# An ontology-driven serious game design for Course of Action Wargaming

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***Abstract. Introduction****: The Brazilian Ministry of Defense intends to simulate the joint planning process for employing the Armed Forces, applying this simulation to Course of Action (COA) Wargaming — an analysis in which each friendly COA developed during this process is contrasted with possible enemy COAs.* ***Objective:*** *This work aims to design a serious game inspired by the concepts and resources of wargames to conduct the COA Wargaming.* ***Methodology****: We propose representing the COA Wargaming as an educational wargame to analyze decisions. We understood the COA Wargaming method, built an ontology for wargame execution, and developed a conceptual model to register the COA Wargaming provenance.* ***Results:*** *The research contributes (i) an OntoUML ontology of wargame execution events, (ii) a provenance model for COA Wargaming, and (iii) a web-based serious-game prototype. A perception-based evaluation with 65 military participants indicated positive perceived utility for supporting COA Wargaming.*

***Keywords*** *game design, ontology-driven design, wargames, COA wargaming*

## 1. Introduction

Military personnel are often trained and prepared for employment in crises or conflicts. Accordingly, they have developed methods and techniques that allow them to practice these activities in peacetime [McHugh 1966]. Wargames are one such technique based on battle simulations. They are defined as a "model involving people making decisions in a synthetic environment of competition or conflict, in which they see the effects of their decisions on that environment and then get to react to those changes" [Perla 2022].

Contemporary political and economic instability can rapidly escalate these crises, resulting in modern conflicts characterized by friction and fog-of-war factors, such as uncertainty, disorder, and limited information about the enemy, the terrain, and sometimes even one's own forces [Miranda and Cummings 2023]. Thus, the military builds scenarios and conducts wargames to anticipate undesirable situations, exercise decision-making, avoid surprises, and plan actions [Neves 2008]. In this context, the Brazilian Ministry of Defense intends to simulate the joint employment of the Armed

Forces in these scenarios through Course of Action (COA) Wargaming, a method for evaluating COAs against potential enemy COAs during military planning. A COA represents a sequence of actions to accomplish a mission [NATO 2019], while an enemy COA describes possible actions that the enemy could adopt to affect mission accomplishment.

In planning and operations, the chain of command comprises the commander (Cmdr) and staff, including the chief of staff and sections that bring together military experts in Intelligence, Operations, Logistics, Planning, Command and Control, among others. Together, they must envision the various actions their units will need to undertake to execute the COA against the enemy COA [United States 2020]. Doctrine further suggests that, during planning, COAs and enemy COAs should be analyzed as in a wargame [Brazil 2020]. Considering this premise, this work aims to design a serious game [Dillon 2013] inspired by wargame concepts and resources to support COA Wargaming and improve the COAs under consideration. Since their names are similar, COA Wargaming and wargames are often misunderstood as the same subject. However, wargames constitute a broader and more complex domain, while COA Wargaming applies concepts from wargames [Ouriques et al. 2022].

The military has been applying this method manually, placing and moving units on a chart or map, deliberating actions, and recording decisions by hand, which creates a risk of knowledge loss. Countries that possess systems for conducting COA Wargaming keep them confidential due to their strategic military, scientific, and technological value. Improving COA Wargaming as a digital system would enable recording the full dynamics of interactions, configuring different scenarios, and using computational resources to support decision-making. Consequently, the military could plan its actions more effectively, assess risks more accurately, and increase the chances of operational success. In addition, such improvement would enhance decision analysis and adjudication, while enabling the collection of decision data for knowledge management and artificial intelligence (AI) applications [Ouriques et al. 2022].

Although prior studies address COA analysis and simulation, few integrate ontology-based wargaming representation, provenance for COA decisions, and expert-evaluated serious games. This work provides: an OntoUML ontology, a provenance model, a web-based serious game, and an evaluation with 65 military participants. In this work, provenance denotes the structured record of who decided what, when, in response to which situation, and what the resulting action is during COA Wargaming.

