, AI, and data. Systems, human–machine teaming (HMT), and behavior are subdivided, followed by unmanned platforms, acoustic, and optical countermeasures. In addition, technology focus areas (TFA), technology readiness levels (TRL) were identified, and target years for technology development were presented (see Table 5) [5].

As a technological challenge, it is expected that the integration of autonomous systems will be widely ubiquitous and operational within the country after 2025, so the communication control and operational integration issues must be addressed. This includes sharing large amounts of data and standardizing operational protocols (conflict resolution, collaboration, mission planning, and data fusion) across a wide range of physical-virtual operating environments. In particular, effective control of large-scale swarms presents significant technological challenges even for developed countries. As AI-enabled systems become more common, the need to define interoperable data and special communication standards will intensify. NATO requires a variety of standards for verification, validation, and accreditation (VV&A) of AI systems to make AI operational decisions for use in military operations. This is because of the different rules for data management, classification and training, the problem of

Table 5 Defense challenges of technology focus Areas (TFA) by NATO Science & Technology Organization

FTA		Defense challenges	TRL	Year
Autonomy	System	Mission autonomous systems, unmanned platforms	6	2025
	HMT	Human and machine interfaces, human-autonomous machine teaming, integrated human–machine hybrid forces	4	2030
	Behavior	Clusters and swarms, sensor integration and networks, secure and resilient Communications, rules of engagement, legal and ethical implications	4	2025
	Counter measures	Active and passive EM, acoustic and optical countermeasures	5	2030
AI	Advanced algorithms	Artificial intelligence, big data and long data processing and analysis, advanced signal processing	4	2030
	Applied	Multi-domain situational awareness, planning and managing uncertainties, human decision-making	6	2030
	HMS(Symbiosis)	Human and machine interfaces, integrated human–machine hybrid forces, human-autonomous machine teaming	4	2035
Data	Advanced analytics	Big data and long data processing and analysis	4	2025
	Communications	Ad hoc and Heterogeneous networks, advanced signal processing, trusted multi-domain information sharing, secure and resilient communications	6	2030
	Advanced decision	Human decision-making, multi-domain situational awareness, planning and managing uncertainties	6	2025
	Sensors	Sensor integration & networks	4	2030

explainability, the concept of human–machine collaboration and symbiosis, and the level of trust in systems and organizations. Given the potential exposure of intellectual property rights and underlying algorithms, commercial interests may reject the requirement.

4.1.3 OODA Area

The DoD will establish the Chief Digital Artificial Intelligence Office (CDAO 2022) organization in June 2022 and serve as the control tower for the joint all-domain command and control (JADC2). The JADC2 strategy is to minimize the OODA loop (time from reconnaissance to strike) by connecting sensors to collect data generated in all areas of the military. It is a strategy to automate work performed by humans with AI and implement technology to share information at high speed through a network. In May 2021, the DoD Commander of the ROK-US Combined Forces Command mentioned interoperability with the ROK military at a hearing before the US House Armed Services Committee [20]. Key projects for implementing JADC2 include Defense Advanced Research Projects Agency (DARPA) Mosaic Warfare, US Air Force Advanced Battle Management System (ABMS), US Army Project Convergence, and US Navy Project Overmatch. The purpose of DoD's autonomous MUM-T is to present the optimal strategy to the human commander after machine agents attached to sensors in all areas judge the battlefield situation, compare and analyze tens of thousands of strategies (Fig. 5).

4.2 Autonomous Unmanned Program Analytics

4.2.1 UAS

UAS, United States Department of Defense (DoD) consists of UAV and GCS. The Army operates the MQ-1C Gray Eagle, the Navy operates the MQ-25 Stingray and MQ-4C Triton, and the Air Force operates the MQ-9 Reaper, RQ-4 Global Hawk, and RQ-170 Sentinel (see Table 6) [21]. 204 Army MQ-1Cs have been procured, and there is no budget allocation for FY2021–2023. The Air Force MQ-9 was not requested for FY2022 procurement, but the House Armed Services Committee of the National Assembly increased significantly by 207.8% compared to the previous year due to the need for procurement of 6 units. The Navy's FY2023 budget request for demonstrating unmanned operationally integrated, complex sea-based C4I (command, control, communications, computer and intelligence) UAS technology increased by 499.3% year over year (Office of the Under Secretary of Defense 2022) [22].

