# THE NEXT STEP IN WARGAMING

Designing a framework for the implementation of Artificial Intelligence into military wargaming

*By*

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## Executive summary:

War is always evolving, becoming more complex over time. With the addition of new technologies and emerging threats the complexity on the battlefield is also growing. Following this trend tools to train new recruits or develop new doctrines also becomes more complex. One of the tools impacted by this is military wargaming. While wargaming is an ancient practice it has developed to follow the growing complexities of war. In the context of military training wargames portray multi-domain battlefield containing artillery, helicopters, tanks, infantry, planes, terrain and much more. To keep the wargames significant and executable the implementation of AI into military wargames was explored. This proved to have an impact on aspects such as data processing, decision making and strategies. Further research shows that while possible and useful the implementation of AI into military wargaming is of an ad hoc nature and lacks any guidance or standardization. That is why this thesis set out to develop a practical and guiding framework for wargame developers for the implementation of AI into military wargaming.

After an exploratory literature review the knowledge gap is identified in the crossing between AI, wargaming and their integration. This lead to the main research question being “Which framework can guide wargame developers in the field of AI and military wargaming through the implementation process ?”. To answer this main research question several sub questions are developed and answered using several research methods.

The first sub question is: “What are the current challenges and constraints in the implementation of AI into military wargaming and how can they be addressed? This question is answered in chapter one with the use of a literature review. It results in more depth into the problem and more insight into the knowledge gap.

The second sub question is: “What are the requirements, that the framework aims to achieve?” This question is answered in chapter two with the use of another literature review and expert interviews. This resulted in three design principles and several requirements. The principles, requirements and their sources can be found in table 4. Furthermore, the result of the expert interviews highlighted the value of a supplementary method, when academic literature is not abundant.

The third sub question is: “How can the design principles and requirements be translated into a framework?” Based on the requirements a preliminary framework is developed. This framework is than tested with a use case to find areas of improvement. The use case was a validation implementation of AI into the military wargame called “Take That Hill”. This resulted in a framework consisting of several phases and activities. The result can be seen in figure 7. Furthermore, the outcome of the use case illustrated the wargame is not properly balanced as it can be won by simply always moving forward. In addition to the direct relation between the requirements and the translation into the framework another finding took place. The use case illustrated the importance of testing the preliminary framework. As the use case uncovered a new dimension in the framework with the core activities, which were not apparent from the theory alone.

The last sub question is: “What is validity of the designed framework?”. This was answered by assessing whether the requirements were met and expert interviews. The requirements assessment can be found in table 6 and the final version of the framework can be found in figure 8. Furthermore, while the validation expert interviews directly improved the framework they also showed the importance of the diversity of experts interviewed. The experts for the requirements focused on time and security, while the experts for the validation focused on the ethical and moral aspects of AI in military wargaming.

In conclusion, this thesis presents a multidisciplinary approach to solving a problem in military training and doctrine development. The development of an practical and guiding framework for AI implementation in military wargaming represents a significant advancement in the field, offering both academic contributions

and practical applications. By aligning with the goals of the Master's program in Complex Systems Engineering and Management, this research exemplifies the integration of complex and complicated domains, ultimately contributing to the enhancement of military preparedness and operational effectiveness.

As this thesis was written as part of a graduation internship at TNO the research recommends the wargame developers of TNO to use this framework as a guide during future implementations of AI into military wargaming and expend on the framework when necessary.

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# Chapter 1: Problem introduction, core concepts and knowledge gap

This chapter aims to illustrate the problem of growing complexity in military wargames, explain core concepts and definitions relating to the implementation of AI into military wargaming, provide a research approach and methods to design an artifact which would address the challenge. Furthermore, this chapter will illustrate how a project with a limited academic papers available can be performed using supplementary methods.

## 1.1 Problem introduction

Wargaming is an ancient practice spanning nearly all early civilizations. It originated as abstract mental exercises designed to train the anticipation of an opponent's moves. The evolution of this strategic engagement method occurred parallel to the refinement of maps, transitioning from abstract exercises to tangible games and tabletop games. In 1811, Baron von Reisswitz's developed the first wargame as a gift for the Prussian army, a significant milestone in the historical trajectory of this strategic discipline called wargaming (Caffrey, 2000). An example of a wargame with a high abstract level would be the popular game RISK. While playing the boardgame the players need to make strategic decisions in diplomacy, conflict and conquest.

As time progressed, wargames evolved from abstract mental exercises into increasingly realistic computer simulations. In the modern-day era, wargaming has emerged as a method for educating military personnel on crucial aspects of military doctrine. These tabletop games, rich in complexity, vividly depict various facets of a battlefield, catering to casual gamers exploring historical scenarios ranging from ancient Greece to futuristic space-based battlefields. In the context of military training, wargames predominantly portray multi-domain battlefields containing artillery, helicopters, tanks, infantry planes, terrain and much more, while being reflective of the current way of warfighting (Perla & McGrady, 2011). Furthermore, wargaming simulations are done to develop new concepts and tactics. Dobias et al. (2022) reviews the development process of two military concept development wargames. The games enabled a successful evaluation of the developed concepts. This type of wargame often portrays a battle between own forces often called blue force and a hostile force often called red force. Comparable to the teams in RISK.

The growth in complexity on the battlefield also lead to the growth in complexity of the wargames and their simulation. Vlahos (1986) shows that this trend goes as far back as 1919. With the wargames becoming more complex the playability and with that the efficacy of the wargames decreases. The problem thus arises that wargaming on one hand needs to follow the complex trends in the military while on the other hand needs to be simple enough to be executable. To be able to incorporate the growing complexity of the wargames while keeping them significant and executable Sun et al., (2022) explores the possibility to use Artificial Intelligence (AI) in the form of deep reinforcement learning to support the combat mission planning in wargaming. They see this as an intelligent development for the field of wargaming and their experiments show that it has significant impact on the aspects of data processing, decision-making speed and strategies. Furthermore, Goodman et al., (2020) illustrated much like normal games, wargames, albeit on a smaller scale, benefit from the implementation of AI into wargaming. Lastly, Goodman et al., (2020) also recommend that a framework for the implementation of AI into wargaming could provide a substantial benefit for later implementations as it would make the implementation of AI into wargaming more achievable. Furthermore, implementing AI into red force could provide great benefit towards the training or objectives of the wargame as it can adapt to the actions of a player in real time as per Kitchen et al, (2023). Lastly, an AI model is custom fitted to a wargame and for each change in the wargame the model must be adapted. For widespread implementation this is cumbersome.

Given the growing complexity of wargames outlined above, this research aims to address the this issue by focusing on the development of a practical and guiding framework for the implementation of AI into military wargames to be used by military wargame developers. The implementation of AI could provide the wargame developer with a tool that can support the player, be the opponent or balance the wargame. This enables wargame developers to include the more complex changes to wargaming without impacting the goal of the wargame. This research aspires to contribute to the ongoing evolution of military training and simulation methodologies, creating a paradigm that helps in ensuring the readiness of the armed forces in the face of diverse and evolving challenges, contributing to the stability and the overall well-being and prosperity of society. Besides a significant social aspect of this problem there is also an academic problem. Literature concerning military activities are limited in nature. When looking deeper into the field of military wargaming and AI there is even less academic literature available. To still be able to develop a practical and guiding framework for military wargame developers there needs to be a supplement for the limited availability of academic literature. Which is why this thesis will use different supplementary methods to uphold the academic relevance of this thesis.

