

Parallel science and technology for C2 in the agentic age: from military operations to peaceful sustainability and resiliency

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ABSTRACT

Command and control (C2) has traditionally been framed as a military problem of sensing, deciding, coordinating, and acting under uncertainty, conflict, and time pressure. In the agentic age, however, this problem is being extended far beyond the battlefield, as human organizations become increasingly embedded in hybrid environments composed of artificial agents, digital twins, social sensing networks, foundation models, autonomous platforms, and cyber–physical–social institutions. This article develops a conceptual framework for parallel science and technology for C2 by revisiting the historical mission of C2 as a quest for certainty under diversity, uncertainty, and complexity (DUC), and by tracing its transformation toward focus, agility, and convergence (FAC). Building on parallel systems, artificial societies, computational experiments, parallel execution (ACP), cyber–physical–social systems (CPSS), C2 management (C2M), planning–readiness–execution–assessment (PREA) loops, social cognition operations, and parallel battlefield intelligence, the article argues that C2 should be reframed as a general science of coordinated adaptation. It further examines emerging agentic societies as a new operating ecology, explains why parallel science and technology are needed, and redefines the mission of future C2 around sustainability and resiliency. Rather than merely accelerating decision cycles or optimizing combat efficiency, parallel C2 aims to support anticipation, adaptation, trust, recovery, and responsible human agency across both military and civilian domains, thereby transforming command and control from post-hoc operational control into a science of sustainable and resilient coordination in the agentic age.

KEYWORDS

agentic society; artificial societies; command and control; C2; ACP; CPSS; parallel intelligence; parallel systems; PREA loop; resilience; sustainability

1 Introduction

Command and control (C2) is conventionally labeled as a military-specific discipline, yet its core logic applies universally to any complex collective system^[1–3]. Fundamentally, C2 addresses how interconnected entities perceive volatile environments, allocate limited resources, coordinate joint actions, and learn iteratively from operational outcomes. Battlefields magnify this set of challenges to an extreme degree, filled with operational friction, adversarial deception, sudden emergent threats, and rigid time constraints. Comparable uncertainty-driven coordination demands exist across civilian domains, including urban emergency dispatch, cross-border renewable energy balancing, social media information regulation, and interregional medical resource redistribution. All these scenarios require closed-loop workflows of observation, interpretation, decision-making, execution, and post-hoc revision. Today, global C2 theory and engineering are standing at a pivotal paradigm transition, pushed forward by two severe, overlapping transformative shocks that render legacy C4ISR architectures—originally designed for mechanized and information-era combat—incapable of meeting modern operational demands^[4–6].

The first disruptive shock originates from innovative

unmanned combat tactics proven in recent high-intensity regional conflicts, including the Russia–Ukraine war and successive confrontations across the Middle East. Low-cost miniature unmanned aerial vehicles, surface drones, and autonomous swarms have become core strike assets, delivering asymmetric combat advantages that outmatch expensive heavy manned weapon platforms. Unmanned systems blur the traditional dividing line between frontlines and rear areas, compress kill chains to ultra-short time windows, and popularize decentralized, distributed mobile command modes. Traditional hierarchical, centralized C2 frameworks built around large manned equipment carry inherent drawbacks: delayed intelligence planning, weak system survivability under enemy strikes, scripted and unrealistic combat training, and a lack of quantitative analytical tools for cross-domain resource scheduling. Practical combat experience demonstrates that simply retrofitting legacy command infrastructure for unmanned swarm operations inevitably triggers broken intelligence pipelines, sluggish decision loops, and disjointed human-machine coordination, generating an urgent imperative for comprehensive C2 system transformation.

The second shock stems from the large-scale deployment of Artificial Intelligence (AI) technologies, large language models,

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and AI agents within military workflows, cultivating an unprecedented hybrid human-machine ecosystem. Unlike traditional information systems that only store and transmit raw data, modern generative agents and multi-agent frameworks can independently generate operational plans, simulate red-blue adversarial scenarios, remotely manipulate unmanned assets, negotiate cross-unit task allocation, and embed themselves end-to-end throughout entire command cycles. Digital twins, cyber-physical-social systems (CPSS), and unmanned combat formations are tightly coupled, forming agentic societies: hybrid groups consisting of human commanders, military organizations, autonomous machines, prescriptive models, sensor networks, and digital platforms that collectively shape real-world operational conditions. The classic OODA loop remains widely adopted to pursue tactical speed and competitive disruption, yet it cannot satisfy the comprehensive coordination requirements of system-of-systems-level C2. In addition, OODA has been mainly constructed on traditional separated human-machine architectures and fail to adapt to the new paradigm where AI agents permeate every command link. Global defense research communities have raised widespread doubts regarding whether conventional C2 frameworks can effectively accommodate general-purpose AI. Existing theories lack clear boundaries for decision authority, human-agent accountability, and evolutionary rules within mixed intelligent ecosystems, and no mature, fully deployable solutions have been formed to date.

Faced with these dual structural pressures, extensive research reports have been released by the RAND Corporation^[7], U.S. military JADC2 programs^[8], the NATO Command and Control Centre of Excellence^[9-10], and British defense research institutions^[3,5], giving rise to four distinct schools of thought concerning the relative priority of human operators and technological systems in future C2. The first perspective is technology-centrism, which argues that AI and unmanned platforms determine victory in future conflicts; technological capability outweighs human experience and training, requiring relaxed human-in-the-loop constraints to enable algorithm-led command cycles. The second viewpoint prioritizes human primacy, maintaining that human commanders' contextual judgment and ultimate decision authority are irreplaceable. Technology merely serves as auxiliary decision support, with strict human oversight mandated to mitigate risks such as algorithmic bias, excessive technological reliance, and unclear accountability. The third school advocates human-technology integrationism, claiming that humans and artificial intelligence fuse into integrated cognitive entities in the agentic age. C2 research must center on symbiotic human-machine coordination mechanisms and redesigned integrated command procedures. The fourth view proposes mutual co-construction, framing humans and technology as mutually supportive and co-evolving: human stakeholders define strategic objectives and ethical boundaries, while AI expands the scope of sensing, simulation, and execution, with no absolute primary or secondary subject. None of these four perspectives has gained universal consensus, leaving ambiguous development pathways for next-generation C2 systems.

Furthermore, mainstream C2 research has long been limited to military combat and national defense operations, ignoring its inherent cross-domain universality. From a long-term global development perspective, next-generation C2 systems must not only serve military operations, but also expand to diverse civilian complex governance scenarios, such as transnational energy scheduling, global public health emergency response, cross-border

cyberspace governance, urban disaster prevention, and global supply chain coordination. A unified coordinated adaptive C2 framework can mitigate cross-regional and cross-domain systemic risks, deliver foundational support for building a community with a shared future for mankind, and facilitate long-term global sustainable development^[11-12].