## 2. Background

### 2.1. Wargames

Wargames represent a “conflict or competition in a synthetic environment in which people make decisions and respond to the consequences of those decisions” [United States 2020]. From a ludic perspective, wargames represent contests between opposing forces that use rules, procedures, and information to simulate scenarios and achieve objectives.

Wargames encourage the military to practice their art and apply the lessons they have learned through active [Pavek and Starken 2014] and experiential learning [Lacey 2016]. Wargames are valuable tools for fostering creativity and innovation,

developing effective strategies [Work 2015], building consensus, understanding the dynamics of conflicts, and exploring alternatives [Sabin 2015], as well as identifying gaps and previously unrecognized issues [NATO 2023], revealing unexpected consequences, identifying improvements, and adapting to change [Perla 2022]. Wargames also enable the exploration of new technologies, emerging scenarios [Haggman 2019], and the evolution of military doctrine and operational concepts [Kainikara 2003]. They provide a safe environment for the military to practice warfare without risking loss of human life or causing damage or attrition to their units, while also offering cost savings [Lee 1990]. The learning process in wargames is more important than the outcomes of units' engagements [Wilkes 2001]. The crucial issue is not winning or losing, but analyzing players' decisions and understanding the reasoning behind them [Perla 1990, Elg 2017, Kainikara 2003].

### 2.2. COA Wargaming

COA Wargaming is a systematic method whose primary objective is to improve COAs by analyzing them against enemy COAs and simulating how a situation might evolve under different decisions. The method visualizes the flow of operations in time and space, taking into account the capabilities and possible dispositions of friendly and enemy forces, the operational area, and the scenario [United States 2020]. COA Wargaming helps identify difficulties, risks, and limitations in COAs, while coordinating actions, effects, and decisive points to achieve objectives [Eikmeier 2015]. Despite its origins in military planning, the method is also applicable to civilian contexts [United Kingdom 2017].

The simplest way to conduct COA Wargaming is through a manual approach, using a map, a chart, or a tabletop to represent the actions planned in the COA. A more sophisticated approach employs models and simulations to execute those actions. The commander and staff determine where and when to employ their units, manage risks, and analyze the logistical sustainment of the COA. Initially, the chief of staff presents the scenario underlying the situation. Next, an operations officer (Blue) presents the COA, and an intelligence officer (Red) presents the enemy COA. The wargaming then proceeds in turns to analyze the COA against the enemy COA [United States 2013].

COA Wargaming is typically conducted in turns consisting of three alternating move interactions: action, reaction, and counteraction. Actions are events initiated by the force that takes the initiative. Reactions are the opposing force's responses to those actions. Counteractions are the initiating force's responses to those reactions [United States 2013]. The turns continue until the commander is confident that the actions effectively counter the enemy or until another stopping criterion is met.

### 2.3. Ontologies

Ontologies describe conceptual models that represent entities recognized by a given theory or cognitive system [Verdonck et al. 2015]. They study the nature of existence, providing a system of domain-independent categories that support the conceptualization of scientific theories, and ensuring the ontological consistency of conceptual modeling languages, including their concepts and grammar [Guizzardi 2006]. Ontologies facilitate domain representation, taxonomy structuring, knowledge management, and semantic interoperability in model integration [Guizzardi et al. 2010].

Improving the quality of modeling languages and conceptual models requires a foundational ontology — a high-level, domain-independent ontology

[Guizzardi et al. 2008]. Such an ontology provides a system of categories grounded in sound and consistent philosophical principles, offering real-world semantics for general-purpose ontological representation languages [Guizzardi 2006]. It also defines the basic concepts upon which any domain-specific ontology is built [Guizzardi and Wagner 2005]. In contrast, a domain ontology is a shared and consensual model within a community that exchanges information about a specific domain [Guizzardi and Halpin 2008]

This work employs the Unified Foundational Ontology (UFO) to support domain analysis in the conceptual modeling of wargames, particularly COA Wargaming. UFO provides core constructs such as object types, taxonomic and part–whole relations between objects, roles, properties, and data types [Guizzardi et al. 2022]. UFO comprises modules, representing specific aspects of reality: UFO-A models individuals that persist over time while maintaining all their parts and identity [Guizzardi et al. 2022]; UFO-B represents temporal entities, such as events and processes [Almeida et al. 2019]; and UFO-C captures intentions and social entities, including objectives, actions, commitments, roles, and social relations [Guizzardi et al. 2008].