## 1.2 Core concepts and definitions

This chapter provides a foundation of core concepts and definitions for the development of a practical and guiding framework implementing AI into military wargaming. The three primary concepts are: framework development, AI and military wargaming.

*Framework development*

Framework development focusses on the key concepts of the frameworks and delineates the definition of a framework in this thesis. According to Upadhyay (2015) frameworks can be split into two categories: conceptual frameworks and theoretical frameworks. Jabareen (2009) argues that conceptual frameworks are a construct of concepts with the aim to provide understanding. Furthermore, he also states that a conceptual framework should be developed and constructed through a process of qualitative analysis. On the other side is a theoretical framework. A theoretical framework is described as a logically developed and connected set of concepts and premises based on several theories according to Varpio et al., (2020). Furthermore, the framework should show the work a researcher engages in to use said theories in research. In the case of this thesis the focus lies on developing a practical and guiding framework as it aims to document the process of implementation and provide wargame developers who aim to integrate AI into their military wargames a guide.

*Artificial Intelligence*

The concept of AI is explained with the use of a definition of AI and demarcate the boundaries of the concept being used in this thesis. The term AI can be very broad. For example, the definition of De Zuniga et al., (2024 page 317): "*the tangible real-world capability of non-human machines or artificial entities to perform, task solve, communicate, interact, and act logically as it occurs with biological humans*". By this definition a calculator could be counted as AI. For this research the recommended definition of Grewal (2014) would be a more accurate definition: "*AI is the mechanical simulation system of collecting knowledge and information and processing intelligence of universe: (collating and interpreting) and disseminating it to the eligible in the form of actionable intelligence*". As this definition encompasses cutting-edge AI systems as ChatGPT and Gemini where a simple algorithm consisting of a single if statement would fit the definition of De Zuniga et al, making their definition too broad for the scope if this thesis.

*Military wargaming*

This section about military wargaming will look into the concepts of wargaming and illustrate the key differences between wargaming and military wargaming. Military wargaming and wargaming are often used synonymously. However, Perla (1985) notes that military wargaming persist of wargaming with the goal of investigating processes and look for "lessons learned". Furthermore, Appleget & Cameron (2015) state that military wargaming is becoming increasingly analytical resulting in wargames being able to generate courses of action and operational plans which in turn could be used to feed other analytical activities. Taking this into account the definition of Banks (2024, p3) is used: "*Wargames are bespoke models designed to represent actual or potential events, which feature human players engaged in consequence-based decision making, which include mechanisms that immerse these players, and which possess adjudication procedures for choosing actions, determining outcomes and determining system dynamics in the wargame*". This definition fits this research best, because it is the most contemporary and accurate definition currently available. This definition also covers the consequence-based actions, which the AI will use to make and base development on.

To gain a better understanding of the difference between wargaming and games the paper by Espen et al, (2003) was used. This paper encompasses the taxonomy of games could be used to analyze existing games. The paper introduces fifteen dimensions on which a game can be classified for example, Space, time and Player count. Using this framework in combination with the definition of Banks (2024) it can be concluded that a wargame is a game that is almost always a two player or multiplayer game, non-deterministic as the human interaction in the games make it non- deterministic, conditional saving, which means saving the game state or restart from certain point in the game. This helps the wargame to generate lessons learned and not start over when not going in the desired direction.

## 1.3 Literature review

To identify the research, gap an exploratory literature review was conducted. This literature review started by finding papers around AI in military wargaming. This yielded very limited results. To gain more insight into the current state of academic literature further literature reviews were conducted in the areas of AI in gaming and wargaming for military training and simulation. This was done to increase the breadth of the search to in turn be able to include as many papers as possible. The search engine used was Scopus as this search engine is a trusted search engine for finding peer-reviewed scientific publications. Furthermore, for the separate areas the searching strategy was based on the PRISMA framework. Prisma is a framework for systematic reviews and meta-analysis (Page et al., 2021). Furthermore, the relevance of the papers was determined by assessing the definitions used in the paper and how much those aligned with the definitions demarcated for this thesis.

The literature review resulted in fourteen academic articles on the topics of AI in gaming, wargaming for military training and simulation in wargaming. The papers are in Table 1.

| Reference | AI | wargaming | gaming | simulation |
|---|---|---|---|---|
| AI in military wargaming | | | | |
| Davis and Bracken (2022) | X | X | | X |
| Goodman et al. (2020) | X | X | X | |
| Sun et al. (2022) | X | X | | X |
| Kitchen et al. (2022) | X | X | | |
| AI in gaming | | | | |
| Verma et al. (2023) | X | | x | |
| Nihalani et al. (2010) | X | | X | |
| Zohaib (2018) | X | | X | |
| Dignum et al. (2009) | X | | X | |
| Wargaming for military purposes | | | | |
| Morgan (1991) | | X | | |
| Lorusso et al. (2023) | | X | | X |
| Elg (2018) | | X | | |
| Bruvoll et al. 2015 | | X | | X |
| Evensen et al,. (2022) | | X | | X |
| Pournelle (2022) | | X | | X |

*Table 1: Literature review selected papers*

### 1.3.1 AI in military wargaming

To find papers in this area a search on Scopus was done with the term Artificial AND intelligence AND military AND wargaming while searching in the article title, abstract and key words. This yielded seventeen documents. After reading the titles the only one applicable to this research was the paper by Davis and Bracken (2022). They discusses the theoretical possibility of using AI in "political-military modeling, simulation and wargaming". However, for the scope of this thesis this was not sufficient. After consulting with a fellow researcher at TNO, the paper of Goodman et al, (2020) was received. This paper discussed the recent progress of AI in the area of gaming. They found that AI – if given enough data – can be more skillful human players in a vast array of games of which wargaming is one. Furthermore, they discuss which artificial advances would suit best by different kind of wargame-specific features. After which snowballing lead to the papers of Sun et al. (2022) and Kitchen et al. (2022). In the paper of Sun et al, (2022) they explore the application of deep reinforcement learning for combat mission planning for wargames. They found that wargaming systems based on deep reinforcement learning has significant advantages over manual wargaming in the fields of data processing, decision-making speed, strategies and thus adaptability. Kitchen et al. (2022) go deeper into the application of AI in combination with agent-based modelling. They illustrated a modelling approach that bridges various control techniques in order to provide cohesive artificial intelligent forces within simulations.

These papers prove that the implementation of AI into wargaming is not only possible, but also beneficial for the intended purpose of the wargame. For this thesis the research previously done shows the possibility of integrating AI into military wargaming and the benefits that come with the implementation.

### 1.3.2 AI in gaming

To expand on the papers found a search on Scopus was performed with the term artificial AND intelligence AND gaming. This yielded 1129 papers. To narrow it down it was chosen to only search within the article title to make the papers found more relevant. This yielded 23 results. After reading titles and abstracts one paper stood out. The paper of Verma et al, (2023) looks into the use of AI to enhance the interaction of players with non-player characters like adversaries in racing games. This bears resemblance to the implementation of AI into the adversaries of wargaming, which is why it was decided to look deeper into this topic. According to Nihalani et al. (2010) most virtual opponents are often based on a deterministic algorithm which dictates how it acts. The algorithms often work with the player provided input like layers, location or health. This would mean that adapting or adjusting the adversary or non-player character could be tweaked depending on the game mechanics. Game mechanics in this case could be movement or randomness.

