Using Modelling & Simulation in the Iterative Concept Development Process towards Multi-Domain Operations

Selma Damsteeg-van Berkel, Peter Langeslag, and Ab de Vos
The Netherlands Organisation for Applied Scientific Research TNO
THE NETHERLANDS

selma.damsteeg@tno.nl, peter.langeslag@tno.nl, ab.devos@tno.nl

Hans Jense
Ministry of Defence
THE NETHERLANDS

gj.jense@mindef.nl

ABSTRACT

Implementing the Multi-Domain Operations (MDO) mindset in real operations involves a diverse and complex set of challenges across strategic, operational and tactical levels. The iterative process of Concept Development & Experimentation (CD&E) provides structure for this development. This paper describes how Modelling & Simulation (M&S) supports CD&E in addressing these challenges. At the strategic level, MDO is about synchronizing military and non-military effects to create effects against the opponent, and at operational level orchestrating military effects across all domains. At these levels, many different elements have to be considered at the same time, like solving a complex 'puzzle'. It is not doable here to analyse every puzzle piece in detail all at the same time. These higher levels of abstraction benefit from table-top games and aggregate level simulations, rather than tactical simulations (involving separate entities moving through time and space). The effective use of table-top games and aggregate level simulations for MDO concepts require further exploration. At the tactical level, sub-questions that tickle down from the operational level should be answered to make sure that the full concept works in practice. This is like analysing a single puzzle piece. Tactical simulations, such as those conducted in our national battle labs, are particularly suitable for this. Crucially, tactical insights must be reintegrated to the overarching MDO concept to maintain coherence.

1.0 INTRODUCTION

In 2023, NATO introduced the concept of Multi-Domain Operations (MDO). This concept responds to two key developments in the changing threat environment. First, global military powers have adopted increasingly assertive postures, raising the likelihood of confrontation with peer adversaries. Second, the emergence of new operational domains – specifically space and cyber – has expanded the scope and complexity of modern warfare, offering novel capabilities and challenges [1]. NATO defines MDO as follows: "The orchestration of military activities, across all domains [including space and cyber] and environments, synchronized with non-military activities, to enable the Alliance to create converging effects at the speed of relevance" [2].

MDO is expected to drive significant changes, mostly at the strategic and operational level[1], where effects are orchestrated to achieve defined objectives. The complexity of this approach arises from the fact that effects can be generated across physical, virtual (e.g. information), and cognitive (e.g. human perception) dimensions of the battlespace, in all domains (land, air, sea, cyber and space), and can be delivered through

[1] Referring to the levels of operation: strategic, operational, and tactical.

both military and non-military activities (Figure 1). At the tactical level, the primary challenge lies not in orchestrating of these effects, but in accounting for the influence and interdependence of other domains and dimensions in planning and execution.