Against this backdrop, this article puts forward two core research questions: How should command and control evolve when artificial agents and agentic societies are fully integrated into operational environments? How can immature yet promising AI for science or parallel science and ACP methodologies restructure C2 theoretical systems, shifting optimization targets beyond narrow military combat efficiency toward long-term systemic resilience and sustainability, while breaking the barriers between national defense and global civilian governance to underpin the sustainable development of the community with a shared future for mankind? This article advances a core thesis: C2 should be redefined as a parallel science of coordinated adaptation. Within this paradigm, physical operations, cyber interactions, social cognitive dynamics, and human decision-making are no longer isolated layers. All dimensions are modeled and represented through parallel systems, verified via repeatable computational experiments, and continuously optimized through parallel execution before, during, and after real-world intervention. This theoretical framework carries natural cross-domain adaptability, capable of migrating to global civilian complex governance scenarios to balance safety, security, stability, and long-term sustainable development goals.

2 A Brief C2 history: the origin and mission

Martin van Creveld, one of the leading "New Wars" scholars of the new "non-Clausewitzian" modern warfare model, stated in his landmark monograph *Command in War*:

"From Plato to NATO, the history of command and control in war consists essentially of an endless quest for certainty."^[13]

This canonical observation captures the primordial driving force behind the entire domain of command and control: every C2 architecture, from ancient military hierarchy to modern intelligent systems, exists to resolve operational ambiguity amid volatile environments. All complex military and social systems are inherently trapped by three intertwined fundamental predicaments, collectively abbreviated as DUC, namely Diversity, Uncertainty, and Complexity, which remains the central problem that C2 science targets to address.

2.1 Early ideological origins and pre-academic development

The integrated logic of pairing "command" with "control" did not first emerge in Western military thought. As widely documented in Cold War military translation archives, Soviet military theorists pioneered the unified framework of *komandovanie i upravlenie* (command and control) as early as the 1930s, embedded within the deep operation theory of Tukhachevsky and Svechin. Unlike Western military doctrine that long separated command authority from operational regulation, Soviet military science treated command and control as an indivisible closed-loop system to mitigate battlefield randomness and ambiguity.

While the Soviet Union established integrated C2 operational doctrines from the interwar period through the 1970s, Western defense communities only treated C2 as auxiliary communication hardware within the C3I technical framework, lacking independent theoretical and academic research. The full English phrase *Command and Control* first entered official U.S. military docu-

mentation during the Korean War, yet for nearly three decades afterward, Western efforts remained limited to engineering development of communication equipment, without systematic disciplinary construction for C2 as a standalone science.

Western strategic scholars often trace the philosophical root of command thinking far earlier to Sun Tzu's *The Art of War*^[14–15]. Notably, both ancient Chinese strategic theories and early Soviet automated Cold War command frameworks converge on the identical core challenge: resolving DUC amid large-scale coordinated collective action.

2.2 Institutionalization of C2 as a formal discipline: 1980s Soviet automated C2 and Western theoretical breakthrough

The institutionalization of modern C2 as an independent academic discipline formally began within Soviet automated military command architectures in the early 1980s, whose core design objective was to quantify and suppress battlefield randomness to offset DUC. Though systematic technical C2 engineering originated from Cold War Soviet military establishments, Western research underwent two successive transformative military intellectual movements throughout the 1990s that reshaped global mainstream C2 paradigms: the Revolution in Military Affairs (RMA) and the subsequent Revolution in Intelligence Affairs (RIA)^[3,16].

RAND researcher Carl H. Builder criticized conventional hierarchical C2 architectures born out of RMA frameworks for over-investing in communication hardware and rigid organizational structures while neglecting commanders' cognitive judgment and operational conceptualization—an inherent defect amplified by DUC-induced information overload. Builder's command-concepts theory offered an early cognitive remedy for information confusion, yet it lacked a complete system framework to resolve cross-domain DUC^[17]. The follow-up RIA further highlighted the failure of legacy C2 to integrate full-cycle intelligence sensing, reasoning, and feedback loops under information-age conditions.

In the mid-1980s, two pivotal works reshaped Western comprehension of C2 beyond pure hardware: Creveld delivered a comprehensive historical analysis of command evolution^[13], establishing the human-cognition dimension of C2 research; concurrently, John Boyd refined the OODA loop, providing a canonical decision-cycle model for battlefield coordination. These two works dismantled the narrow equipment-only perspective that dominated Western defense research for decades.

Against this backdrop, David S. Alberts and his group launched an ambitious research on C2 within the U.S. Department of Defense starting in the mid-1980s, separating C2 research from traditional C3I communication engineering and framing it as an interdisciplinary complex-system science covering human organizations, information flows, and iterative decision-making. In 1994, Alberts formally founded the DoD Command and Control Research Program (CCRP)—the world's first institutional research body dedicated exclusively to C2 theory. CCRP organized cross-domain academic symposia, published foundational monographs, and launched a dedicated C2 journal, although short-lived, unifying fragmented C2 research into a coherent disciplinary system and cementing C2's status as an independent field worldwide.

Alberts put forward a disruptive landmark thesis that redefined the ultimate direction of C2 evolution^[18]:

“The future of command and control is not Command and Control, but Focus and Convergence.”

Essentially, CCRP identified three ultimate performance objectives to reshape rigid top-down hierarchical C2 logic: Focus,

Agility, and Convergence, abbreviated as FAC. Nevertheless, the CCRP framework only proposed conceptual transformation targets, without offering a complete systematic technical and experimental pathway to realize the shift from DUC to FAC, leaving a critical theoretical vacancy that parallel C2 theory systematically addresses.

2.3 Expansion of C2 theory: parallel C2, C2M, and cross-domain generalization

The theoretical gap left by Western mainstream C2 schools spanning RMA and RIA to CCRP is fully resolved by the parallel command and control paradigm proposed in prior work^[2,4]. In Ref. [2], the core mission of parallel C2 was defined: constructing virtual-real interactive mechanisms supported by the ACP framework, namely Artificial Societies, Computational Experiments, and Parallel Execution, together with CPSS, namely Cyber–Physical–Social Systems infrastructure. This framework transforms the inherent DUC of human–military–social complex systems into the FAC state targeted by CCRP.

To break the historical long-standing separation between wartime military combat C2 and peacetime civilian social governance, a unified C2M, or command, control, and management, paradigm was proposed, integrating military C2 with civilian complex-system management. Research verifies that high-bandwidth, low-latency 5G communication infrastructure provides indispensable underlying support for cross-domain DUC-to-FAC transformation under the C2M framework^[19]. The core engineering carrier materializing this DUC–FAC transition is the Parallel Decision Theater, built atop the ACP–CPSS parallel architecture as a universal computational experiment platform. It enables closed-loop iterative operation of both OODA and the indigenous PREA loops^[20–21], supporting descriptive recording, predictive deduction, and prescriptive intervention for diverse complex scenarios. This translates CCRP's abstract FAC conceptual goals into quantifiable and deployable system capabilities, and extends the scope of C2 beyond exclusive military combat.