## 3. Related Work

Prior work characterizes wargames as structured narratives [Appleget 2022] and emphasizes player interactions [Christensen and Dobias 2021, Makowiec 2024]. Computational approaches have applied the COA Wargaming method through wargames and simulators, either to support decision-making [Guarda et al. 2017] by representing sequences of actions as decision trees [Hanley Jr. 2017, Hernandez 2015] or assessing COAs in terms of mission success and operational effectiveness [Boron and Darken 2020, Yuksek et al. 2023], while managing risks [DeBerry et al. 2021] and identifying ways for an enemy COA to counter a given COA [Chance et al. 2024]. Finally, ontologies have been proposed to represent decision problems [Kornyshova and Deneckère 2010] and to record game provenance [Kohwalter et al. 2012]. The novelty of this work lies in integrating an ontology-grounded representation of COA Wargaming events, a provenance model for recording decisions and interactions, and a collaborative web-based serious game with mechanics that support military planning.

## 4. Method

Design Science underpins this research as its epistemological paradigm, focusing on building knowledge through the design or improvement of artifacts to solve a specific problem or a class of similar problems [Johannesson and Perjons 2021]. Design Science Research is the adopted approach, establishing a strategy for guiding the development and evaluation of artifacts based on problem understanding [Dresch et al. 2015].

Previous works have analyzed the wargame domain by developing ontologies to identify its main elements and relationships through a wargame design process [Ouriques et al. 2025], and by structuring how staff conducts COA Wargaming within the military planning process, thereby enabling computational support [Ouriques et al. 2022]. This work focuses on the game design of a serious game for conducting COA Wargaming, with the aim of improving COAs and recording decisions. Quantitative research, conducted with domain experts, evaluated the game to assess whether it accurately reflects the method, enables COA improvement, and enhances learning.

## 5. Game Design

Given their potential for teaching and knowledge generation, games have been used in military learning and training, proving effective for supporting data analysis in decision-making processes [Wong et al. 2019]. Learning from a game requires understanding why players make certain decisions and how those decisions lead to specific sequences of events [Perla and Barrett 1985]. Considering that games can be understood as information systems [Xexéo et al. 2021], we developed the game from a systemic perspective, following a serious game design methodology [Mangeli et al. 2022].

First, we built an ontology based on wargame domain ontologies [Ouriques et al. 2025], representing the dynamics of wargame execution as events that require decision-making (Figure 1). We implemented the ontology in OntoUML, a language for creating well-founded ontologies, derived from UML class diagrams [OMG 2017] and grounded in UFO for its development and application [Guizzardi et al. 2018].

*Scenario* and *Decision Point* describe the contexts in which decisions are made. A decision point requires a decision event for the players, which may lead to another decision point. *Decision Event* represents the main event that aggregates the *Decision-Making* and *Adjudication* events. *Alternative* indicates two or more options within a decision event. *Deliberation* represents the process of discussing and carefully evaluating alternatives before making a decision, aimed at helping achieve an *Objective*.

*Players* make decisions based on their experience (*Player Expertise* and *Player Intention*), as well as on *Information* available in *Rules*, *Databases*, and *Doctrine*. A *Decision* consists of the selection of an *Alternative* and is expressed through the *Decision Resulting Action* event. This event is then manifested as an *Action* that typically updates the *Location* of one or more *Units* in the Setting.