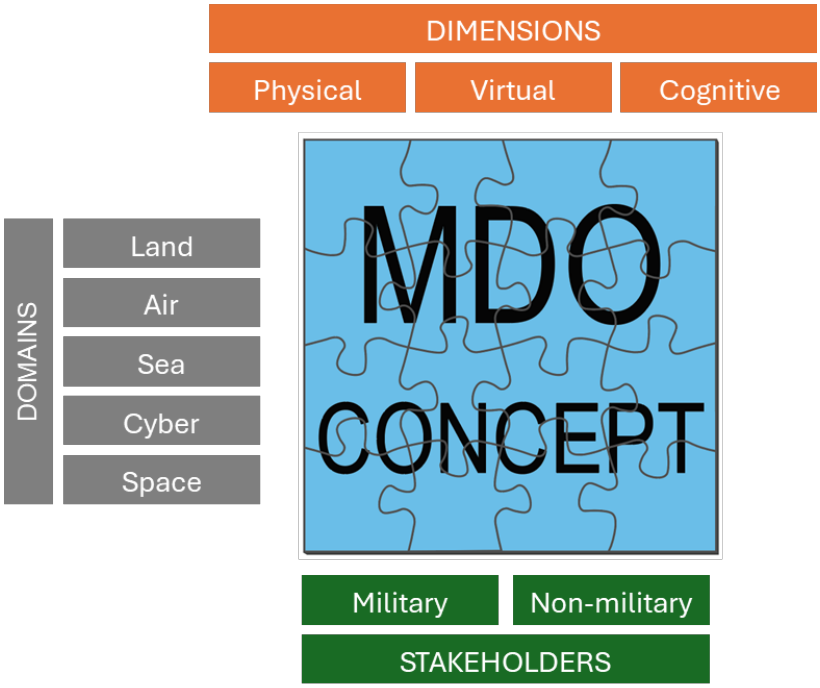

Figure 1: Multi-Domain Operations (MDO) is such a complex 'puzzle', as it concerns all five domains, three dimensions and many different military and non-military actors. In this paper we choose for the analogy of a puzzle for simplicity, although a complex 3D puzzle would be more accurate.

Despite its strategic relevance, MDO remains underdeveloped both conceptually and operationally. A major challenge lies in translating this conceptual foundation into practical adjustments to current military operations. That might be one of the reasons that the implementation of MDO varies among NATO members and interpretations of MDO may differ [1], [3]. Because of this, it should be emphasized that the aim is not to develop a single, unified MDO concept. Rather, the focus lies in formulating a range of military concepts – Courses of Action, Doctrines, Future Operating Concepts, Concepts of Operation, etc. – that align with the principles of MDO. For simplicity, this paper refers to such concepts as an 'MDO concept'.

The Concept Development & Experimentation (CD&E) approach, elaborated on later in this paper, offers a structured approach for putting comprehensive and complex MDO concepts into practice. It enables the translation of abstract principles into concrete outcomes across strategic, operational and tactical levels. Within the iterative CD&E process, Modelling & Simulation (M&S) can play a critical role.

This paper focuses specifically on the use of M&S in the development of MDO concepts. Our aim is to bridge the gap between the military need for MDO concept development at one side, and the capabilities offered by the M&S community at the other. In our professional environment, discussions with both military and technical stakeholders have often revealed a significant disconnect between those working areas. Stakeholders from the operational side have, at times, requested to "simulate MDO," often without understanding of the capabilities and limitations of existing M&S tools. Conversely, the M&S community often adopts a technology-push approach, aiming to develop cross-domain simulation environments without clearly defined operational questions rooted in MDO thinking.

2.0 UNDERSTANDING THE COMPLEX MDO PUZZLE

2.1 Explore MDO's Full Scope

The development of novel MDO concepts presents a unique set of challenges, particularly at the more abstract strategic and operational levels. One of the central issues lies in balancing the deployment of various Defence effects with economic and political instruments. This balancing act is complicated by the fact that experts from different domains often lack a shared understanding of each other's strengths and do not speak a common conceptual language. Even when similar terminology is used, the underlying meanings may diverge significantly. A telling example is the term "neutralizing an enemy". A military expert might interpret this as eliminating the adversary, while a cybersecurity specialist would think in terms of preventing further intrusion, whereas in political circles, it could mean undermining an opponent's influence. These interpretations are not necessarily wrong, but they highlight the challenge of aligning such diverse domains, an issue that must be addressed early in MDO development.

At the earliest stages of concept development, an MDO concept may exist only as a concise document – perhaps no more than several pages. Importantly, such brevity is not a flaw but a deliberate and desirable feature at this phase. At this early stage, the goal is not yet to test the concept in a simulated environment, but rather to explore how this intangible description can be made more concrete. A crucial step in this process is to examine the concept in the context of a specific adversary scenario. The effectiveness of MDO is inherently tied to the nature of the conflict and the characteristics of the adversary; only then can the desired converging effects be identified and applied with precision [4].

In this paper we address the overarching question: How can Modelling & Simulation (M&S) be leveraged to support such abstract and strategic-level concept development? However, before exploring how M&S can be applied, it is essential to understand how it cannot be effectively used in this context. Within the NATO Modelling and Simulation Group (NMSG) community, many advanced simulation environments operate primarily at the tactical and low-operational level. These simulations typically model entities – essentially tactical units on a map. While highly detailed, this type of simulation is ill-suited for addressing the strategic and operational questions arising in the early stage of MDO concept development. Before delving into unit-level details, it is necessary to first clarify the overarching effects and relationships. This high level of abstraction benefit more from table-top games than from computer-based simulations of weapon systems and tactical entities or units moving in time and space. Considering the MDO concept as a whole is like trying to solve a complex puzzle, where all pieces demand attention at once. However, examining every detail simultaneously is impractical and would make the problem excessively complex. Therefore, MDO should initially be addressed using abstract methods, allowing for meaningful exploration without being overwhelmed by operational or tactical details (Figure 2). Once the overall framework is established, specific sub-questions on the low-operational and tactical level can be explored, as described in Section 2.2.