By expending the definition of AI to include none deep learning methods some more results were found. One of the methods of increasing the dynamic experience in games is dynamic difficulty adjustment (DDA). This method “automatically modifies a game’s features, behaviors, and scenarios in real-time, depending on the player’s skill [level], so that the player, when the game is very simple, does not feel bored or frustrated, when it is very difficult.” according to Zohaib (2018, p1). This could be implemented in military wargaming for educational purposes as this would provide a dynamic experience. Furthermore, Dignum et al. (2009) illustrate that multi agent systems research can be used to provide nonplaying characters (NPC’s) with more natural and cognitive intelligent behavior. This in turn could be used to enhance the realism of the computer-based opponent and its adaptability to diverse scenario’s. For this thesis the research previously done proves the different approaches towards AI in an adversary role.

### 1.3.3 Wargaming for military purposes

To find what wargaming and more specifically military wargaming entails a search on Scopus was conducted with the term wargaming. Understanding military wargaming and its purpose would provide insight into the possible need for the implementation of AI. This resulted in 363 papers. Limiting the keywords to: wargaming, wargames and wargame, the result was narrowed down to 190 documents. After which it was narrowed down further by only searching within the article title. Now 87 documents remained and the most relevant once were picked based on their title and abstract.

According to Morgan (1991) the history of military wargames traces back to Sun Tzu in ancient China, with significant development in 18th-century Germany. Baron von Reisswitz's sand table wargame in 1811 influenced Prussian military training. The U.S. Navy adopted wargaming at the Naval War College, and the Korean War highlighted its role in military preparation. In the aftermath, the 2d Infantry Division actively employs wargames along the Korean Demilitarized Zone. Modern computer-assisted wargames enhance training by simulating scenarios, aiding decision-making skills. Wargames, while not predictive, offer valuable insights for military leaders, bridging the gap between historical analysis and real-world application

.

Furthermore, Lorusso et al. (2023) illustrate the importance of wargaming in teaching split second decision making in complex systems. Elg (2018) reflects on four initial conjectures about the factors influencing the form of educational wargaming, based on experiences at the Defense University in Sweden. These conjectures involve differences in wargaming patterns among countries, the impact of foreign concepts and national traditions, the role of Commercial Off-The-Shelf (COTS) games, and the connection between wargaming forms and educational processes. The author highlights the central role of individual game directors in wargaming, and the findings imply that there is complex interplay between different factors in shaping wargaming practices.

Another use of wargaming is more analytical. For example, the paper of Bruvoll et al. (2015) discusses ongoing work in Norway on Simulation-supported Wargaming for Analysis of Plans (SWAP). Traditionally, wargaming in military decision-making involves manual processes on paper maps. SWAP integrates a computer-generated force with an agent-based simulation, enhancing plan analysis by focusing on synchronizing cooperating and supporting units. The goal of the paper of Bruvoll et al, (2015) was to streamline the distribution of supporting units when needed, improving plan quality and reducing planning time. The tool utilizes a web-based interface, aligning with C2 to Simulation (C2SIM) standards for interoperability, and employs a time-managed High-Level Architecture (HLA) federation for simulation. This approach enhances the planning process, offering real-time feedback and critical information.

Another paper by the Norwegian Defense Research Establishment illustrates the benefit of simulation supported wargaming for the assesment of force structures. It enabled Evensen et al,. (2022) to assess different force structeres based on data collected during the wargaming sessions. Lastly, Pournelle (2022) illustrates the abundance of moddeling and simulation for military puroposes, but also the absence of moddeling and simulation in wargaming while stating the importance of wargaming in the military.

For this theses the previous research found illustrates that the current state of wargames is steadily moving towards a more digital environment including more simulation. Furthermore, the rise of AI into wargaming is present and useful. This means that there is a need to include the growing complexity of wargaming into the next generation of wargaming.

### 1.3.4 Knowledge gap and research question

The literature review has pointed towards existing literature exploring AI in gaming, wargaming in military training and the integration of simulation into wargaming. While AI in gaming has been progressing with more advancements looming on the horizon its application in military wargaming remains to fall behind with only a limited number of academic papers indicating a possibility and feasibility. Furthermore, with wargaming being one of the oldest and widespread tools available to militaries across the world it fulfills an important role. However, as illustrated in the literature review there is still potential for advancement with integration of AI and multi agent systems.

Based on this information the knowledge gap in this case lies in the crossing between AI, wargaming and their integration. The integration of AI has proven possible and feasible yet remains largely unapplied and case dependent. To address the knowledge gap this thesis aims to develop a framework for the implementation of AI into military wargaming. That is why this thesis will aim to merge the knowledge of these fields. The aim of this thesis is to develop a practical and guiding framework to support wargame developers with the implementations process. The importance of this was further stated by Goodman et al. (2020) who already mention that the development of a wargame AI framework could open the door for further exploration and application of AI into military wargaming. Furthermore, this thesis is commissioned by TNO. Taking the literature review and the research objective of TNO into account the following research question was formulated:

“Which framework can guide wargame developers in the field of AI and military wargaming through the implementation process?”

## 1.4 Research Approach , sub questions and research methods

This thesis results in the design and demonstration of a practical and guiding framework. Which in turn would make the implementation of AI into wargaming more accessible. It was decided to design a practical and guiding framework as this would provide tacit insights for wargame developers. For this purpose the design science approach by Johannesson & Perjons (2021) is very suitable for this approach. More specifically this approach is a good fit as it specifically looks into design science research in information systems which in the case of this research is AI systems. The researchers provide a framework for design science which includes six steps: Explicate Problem, define requirement, design and develop artifact, demonstrate artifact, evaluate artefact, and communication. Formulating these steps as research questions will systematically outline this research objectives. Furthermore, as both demonstration and validation is done towards experts and with experts it was chosen to merge these into one sub question. Lastly, the communication phase will also be integrated with the demonstration and validation phase as, this thesis is published in the TU Delft repository and the TNO repository. Furthermore, this section will also explain the methods used to answer the sub questions.

1. In the case of this research the problem identification focusses on what the problem is and what the value of the perceived solution is. Furthermore, requirements for a to be designed artifact are identified. Resulting in the following sub question:
    i. What are the current challenges and constraints in the implementation of AI into military wargaming and how can they be addressed?

    This question is answered by means of a literature review. A literature review suits best as it is the most accessible method of gaining insides to the scientific actualities in the subject area. This is also supported by Snyder (2019) which states that a literature review as a research methodology is a great way to synthesize research findings and uncover knowledge gaps, which in turn is critical for the creation of a framework. The data for this literature review is gathered by conducting a systematic approach on the Scopus research database with the key words: artificial and intelligence and military and wargaming.

2. Defining the objectives for a solution zooms in on the solution space and demarcates the boundaries. In addition, it also considers possible objectives and goals for the framework. Resulting in the following sub question:
    i. What are the requirements, that the framework aims to meet and what design principles should be followed?