*Adjudication* defines the events in which decisions are evaluated. *Rule*, *Umpire*, and *Human Player* may participate in adjudication. Thus, both umpires and players may evaluate decisions based on their experience and available information. Similarly, *Umpire Experience* and *Umpire Intention* describe the disposition of umpires in these events.

Next, we built a conceptual model of COA Wargaming based on its process model [Ouriques et al. 2022], this ontology of wargame events, and provenance solutions in games [Kohwalter et al. 2012], to record updates to unit locations, interactions, and decisions throughout turns and moves. Figure 2 presents the UML class diagram of the proposed model. The model represents COA Wargaming as an analysis within a *Planning* process designed to solve a military *problem*, achieve *Objectives*, and fulfill the *mission*. The *COA* class characterizes both COAs and enemy COAs by a *number* and distinguishes them by *type*. The *COA Elem* class further decomposes them into phases, decisive points, effects, and actions, each identified by a *number* and a time interval. During the Prepare for the Wargame, COAs and enemy COAs *assign Units* and define their *Locations*.

COA Wargaming inputs include the COA, the enemy COA, the conduct *method*, and the number of *moves* per turn. The selected method defines the number of turns and is associated with COA elements. *Unit assignments* in the COA and enemy COA, as well as their *Locations*, are replicated in the COA Wargaming context. However, COA Wargaming may assign new units or remove existing ones.

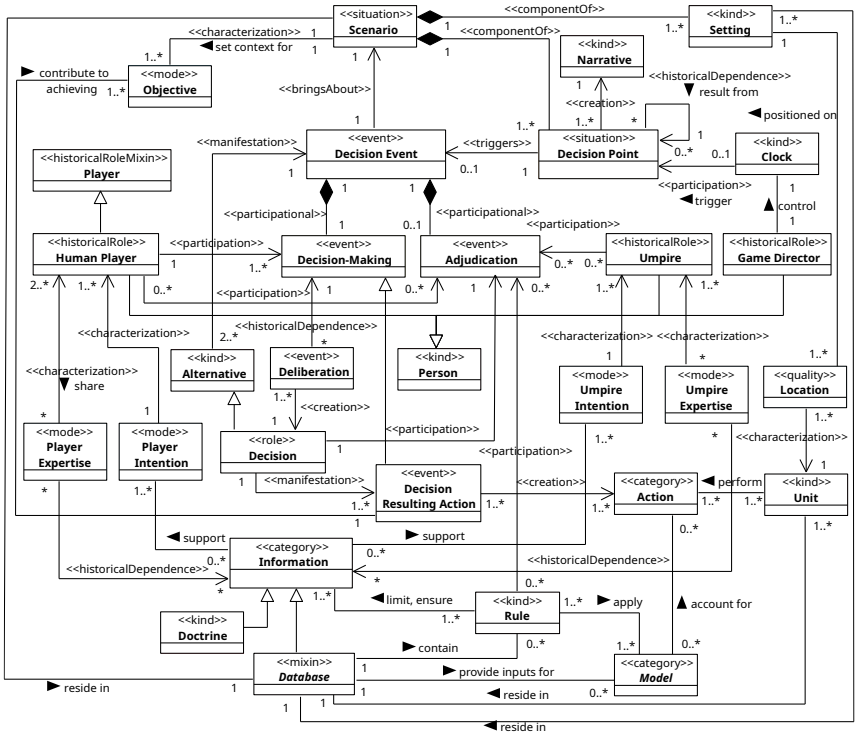


**Figure 1. Events of the wargame execution.**

A *Turn* is characterized by a *number*, the side holding the *initiative* for actions (Blue or Red), and a time interval. This interval refers to the COA element but may be adjusted during COA Wargaming. A *Move* within a turn is characterized by a *number*, a *date*, and the *side* responsible for expressing move intentions.