A consistent theoretical limitation permeates Western mainstream C2 theories from RMA/RIA CCRP: all frameworks center on battlefield adversarial dominance and fail to incorporate Sun Tzu's core strategic proposition of “Subduing the Enemy without Fighting.” Traditional Western C2 schemes primarily accelerate kill chains to defeat opponents, while parallel C2M supported by parallel decision theaters delivers a viable technical route to implement non-conflict strategic thought. Through multi-round simulation and risk deduction within virtual parallel spaces, decision-makers can generate convergent non-intervention schemes in advance, shifting C2's long-term mission from post-hoc combat control to pre-crisis risk prevention and sustained systemic resilience. From this perspective, the DUC-to-FAC transformation is not merely a technical upgrade of command hardware, but a fundamental conceptual reorientation of C2 toward cross-domain resilient and sustainable governance.

Nobel laureate Thomas Schelling, one of the earliest scholars to use the term “Command and Control” within mainstream social science literature^[22], once pointed out that the concept of C2 carries strong coercive connotations when extended to civilian social domains. For this reason, scholars long preferred game theory as the primary analytical tool for social and economic issues. Today, however, parallel systems built on artificial societies and repeatable computational experiments provide a novel methodological path: they can mitigate randomness not only on military battlefields, but also resolve the deep complexity embedded within

civilian economic, public health, urban governance, and supply-chain operations, enabling maximum predictable certainty for coordinated control across military and civilian affairs alike.

This theoretical breakthrough unlocks broad prospects for cross-domain generalization of C2 science. Explorations of civilian C2 applications have long existed, yet the rise of agentic societies renders this interdisciplinary expansion far more urgent than ever before, laying the groundwork for redefining C2 as a universal science of coordinated adaptation for all complex human-machine-social ecosystems.

3 The impact of emerging agentic societies

The rise of agentic societies represents a structural transformation of the environment in which command and control operates. In traditional C2 theory, the operating environment is divided into human commanders, information systems, weapon platforms, and organizational procedures. AI mainly appears as a supporting tool for sensing, communication, or decision assistance. In the agentic age, this separation is rapidly dissolving. Foundation models, autonomous platforms, digital twins, intelligent sensors, social media systems, and multi-agent infrastructures are no longer passive instruments waiting for human instruction. They can perceive, generate hypotheses, recommend actions, negotiate tasks, trigger workflows, and reshape the information ecology in which human decisions are made. As a result, C2 is moving from the coordination of human-led organizations toward the governance of hybrid human-machine-social ecosystems.

An agentic society can be understood as a cyber-physical-social formation composed of human actors, artificial agents, organizations, platforms, machines, data streams, and institutional rules^[23-24]. Its defining feature is not simply the existence of AI agents, but the emergence of distributed agency across multiple interacting layers. A battlefield drone swarm, a logistics platform guided by predictive models, a public-health warning network, a financial risk-control system, and a social media governance mechanism may all contain agentic components that sense, decide, and act within partially autonomous loops. Once such components are connected, they generate new forms of collective behavior that cannot be fully explained by the intention of any single commander, designer, or operator. This is the fundamental impact of agentic societies on C2: the object of command is no longer a clearly bounded organization, but an evolving ecology of human and artificial agencies.

This shift intensifies the classical DUC predicament. Diversity expands because the participants in C2 systems now include humans, institutions, robots, algorithms, data infrastructures, and social groups with heterogeneous goals and constraints. Uncertainty increases because artificial agents may generate plans, classifications, recommendations, and interactions whose consequences unfold faster than human organizations can evaluate. Complexity deepens because cyber processes, physical actions, and social cognition are tightly coupled: a model output may influence a commander, a platform decision may redirect physical assets, and an online narrative may change the legitimacy of an operation. In such conditions, the traditional assumption that better information automatically produces better command becomes insufficient. More data and faster communication may even amplify confusion if they are not embedded in a coordinated experimental and governance framework.

The first major impact of agentic societies is the compression of decision time. Autonomous systems can shorten the interval between observation and action, enabling rapid response in mili-

tary, emergency, industrial, and public governance scenarios. However, speed alone does not guarantee effective C2. When multiple agents operate concurrently, local optimization may produce global instability. A fast drone swarm may overwhelm enemy defenses, but similar mechanisms may also trigger accidental escalation, misidentification, or cascading failure. A public emergency platform may allocate resources efficiently, but biased models or incomplete social data may deepen inequality or distrust. Therefore, the agentic age shifts the central problem from accelerating decision loops to governing coupled decision loops. Future C2 must ask not only how to act faster, but also how to make fast actions interpretable, accountable, reversible, and aligned with long-term system stability.

The second impact is the transformation of authority and responsibility. Classical C2 presumes a relatively clear chain of command, even when decisions are distributed. Agentic societies blur this chain. Human commanders may rely on AI-generated assessments; agents may coordinate with other agents; digital twins may provide simulated futures that shape strategic judgment; social platforms may influence public perception before formal decisions are made. In this hybrid setting, responsibility cannot be reduced to a single human button-pusher or a single technical artifact. It must be distributed across design, deployment, supervision, feedback, and institutional correction. This requires C2 theory to move beyond the binary debate between human primacy and machine autonomy. The key issue is not whether humans or machines dominate, but how their co-evolution can be organized under explicit rules of purpose, evidence, verification, certification, and accountability.

The third impact is the expansion of C2 from military operations to general societal governance. Agentic societies already exist in domains such as smart cities, energy systems, transportation networks, public health, financial regulation, education platforms, and cyberspace. These domains face the same essential C2 question: how to coordinate distributed actors under DUC while maintaining safety, trust, resilience, and collective purpose. The difference is that the consequences may not appear as immediate battlefield victory or defeat, but as delayed ecological stress, public distrust, infrastructure fragility, information disorder, or institutional failure. Thus, the agentic society forces C2 to rediscover its universal nature. C2 should not be confined to warfighting; it should become a general methodology for coordinated adaptation across military and civilian systems.

For this reason, emerging agentic societies make parallel C2 not optional but necessary. Real-world agentic systems are too complex, too fast, and too socially embedded to be governed only through post-hoc correction. They require artificial societies to represent possible structures of interaction, computational experiments to test alternative interventions, and parallel execution to connect virtual deduction with real-world feedback. Through ACP and CPSS, decision-makers can observe not only what is happening, but also what might happen under different policies, missions, narratives, and technological configurations. The aim is to transform uncontrollable DUC into operational FAC: focus under information overload, agility under environmental turbulence, and convergence among heterogeneous human and artificial actors.

Therefore, the impact of agentic societies is both disruptive and constructive. They destabilize inherited C2 assumptions about hierarchy, authority, speed, and control, but they also open the possibility of a broader science of coordination. If C2 remains limited to faster kill chains and narrower operational efficiency, agentic societies may intensify systemic risk. If C2 is recon-

structured through parallel science and technology, they may become the foundation for anticipatory governance, resilient recovery, and sustainable cooperation. The next task is therefore to explain why parallel science and technology provide the methodological basis for this reconstruction.

4 Why parallel science and technology

The preceding sections have shown that emerging agentic societies are transforming C2 from a battlefield-centered discipline into a general problem of coordinated adaptation across CPSS. This transformation raises a deeper methodological question: what kind of science can study, design, verify, and govern such systems? Traditional natural science is powerful in discovering laws of the physical world; social science is indispensable for understanding human intention, cognition, organization, and legitimacy; engineering science provides tools for building machines, infrastructures, and operational platforms. Yet agentic societies do not belong to any single one of these domains. They are simultaneously physical, psychological, informational, artificial, organizational, and normative. Therefore, the C2 of the agentic age requires not only new technologies, but also a new scientific paradigm. This is why parallel science and technology become necessary.

