Intelligent Decision Support and Meaningful Human Control in Multi-Domain Operations

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ABSTRACT

Future military operations take place across multiple domains (land, sea, air, cyber, space) and include multiple layers in time and distance. Planning involves making sense of information across different domains and developing creative solutions that produce converging effects in various dimensions (e.g. physical, cognitive, virtual). Multi-domain operations (MDO) require large and heterogeneous streams of data to be monitored, appreciated, and managed to effectively plan an operation. Due to this, decision makers are at risk of being overloaded with information. Many emphasize the use of artificial intelligence (AI) to support the planning of MDOs. AI-based systems may offer a wide variety of support to the decision maker, like collecting and analyzing evidence; detecting familiar patterns in the data; suggesting courses of action (COA); comparing different COAs by performing wargaming in the background; and signalling potential cognitive bias. The prevailing view is that AI may be of help, but that its deployment is not without risks. AI may potentially harm a human's control over the decision making process in several ways, e.g., AI presents improper analysis due to lack of relevant training data; human fails to comprehend the AI's analysis and recommendations; and AI induces automation bias and tunnel vision in the human. Careful consideration is therefore necessary when integrating AI-support into the process of MDO-planning. It is essential that the human maintains meaningful human control over decision making, and that AI-assisted decision-making achieves complementary performance. The design guidelines discussed in this paper emphasize critical capabilities of both human and AI, and underline that human and AI should be supported to jointly and iteratively refine their understanding of the situation and of each other.

1.0 INTRODUCTION

Modern and future conflicts demand operations that take place across multiple domains (land, sea, air, cyber, space) and requires the collaboration of multiple military and civil organizations. The planning of such multi-domain operations (MDO) demands insight and oversight of all domains and dimensions (virtual, cognitive and physical), managing large quantities of information, being adaptive of the rapidly changing circumstances, taking advantage of opportunities, while being alert for circumstantial risks and adversarial threats at the same time. Due to this complexity, the planning of MDOs often exceed the cognitive abilities of individuals and teams. Many therefore argue to utilize artificial intelligence (AI) to develop Intelligent Decision Support for the planning of complex operations. AI may indeed offer a wide variety of support to planners, but its deployment may also potentially harm a human's control over the decision making process in several ways. This paper discusses the nature of MDO and identifies the MDO challenges during planning. It addresses different types of AI-support, and reviews the risks that they impose in terms of meaningful human control. The final section of the paper addresses how these risks may be mitigated by appropriate design of human-AI collaboration, and identifies some important topics for future research.

2.0 MULTI-DOMAIN OPERATIONS

In the past, military conflicts were oftentimes settled by conducting operations in one or few domains (e.g., an army entering a disputed area, covered by air support if needed). However, political, social and technological developments have changed the needs for military operations. Situations in modern and future conflicts will be rapidly evolving, become more complex and uncertain, include more parties, involve more information, and require shorter decision times (Ellison & Sweijs, 2023). The traditional military operations approach is no longer sufficient to meet these complex challenges. In response to these developments, NATO developed a new doctrine to military command called Multi-Domain Operations (MDO) (Giordano, 2023). MDO involves the orchestration and synchronization of military and non-military activities in different domains to create converging effects (Schwartz et al., 2020). MDO aims to combine and coordinate effects from military and sometimes non-military actors. It emphasizes the need to act synergistically across military services and to coordinate activities with civilian organizations.

Some MDO activities may be aimed at achieving effects in the physical dimension (for example: disabling a bridge or airfield; capturing an area); other activities may be aimed at inducing effects in the cognitive dimension (for example: deterring the adversary; influencing enemy's judgment), and other activities may be aimed at effects in the virtual dimension (for example: inactivating digital security; penetrating enemy databases). By carefully aligning ('orchestrating') and executing ('synchronizing') military and non-military activities, greater mission impact can be achieved than these activities would induce separately. In a MDO context this is called 'convergence (of effects)'.