4.2.2 UGV

The US Army is promoting AI-enabled autonomous UGV from 2021 to improve MUM-T problems. Automatic Target Recognition (ATR) System Development, The Navy is developing Phalanx 20 mm, a high-speed machine gun mounted on ships in 1988, for UGV. The main reason is that it is mass-produced enough to be mounted on 187 ships of the Navy,

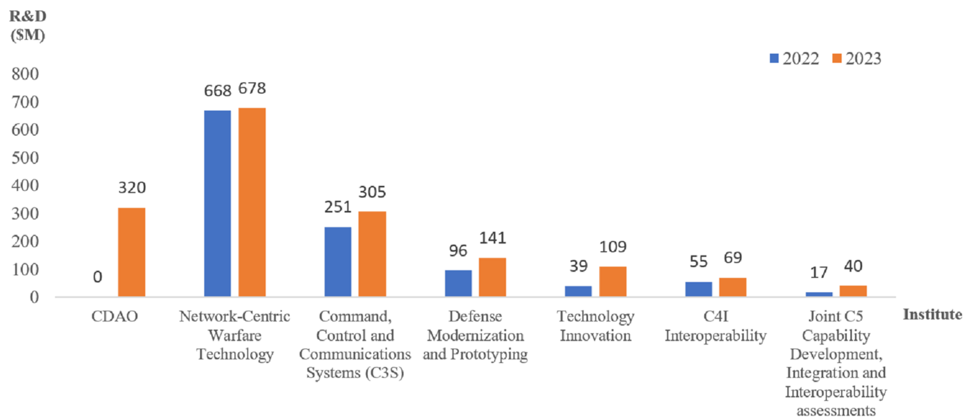

Fig. 5 Development program level for AI MUM-T interoperability and platform operation by DoD budget materials (FY2023) analysis (unit: $m)

Table 6 UAS operation program level by DoD

DoD	UAS	Max. alt. (ft)	Weight (lb.)	Payload (lb.)	Wing (ft)	Length (ft)	Speed (knots)	Endu. (hours)
Army	MQ-1C	25,000	3600	1075	28	56	150	27
Air force	RQ-4	60,000	32,250	3000	47	130	310	34
	MQ-9	50,000	10,500	3850	36	66	240	24
	RQ-170	–	–	–	15	65	–	–
Navy	MQ-25	–	–	–	51	75	–	–
	MQ-4C	50,000	32,250	–	47	130	320	24

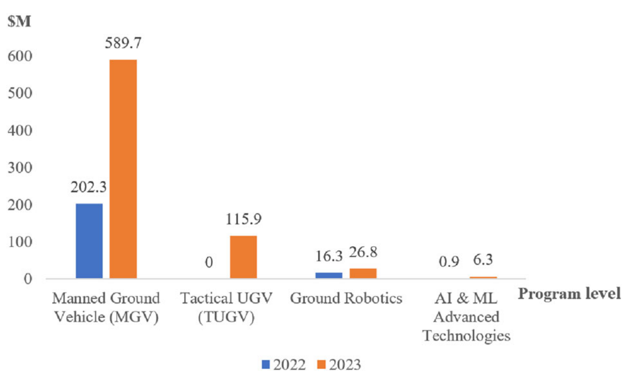

Fig. 6 AI-UGV development program level by DoD budget materials (FY2023) analysis (unit: $M)

so the unit price is cheap and there is no additional R&D cost. The U.S. Army's Army Futures Command (AFC) is advancing the realization of precision strikes by accurately identifying the movement and movement of a specific target through the convergence of ATR and remote weapon system (RWS) for machine-speed warfare implementation, and AI grafting. It is to connect various machine learning (ML) technologies for civilian use to military UGV. The US Army's FY 2023 budget request includes a significant increase in manned ground vehicle (MGV) by 191.5%, Ground Robotics by 63.9%, and AI and ML by 603.5% (from 0.9 to 6.3$M) (see Fig. 6). It is characterized by strengthening AI MUM-T (Office of the Under Secretary of Defense 2022).