*Decisions* are made during turn moves and concern unit positioning and the actions units will undertake. A decision results from selecting an *Alternative*. A *Staff* member records each alternative, specifying its *Action*, *description*, and *justification*. An alternative may refer to a *Move* or, more specifically, to one or more *Units*. The model structures each alternative according to the 5W1H method [Kipling 1902]: *What* (action), *Why* (justification), *Where* (location), *When* (date), *Who* (unit), and *How* (description), and the staff member responsible for recording it. *Decisions* involving unit engagement include *Adjudication*. Hence, the model enables the reproduction of a COA Wargaming, supporting the analysis of the commander's decisions and facilitating knowledge sharing. We updated the model while implementing the COA Wargaming game mechanics.

## 6. Prototype and Evaluation with Military Personnel

The game design focuses on the Prepare and Conduct phases of COA Wargaming [Ouriques et al. 2022]. Figure 3 depicts a fictitious scenario describing a crisis between two countries — Blue and Red — in which Red claims a portion of Blue territory, highlighted in orange. During preparation, the staff formulates the COAs and enemy COAs. To assign units, the player must select them from the database and place them on the map. Time advances in discrete steps, starting at D+0. To update unit locations, the player increments the date, then drags units on the map or assigns new positions.

After preparation, the COA Wargame conduction begins. The staff can create a new analysis (wargame) or load an existing one. The setup panel (Figure 4) also presents

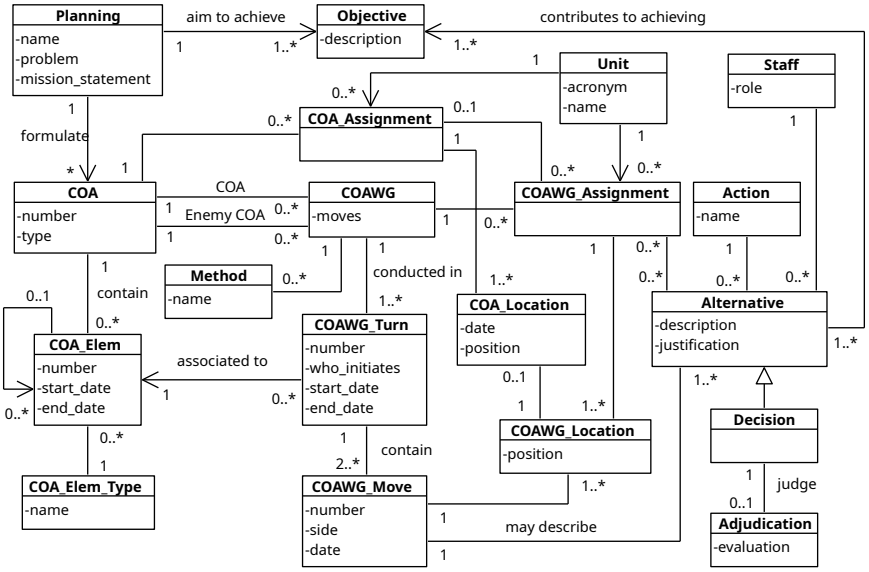


**Figure 2. UML class diagram of the COA Wargaming provenance model**

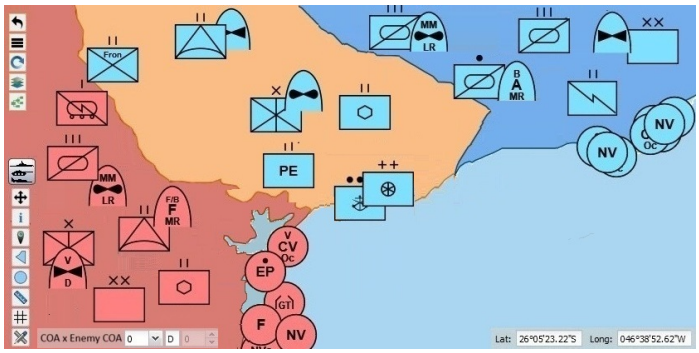


**Figure 3. Defining COAs and enemy COAs in Prepare for the Wargame**

the mission statement and the guidelines issued by the chief of staff, who serves as the wargame coordinator.