NATO identifies key principles for MDOs to be successful: unity, interconnectivity, creativity and agility (Grijpstra et al., 2023), see Figure 1. *Unity* among MDO-participants is required for successful orchestration of activities (military and non-military) to achieve a common and shared objective. *Interconnectivity* involves a shared understanding among partners about the current situation, the objective of the operation, and the course to achieve it. *Creativity* is key for being able to develop new and, for the enemy, unexpected solutions. *Agility* is needed to respond constructively to setbacks, and also for being able to take advantage of unexpected and fleeting opportunities. Finally, the *data centric* nature of MDO implies that near real-time data and information can be accessed, enabling NATO to take advantage of opportunities quickly, and have credible and actionable information.

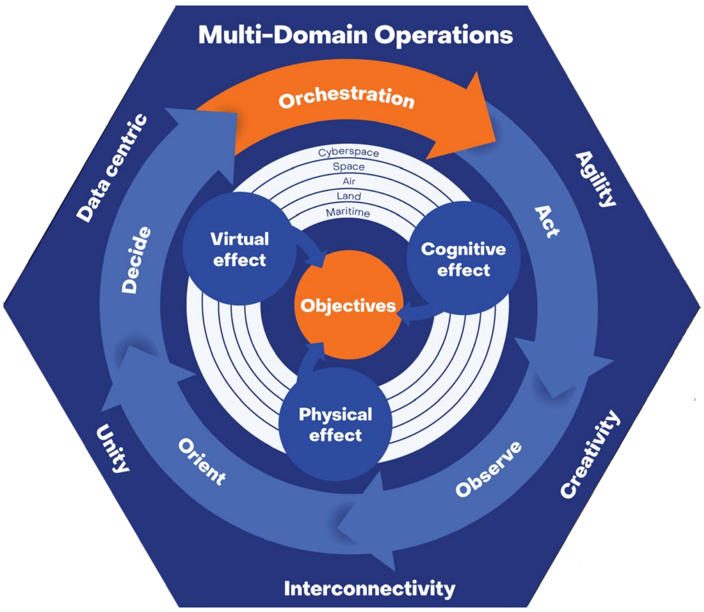

Figure 1: Multi domain operations.

3.0 DEMANDS SET BY MULTI-DOMAIN OPERATIONS

Based on the MDO principles as described above, it is clear that developing an approach for future warfare that embraces the complexity of operational environments and novel technologies requires a new mindset and operating concepts at all levels of involved organizations (Geiß & Lahmann, 2024). Recently, Koning-Eikenhout et al. (2024) developed a matrix-based framework to list the mindset and skills required for MDO (see Table 1). On one axis it distinguishes between three main categories of skills considered essential for MDO: *decision making*; *collaborating*, and *information-processing*. The other axis distinguishes between four ways in which these skills should be applied in an MDO-context.

Table 1: Framework of mindset and skills for MDO (Koning-Eikenhout et al., 2024). This excerpt shows an example for each cell.

	Willingness	Knowledge	Skill	Behavior
Information processing	Being open to utilize technological aids	Knowing the information needs of partners	Adequately interpreting information	Smart deployment of information technology
Collabo-rating	Trust in own expertise and that of partners	Knowing habits and cultural values of partners	Social skills for effective communication	Creating shared under-standing and goal setting
Decision-making	Acknowledging the complexity of orchestrated operation	Knowing opportunities and limitations of partners	Searching for capabilities of partners to develop creative solutions	Adapting and revising decisions if circumstances require to do so

Willingness pertains to the intrinsic desire to behave in accordance with the principles of MDO, also often referred to as the right *mindset*. By *mindset* we mean the insight that in complex situations it is necessary for different domains to act jointly and in unison, and that the goal of the over-all operation must be leading in all constituent activities. Not only the insight that joint action is necessary, but also the willingness to do so. Furthermore, planners of MDO need *knowledge* of their own domain, but also of related domains in the MDO to understand the relevance of events; they need the *skills* to design and orchestrate activities appropriate to the situation and mission objective (planning), and they also need to actually demonstrate this in their *behavior* (execution). Jones and de Leon (2020) illustrate what the transformation from traditional military operations to MDO means for military commanders:

> *"This means that a Major in his early 30s with service background 'x', (let's say an army officer), has to familiarise himself rather quickly with capabilities beyond his or her particular combat background, but also develop a working familiarity with other service capabilities. The more that individual knows, the better. This is the foundation for future General Officers.[..] this combination of knowledge of different service capabilities, and even of external resources, such as civilian agencies, and perhaps, even non-governmental organizations (NGOs), helps a staff conduct the holistic planning and thinking by which to base operational design and execution to updates."*

4.0 WHY PLANNING MULTI-DOMAIN OPERATIONS IS DIFFICULT

Developing multi-domain activities that bring converging effects in different dimensions demand high standards on the abilities of individuals and teams with respect to e.g., team assembly, goal alignment, communication, coordination, and social intelligence. MDOs pose significant challenges developing and maintaining Situational Awareness (SA) due the large volumes of information involved and the need to integrate data from multiple participating partners and domains (Alami et al., 2023; Horyń et al., 2021;

Schwartz et al., 2020). One problem is when the staff responsible for the operational planning of an MDO is not fully familiar with one or more partners and with the activities that they contribute in their domain. Furthermore, it is often uncertain whether domain professionals can be quickly available, if at all (Fazekas, 2021). Another problem is that an activity planned to be performed by a particular partner is often dependent on information elsewhere in the operation, for example to be obtained from a partner. The staff needs to be aware of this information dependency, make sure to establish and understand the information flow between the respective partners, and to monitor the status in light of the over-all mission. Additionally, information exchange is oftentimes a continuous exchange of information to communicate the current status dynamically and in real-time. To prevent overload, the MDO-staff should therefore be able to regulate the information flow needed to streamline various activities. Moreover, the necessity to include non-military factors into the planning process, such as (social) media, civilian populations, international governmental organizations (IGO), and non-governmental organizations (NGOs) adds complexity to the operations for decision makers on all levels (Horyń et al., 2021). In fact, a planned MDO may become very complex, potentially evoking humans to oversimplify situations (Metcalfe et al., 2021). As a result, many assumptions often go untested, and a small number of Course of Actions (COAs) may be considered. The COA that is finally selected might therefore miss opportunities or overlook risks (Schwartz et al., 2020). Ellison and Sweijs (2023) identify a series of risks associated with MDO in terms of its command (see Table 2).

Table 2: Risks associated with the implementation of MDO (taken from Ellison and Sweijs (2023)).

Risk	Description	Impact
Overloading commanders	Commanders become overwhelmed by the need to coordinate too many tasks not within their normal span of control	Significant; overload risks paralysed command decisions and poor inter-government relations
Over-reliance on connectivity	Armed forces over-rely on assured connectivity when planning for and engaging in combat	Significant; the possibility that adversaries or battlefield friction can disrupt communications is a serious risk
Over-engineered staff-heavy approach	Headquarters are too large to effectively manage and process replaces output	Significant; Western militaries have large, top-heavy staff systems that often enforce process over actual success
Over-promising	That MDO will combine domain actions to have greater impact than service-specific actions	Moderate; there is risk that MDO cannot deliver upon its promises, but this remains to be effectively tested

5.0 UTILIZING ARTIFICIAL INTELLIGENCE FOR MDO

Given the requirements and conditions of MDO and the high demands they impose on the planning staff, it is reasonable to believe that mission analysis and COA development could be greatly enhanced through the application of AI (Alami et al., 2023; Barnes et al., 2017; Fazekas, 2021; Geiß & Lahmann, 2024; J. Johnson, 2022; Schubert et al., 2018; Schwartz et al., 2020). The world's powerful nations have recognized the potential of AI for military purposes and invest accordingly (Kugler, 2021; Lewis & Vavrichek, 2024).