NATO (2021) autonomous UGV programs include THeMIS, Type-X, Ripsaw, Black KnightHusky, Mission Master, Nerva, Perun, and VIKING 6 × 6 and are being developed by the USA, UK, Germany, France, and Poland AI [13]. The Ripsaw model was delivered in 2021 after the US Army signed a contract for the Robotic Combat Vehicle-Medium (RCV-M) program in January 2020. As of 2022, the Black Knight model is being evaluated by the U.S. Army for a concept evaluation of a military unmanned vehicle as a combat asset using a vehicle designed by British company BAE Systems (see Table 7).

4.2.3 USV

The United States Government Accountability Office (GAO 2022.4) reported uncrewed maritime systems (UCMS) to a congressional committee that the Navy has operated UAVs for more than 30 years, but the technical and operational aspects of UMS (UAV, UGV, USV, and UUV) are still unknown. It is an early stage. It raised the need for significant investment in technology development to enable autonomous or semi-autonomous operation with existing fleets [23]. A strong effort was undertaken to overcome the resulting technical problems. They plan to introduce UMS over the next few decades. The plan is to develop unmanned surface vehicles (USV) and unmanned underwater vehicles (UUV), as well as software such as data storage and modeling, digital

Table 7 Autonomous UGV model in NATO

Model	Company	Payload	Speed	Specifications
THeMIS (2015)	Milrem Robotics (Estonia)	1200 kg	20 km/h	Weight (3590 lb.), length (94 in), width (79 in), height (45 in)
Type-X (2020)	Milrem Robotics (Estonia)	4100 kg	80 km/h	Weight (26,000 lb.), Length (240 in), Width (110 in), Height (87 in)
Ripsaw (2021)	Textron Systems	910 kg	105 km/h	Weight (4,100 kg), Height (180 cm), explorer garden 2 people
Black Knight (2022)	BAE Systems (2022)	–	77 km/h	Length (16 ft 5 in), width (7 ft 10 in), height (6 ft 7 in)

Table 8 Autonomous USV and UUV program level in US Navy

USV	Demo event	Quantity	Mission
S-SUV	Reconnaissance payload 2018, advanced autonomy 2020, classification payload 2021	Delivered: 2	Support M-USV, L-USV
O-SUV	Electronic warfare payload 2020, autonomous movement 2021	Delivered: 2, 2023: 2	Support M-USV, L-USV
M-USV	Expected delivery 2023	Delivered: 0, Planned: 2	Multi-mission assets with interchangeable payloads
L-USV	Concept design research 2019	Delivered: 0	Water war
XL-UUV	Delivery completed 2022	Delivered: 0, Under Construction: 5	Modular payloads on the seabed
LD-UUV	Delivery completed 2022	Under construction: 1, Under Plan: 2	Interchangeable payloads, submarine launch

infrastructure functions, and AI functions, so that the system can be operated without a crew. In April 2022, two sea hunter (or Seahawk) medium displacement unmanned surface vessels (S-SUVs) and two overlord unmanned surface vessels (O-SUVs) were delivered with AI-autonomy capabilities. The medium unmanned surface vessel (M-USV) is in the conceptual design stage to provide an inexpensive, disposable vessel to enhance surface fleet intelligence, surveillance, reconnaissance, and electronic warfare capabilities. The large unmanned surface vessel (L-USV) system increases the capabilities of crewed ships by providing them with greater missile capacity, capable of attacking the enemy in their initial mission. It is scheduled to be delivered in 2023, and currently two units are planned. In July 2022, the Turkish Defence Industries Presidency (SSB) of Turkey unveiled four USVs (USV Corps consisting of ULAQ, SALVO, SANCAR, Albatros, and MIR) that the defense contractor is working on. In particular, SANCAR USV (Yonca Onuk Shipyard—AVELSAN) is an armed unmanned submersible developed by Yonca Onuk and Havelsan Partnership. It is equipped with a next-generation command and control system tailored to the needs of Havelsan's network-centric concept of operations. Aselsan ALBATROS and Sefine MIR perform the four major SWARMs [24]. ALBATROS continues its mission despite the loss of individual platforms by avoiding other components and obstacles (including moving hazards). The MIR carries a large payload, is equipped with a variable depth sonar (VDS), and is designed to meet the durability, seakeeping and maneuverability requirements of defensive ASW operations in coastal waters (see Table 8).