MDO Reflex is an example of a digitally-supported table-top game, currently under development by TNO in collaboration with the Netherlands Ministry of Defence. The primary goal of MDO Reflex is not to refine the MDO concept itself, but to allow stakeholders, especially those less familiar with MDO, to experience its added value by doing. This input is crucial during the initial stages of concept development. In MDO Reflex, participants engage in strategic and operational decision-making within a 30-minute session based on a specific vignette. When played with members of the Joint Force Command, the game sparked discussions that had not previously taken place, highlighting its potential as a catalyst for conceptual exploration. Expanding the use of such table-top games in MDO concept development offers promising opportunities. The focus should be on exploring and evaluating the concept within the context of a defined adversary.

Figure 2: The MDO concept presents challenges at the strategic and operational level. To explore MDO's full scope, abstract approaches such as table-top games or aggregate level simulations are useful.

To support MDO concept development at the operational level with computer simulations, one must look to aggregate level simulation tools[2] operating at NATO level. A direction for future research is identifying how existing simulation tools can be flexibly used to support (early-stage) concept development in MDO.

2.2 Understanding a Tactical Puzzle Piece

Within a Multi-Domain Operations (MDO) concept, directives flow from the strategic level to the operational level (e.g. Joint Force Command) down to the tactical level. Note that not all elements of the overarching MDO concept are directly relevant at the tactical level. For instance, an army leader may not engage with economic or political instruments of power. However, understanding how to operate effectively within a multi-layered battlespace, such as operating in the electromagnetic spectrum or remaining undetected by surveillance satellites, is crucial.

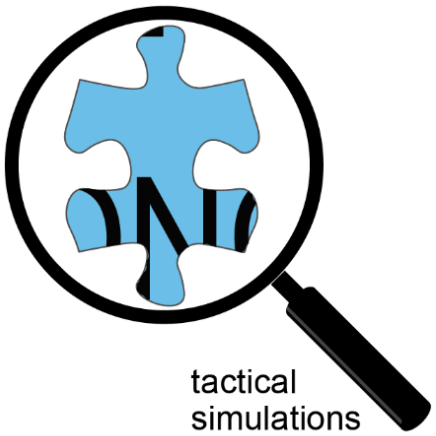

Figure 3: Tactical-level simulation environments are well-suited to explore sub-questions of the Multi-Domain Operations concept that trickle down to the tactical layer.

[2] Aggregate level simulations refer to a category of modeling and simulation that operates at a higher level of abstraction, typically representing groups of entities (such as units or formations) rather than individual components or actors.

The challenge at the low-operational and tactical level lies in ensuring that individual units and processes – each representing a single 'puzzle piece' – function appropriately and all units maintain awareness of their role within the broader context. Only under these conditions, the activities orchestrated at the operational level can be carried out as intended. Tactical-level simulation offers valuable potential in this regard (Figure 3), for example through the Modelling & Simulation tools in our national Battle Labs.

An example of a 'puzzle piece' involves intelligence that is combined from different military domains – for example from space and air – and then transferred to another domain where it needs to be integrated in the Common Operational Picture of operators. This example is particularly relevant, as key questions from MDO lies in the area of C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance). Despite significant attention to C4ISR in previous concepts such as 'joint operations', substantial progress is still needed to enable seamless cross-domain integration [4]. This is not only about technical interoperability, but also procedural (e.g. shared procedures) and human interoperability (e.g. trust and a common language) [5]. Depending on the nature of the C4ISR-related issue – whether technical, procedural or human – a specific tactical simulation environment is selected to focus on the particular question at hand.

To address the broad range of sub-questions that arise within an MDO concept, it is beneficial to design a modular and adaptable M&S framework. Such an framework should consist of building blocks that can be assembled to create a fit-for-purpose experimentation environment, tailored to answer a specific set of questions or to test particular types of hypotheses. A one-size-fits-all M&S environment for any experiment on the tactical level is highly unlikely. The specific objectives of each experiment determine which variables must be adjusted and which models require high fidelity. Keeping in mind, as stated in the GUIDEx [6]: "The used M&S environment should be as simple as possible while remaining adequate for the task at hand […]. [This] will in some cases still be very complex: it just should not be over-complex."