Figure 5 presents the gameplay for conducting COA Wargaming. The top bar contains buttons to switch the main view, with the map and chess clock currently active. The latter presents the turn-and-move panel, indicating that a phased wargame has been loaded and showing the number of moves per turn. By default, each turn implements the doctrinal action-reaction-counteraction sequence in three moves. The commander may add extra moves when deeper analysis is required. Map controls allow players to zoom in and out, measure distances, identify coordinates, and display a grid. To update unit locations during a turn-based move, the player drags units on the map. When a turn move is selected, the game updates the map scenario, the turn and move displays, and the list of units for the side (Blue or Red) that may adjust them in that move. The game also allows adding and removing units from the COA, adjusting combat power as needed for the mission. Figure 5 also depicts the detection mechanic, displaying each unit's sensor range to assess mutual visibility. In combat, a similar mechanic shows weapon range to assess potential damage exchange.

The game records the full dynamics of interactions between units throughout turn moves. The player registers an operational action by selecting a turn move and specifies

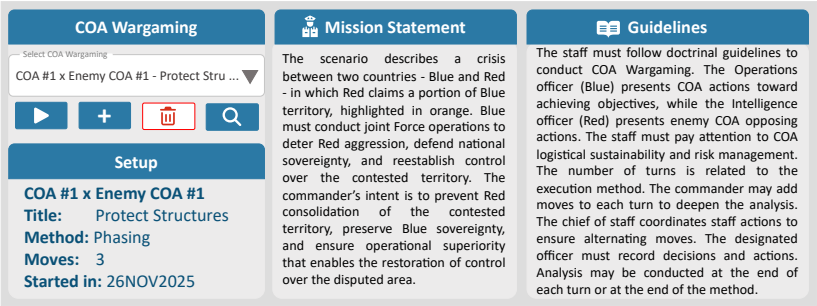


**Figure 4. Setup Panel for COA Wargaming**

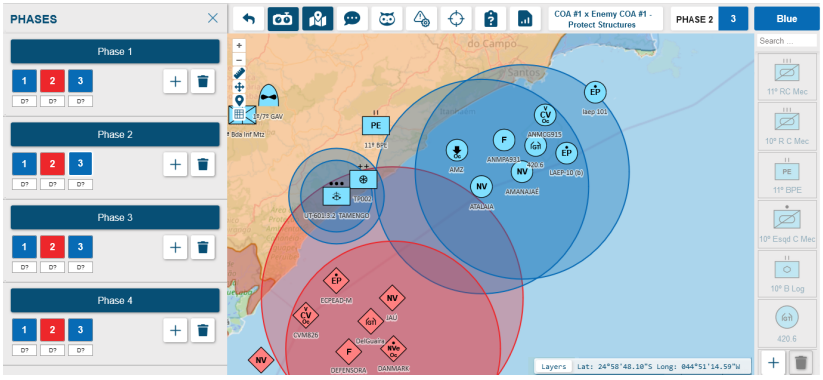


**Figure 5. Gameplay for COA Wargaming depicting the detection mechanic**

tactical actions by selecting units on the map. When an action involves an engagement, the game allows the selection of units from both friendly and enemy forces. Figure 6 shows the recording of a commander's decision, indicating the staff member who registered it, the units involved, the resulting action, as well as its description and justification.

These decisions form the COA Wargaming narrative, accessible via the message bubble button, which enables the review and collaborative recording of actions, decisions, and comments throughout turn moves (Figure 7). Messaging applications inspired this mechanic. Records from the chief of staff, Operations, and other sections appear in blue, while Intelligence section records appear in red. The commander's decisions and instructors' analyses (in planning exercises) appear in white. Players can also reply to records, enabling responses to be grouped and revealing the deliberations.