4.3 Autonomous MUM-T Program Analytics

4.3.1 Helicopter

DoD's UAS in 2011, the USA succeeded in the world's first MUM-T LOI level 2 technology, and in 2015, the MUM-T battalion of LOI 3–4 class helicopters was established and deployed. The AH-64 Apache manned aircraft secures LOI 3–4 level control capability for unmanned aerial vehicles. France, the second-ranked country in the establishment of a defense IA strategy, conducted a LOI 5 demonstration flight in 2022. We are implementing AI, autonomy, and data link weapon system operation at our best. South Korea is planning for actual deployment in 2025. In 2020, the UK

Table 9 Helicopter MUM-T program levels by countries

Country	Manned	Unmanned	Note
USA (2015)	AH-64 Apache	MQ-5 Hunter Boeing H-6 Little Bird Q-1C Gray Eagle	Securing LOI 3 ~ 4 control capability Establishment of MUM-T battalion (MUM-T electrification)
France (2021)	H145 (Airbus)	S-100 Accepter (Austria Schiebel)	LOI 5 demonstration flight Understand that the data link must be much stronger and more accurate to ensure the control of the UAV and the continuous supply of data from the sensors
UK (2020)	AW159 Wildcat	Callen-Lenz	LOI 4 operation possible Human machine interface (HMI): controls the UAV's flight path and loaded equipment using a gateway processor
Korea (2022)	KUH-1 LAH	Canister (KAI	Actual deployment plan 2025 MUM-T interconnection system demonstration began in 2022

Table 10 Fighter plane MUM-T program levels by countries

Country	Manned	Unmanned	Note
USA (2022)	F-18E/F Super Hornet	BQM-34 Fire bee	MUM-T successful flight test completed Pilot interacts with unmanned vehicle using HMI monitoring device
UK (2022)	F-22 F-35	UTAP-22	Drones control unmanned aerial vehicles Equipped with artificial intelligence-supported autonomous systems and data sharing technology
Germany (2021)	A400M	Do-DT45 RC (Remote Carrier)	Mechanism prototype ground test for RC deployment
Australia (2022)	F/A-18F Super Hornet	Loyal wingman (ATS)	Autonomous control through artificial intelligence The government invests an additional 400 billion won in the Loyal Wingman program

conducted MUM-T operational tests using a Leonardo Wildcat manned helicopter and Callen-Lenz's semi-autonomous UAV. A Leonardo manned pilot can operate LOI 4 level, which can control the UAV's flight path and loaded equipment using the Gateway Processor, that is, the Human Machine Interface, even while piloting the helicopter. However, from the second stage of STANAG 4586 LOI, it is a non-disclosed situation. The ROK Army, in collaboration with the Agency for Defense Development (ADD), is conducting preliminary concept research on the necessity, operational concept, and operational performance of MUM-T (see Table 9).

4.3.2 Fighter Plane

In 2015, through the LOW-COST AT TRITABLE AIRCRAFT TECHNOLOGY (LCATT) program, the US Air Force began research on low-cost, expendable, or semi-expendable unmanned aerial vehicles rather than large, expensive unmanned aerial vehicles. Prior to this, plan to conduct reconnaissance in enemy territory or perform missions to eliminate radar or air defense weapons. In March 2022, DOD tested a successful flight of the evolved MUM-T technology with a BAE Systems company. The manned fighter is the F-18E/F Super Hornet aircraft, and the UAV type is the BQM-34 Firebee. The UK completed testing of its Skyborg program, an AI-assisted autonomous system in which XQ-58 Valkyrie drones control unmanned aerial vehicles, in July 2022. The Royal Australian Air Force is developing an escort aircraft, the Loyal Wingman [or Airpower Team system (ATS)] UAV, with Boeing. This drone is capable of autonomous control through AI and aims to be able to perform simultaneous operations with F/A-18F BOEING, F-35A fighters, and maritime patrol aircraft. Loyal wingman escorts manned planes or approaches threats ahead of manned planes to perform high-risk missions. Also, it is possible to perform missions flexibly by replacing modularly designed nose sensors and mission equipment (see Table 9). In May 2022, the Australian government decided to invest an additional $317 million (USD $317 million) in the Loyal Wingman programme. It will be delivered to the Royal Australian Air Force (RAAF) in Australia within the next three years under the designation MQ-28A Ghost Bat drone (Table 10).