The starting point is the recognition of Karl Popper's World Model of three worlds. The first is the physical world, where material systems, infrastructures, platforms, energy, weapons, sensors, vehicles, and robotic entities operate. The second is the mental or psychological world, where perception, belief, intention, emotion, trust, fear, responsibility, and strategic judgment are formed. The third is the artificial world, where models, simulations, digital twins, foundation models, algorithms, intelligent agents, virtual organizations, and artificial societies are constructed. Classical C2 mainly connected the first two worlds: commanders attempted to understand physical conditions through human cognition and then issued orders to reshape material reality. Information-era C2 added communication networks and data systems, but it still treated the artificial layer mainly as an auxiliary representation of the real world. In the agentic age, however, the artificial world becomes an active participant. Digital agents do not merely display information; they generate plans, test futures, negotiate tasks, learn from feedback, and sometimes trigger action. Thus, C2 must operate across three worlds rather than within a single physical battlefield.

Corresponding to these three worlds are three types of scientists, as shown in Fig. 1. The first type is the biological or natural human scientist, who provides value judgment, ethical responsibility, strategic imagination, and ultimate accountability. The second type is the robotic scientist, which connects scientific reasoning with physical experimentation and operational execution through autonomous laboratories, unmanned platforms, field robots, and embodied systems. The third type is the digital scientist, represented by foundation-model-based agents, knowledge engines, digital researchers, and virtual experts that can read, reason, design experiments, generate hypotheses, and participate in large-scale computational exploration. In this sense, future C2 research cannot rely only on human experts writing doctrines or engineers building platforms. It must become a parallel activity conducted by parallel scientists, consisting of biological, digital, and robotic scientists working together in continuous loops of description, prediction, prescription, and execution, that is:

$$P_{\text{Sci}} = \eta_1 H_{\text{Sci}} + \eta_2 R_{\text{Sci}} + \eta_3 D_{\text{Sci}} \quad (1)$$

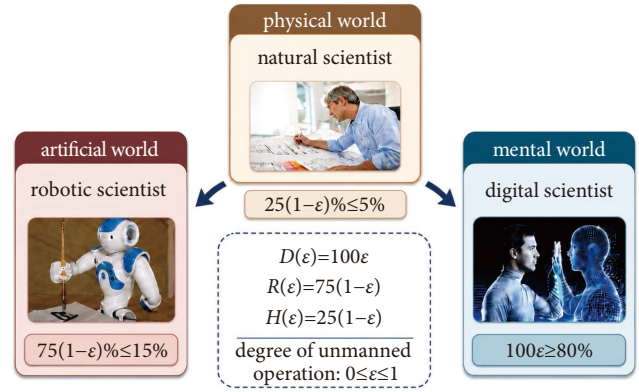


Figure 1 Three worlds and three types of scientists.

where P_{Sci} denotes parallel scientists. H_{Sci} , R_{Sci} , and D_{Sci} represent human scientists, robotic scientists, and digital scientists, respectively. η_1 , η_2 , and η_3 denote their corresponding configuration weights.

Parallel science can therefore be defined as a scientific paradigm that constructs artificial systems parallel to natural and social systems, uses computational experiments to explore possible states and interventions, and couples virtual and real systems through parallel execution. It does not replace natural science, social science, or engineering science. Rather, it reorganizes them under a common framework for complex systems whose causal mechanisms cannot be fully observed, isolated, or experimentally manipulated in the real world. For C2, this is crucial. A commander or policymaker cannot repeatedly test escalation control, disaster response, public opinion stabilization, autonomous swarm deployment, or global supply-chain intervention directly in reality. Parallel science makes such counterfactual and prospective experiments possible by building artificial C2 worlds in which different strategies, organizations, technologies, and narratives can be tested before real-world deployment.

Under this paradigm, C2 research should be carried out by three classes of scientists with differentiated responsibilities. Biological human scientists should define the mission, boundary conditions, ethical constraints, strategic objectives, and criteria of acceptable risk. They are responsible for asking whether an action should be taken, not merely whether it can be optimized. Digital scientists should construct models of operational environments, generate scenarios, search policy spaces, evaluate alternative courses of action, and discover hidden correlations across physical, informational, and social layers. They are responsible for expanding the scale, speed, and diversity of reasoning. Robotic scientists should connect the cyber and artificial layers to the physical world through sensing, testing, field operation, and embodied feedback. They are responsible for validating whether a virtual prescription can survive material constraints, environmental disturbance, and operational friction. Together, these three types of scientists form the research subject of parallel C2.

This triadic structure changes the meaning of C2 research. In conventional C2 studies, a small group of human researchers or commanders often analyzes organizational charts, communication chains, decision cycles, and weapon-platform coordination. In parallel C2, the research system itself becomes an intelligent organization. Digital scientists continuously construct artificial battlefields, artificial cities, artificial institutions, artificial social networks, and artificial crises. Robotic scientists test the feasibility of sensing, maneuvering, logistics, and intervention in physical or semi-physical environments. Human scientists supervise goals,

interpret consequences, correct biases, and make value-laden judgments. C2 research is no longer an external observation of command systems; it becomes an internally organized parallel operation of human, digital, and robotic agencies.

The practical question is how to organize these three types of scientists. A feasible answer is provided by intelligent parallel organizations (IPOs). An IPO is not a traditional hierarchical research institute, nor a purely decentralized crowd of agents. It is a hybrid organizational architecture that integrates artificial resources and talents, cyber movement organizations (CMO), action and capability transformation, no people organizations (NPO), one person organizations (OPO), and many people organizations (MPO). In such an architecture as shown in Fig. 2, artificial society (ART) provides artificial scientists, models, data, tools, and knowledge assets; actual society (ACT) turns validated plans into deployable capabilities; and the core organizational forms are coordinated through CMO, NPO, OPO, and MPO.

More specifically, the CMO coordinates cyber-space mobilization, task routing, model orchestration, and distributed knowledge flows. NPO represents highly automated digital systems and autonomous workflows that can operate without direct human participation. OPO indicates human-centered micro-organizations in which a single biological scientist, commander, or decision-maker is augmented by many digital and robotic agents. MPO represents conventional or hybrid teams composed of multiple human stakeholders, institutions, expert communities, and operational units. The essence of IPO is to combine these organizational forms according to the mission, risk level, and maturity of the task. This relation can be expressed as:

$$O_{\text{IPO}} = \varepsilon_0 O_{\text{CMO}} + \varepsilon_1 O_{\text{NPO}} + \varepsilon_2 O_{\text{OPO}} + \varepsilon_3 O_{\text{MPO}} \quad (2)$$

where ε_0 , ε_1 , ε_2 , and ε_3 denote mission-dependent weights. They describe how much a specific C2 research task depends on cyber movement coordination, autonomous no-people operation, one-person augmented command, and many-people institutional collaboration. In normalized implementations, these weights may be constrained by $\sum_{i=0}^3 \varepsilon_i = 1$, but conceptually they should remain adaptive, because different C2 problems require different organizational mixtures.