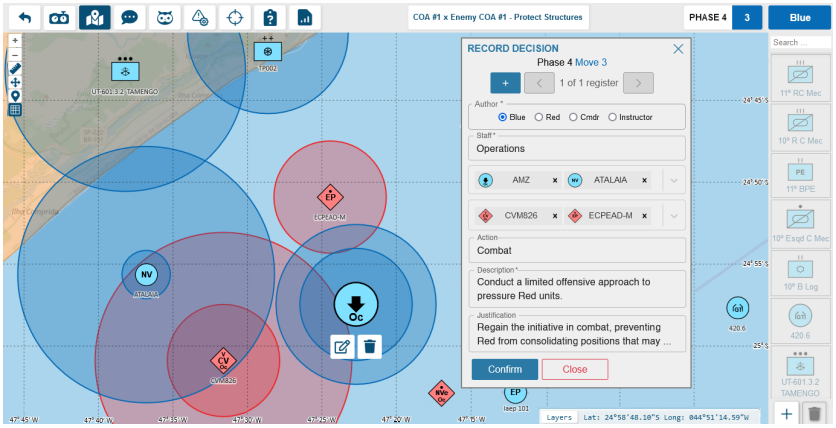


**Figure 6. Recording a decision and the resulting action among opposing units**

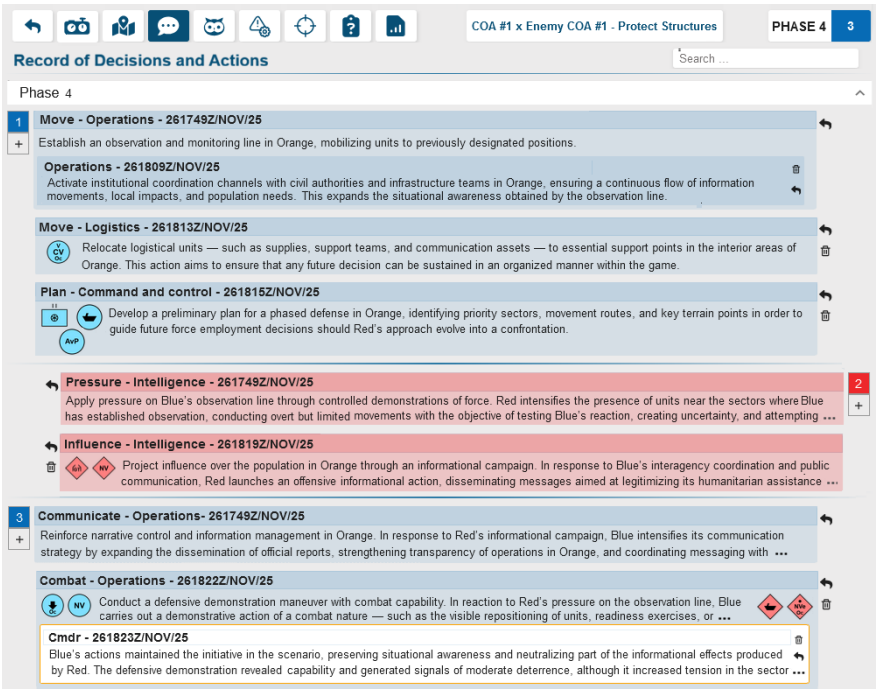


**Figure 7. COA Wargaming narrative that describes decisions and actions**

The game includes additional mechanics available through the owl, alert, and gun sight buttons, which respectively support COA risk management and the updating of target identification and intelligence requirements. The latter refers to knowledge needed to improve planning or enhance situational awareness of the mission [Brazil 2020]. After completing the turns, all COA improvements and planning outcomes require analysis to assess whether they will be implemented. The game runs in a web browser with a React/OpenLayers front end and Spring Boot microservices back end. WebSocket syncs player views, and PostgreSQL/PostGIS stores provenance and unit locations.

Finally, we evaluated the game design using quantitative research to assess whether it correctly implements the COA Wargaming method, enables COA refinement, and enhances learning. We used MEEGA+ (Model for the Evaluation of Educational Games for Computing Education) [Petri et al. 2019] because it provides a concise way to evaluate serious games compared to other approaches ([Fu et al. 2009, Savi et al. 2011, Moizer et al. 2019, Vaz 2025]), focusing on key aspects for this work, such as usability, player experience, and the game's ability to motivate learning.