Once a sub-question is answered through tactical-level experimentation, the next step is to assess how the findings fit into the broader 'puzzle' of the MDO concept. This involves evaluating the impact of the findings on the 'adjacent puzzle pieces', embracing a system-thinking approach (Figure 4). Subject Matter Experts play a key role in this process. Tactical-level insights may expose friction points that challenge assumptions made at higher levels or reveal secondary effects on other tactical aspects of the concept. In such cases, the specific element of the concept under test may need to be revised, potentially through follow-up experiments, or adjacent elements may require adjustments based on the findings. Finally, these findings must be fed back into the overarching MDO concept to ensure coherence.

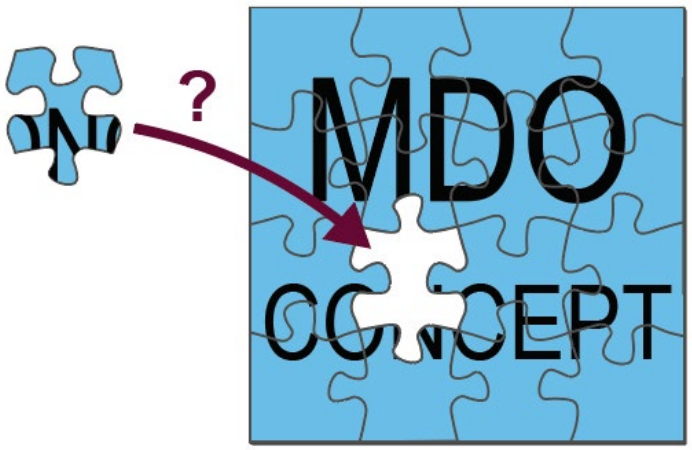

Figure 4: The impact of sub-question outcomes on the broader context should be assessed using a systems-thinking approach. Further iterations are expected, as part of the iterative CD&E process.

Note that we do not aim to simulate all tactical-level effects of the MDO concept in a single experiment. This would demand excessive preparation time and a large number of operators, especially in human-in-the-loop simulations . Instead, tactical simulations are well-suited for addressing specific sub-questions, providing timely insights without overwhelming complexity. In these experiments, the goal is not to adjust all variables simultaneously, but rather to isolate and examine the relationship between selected variables – keeping others constant to maintain a structured approach.

Not every puzzle piece can be analysed in full detail. In many cases, assumptions or expert judgments (e.g., via Subject Matter Experts in the CD&E process) must be made. Simulation offers valuable insights, but it does not provide definitive answers about the viability of an MDO concept. It is a tool for exploration, iteration, and refinement – not a final verdict.

3.0 APPLYING CONCEPT DEVELOPMENT & EXPERIMENTAION TO SOLVE THE PUZZLE

3.1 The Iterative CD&E Approach

The approach described throughout this paper is deeply rooted in the principles of Concept Development & Experimentation (CD&E). CD&E outlines an iterative process that transforms promising ideas into actionable concepts, ultimately aiming for practical implementation: the “dot on the horizon”. Rather than prescribing a rigid step-by-step methodology, CD&E offers a flexible framework enriched with best practices and structured guidance.

At its core, CD&E is an iterative cycle of concept development, and evaluation of the concept through experimentation and analysis [7], [8]. Simulation can support both phases: either exploratively, to identify opportunities and outline the scope of the concept (concept development); or analytically, to test specific hypotheses (evaluation).

A single M&S experiment does not constitute CD&E. Instead, the M&S experiment must be embedded within a broader CD&E process. This process begins with initiation, driven by an operational need or opportunity. The initiator may be a warfare centre, an operational unit, or another stakeholder. To ensure continuity and relevance, it is advisable to establish a permanent project team early in the CD&E process, with simulation experts involved early on in time to advice on the possibilities and impossibilities of simulation for various steps in the CD&E process. The M&S expertise that should be involved, depends on the level and scope of the questions that should be answered with the M&S experiment [9].