    This question requires a two-pronged approach a literature review to lay the foundation of the framework and expert interviews to ensure that the framework will provide adequate value for the wargame developers. The requirements related to the AI in wargaming is deduced from the literature review done for SQ1. In addition to the first literature review, a secondary literature review is conducted to uncover the requirements related to a framework specifically. This literature review is done by conducting a systematic literature review on the Scopus research database with the key words: Objectives and Goals and Framework.

    Secondly, as a supplementary method, expert interviews are conducted to uncover the requirements of experts in the field of military wargaming to ensure the framework provides value for the subject matter experts. An expert interview lends itself for this perfectly as illustrated by van Audenhove and Donders (2019). They state that expert interviews can lead to objective knowledge. However, the researcher should take into account that experts can have a potential (subconscious) bias that can influence the outcome of the interview. The expert interviews are conducted by using semi-structured interviews with experts from TNO. The semi-structured interviews enable the researcher to ask some predetermined questions, but also allow for the interview to follow its natural flow to gain some valuable insights as per Mathers et al. (2000).

3. The design and development phase is in this thesis focuses on the development of a practical and guiding framework. This framework is based on the requirements developed in the second chapter. To accomplish this the following sub question was devised:
    i. How can the design principles and requirements be translated into a framework?

   This question requires a translation from the requirements into a practical and guiding framework. This is done by grouping the requirements together and creating phases in the framework. After the phases are devised they will be placed into a logical order and the whole preliminary framework will be tested by a use case. Baxter & Jack (2008) state that case studies provide information in supports of refining of a theory. In this research the framework would the to be refined object. The approach to this case study would be the instrumental approach. Stake (1995) states that the instrumental approach aims to gain insights into the case or to help refine a theory. This aligns well with this research as the aim of the case study would be to refine the framework and put it into action.

   Specifically in this thesis the game of Take that Hill is used. In this game one or two players command a platoon of soldiers which need to take an entrenched enemy position. The game was developed by Professor Phil Sabin for the British military (The Cove, 2023). Furthermore, the game is a relatively simple turn based table top strategy game with a limited map. The simplicity of the game and the ability to be played by two players lends itself well for training an AI model. The game can also be increased or decreased in complexity. Which in turn would enable the AI to learn in different stages. For this thesis the AI is trained by reinforcement learning on a neural network. Deep reinforcement learning was chosen, because this is the industry standard when training AI on games. Furthermore, for wargames specifically there is very little data available. To generate this data the AI will play the game by itself and learn over time what it should or should not do.

4. The demonstration and validation of the framework is important to deliver a framework valuable to wargame developers this results in the following sub question:
    i. What is validity of the designed framework?

   With the framework aiming to support subject matter experts their criteria should be considered when assessing the validity of the framework. That is why the framework is demonstrated to experts and they are asked to validate the framework at the same time. This is be done by a presentation and semi structured interviews (Mathers et al. 2000).

## 1.5 Research flow and data management plan

To visualize the structure of this research a research flow table was made. Table 2 illustrates what methods are used in various chapters of the research.

| Research Phase and chapter | Input | Process | Output | Research question | Research methods |
|---|---|---|---|---|---|
| Problem identification and motivation (chapter 1) | Academic literature on the integration of AI into military wargaming | Literature review conducted on Scopus to gain insight into the current state of AI in military wargaming. | Problem statement<br>Definition of core concepts<br>Main Research question and subquestions | SQ 1 | Literature review |
| Definition of the objectives for a solution (chapter 2) | Academic literature on the integration of AI into military wargaming<br>Expert interviews | Literature review conducted on Scopus and Interviews conducted with experts. | Requirements and objectives which the framework needs to meet. | SQ 2 | Literature review and expert interviews |
| Design and development (chapter 3) | Academic literature on the design process of a framework<br>Academic literature on the integration of AI into military wargaming<br>Take that Hill (wargame)<br>Preliminary framework | Literature review for the design process of a framework.<br>Design of the framework<br>Integration of AI into the wargame take that hill following the preliminary framework | Preliminary framework for the integration of Ai into military wargaming.<br>AI Model Framework | SQ 3 | Literature review<br>Case study |
| Demonstration & Evaluation (chapter 4) | Requirements and objectives.<br>Expert interviews<br>Presentation | Evaluation of the developed AI Model and the framework | Evaluation of the Framework | SQ 4 | Expert Interviews And Presentation |

*Table 2: Research flow table*

### 1.5.1 Data management plan

The data collected from the literature research is saved onto the non-public servers of TNO. Further information collected from the expert interviews will also be saved to the non-public servers of the TU-Delft if the interviewees give their content. The personal data collected during this research will only be available to the main researcher and to the university supervisors. Furthermore, this research has been approved according to the HREC guidelines of Delft University of Technology with the application number: 4365.

# Chapter 2: Requirements engineering

This chapter aims to define the requirements for the framework by providing insights into the objectives and goals that the framework should achieve. This will be done by answering sub question 2:

- "What are the objectives and goals that the framework aims to achieve and what design principles should be followed?"

To answer this question an exploratory literature review was conducted to build on the literature review done for SQ1. To validate the requirements and find more requirements two expert interviews were conducted. The outcome of these methods is a list of design principles and requirements for the framework.

## 2.1 Literature review

With literature on this topic proving to be scarce it was decided to uncouple the topics and do small exploratory literature reviews on the topics of framework design, wargame digitalization, artificial intelligence development, and artificial intelligence in gaming.

### 2.1.1 generic requirements for the framework design

For this topic the key words conceptual framework development were used to find papers on Scopus. After looking through the sources of several papers the paper of Hills and Gibson (1992) was found. From there paper several requirements for which are valid for nearly all conceptual frameworks were deduced. Thus it was decided that the practical and guiding framework being developed in this thesis is required to meet these requirements:

1. The framework must build on the work of other authors to integrate their knowledge into a practical and guiding framework.
   This requirement aims to ensure the academic value of the designed framework.
2. The framework must indicate its purpose.
   This requirement aims to inform the wargame developers what the framework should be used for.
3. It must be clear to what system of interest the framework is applicable.
   This requirement aims to inform the wargame developers what cases the framework can be used for.
   Furthermore, this requirement must provide guidance for the selection of data, training method and algorithm.
4. The framework must specify the process needed to navigate the framework.
   This requirement ensures that the person using the designed framework can use the framework as a whole to increase the value of the framework.
5. The framework must suggest an approach which entails the angle of which the framework approaches the process.
   This requirements aims to align the views of the wargame developers with the intended vision of the framework.
6. The framework must illustrate the needed competences to successfully apply the framework.
   This requirement aims to inform the wargame developers which competences are needed to ensure successful use of the framework.

### 2.1.2 wargame digitalization

The key words wargame digitalization yielded no results on Scopus. Thus it was chosen to continue with the key words game digitalization. This yielded 591 results. Limiting to English and Digitalization gives 124 results. Limiting to article titles gives 8 results. Not limiting to digitalization gives 25 results none of which were useful. After this the key words were changed to digitizing board games which resulted in the paper of Rogerson et al, (2015). This paper first stated that it is important to understand the game and its mechanics before one should attempt to digitize it. This part only focusses on requirements for specifically game digitalization. From the paper of Rogerson et al, (2015) the following requirements were deduced:

7. The framework must provide guidance in finding the balance in the trade-off between the authenticity of the game and the amount of digitization needed.
   This requirement aims to keep the digitized wargame as close to the original version as possible.
8. The framework should provide guidance in finding the level of abstraction needed for the digitization process.
   This requirement also aims to keep the digitized wargame as close to the original version as possible.
9. The framework must provide a handle for the correct digitization of the randomness of a game.
   This requirement aims to provide insight into the stochastic parts of the wargame.