The current state of AI research suggests that advanced AI-driven applications could be introduced in the process of planning MDOs, to facilitate data collection and processing and to mitigate potential human errors in situation assessment and decision making (Baker et al., 2020; McKendrick, 2017; Metcalfe et al., 2021). It is currently explored whether generative AI (i.e., Large Language Models) can be used to support planners of MDO with generating plans intended to confront opponents with a dilemma (Solaki et al., 2024). Intelligent decision support systems can provide support to the human in many manners, for example by *informational support*: e.g., collecting, analyzing, and summarizing data, and detecting familiar patterns in data. Providing *visual support* is also possible*:* e.g., depicting geospatial terrain information, network visualization, and showing cause-and-effect relations through causal diagrams or knowledge graphs. Based on its representation of the problem space, an intelligent decision support system may support the human with *automated reasoning and planning*: AI can run in a matter of minutes extensive simulations to test the validity and feasibility of large numbers of potential COAs, can be used for highlighting potential issues, and can significantly reduce the time it takes to test and analyze courses of action in the real world (Fazekas, 2021).

Building an adequate knowledge representation for the problems in a particular MDO is a crucial step for developing sound AI-based decision support. Although the field reports rapid progress with advanced AI techniques (e.g., Zewe, 2023), it is important to note that artificial intelligence is still not that intelligent as often believed (Endsley, 2023). It still is a challenge to create adequate, appropriate and useful knowledge representation of complex problems, as is the case in MDO.

In sum, the prospect of AI for the armed forces is that it can be used to deliver critical system support when time is limited or when the number of choices is too large for people to be able to analyze all alternatives (Schubert et al., 2018). The challenge is to design team of humans and AI whose decision outcomes surpass what either the human or AI could have achieved alone (Ma et al., 2024).

6.0 RISKS OF ARTIFICIAL INTELLIGENCE FOR MDO

Despite the opportunities that AI offers, questions arise about the risks that AI-technologies may induce (Boulanin, 2024; Cooper et al., 2024; Erskine & Miller, 2024; Horyń et al., 2021). Cooper (2024) identifies the following operational risks that may arise from the design, programming and functioning of AI: *brittleness*, *unreliability*, *unpredictability* and *bias*. Brittleness refers to the limitation of AI that algorithms developed for a specific task environment may show superior performance, but that performance often deteriorates drastically when even slight changes to the environment or task occur. Human users of the AI-support system may not always be aware of this, running the risk of unwarrantedly relying on the algorithm. Another feature of AI-models is that they continuously learn and that for this reason the models rapidly evolve. This can make it hard for people to understand the model's output, and to assess the relevancy and adequacy of results. This lack of certainty over AI systems' capabilities makes it difficult to establish the appropriate type of human control for a system. Building upon Bainbridge's 'ironies of automation' (1983), Endsley (2023) calls this 'ironies of artificial intelligence', the paradox that increased AI-capabilities also increase the challenges faced by human operators. A fourth risk that Cooper brings forward is that the data sets used for training the AI algorithms may be biased. For example, the available data for training may just represent a specific conflict and type of operation that is not applicable to broader applications. An AI-model's outputs then runs the risk of being inaccurate when used in operations not covered by the training data. Therefore, the model's development should be monitored and the data need to be as unbiased as possible. This is important not only from an ethical point of view, but also from a performance point of view (Gadek, 2024). However, as the planning of MDO involves inherently complex situations, there may in many cases be a shortage of data. This may negatively impact the quality of the developed AI-models.

Empirical studies show that people often experience 'automation bias', or the tendency of humans to accept computer-generated outputs without critical reflection upon machine-generated recommendations (e.g., Cummings, 2017). Detrimental consequences of automation bias may include human's moral dissociation of decision making (Erskine & Miller, 2024). Some claim that automation bias may have already caused moral implications in real-world applications of AI-supported decision making (Yuval, 2024).

7.0 THE NEED FOR MEANINGFUL HUMAN CONTROL

As AI learns from new data, it may accordingly adapts its behavior (Baker et al., 2020) causing it to diverge from the behavior initially contemplated by developers and users. When intelligent technology is used to support decision making in complex and critical tasks, it is essential to maintain Meaningful Human Control (MHC) (Boardman & Butcher, 2019; Cavalcante Siebert et al., 2023). This means that the human should have the opportunity and ability to maintain situation awareness when overseeing the performance of the AI-based system(s) and has the possibility to take corrective actions over the AI-based systems in a timely manner (Endsley, 2023). This supports the human to ensure that a system performs in a safe, ethical, and legally compliant manner (Davidovic, 2023).