For example, autonomous swarm verification may rely heavily on NPO and robotic scientists, while crisis communication and social trust recovery may require stronger MPO participation. A strategic simulation of deterrence, escalation, and non-conflict resolution may be conducted mainly by digital scientists in CMO-supported artificial societies, but its final interpretation must return to OPO- or MPO-based human judgment. Emergency response under disaster conditions may shift dynamically: before the crisis, digital scientists run computational experiments in artificial societies; during the crisis, robotic scientists and NPO workflows execute sensing and logistics; after the crisis, human scientists and MPO institutions evaluate accountability, recovery, and public legitimacy. The IPO formula therefore does not describe a fixed organization. It describes a reconfigurable organizational mechanism for conducting parallel C2 research.

This organizational view also clarifies why parallel science and technology are superior to merely adding AI tools to existing research processes. If AI is only used as a faster assistant, it may improve writing, coding, modeling, or data processing, but it does not fundamentally change the epistemic structure of C2. Parallel science changes the structure itself. It creates artificial worlds for experimentation, digital scientists for scalable reasoning, robotic scientists for embodied validation, and IPOs for coordinated research operations. Through this structure, C2 can move from

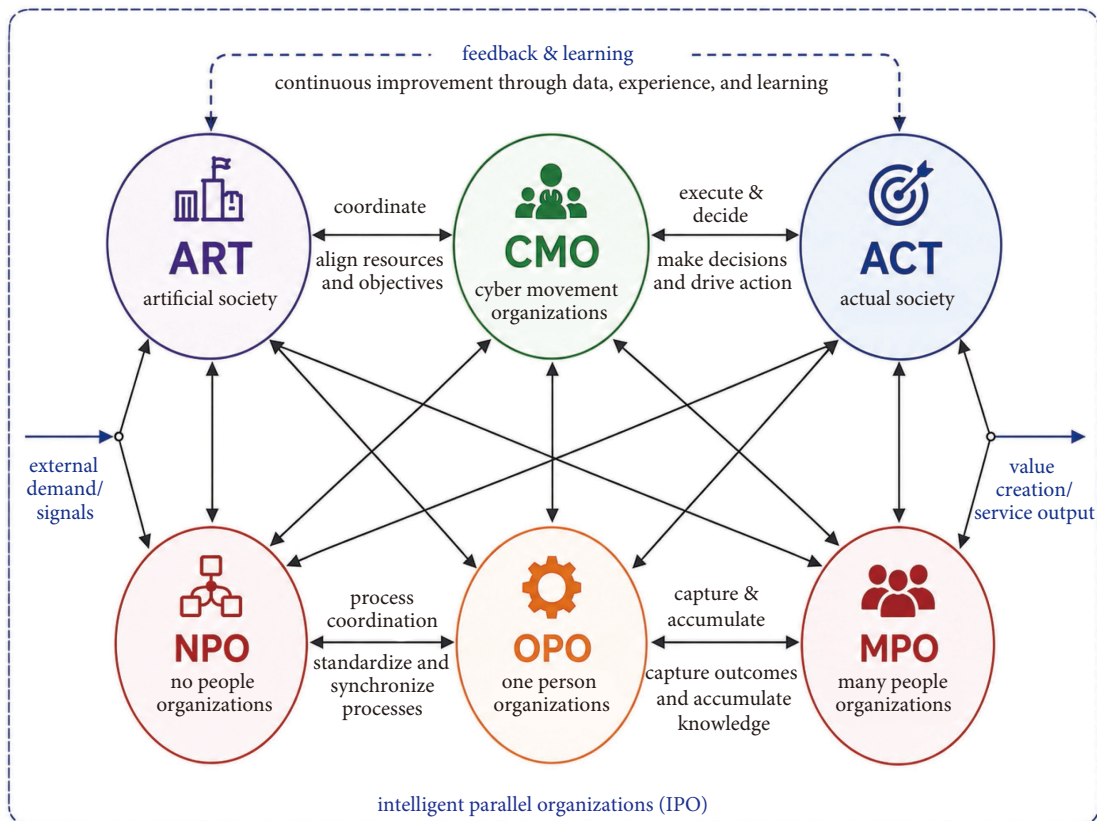


Figure 2 Architecture of closed-loop organizational intelligence.

experience-based doctrine to experiment-based governance, from isolated models to artificial societies, from static command chains to adaptive organizations, and from post-hoc control to anticipatory coordination.

Therefore, parallel science and technology provide the methodological foundation for C2 in the agentic age. They allow C2 to study three worlds, mobilize three types of scientists, and organize them through intelligent parallel organizations. The goal is not simply to make command faster or more automated, but to make command more experimental, interpretable, responsible, and resilient. Only through such a paradigm can C2 transform DUC into FAC under the conditions of agentic societies and support the broader mission of resilient and sustainable governance.

5 New science and new warfare

Parallel science and technology redefine C2 beyond a narrow tactical operational function, establishing a brand-new disciplinary framework for analyzing and governing complex adversary and conflicted systems. Conventional C2 theories were constructed around bounded, hierarchical military organizations with observable operating logic. Their core research questions revolve around information transmission, intelligence collection, force deployment, decision cycle compression, and the maintenance of command authority under uncertain battlefield conditions. While these research themes remain valuable, they cannot fully adapt to the operating logic of agentic societies. In the agentic age, physical combat operations, cyberspace interactions, social cognitive dynamics, autonomous unmanned platforms, intelligent agents, and institutional public narratives are deeply coupled and mutually restrictive. The governance object of C2 is no longer limited to troop formations, weapon platforms or vertical command chains, but a dynamically evolving CPSS hybrid ecosystem. Within such an ecosystem, pure speed of perception and communication or centralized top-down control cannot eliminate inherent uncertainty. Instead, researchers must rely on artificial modeling, repeatable computational experiments and closed-loop parallel execution to continuously dissect, test, and transform the DUC predicament.

Against this backdrop, parallel science lays a brand-new epistemological foundation for modern C2, shifting command research from experience-driven military dogma to experiment-oriented coordinated governance. Classical military research can only summarize the laws of conflict after wars break out: conflict escalation, deterrence failure, systemic resource collapse, mass public panic, disinformation diffusion and unintended humanitarian losses are often recognized only after irreversible damage occurs. Parallel science fundamentally reverses this passive research paradigm by constructing complete artificial C2 spaces in advance, covering simulated battlefields, artificial social groups, virtual commanders, simulated organizational structures, public opinion evolution models and adversarial agent systems. Through large-scale iterative computational experiments, decision-makers can pre-simulate the evolutionary trends of complex systems under different strategic paths, public narratives, technical architectures and intervention schemes. Combined with real-time feedback loops via parallel execution, virtual deduction results are continuously calibrated against real-world operations, enabling C2 systems to conduct full-cycle learning before, during and after actual operations. In this sense, ACP/CPSS and parallel intelligence are far more than auxiliary technical tools; they constitute a complete scientific paradigm that converts DUC into FAC within complex adversary and conflicted systems.