After snowballing the paper of Paul (2011) was found. He speaks about the impact of digitalization on the gameplay and that digitization often shows imbalance of game mechanics or artifacts. This according to him leads to a shift from playing the game for sheer entertainment value to an approach aimed at the optimization of the gaming process itself. From Paul (2011) two relevant requirements were extracted:

10. The framework should provide guidance on tackling game breaking imbalances during the digitization process.
    This requirement aims to balance the wargame before the AI is implemented as AI often finds exploits in games that are not balanced.
11. The framework should provide insight into game mechanics leading to theory crafting.
    This requirement aims to keep intended way of playing the wargame intact. Theory crafting is an analytic process where often players try out and test mathematical simulations to uncover underlying game mechanics. Theory crafting is not beneficial to the intended goals of the wargame. As it takes away from the learning objectives a wargame has.

### 2.1.3 Artificial intelligence development

With this thesis focusing on reinforcement learning the search was narrowed down to the key words: artificial intelligence AND reinforcement learning. This yielded the paper of Barto & Sutton (1997). This paper aims to provide insights into the concept of reinforcement learning. Requirements deduced from this paper are:

12. The framework must provide insight into the simplification process used to enable the algorithm to learn in steps.
    This requirement aims to support the wargame developer in taking the correct steps in simplifying the implementation to enable it to be done in steps while preventing oversimplification.
13. The framework should provide guidance in the ways the algorithm can be altered to ensure the usefulness of the algorithm.
    This requirement aims to support the wargame developer in the implementation process. With reinforcement learning the only way to alter the outcome is to alter the algorithm this is why it needs extra guidance.
14. The framework should provide insight into resource requirements for the development of an artificial intelligence algorithm.
    This requirement aims to inform the wargame developer on what resources would be required for their scale of implementation. This is important as the training of a reinforcement learning model takes significant amounts of computing power.

### 2.1.4 Artificial intelligence in gaming

The paper of Pearce & Zhy (2022) explores the implementation of deep neural networks into the popular game “CSGO”. The most interesting part of this paper is that they trained the AI only on input a human player would also receive. This in turn leads to the development of human like behavior in the game. Furthermore, they illustrated the lack of data they could process for their research and were forced to use a lower quality. From this paper one requirement was deducted:

15. The framework should provide an insight as what the impact of different quality of data would have on the algorithm.
    This requirement aims to uphold the quality of the output of the model.

Furthermore, when using the key words artificial intelligence in board games Scopus showed 324 results which after scanning the titles, were deemed not useful. Using google scholar the paper of Mesentier et al (2017) was found. This paper focusses on the possibility of using AI for playtesting of contemporary board games. This connects the digitization of the wargame with the eventual implementation. From the paper of Mesentier et al (2017) two requirements were come up with:

16. The framework should provide a way to assess the degrees of freedom the wargame has.
    This requirement aims to inform the wargame developers on possible complications that arise when implementing AI. Mainly on the complexity as more degrees of freedom make the implementation harder. In addition to making the implementation harder, the degrees of freedom in the wargame also have an exponential impact on the training time of the AI.
17. The framework must illustrate the impact of change in the algorithm or game.
    The training of AI is a very delicate process any change in the algorithm or game could have the AI behave completely different. That is why this requirement aims to inform the wargame developer about possible issues arising from change.

Lastly, using the key words artificial intelligence in board games on Google Scholar the paper by Gomes-Maureira et al (2020) stood out. Their paper aims to lay the groundworks for a taxonomy of AI in hybrid board games. More interestingly this paper focused on the interaction between digital and physical aspects of a game. With the purpose of a wargame being its most valuable aspect this is an important factor. This resulted in the following requirement:

18. The framework must provide insight into the interaction between digital and (semi)physical domains of the game.
    This requirement aims to provide insight to the wargame developer to keep the purpose of the physical wargame as intended in the digitized game.

## 2.3 Design principles

From the literature three distinct design principles were devised to focus on the framework, wargame digitalization and AI development:

1. Design principle for framework development

Principle: Academic design for a tacit framework
Description: The framework should build upon existing research and expert knowledge to create a comprehensive and cohesive guideline. It must incorporate diverse perspectives and findings to enhance its academic validity and real world applicability.
Rationale: This principle ensures that the framework leverages established theories and practices for the development of a framework, thereby enhancing its academic and practical value. Furthermore, this principle encompasses requirements 1 through 6.

2. Design principle for wargame digitalization

Principle: Authenticity preservation for wargame digitalization
Description: The framework should maintain the mechanics, intent and purpose of the original wargame during the digitalization process. It must provide guidelines to balance authenticity and necessary digital enhancements to enable AI integration.
Rationale: Preserving the essence of the original wargame ensures that its educational or strategic objectives remain intact. This principle helps in achieving the digitalization of the wargame to enable AI integration. Furthermore, this principle encompasses requirements 7 through 14.

3. Design principle for AI development

Principle: Iterative simplification for AI development
Description: The framework should support an iterative process for simplifying the AI implementation, ensuring that each step is manageable while preventing oversimplification. It must provide clear guidelines for resource allocation and algorithm adjustments.
Rationale: AI development, particularly reinforcement learning, requires a step-by-step approach to manage the development of the algorithm. This principle ensures that the implementation is feasible and efficient, allowing for gradual refinement and optimization of the AI model.
These principles guide the development of a robust, tacit, and manageable framework that integrates AI into military wargaming effectively. Furthermore, this principle encompasses requirements 15 through 18.

## 2.4 Interview Protocol

To ensure wargame designers find the framework valuable for their implementation purposes two expert interviews were conducted. The interviews had the objective to provide new requirements and validate the existing ones. To setup the semi-structured interviews the paper of Newsomer et al, (2015) was used. They state that semi-structured interviews are particularly well suited for situations where multiple open-ended questions might require follow-up questions. Which is the case in these interviews. Furthermore, to keep the wargame designers as open minded as possible the questions designed to slowly introduce the designers to the topic of implementation of AI into military wargaming and their expert opinions on the requirement found previously. Furthermore, the experts were selected by their experience in the fields of AI and wargaming. The interviewees are asked for their consent using an informed consent form. In the table below more details are provided. The information gathered from the interviews was analyzed by using conversation analyses as per Talja (1999). This analysis aims to generate insights while taking into account the interviewees personal experiences.

| Interviewee | Experience | Date | Medium |
|---|---|---|---|
| 1 | 10+ Years | 13-6-2024 | Face to Face |
| 2 | 10+ Years | 13-6-2024 | Face to Face |

*Table 3: Interviewee information*

### 2.4.1 Questions

The first questions are designed to ask them about previous experience in the fields of AI and wargaming. To gauge the experience they had and what angle they would look at the requirements at.

Have you worked with wargames before, if yes in what capacity?

Have you worked with AI before, if yes in what capacity?

The second set of questions are designed to ask them about their view regarding possible solutions and hurdles concerning the implementation of AI into military wargaming.