It is important to note that - no matter how advanced AI-based systems become - there will always be opportunities for humans to exercise control over the system at some stage, e.g., in preparation, issuing commands, or during mission execution (van Diggelen et al., 2024). For example, humans select data for training the AI; audit and maintain the AI-based system; define policies for usage; and exercise control over the system during the operation. So at least on a general level, there will always be interaction between various humans and AI systems, allowing humans in the loop to exert control (Christen et al., 2023). For example, a human designer may exert *prior* control by instructing the AI support system how to interpret a particular event before it actually occurs. A human operator may take r*eal-time* control, e.g., by temporarily decommissioning the support system. Thus, meaningful human control may be executed by multiple actors at different moments, rendering MHC to be an emergent property of an AI-system that emerges from the interactions between multiple humans and technology over a longer period of time (van Diggelen et al., 2024).

What is needed to let human control over AI-based systems be meaningful? Boardman et al. (2019) identify a series of conditions:

- The human has freedom of choice.
  - i.e., other decisions than suggested by the AI-system are possible and available.
- The human has ability to impact the behaviour of the system.
  - i.e., adapting the parameters of the AI-based system, affecting its outcomes.
- The human has time to decide to engage with the AI-based system and alter its behaviour.
  - i.e., sufficient time for interactions with the system to explore its output.
- The human has sufficient situation understanding.
  - i.e., the information, knowledge and skills, and time to understand the decision problem at hand.
- The human has sufficient understanding of the AI-based system.
  - i.e., understanding of the AI-based system state to understand the provenance, quality and accuracy of the information and the rationale of the decisions and recommendations made.
- The human is capable to predict the AI-based system's behaviour and the effects of its decisions on the environment.
  - i.e., the human is able to predict how the system will behave in different circumstances.

Boardman et al. (2019) conclude that the degree and nature of human control is dynamic, highly context dependent and made up of multiple factors which are more or less important depending on the situation and nature of the system and potential benefits and consequences provided by the system.

8.0 DESIGNING FOR MEANINGFUL HUMAN CONTROL

Due to the lack of certainty over AI systems' capabilities, careful consideration is necessary to design teams in which human decision makers effectively collaborate with AI, while maintaining meaningful human control over the AI's conclusions, advice, and actions (Baker et al., 2020). The literature already provides many suggestions for this. Below we will discuss some of these. Some recommendations concern to ensure qualities of the human and AI that are essential for MHC; other recommendations to foster MHC pertain to the design of tasks, team, and collaboration.

8.1 Fostering MHC Through Capabilities and Properties

In human-machine teams that employ AI-based technology, human control is not self-evident as the technology may behave unpredictably and unexpectedly in the eyes of the human. To reduce the risk that decisions are being made outside the control of humans, both the human and AI should be *observable*, *predictable* and *directable* (M. Johnson et al., 2014). Observability implies that the human agent and the AI-based system are informed of their own actions, each other's actions, and the status of their objectives and progress. Predictability refers to behavior that is -to some extent- expected by team members, so that they can understand it, and anticipate to it. During teamwork, there inevitably arise circumstances where partners need clarification of each other's behavior. This may be achieved through explanations. Both the human and AI should have the capabilities to diagnose the state of the other, the cause of the partner's request for clarification, and the ability to generate appropriate explanations. Directability refers to the possibility that humans and machines can reactively and proactively assign – and take over – tasks, from each other.

Trust is a fundamental aspect of collaboration, typically more important in a cooperation that involves uncertainty, risk and vulnerability (Lee & See, 2004), which are typical features of multi-domain operations. Trust development is a continuous process in teamwork, involving trust establishment and adjustment based on team-members' experiences concerning each other's performances and the overall team performance. Both the human and AI should have the capabilities to make the assessments required for trust calibration.