The research involved 65 military personnel — 32 from the Navy, 17 from the Air Force, and 16 from the Army — including instructors in military planning and wargaming. We conducted the game demonstration in person and provided a video for those who could not attend. Following the demonstration, participants completed the MEEGA+ questionnaire using a 5-point Likert scale to evaluate the game. The results showed that more than 80% of participants rated it positively, indicating that the game has the potential to support the COA Wargaming method in military planning, although it could better encourage player immersion (Figure 8). We obtained similar results for usability and player experience [Ouriques 2025]. These results should be interpreted as initial evidence of perceived utility, since this work did not compare the prototype with the current manual process and did not measure objective learning or planning performance.

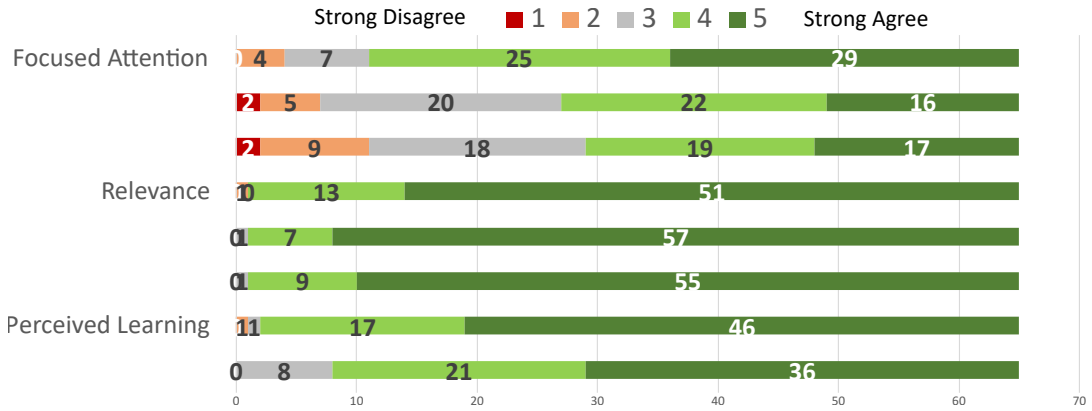


**Figure 8. Game evaluation of learning motivation**

## 7. Conclusion

This work aimed to design a serious game to support the preparation and execution of the COA Wargaming method for analyzing COAs in military planning. We implemented this method as a wargame, in accordance with military doctrine. The game mechanics enable the commander and staff to refine COAs by considering the three operational factors (force, space, and time) and to record decisions, resulting actions, and interactions between units, as well as the staff's ideas, perceptions, and discussions. The contributions of this work include the COA Wargaming provenance model and the game design itself.

We built this provenance model based on the ontology of wargame event execution, although an ontology for COA Wargaming could also have been developed. The recorded provenance may serve as a structured dataset for future AI-based assistance, such as decision suggestion or adjudication support. Investigating these applications is outside the scope of the present work.

The game design prioritizes the operational level, focusing on objectives, sequence, and synchronization of unit actions, but the game also has the potential to support other decision levels. Other limitations relate to the game mechanics, since the game could include kinematic models to analyze time and distance factors in unit movements, logistical models to assess COA sustainability, and combat outcome tables or models to assist umpires in adjudication, thereby reducing judgmental subjectivity.

Future work includes improving and diversifying the game mechanics to provide greater challenges, strengthening support for decision-making, assisting in decision analysis, fostering learning, increasing immersion, and promoting collaboration. Additional features could estimate the enemy's ability to counter the COA and probable losses, suggest supporting actions or force division, and identify COA vulnerabilities. Encouraging the use of the game in military planning exercises can further refine it and generate more accurate, relevant feedback through active learning.

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