This emerging paradigm also reshapes the logical boundary between AI for science (AI4S) and military research. Traditional AI4S refers to deploying artificial intelligence to accelerate discoveries in materials, biology, climate and other basic disciplines. Extending this logic to the battlefield, the parallel framework proposed in this article forms AI for military science (AI4MS). Driven by AI4MS, intelligent models, digital scientists, robotic experimental platforms and artificial societies jointly reveal hidden mechanisms of conflict escalation, strategic deterrence, social mobilization, logistics support, situational perception, social trust reconstruction and post-crisis recovery. This AI4MS approach ultimately fosters a new science of C2, which further gives rise to a brand-new warfare ecosystem—this fundamental evolution explains why a renovated C2 theoretical system is urgently required in the agentic age. Freed from over-reliance on historical summaries, doctrinal reasoning and physical field drills, military science evolves into an AI-native discipline supported by parallel systems. Parallel platforms generate massive scenario samples, computational experiments compare the effectiveness of alternative intervention strategies, and multi-agent intelligent bodies assist scholars in extracting universal operational laws, as shown in Fig. 3.

From this evolutionary perspective, AI4MS empowers the modernization of military science, military science evolves into parallel military theory, and parallel military theory further gives birth to the theoretical system of parallel warfare. Parallel military research does not seek to replace human commanders with algorithms or reduce warfare to pure automated machine confrontation. Instead, it builds a complete virtual-real integrated military ecosystem, where human commanders, digital intelligent agents, autonomous robotic platforms, artificial battlefields and real operational environments operate collaboratively as a whole. Its core scientific carrier is parallel C2, which supports the descriptive recording of real adversary and conflicted systems, predictive deduction of potential evolutionary paths, and prescriptive design of intervention schemes before destructive physical confrontation erupts. Accordingly, future military science cannot be simply understood as traditional defense research superimposed with AI tools; it must be reconstructed as an AI-native theoretical system built on ACP, CPSS, parallel intelligence and computational adversarial experiments.

This would enable the warfare evolution from War 1.0 to War 5.0, as shown in Fig. 4, which can be interpreted from the dual dimensions of underlying technical infrastructure and core confrontation mechanisms. Each generation of warfare represents a progressive shift in the scope and carrier of confrontation. War 1.0 centers on physical force confrontation; War 2.0 and War 3.0 focus on signal and information confrontation, respectively; War 4.0 features networked systemic confrontation. War 5.0 stands for parallelization and intelligent confrontation. Its core carrier is the intelligent parallel machine: a complete CPSS system capable of generating massive artificial scenarios, carrying out large-scale computational experiments, comparing multi-dimensional future paths, and coupling virtual decision-making schemes with real-world execution feedback.

It is critical to distinguish parallel warfare from simple AI warfare. AI warfare generally focuses on leveraging artificial intelligence to upgrade weapons, enhance perception accuracy, optimize target strike efficiency and accelerate command response speed. Parallel warfare represents a more fundamental disciplinary revolution: it reconstructs the full logic of confrontation expression, experimental verification, risk transfer and systematic governance through artificial spaces, artificial societies, computa-

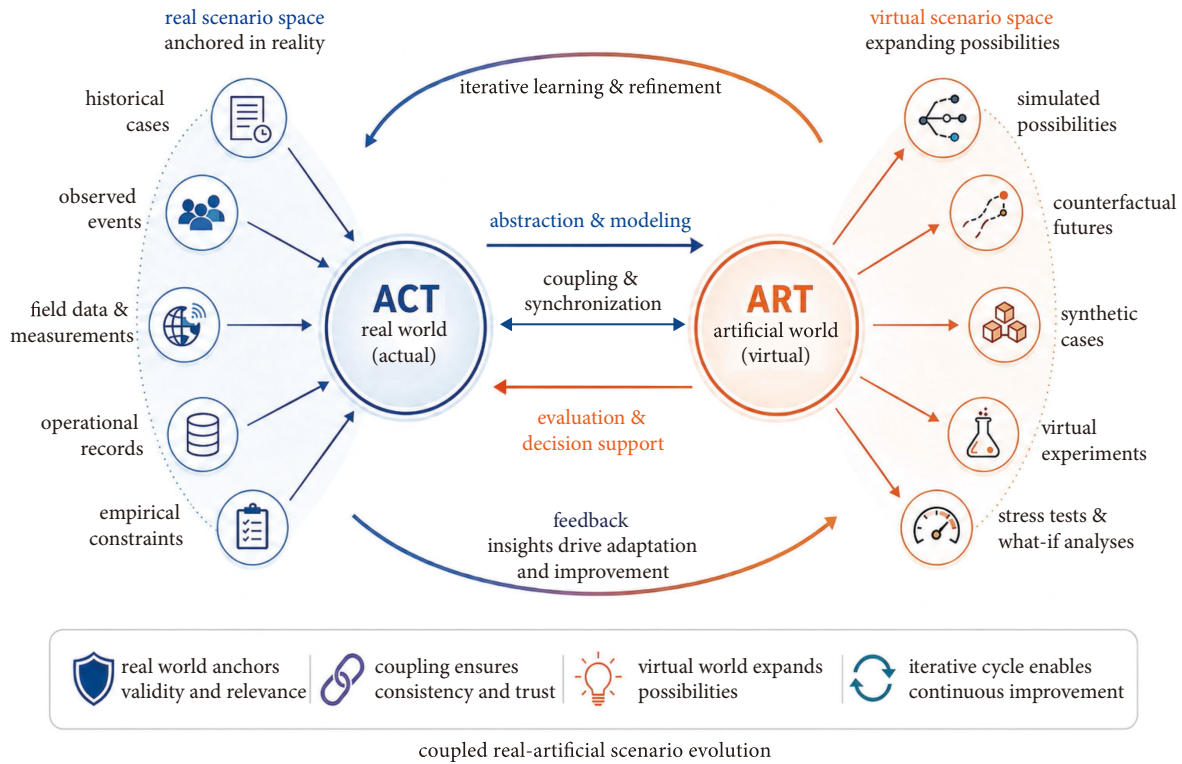


Figure 3 Parallel platform for AI4MS.

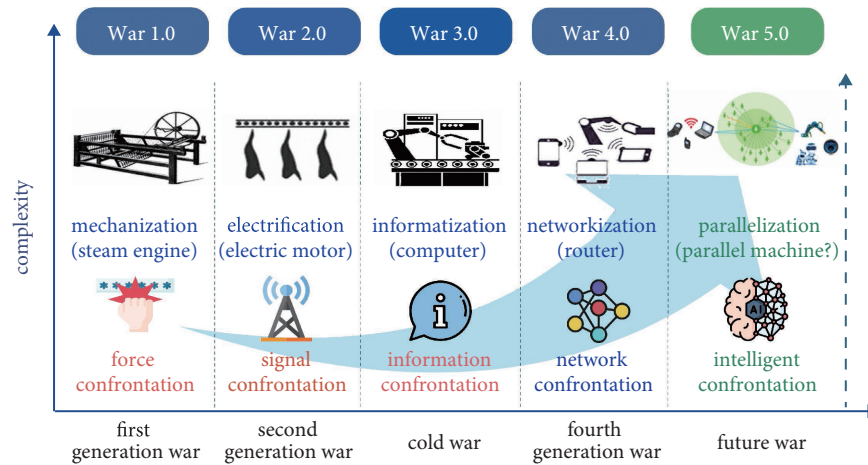


Figure 4 The evolution from War 1.0 to War 5.0: from force confrontation to intelligent confrontation.

tional experiments and parallel closed-loop execution. The core decisive capability of War 5.0 is not merely faster intelligence processing or more autonomous combat equipment, but the ability to construct and operate cross-domain virtual-real confrontation systems that unify the physical, mental and artificial three worlds.