5 Conclusions

The future battlefield environment will change rapidly due to the development of future defense technologies, technology challenges, and programs for their utilization. The existing MUM-T concept does not reflect AI-enabled autonomy, full-field battlefield, and complex combat system. After the fourth industrial revolution, the interoperability of AI-enabled autonomous MUM-T is a new concept weapon system, not a weapon system with a fully established operational concept. In response to these changes in the environment of future weapon systems, countries such as the USA and the UK, which are member countries of NATO, are accelerating the challenge of developing MUM-T efficiency technology and programs, which are essential for realizing the operation concept of combined combat systems. Since the MUM-T platform enables communication between heterogeneous platforms, it is essential to develop a common architecture and standard protocol. Autonomous swarm flight can reduce the workload of manned pilots and simultaneously operate multiple unmanned aerial vehicles. AI-based autonomous swarm flight and mission assignment technology development is required. Development technology for a command-based decision support system based on pilot commands, technology for miniaturization and weight reduction of communication and control equipment for UAVs mounted on manned aircraft, technology for automatic area of interest setting and target identification between UAV reconnaissance missions, and information convergence technology collected from multiple UAVs are required. As technology develops to automate the flight and mission of UAVs and reduce the missions of manned pilots, the authority to control UAVs is shifted from the existing ground control system (GCS) to manned aircraft, and one manned aircraft can fly multiple types of UAVs depending on its mission and purpose. It develops in the direction of complex management. Beyond the combined operation between manned and unmanned flight platforms, it will develop into an operation concept of various combinations of air, sea, underwater, ground manned platforms, and unmanned platforms. It will evolve from 1 to 1 and 1 to N concepts to N to N combined operation. The significant of this study is that the core technologies of the fourth industrial revolution, such as AI, autonomy, and data interoperability, are reflected in the MUM-T system, as shown in Table 1. In addition, as shown in Fig. 2, an AI-enabled autonomous MUM-T operation and facility classification system was established by reflecting AI and autonomy in the existing UMS taxonomy, and this were considered when the level and program were analyzed. This study is useful for governments, companies, and researchers to analyze the core technology and program level in relation to the construction and operation of the AI MUM-T complex combat system.

Acknowledgements This thesis is the result of ETRI's basic project "National Intelligence Technology Policy and Standardization Research (23ZR1400)."

Data availability All data generated or analyzed during this study are included in this published article.

References

1. Dempsey ME (2010) US ARMY roadmap for unmanned aircraft systems 2010–2035. US Army UAS Center of Excellence (UAUCE), Washington, pp 8–72
2. Winnefeld JA, Admiral J (2011) Unmanned systems integrated roadmap FY2011–2036, Department of Defense (DoD). DoD, Washington, pp 13–86
3. Rossetti L (2020) Transforming joint air and space power. J JAPCC (Jt Air Power Competence Centre) 29:42–47
4. Lee C, Hong S, Hong S, Kim T (2020) Performance analysis of local exit for distributed deep neural networks over cloud and edge computing. ETRI J 42(5):658–668
5. Reding DF, Eaton J (2020) Science & technology trends 2020–2040, NATO Science & Technology Organization. Brussels, Belgium. https://www.nato.int/nato_static_fl2014/assets/pdf/2020/4/pdf/190422-ST_Tech_Trends_Report_2020-040.pdf. Accessed 01 Jan 2023
6. Taylor G, Turpin T (2015) Army aviation manned-unmanned teaming: past, present, and future. In: 18th International Symposium on Aviation Psychology, USA. WSU, Washington, pp 560–565
7. Lee JY (2018) Manned-unmanned collaborative combat system (MUM-CCS) operation concept and development direction. Korea Research Institute for National Strategy KRINS, Seoul, pp 194–214
8. Ministry of Defence (2022) Defence artificial intelligence strategy. MoD, London, pp 4–65. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachmentdata/file/1082416/Defence_Artificial_Intelligence_Strategy.pdf. Accessed 05 Jan 2023
9. Huang HM, Messina E, Albus J (2003) Toward a generic model for autonomy levels for unmanned systems (ALFUS). In: Proceedings of the 2003 performance metrics for intelligent systems (PerMIS) Workshop. Gaithersburg, Maryland, August 2003, pp 1–6
10. Seo S, Ko DE, Chung JM (2020) Combined time bound optimization of control, communication, and data processing for FSO-based 6G UAV aerial networks. ETRI J 42(5):700–711
11. Huang HM, Pavek K, Albus J, Messina E (2005) Autonomy levels for unmanned systems (ALFUS) framework: An update, pp 6–9. https://tsapps.nist.gov/publication/getpdf.cfm?pubid=822672. Accessed 03 Jan 2023
12. Huang HM, Pavek K, Novak B, Albus J, Messina E (2005) A framework for autonomy levels for unmanned systems