In your eyes what could be potential benefits of implementing AI into military wargaming?

In your eyes what could be potential hurdles during the implementation process?

With the experts now thinking about benefits and potential hurdles a question is designed to ask them about what requirements they would have for a framework guiding military wargame developers with the implementation of AI into their wargames.

In your eyes what would be requirements regarding a framework designed to guide wargame developers during the implementation process?

The last set of questions are designed to specifically ask them about the previously developed design principles and requirements.

What do you think about these design principles?

What do you think about these requirements?

### 2.4.2 Results

Interviewee one was positive about the requirements thus far, but found several valuable additions. These requirements concerned both requirements for the framework as a whole as well as requirements for the digitization of the wargame. The requirements regarding the framework focused on promoting interoperability between the implementation of AI into a wargame and other simulation models being used in the wargame. Secondly the interviewee illustrated the need for security concerning final product ensuring it does not fall into the hands of malicious persons. Lastly, the interviewee mentioned that the aspect of time should play a bigger role as it is important during the development process as well as the use of the final product.

Interviewee two was also of the opinion that the aspect of time should play a bigger role in the framework. Furthermore, the interviewee also mentioned the need for some kind of benchmarking for the performance of the AI. Lastly, the interviewee mentioned that including the doctrine or behavior of opposing is beneficial for the development of the AI. Together with the interviewees several requirements devised a full report of the interviews can be found in appendix A.

From the interviews the following requirements were derived for the framework:

1. The framework must provide the wargame developer with guidance to ensure the security of the model.
   This entails the operational security during use of the model, but also the data used during the development process.
2. The framework should provide the wargame developers with guidance on where to implement the Ai in the wargame.
3. The framework could provide the wargame developers with the possibility to update the framework in the future.
4. The framework must take into account the aspect of time.
   This entails the time it take to build and train the model. Furthermore, it also entails factors such as the time it takes to setup the AI while deploying the wargame and the response time of the AI.
5. The framework would need to provide the wargame developers with the insights needed to source data for the training of their AI model.

For the wargame digitalization the following requirements were derived from the interviews:

6. The framework must provide the wargame developers with the insight that the focus of a wargame is to keep the players thinking and learning.

For the development of the AI the following requirements were derived from the interviews:

7. The framework should provide the wargame developers with guidance on how to implement the behavior the AI should replicate.
8. The framework should provide insight into the effect of different quality of data on the quality of the AI.
9. The framework should provide insight into the process of benchmarking the AI.
10. The framework must provide guidance into the verification and validation of the AI.

## Conclusion

The focus of this chapter was answering the question: "What are the requirements that the framework aims to meet?" To answer this question three design principles and various requirements were devised. To provide insight they are listed and grouped in table 4. It must be noted that grouping these requirements in strictly three groups does not illustrate the dependence between some of these requirements which can stretch multiple design principles. The requirements were prioritized using the MoSCoW method as used by Kravchenko et al, (2022). MoSCoW was chosen, because it gives insight into the priority certain requirements have over other requirements. Furthermore, to illustrate where the requirements originate from the source is added in the last column.

| Design principle | Requirement | Source |
|---|---|---|
| An academic design for a framework | 1. The framework must build on the work of other authors to integrate their knowledge into a conceptual framework. | Hills and Gibson (1992) |
| | 2. The framework must indicate its purpose. | Idem |
| | 3. It must be clear to what system of interest the framework is applicable. | Idem |
| | 4. The framework should specify the process needed to navigate the framework. | Idem |
| | 5. The framework should suggest an approach which entails the angle of which the framework approaches the process. | Idem |
| | 6. The framework must illustrated the needed competences to successfully apply the framework. | Idem |
| | 7. The framework must provide insight into resource requirements for the development of an artificial intelligence algorithm. | Barto & Sutton (1997) |
| | 8. The framework must provide the wargame developer with guidance to ensure the security of the model. This entails the operational security during use of the model, but also the data used during the development process. | Interview 1 |
| | 9. The framework should provide the wargame developers with guidance on where to implement the AI in the wargame. | Interview 1 |
| | 10. The framework could provide the wargame developers with the possibility to update the framework in the future. | Interview 1 |
| | 11. The framework must take into account the aspect of time. This entails the time it take to build and train the model. Furthermore, it also entails factors such as the time it takes to setup the AI while deploying the wargame and the response time of the AI. | Interview 1&2 |
| | 12. The framework would need to provide the wargame developers with the insights | Interview 2 |

| | | |
|---|---|---|
| | needed to source data for the training of their AI model. | |
| Authenticity preservation for wargame digitalization | 13. The framework must provide guidance in finding the balance in the trade-off between the authenticity of the game and the amount of digitization needed.<br>14. The framework should provide guidance in finding the level of abstraction needed for the digitization process.<br>15. The framework must provide a handle for the correct digitization of the randomness of a game.<br>16. The framework should provide guidance on tackling game breaking imbalances during the digitization process.<br>17. The framework should provide insight into game mechanics leading to theory crafting.<br>18. The framework should provide insight into the interaction between digital and (semi)physical domains of the game.<br>19. The framework must provide the wargame developers with the insight that the focus of a wargame is to keep the players thinking and learning. | Rogerson et al, (2015)<br>Idem<br>Idem<br>Paul (2011)<br>Idem<br>Maurerira et al, (2020)<br>Interview 1 |
| Iterative simplification for AI development | 20. The framework should provide the wargame developers with guidance on how to implement the behavior the AI should replicate.<br>21. The framework must provide insight into the simplification process used to enable the algorithm to learn in steps.<br>22. The framework should provide an insight as what the impact of different quality of data would have on the AI.<br>23. The framework should provide a way to assess the degrees of freedom the wargame has.<br>24. The framework must illustrate the impact of change in the algorithm or wargame.<br>25. The framework should provide insight into the process of benchmarking the AI.<br>26. The framework must provide guidance into the verification and validation of the AI. | Interview 2<br>Barto & Sutton (1997)<br>Interview 1<br>Mesentier et al, (2017)<br>Idem<br>Interview 2<br>Interview 1&2 |

*Table 4: Design principles and requirements*

This section aimed to answer the question: "What are the requirements that the framework aims meet and design principles need to be followed?". With the previously established design principles and requirements this question is answered. While it is clear what purpose these requirements serve for the rest of the thesis, the academic value of these requirements and the requirement engineering is not to be underestimated. The process used for these requirements illustrates the added value of expert interviews with 10 of the 26 requirements stemming from the interviews.

# Chapter 3: Framework development

This chapter aims to answer SQ3: “How can the design principles and requirements be translated into a framework?”. This is done by developing a preliminary framework based on the requirements and following it up with a use case. The use case aims to uncover new parts of the framework which are not apparent from the theory alone. This results in a framework that is applicable to the implementation of AI into military wargaming.

## 3.1 Phase development

The preliminary framework is based on the literature searches conducted in chapter 1&2 and expert interviews. To start, the framework was divided in two sides. The left side is focused on the wargame and the digitization of the wargame and the right side is for the AI and development of the AI. After this the requirements were used to develop several phases for the framework. This division was made as in some cases the wargame is already digitized this would mean that that side of the framework can largely be omitted.