This evolutionary logic can be further clarified by embedding the five warfare generations into Popper's three-world theoretical framework, as shown in Fig. 5. War 1.0 is mainly rooted in World 1—the physical world, corresponding to agricultural civilization and material power asymmetry. At this stage, victory is determined by the possession of manpower, weapons, land, fortifications and material resources. War 2.0 and War 3.0 gradually shift the core of competition to World 2—the mental and cognitive world, matching industrial civilization and information asymmetry. Signal transmission, organizational mobilization, cognitive judgment and information processing become decisive competi-

tive factors. War 4.0 deepens this transformation via network confrontation, connecting physical combat platforms and human

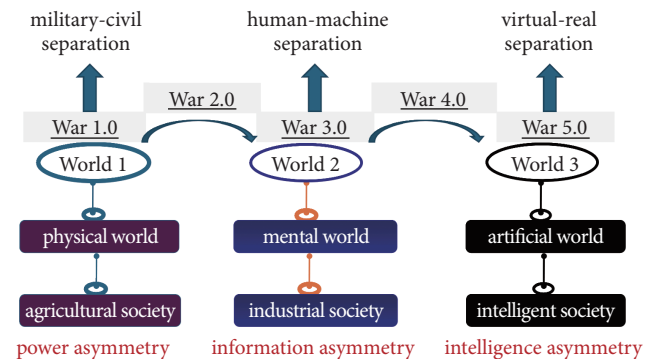


Figure 5 From military-civil separation to virtual-real separation.

cognitive decision-making through distributed information infrastructure. War 5.0 fully unlocks World 3—the artificial world, corresponding to agentic intelligent civilization and intelligence asymmetry. Its core competitive advantage lies in the capacity to construct and coordinate cross-three-world parallel systems.

The core philosophical foundation of parallel warfare is the logic of separation, which embodies progressive civilizational upgrading by gradually restricting the carriers of confrontation and reducing unnecessary casualties and social losses.

First, military–civil separation. This represents the basic ethical bottom line of modern warfare. Conflicts should only target military personnel, while civilians must be protected. Deliberate injury to civilians violates international norms and will lead to accountability before international tribunals after conflicts end. This separation draws a clear legal and ethical boundary between combatants and non-combatants.

Second, human–machine separation, an advanced constraint beyond military–civil division. Under this rule, confrontations are confined exclusively to automated equipment and intelligent platforms, while all human personnel, including military operators, are kept away from direct lethal engagement to avoid human casualties entirely.

Third, reality–artificial separation, the highest stage of civilizational evolution for conflict governance. All confrontational behaviors are transferred to virtual artificial spaces instead of unfolding in real physical domains, which fundamentally avoids damage to physical assets, social operations and ecological environments.

Artificial adversarial experiments supported by the ACP framework constitute the core operational mechanism for those three separations in parallel warfare. The goal is to replace physical confrontation with computational confrontation to the maximum extent, and reduce the loss caused by unavoidable real-world operations through parallel closed-loop iteration. Any conflict path that can be fully deduced in artificial spaces should avoid direct physical escalation; any strategic scheme that fails repeatedly in computational experiments should not be casually put into real-world practice; any policy that brings short-term military advantages but long-term social distrust, ecological damage or humanitarian crisis must be eliminated in advance during simulation. Parallel warfare thus shifts the core mission of C2 from pursuing victory in post-hoc physical combat to preempting, redirecting and regulating adversary and conflicted systems.

This philosophical orientation also explains why parallel warfare advances a new safety standard known as 300% safety. The first layer is physical safety: minimizing combat casualties, infrastructure ruin, operational accidents and material depletion. The second layer is cyber and operational safety: safeguarding data assets, decision pipelines, logistics networks, command legitimacy and organizational continuity. The third layer is ecological and societal safety: mitigating lasting public distrust, social trauma, environmental degradation, economic breakdown and institutional collapse. These three layers correspond to the physical, cyber-operational and ecological-social dimensions of next-generation C2.

From this perspective, War 5.0 is not a celebration of intelligent weaponry, but a systematic scientific paradigm that renders adversary and conflicted systems controllable, reversible and governable. Parallel warfare integrates military science, social science, artificial intelligence, digital scientists, robotic scientists and human commanders to assess operational consequences before irreversible physical actions take place. Its fundamental mission is not to simplify combat operations, but to create feasible paths for

peacebuilding, post-crisis recovery, systemic resilience and long-term sustainable coordination. Therefore, the renewed scientific logic of C2 must transcend the binary logic of victory and defeat, and embrace a broader humanistic objective: to protect human lives, preserve civilizational continuity, mitigate systemic risks, and sustain long-term human coexistence under intelligent adversarial conditions. This naturally leads to the subsequent discussion on the new mission for humanity in the agentic age.

6 New mission for the future humanity

If parallel warfare built upon agentic societies redefines the logic of confrontation, the core question shifts away from merely pursuing victory in armed conflicts, and turns toward preventing human civilization from being trapped in a cycle dominated by warfare-centric thinking. The renewed mission of C2 is no longer limited to battlefield supremacy, national defense, and military strategic advantage. Its ultimate goal lies in constructing a resilient, self-sustaining integrated ecosystem where military, industrial, social, and ecological sectors coordinate and reinforce one another amid persistent DUC constraints.

This transformation draws a crucial lesson from the collapse of the Soviet Union: excessive expansion of military industries crowded out civilian production, diverted massive labor, energy, and fiscal resources toward defense, and triggered severe structural economic imbalance. This historical warning compels us to rethink the composition and resource of armed forces within agentic societies. We therefore break down this new mission into three interrelated dimensions.

First, military forces will evolve into hybrid parallel troop formations consisting of human, robotic, and digital soldiers, as defined by

$$P_{\text{Sol}} = n_1 H_{\text{Sol}} + n_2 R_{\text{Sol}} + n_3 D_{\text{Sol}} \quad (3)$$

Robotic troops can be deployed on a large scale with low marginal costs, while digital soldiers have no numerical upper limit; energy consumption constitutes their only long-term operating expense. With mature green and renewable energy technologies eliminating energy bottlenecks, military forces theoretically gain access to nearly unlimited operational resources. This subverts the traditional model where armed forces rely heavily on civilian society for food, equipment, logistics, and huge fiscal appropriations. Future military systems will build closed-loop self-production and self-operation capabilities, capable of autonomously generating supplies, manufacturing hardware, and running full-cycle logistics, thus realizing independent sustainable operation without over-reliance on external civilian input.