3.2 Building Fit-For-Purpose Simulation Environments

To experiment with a military concept (such as an MDO concept) within an M&S environment, it is essential to first ensure that the simulation setup is fit-for-purpose. The key principle here is to maintain a clear distinction between simulation development and concept development. Although this may seem self-evident when stated this explicitly, in practice the line between the two is often blurred, among others due to differences in terminology. The military concept, such as the MDO concept, represents an operational idea, whereas the ‘conceptual model’ as defined in the M&S community is a simplified representation of the overall military concept to shape the scenario being simulated [10].

The Distributed Simulation Engineering and Execution Process (DSEEP), see textbox below, provides a structured framework for the engineering of simulation environments. It supports clarification of the purpose of the environment and guides the process through simulation development, integration, testing and evaluation phases.

DSEEP summarized [10]

1. Determine goals and constraints
2. Perform conceptual analysis
3. Design simulation environment
4. Develop simulation environment
5. Integrate and test simulation environment
6. Run, execute simulation environment
7. Analyse data and evaluate results

Although DSEEP is a process model to structure an M&S experiment, it does not cover the full scope of CD&E. Even before DSEEP's first step, "Determine goals and constraints", a deliberate decision must be made to use simulation at all. After step 7 (evaluation of results) the CD&E process continues: findings should be integrated into the concept, like placing the puzzle piece back into the bigger picture. This may lead to new questions or reveal the concept in its current form is not viable. Furthermore, other steps will be required in the preparation of a specific experiment, such as preparing the participants. This could involve operational briefings and additional briefings to ensure the participants are aligned with the objectives and context of the experiments.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The implementation of Multi-Domain Operations (MDO) concepts, will primarily impact strategic and high-operational levels. Abstract forms of simulation such as digitally-supported table-top games are suited to address questions at these abstract levels. Aggregate level simulations offer potential for supporting early-stage MDO concept development at the operational level. The M&S that is available in our national Battle Labs is mainly focussed on the tactical level and not well-suited for answering questions at the operational level. However, tactical level simulations remain highly valuable for answering specific sub-questions that trickle down from the overall concept to the tactical layer (Figure 5). To support answering sub-questions with simulation, it is recommended that the NMSG community prioritizes the integration of models representing emerging capabilities – integral to MDO execution – into existing tactical simulation environments. This includes, for example, modelling satellite overflight in the space domain and effects within the electromagnetic spectrum. Such simulation components can and should be developed in a cross-domain manner, supporting interoperability and coherence across domains.

During the CD&E process, different type of tactical-level questions may arise. To address these effectively, we envision a suite of fit-for-purpose simulation environments, each designed for specific purposes.

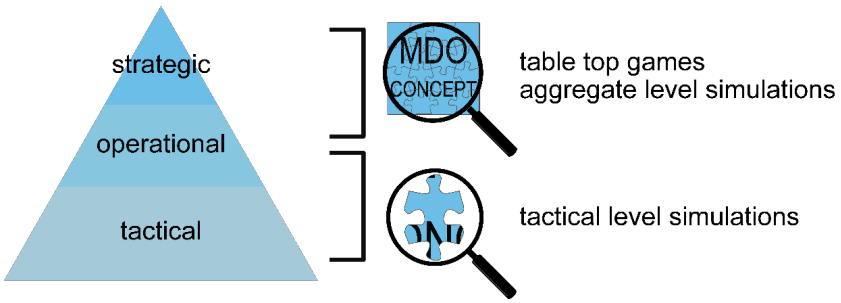

Figure 5: The development of comprehensive MDO concepts is best supported by abstract methods such as table-top games and aggregate level simulations. In contrast, questions that arise at the tactical or low-operational levels are effectively addressed through fit-for-purpose tactical level simulations.

To fully leverage M&S in support of MDO development, stronger collaboration is required between the military operation and simulation communities. Currently, the military operation side does not always fully understand the capabilities and limitations of M&S, while the M&S community often operates from a technology-push perspective, rather than responding directly to operational needs. Bridging this gap is essential for advancing concepts like MDO with the use of Modelling & simulation. Finally, a practical recommendation to bridge this gap is: keep it simple. This applies not only to experiment design and the simulation environment, but also to communication and collaboration, in order to increase the human interoperability. Clear objectives, shared understanding and pragmatic tools are key to successful concept development and experimentation.

5.0 REFERENCES

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