Firstly, the focus was on the digitalization of the wargame. This started with the “Understanding the purpose of your wargame” phase was devised which is based on requirement 19. The second phase concerning the digitalization of the wargame was the “Understanding the mechanics of your wargame” phase. This phase is based on requirements 15, 16 ,17 and 23. Logically, before starting the digitization process a planning phase is a must. This lead to the “Planning the digitization of your wargame” phase. This phase is based on with requirements 6, 7, 11, 13, 14 and 18. Lastly, the “Digitalization of your wargame” phase was developed. This phase is not linked to a specific requirement, but is necessary for the completion of implementation process.

For the AI side of the implementation several other phases were deduced. Firstly, the “Understanding the purpose of your Artificial Intelligence” phase was created. This phase is based on requirement 9. As with the digitization of the wargame the development phase has to be preceded by a planning phase. This is where the “planning the development of your Artificial Intelligence” phase was developed. This phase contains requirements 6, 7, 11, 20, 21, 22 and 25. Lastly, the AI needs to be developed. The development takes place in the “Development of your Artificial Intelligence” phase. This phase is based on requirements 12 and 24.

Two phases merge both the digitalization and the development of the wargame and the AI. The first is the overall “Implementation of the AI into the wargame” phase. This phase is based on requirement 26. Secondly, the “Maintenance, security and updates” phase is also combined as it entails the final product. This phase is based on requirement 8.

## 3.2 Preliminary framework

Based on the phases developed in section 3.1, a preliminary framework was developed. This was done by finding a logical order in which these phases should take place. This was done by sketching the framework and logical thinking. As mentioned the planning phases come before the development phases. This framework gives a comprehensive overview of the implementation process and guide the wargame developers through the use of the framework by acting as a high level flow chart. Some tasks can be done in parallel, for example the planning phases, while others must be done sequentially for example the development phase after the planning phase. Lastly, as the development of AI and maintenance are inherently iterative there are a feedback loops in those steps. Furthermore, the preliminary framework is extended and refined by using a use case where an AI is implemented into a digitized version of “take that hill”. The preliminary framework can be found in figure 1.

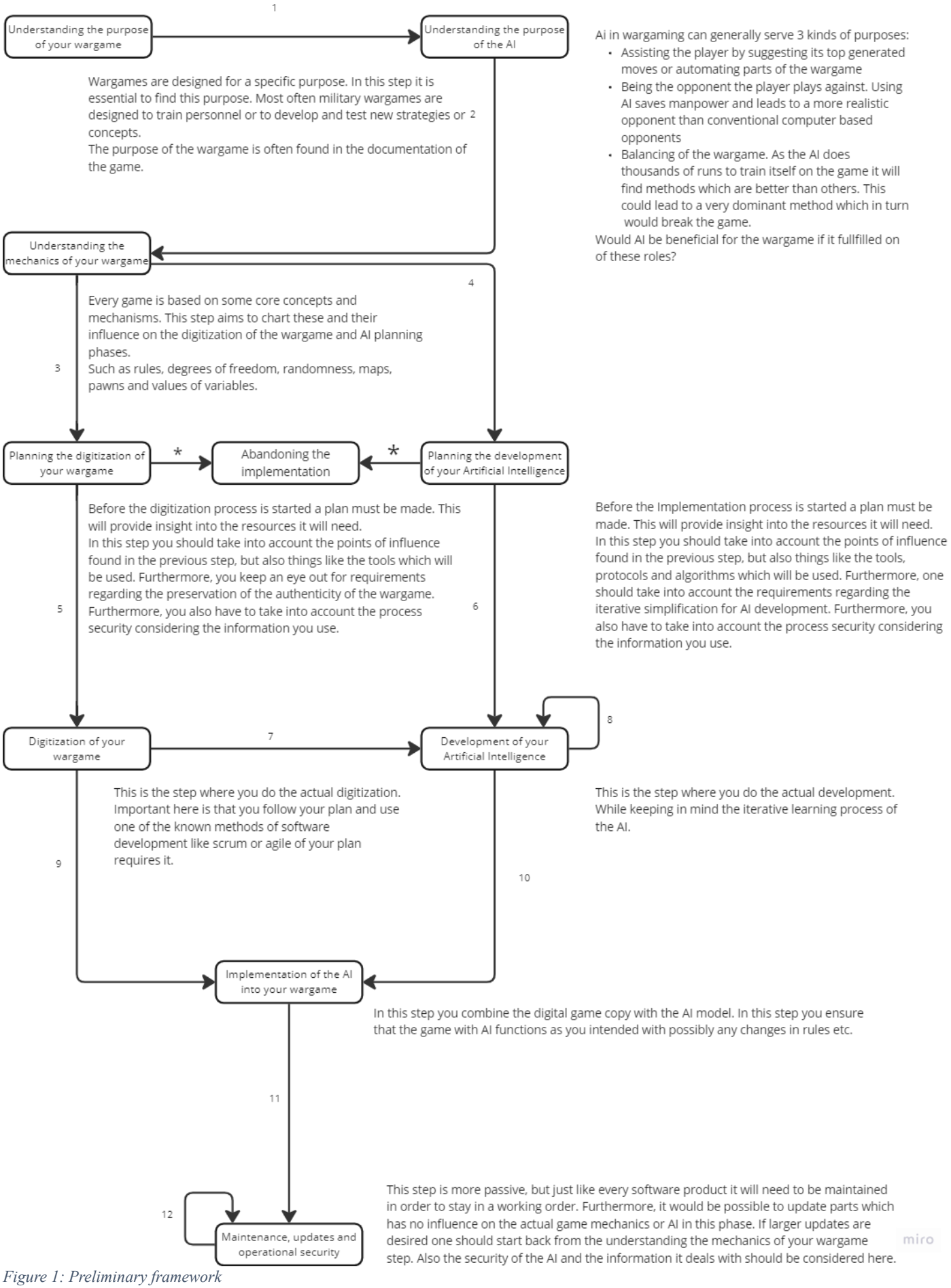


*Figure 1: Preliminary framework*

Explanation of the arrows:

1. After you find the purpose of your wargame it is important to find why you want AI and what you want the AI to achieve.
2. After you have decided on the purpose of the AI it is important to start thinking about how the implementation and development of the AI will take place. To do this one needs to know the inner workings of the wargame.
3. After the wargame has been analyzed one can start to plan the digitization of the wargame. This can be done in parallel to the planning of the development of the AI.
4. After the points with impact on the development of the AI have been identified one can start planning the development of the AI. This can be done in parallel with the planning of the digitization of the wargame.
5. After a plan of action has been devised one can start the digitization of the wargame.
6. After a plan of action has been devised one can start the development of the AI. However, the actual training of the AI has to wait until the minimum digitization has finished.
7. Once the minimum digitization for the AI development has concluded one can start to train the AI on the game.
8. The training and development of the AI has to be done in steps which means this step feeds itself and is iterative.
9. After the remainder of the game is digitized one can move forward towards the implementation.
10. After the AI is trained and ready to be implemented one move forward towards the implementation.
11. One the AI is successfully implemented one should shift the focus to maintaining and possible upgrading the AI when necessary.
12. Like most software packages the AI must be maintained continuously.

The * arrow is only used when during the planning phase of the digitization or the AI it is decided that the resources needed do not outweigh the potential benefit of the implementation of AI.