Second, the functional boundary of armed forces needs to be significantly expanded, far beyond the narrow scope of traditional combat tasks. The classic military concept MOOTW, namely Military Operations Other Than War, only summarizes scattered auxiliary tasks as a supplementary add-on to warfare, carrying an inherent passive and combat-centered bias. From the perspective of parallel science and agentic societal governance, we need to elevate this set of non-combat missions to a higher theoretical level, forming a systematic and forward-looking governance framework independent of combat operations. This upgraded framework incorporates large-scale humanitarian assistance, cross-regional disaster relief, long-term public security stabilization, and multi-scenario emergency support, positioning military forces as core public guarantors of social resilience rather than mere combat tools. Unlike the fragmented positioning of MOOTW, the new framework regards these cross-domain public service

responsibilities as intrinsic core missions for future human-machine integrated armed forces, serving the long-term sustainable development of all society.

Third, the C2M paradigm integrating command, control, and management provides a balanced path for innovative military-civilian integration. Parallel C2M bridges military operational logic and civilian economic governance, enabling two-way resource circulation, technology sharing, and coordinated risk response across defense and civilian sectors. This mechanism avoids the distorted resource allocation seen in the U.S. military-industrial complex, where oversized defense industries monopolize production factors and impose lasting fiscal burdens on civilian livelihoods. Guided by ACP computational experiment verification, military and civilian systems maintain clear ethical and institutional boundaries while sharing infrastructure, technology, and talent, achieving balanced symbiosis instead of one-sided resource predation.

Once self-sustaining military circulation, upgraded cross-domain public service missions, and balanced C2 military-civilian integration are fully realized, a brand-new human social development ecology will emerge. Auguste Comte, the founder of sociology, proposed a three-stage civilizational evolution trajectory: the military stage centered on violent domination, the legal stage built on normative governance, and the industrial stage driven by material production. Under agentic parallel intelligence, this evolutionary path undergoes profound restructuring. Civilization will transition from the original military-dominated phase to an intelligent society governed by multi-agent autonomous contracts and parallel experimental supervision, and further evolve into an intelligent-industrial society oriented toward sustainability and resilience. Within this new developmental sequence, military power abandons its identity as a tool for zero-sum confrontation and becomes a fundamental stabilizing force supporting coordinated global sustainable development.

Parallel decision intelligence underpins all three dimensions of this transformation. Derived from the theoretical lineage of ISDOS, metasynthetic engineering, CPSS, and parallel decision theaters, modern Decision 5.0 leverages large language models, autonomous agents, and virtual-real parallel architectures to build interactive decision platforms. Inside parallel decision theaters, human specialists, digital scientists, and robotic agents jointly generate multi-dimensional scenarios and compare alternative intervention paths to deliver accountable decision support before crises break out^[12,25].

Traditional isolated command posts and static dashboards cannot meet the demands of CPSS-embedded future C2. Pre-crisis, parallel theaters simulate cascading systemic risks, evaluate food-energy supply resilience, and train hybrid human-agent coordination teams. During emergencies, they support integrated situational awareness and cross-domain resource scheduling. Post-crisis, they enable institutional accountability review and iterative systemic optimization, forming a full-cycle governance mechanism covering preparation, response, recovery, and institutional reconstruction.

Future crises rarely remain confined to a single domain. Regional armed conflicts may simultaneously trigger energy shortages, food insecurity, cyber breakdowns, and mass refugee flows; climate catastrophes can paralyze military installations, ports, and medical systems all at once; public health emergencies easily escalate into cross-regional logistics and trust crises. Accordingly, C2 evolves into an extended C⁺⁺ISR framework that integrates traditional command, control, communication, computing, intelligence, surveillance, and reconnaissance, together

with cross-domain coordination, social cognition, collective consciousness, and full-cycle accountability. Its governance scope expands from single combat theaters to the interconnected life-support ecosystem^[26].

Intelligent parallel industries form the material foundation of this new social ecology, including parallel agricultural systems, autonomous manufacturing modules, distributed energy micro-grids, and digital supply chains. Self-sustaining military organizations integrate these industrial assets to reduce reliance on fragile external supply networks and deliver critical public services when civilian systems collapse. This redefined military-civilian integration realizes simultaneous separation and coordination: military and civilian domains retain independent accountability frameworks, while platforms support joint resilience testing and mutual resource support.

The multi-layered 300% safety standard introduced in the previous section serves as actionable operational guidance under this new mission. Physical safety safeguards human lives, infrastructure, food, water, and energy reserves; cyber-operational safety protects data assets, decision pipelines, and logistics continuity; ecological and societal safety preserves social trust, biodiversity, climate stability, and long-term civilizational welfare. A future C2 system that achieves battlefield victory yet sacrifices these three tiers of safety cannot be deemed successful. Well-designed parallel C2 transforms military institutions into permanent cross-domain guardians of civilizational resilience.

The ultimate shared mission of humanity is to build intelligent, resilient, humane, and sustainable integrated systems. This goal cannot be achieved by technology, military power, or social governance in isolation; it requires a unified synthesis of parallel science, intelligent industry, adaptive military institutions, humanitarian service mechanisms, and ecological value constraints, with human rational judgment as the ultimate ethical anchor.

From this perspective, the new civilizational trajectory guided by parallel intelligence neither naively seeks to eliminate all conflicts nor replaces human accountability with algorithms, nor completely isolates military systems from civilian society. Instead, it leverages parallel decision theaters, self-sustaining military formations, and intelligent parallel industries to transform command and control from a tool of violent force deployment into a foundational guarantee of long-term human resilience, social stability, and shared sustainable development.

7 Concluding remarks

This article puts forward a brand-new systematic understanding of C2 science and technology built upon parallel frameworks for the agentic age. We argue that AI, integrated with ACP, CPSS and parallel execution mechanisms, will reshape the fundamental forms of military operations and usher in a new paradigm of warfare. Nevertheless, we must guard against blind utopian thinking surrounding intelligent military systems, as over-idealized grand narratives may bring unforeseen harm to human society. Continuous critical reflection is therefore indispensable: our theories, conceptual frameworks and practical paradigms should be iteratively revised and adjusted in response to real-world developments, systemic risks and emerging social demands.

We firmly believe that AI can deliver lasting good for humanity. Yet we cannot afford unregulated development that allows small groups to wield such powerful technologies to arbitrarily infringe upon the rights and interests of the broader public, which would trigger devastating shocks to social order and civilizational stability. Against such risks, we must adhere to rigorous, down-to-

earth research on the future of military affairs empowered by new AI technologies, grounded in the logic of coordinated adaptation, sustainability and cross-domain resilience inherent to parallel C2 systems.

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Data availability

All data needed to support the conclusions in the paper are presented in the manuscript. Additional data related to this paper may be requested from the corresponding author upon request.

Declaration of competing interest

The author reports no conflict of interest in this work.

Author contribution statement

The author confirms sole responsibility for the conception of the study and manuscript preparation.

Use of AI statement

None.

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