(ALFUS), pp 2–8. https://tsapps.nist.gov/publication/get.pdf.cfm?Pubid=824538. Accessed 15 Jan 2023
13. Gray M, Ertan A (2021) Artificial intelligence and autonomy in the military: an overview of NATO member states' strategies and deployment, NATO Cooperative Cyber Defense Centre of Excellence (CCDCOE). https://ccdcoe.org/uploads/2021/12/StrategiesandDeploymentA4.pdf. Accessed 30 Jan 2023
14. Parasuraman R, Sheridan TB, Wickens CD (2000) A model for types and levels of human interaction with automation, IEEE Transactions on systems, man, and cybernetics - Part A: systems and humans. 30(3): 286–297. https://www.ida.liu.se/~769A09/Literature/Automation/arasuraman,20Sheridan,%20Wickens_2000.pdf. Accessed 25 Jan 2023
15. Sycara K, Lewis M (2004) Integrating intelligent agents into human teams. In: Salas E, Fiore SM (eds) Team cognition: understanding the factors that drive process and performance. American Psychological Association APA, Washington, pp 203–231
16. Clough BT (2002) Metrics, Schmetrics! How the heck do you determine a UAV's autonomy anyway? In: Proceedings of the performance metrics for intelligent systems workshop, Gaithersburg, Maryland, pp 3–8. https://apps.dtic.mil/sti/pdfs/ADA515926.pdf. Accessed 03 Jan 2023
17. Huang HM, Messina E, Albus J (2007) Autonomy levels for unmanned systems (ALFUS) framework, volume II: framework model version 1.0, pp 15–20, https://tsapps.nist.gov/ublication/get_pdf.cfm?pub_id=823618. Accessed 21 Jan 2023
18. Luzum N, Nelson N (2022) NATO must embrace AI and autonomous weapons, The Center for European Policy Analysis. CEPA, Washington. https://cepa.org/nato-must-embrace-ai-and-autonomous-weapons/. Accessed 05 Jan 2023
19. Fahey KM, Miller MM (2017) Unmanned systems integrated roadmap 2017–2042, Department of Defense (DoD). DoD, Washington, pp 6–39
20. Han H, Shin G (2019) Head flexion angle when web-browsing and texting using a smartphone while walking. Appl Ergon 81:102884
21. Hoehn JR et al (2022) Unmanned aircraft systems: roles, missions, and future concepts. https://crsreports.congress.gov/search/#/?termsToSearch=Unmanned%20Aircraft%20Systems:%20Roles,%20Missions,%20and%20Future%20Concepts&orderBy=Relevance
22. Office of the Under Secretary of Defense (2022) DoD budget request: defense budget materials (FY2023), research development, test & evaluation programs (R-1). OUSD, Washington. https://comptroller.defense.gov/Budget-Materials/#detailed. Accessed 07 Jan 2023
23. Oakley SS (2022) Uncrewed maritime systems: Navy should improve its approach to maximize early investments. United States Government Accountability Office. GAO, Washington: GAO. https://www.gao.gov/products/gao-22-104567. Accessed 24 Jan 2023
24. Ozberk T (2022) Here are the four USV programs Turkiye is working on, Paris: NAVALNEWS. https://www.navalnews.com/naval-news/2022/08/here-are-the-four-usv-programs-turkiye-is-working-on/. Accessed 30 Jan 2023