In a well-functioning human-AI team, the team-members need to be able to develop 'self-awareness' of their own state and role, and to construct a 'Theory of Mind' of partners (i.e., knowledge of the other, (Baillie et al., 2024)). With the capabilities to form self-awareness and Theories of Mind, humans and AI-based systems can maintain common ground (Klein et al., 2004). This can be considered a form of meaningful control because common ground supports the human to understand the AI-system, which reduces the risk that the AI-based system proposes or takes inappropriate decisions. Common ground enables an AI-based system to adapt to the strategies of the human decision maker, helping the team to make decisions better and faster (Walsh & Feigh, 2022).

8.2 Fostering MHC through design

One recommendation for the design of **teams of human planners and AI-based support systems** is to establish a proper task division among the human and machine members of the team, and to allow this to change dynamically if the circumstances demand so (Van Der Waa et al., 2020). Adaptive task allocation may be achieved, for instance, through the use of Plays and a Playbook (Handelman et al., 2023; Miller, 2005; Miller & Parasuraman, 2007), which determine on a variable level of abstraction the goals of a team, how they need to be achieved, and who does what. A related approach is to use **Team Design Patterns** (TDPs) (Van Diggelen & Johnson, 2019), which are reusable and proven solutions to common problems, described in an structured format. Human-machine teams may select TDPs to address a certain situation.

Another recommendation is designing the team and task in such a way that humans are provided with the right conditions to make decisions in complex situations. This includes having sufficient time to develop situation awareness (van Diggelen et al., 2024), and being able to reflect upon the decision to be made (Van

Den Bosch & Bronkhorst, 2018). AI itself may be of assistance to the human with reflecting upon suggestions made by the AI-based support system. Recently it has been proposed to introduce a 'reflection machine' in human-AI teams (Banga et al., 2023; Cornelissen et al., 2022; Haselager & Mecacci, 2024). Reflection machines asks human users questions about their decision strategy and prompts them to evaluate their own decisions critically, thus actively supporting the human to be involved throughout the decision process. A related effort has recently been proposed by Ma and colleagues (Ma et al., 2024). They propose 'Human-AI Deliberation', a novel framework to promote human reflection and discussion on conflicting human-AI opinions in decision-making. The framework engages humans and AI in opinion elicitation, deliberative discussion, and decision updates. An explorative study provided indications that Deliberative AI improved decision accuracy and promoted more appropriate human reliance on AI (Ma et al., 2024).

Designing a HMT's task environment in such a fashion that humans and AI-based partners can learn about the task, about themselves, and about the other(s) is important to achieve MHC. The environments of MDOs are typically dynamic in nature: humans and AI-based systems have to be able to continuously adjust their representations in accordance with how events change the world. Human-AI co-learning is needed for collaborating teammates to adapt to each other and to learn together over time (Baker et al., 2020; Holstein et al., 2020; Van Den Bosch et al., 2019; Van Zoelen et al., 2021). There is evidence that design patterns intended to invoke and facilitate human-AI co-learning improves team performance (Schoonderwoerd et al., 2022).

9.0 CONCLUSION

Dependencies between activities in multiple domains and effects in multiple dimensions makes the planning of multi-domain operations very complex. To effectively design an operation, large and heterogeneous data streams must be monitored, appreciated, and managed. AI may offer a wide variety of support to the decision maker (Arnott & Pervan, 2014; Van Den Bosch & Bronkhorst, 2018), but its deployment also impose the risk of harming a human's control over the decision making process (Endsley, 2023). A complicating factor is that although AI-based support is generally viewed as one unified system, in reality it is often a system of collaborating algorithms or agents, whose functioning may or not be monitored and controlled by the human. This reduces the transparency of human control over the system(s). The challenge is therefore to integrate AI-support into the process of MDO-planning in such a manner that the human maintains meaningful human control over decision making. The design guidelines discussed in this paper emphasize the critical capabilities of both human and AI to achieve MHC, and underline that designs supporting the human and AI to jointly and iteratively refine their understanding yield teams that are more likely to perform with meaningful human control.

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