## 3.3 Use Case

The goal of the use case was to expend and enhance the framework. This was done by a walkthrough exercise following the previously developed framework, while implementing AI into "Take That Hill". It was chosen to do it this way, because this simulates how a wargame developer goes through the framework. This way the framework based on literature and expert interviews was translated into a framework that can be used by a wargame developer.

### 3.3.1 Preconditions for the usage of the framework

The purpose of this framework is to guide a wargame developer during the implementation of AI into the digitized wargame. Furthermore, the user of this framework must take into account the approach needed to understand the angle of which the framework approaches the process. This framework approaches the implementations of AI into military wargaming from the eyes of a wargame developer. Meaning that the framework focusses on the process as a whole and is understandable to people with limited knowledge of digitization or AI development. When using a purely physical wargame some digitization is required to take place before the AI can be implemented. In the case that the wargame is already digitized it is required to look into the possibility of implementation of AI into this digitized version of the wargame.

This framework aims to be applicable to military wargames of any nature. This can range from real time to turn based wargames and everything in between. To navigate this framework one is ought to start from the "Understanding the purpose of your wargame" and finish at the "maintenance security and updates" phase. With the exception being when the decision is made to abandon the implementation. When working on larger projects or with larger teams several phases can be done in parallel. Such as the "Planning the digitalization of your wargame" and the "Planning the development of the AI" phases. Lastly, once a minimal viable product has been produced in the "Digitization of your wargame" phase, one is able to start the "Development of your AI" phase.

### 3.3.2 Understanding the purpose of the wargame

Wargames are designed for specific purpose. In this step it is essential to find this purpose. Most often military wargames are designed to train personnel or to develop and test new strategies or concepts.
In the case of take that hill the game was developed to teach new commanders the concept of dismounted infantry platoon attack. From the manual (The Cove, 2023): "*Take That Hill can be used in a classroom setting as a vehicle to encourage discussion and prompt the level of knowledge around fire and movement, fire support coordination and, command and control (C2). This wargame does a number of things well. It highlights the binary nature of fire and movement (one precludes the other but also requires the other) and the difficulties of sequencing this in reality vs in planning. It encourages an adaptive mindset rather than a rigid adherence to a plan; switching sections around to maximize their fire or movement potential based on a turn by turn appreciation of the situation. It acutely demonstrates the whims of chance in combat – you can't be certain that your fire will suppress the enemy and in turn that you may be lucky and not get hit doing a risky move. It also enables a debate on the positioning and relationship of the Pl HQ to the sections in maintaining momentum (though perhaps some would disagree with how this is precisely modelled*)."

Furthermore, to develop a feeling for how the game works and its purpose it is beneficial to play the game before moving on to the next step. Especially if it is not a game the wargame developer has made. This will also help retain the purpose and authenticity of the wargame in later phases.

### 3.3.3 Assessing the need for AI

As developing and implementing AI is a time intensive and costly process it is important to first decide whether AI is needed in the first place. Improving a wargame can be done by integrating simulations or other types of machine learning algorithms besides deep learning. The wargame developer must make a choice whether or not their wargame requires AI to meet the purpose of their wargame. However, the implementation of AI can also be abandoned at a later stage. This means that in case of doubt the wargame developer can still decide to move forward.

**Use case**

*For "Take That Hill" it was decided to go forward with the implementation. This was based on the fact that "Take That Hill" has been evolving since its inception with the addition of more complex elements such as support weapons and mortars. To keep this trend going it was decided to go for the next step and implement AI into the wargame. Furthermore, the core mechanics of the wargame have been left unchanged since it inception. Which in itself is another reason to try and find a way to keep the wargame relevant. In this case with the implementation of AI.*

### 3.3.4 Understanding the purpose of your AI

This framework focusses on deep learning AI this means that the AI uses an algorithm with a neural network to learn. As seen in figure 2 the AI can have three purposes: Assisting the player, being the opponent and validation of the wargame. These three purposes stem from the literature review and expert interviews. Firstly, assisting the player can be done in two distinct ways. The first is classification and the second is optimization. In the case of wargaming the classification entails the interpretation of data. An example of this would be the AI identifying enemy units using sensor data (drones, radar, etc.). This helps the player make informed decisions. Optimization could take place in for example resource allocation. An example of this could be suggesting to deliver supplies via a safe yet fast route. Being the opponent would require the AI to clone the desired behavior of an opponent. An example of this would be the opponent reacting to the type of units it has under its control. Behaving differently when it's an armored brigade vs when it is an air assault brigade. Lastly, AI can be used to test the validation of this game. This would be done by having the AI play the game over and over again until it finds an optimized strategy, which in turn could be used to see what parts of the game work or do not work. An example of this would be the AI taking a route which makes it less probable to be intercepted.

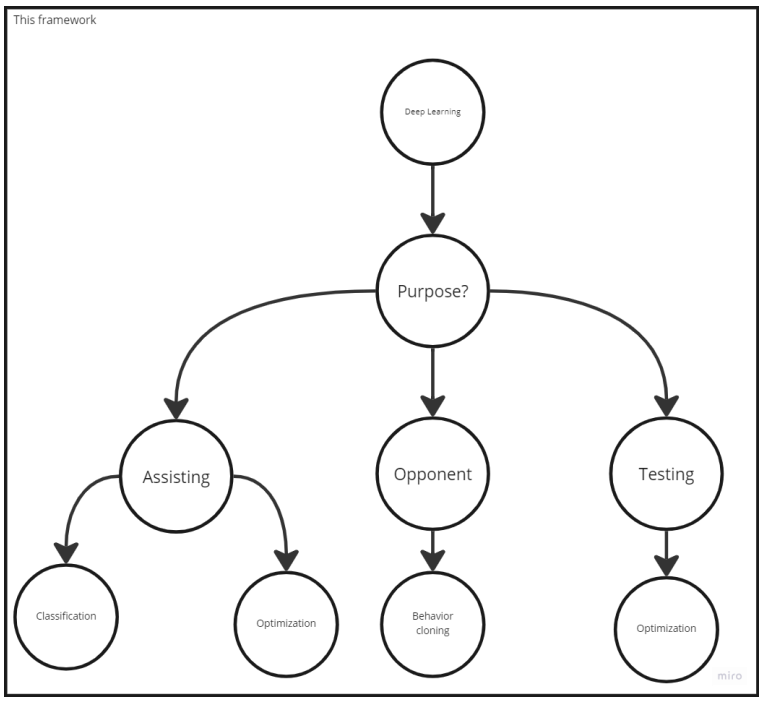

*Figure 2: AI purpose*

**Use case**

*In the case of "Take That Hill" the AI is developed to find the imbalance of the game. Aiming to improve the wargame and better the purpose of the game. This means that the use case is a validation of the wargame. It was chosen to validate this game as it is old and could benefit from updates. Furthermore, this wargame is relatively simple making it less complex to implement AI into the wargame..*

### 3.3.5 Understanding the mechanics of your wargame

Game mechanics are the rules and systems that define how a game works and how it is played. Understanding the mechanics of the wargame can be done by several methods. First of all, playing the game would provide insights into how the game works. Furthermore, reading the documentation of the game such as the rules and the components of will provide insights into the reasoning behind some of the mechanics. Lastly, combining these methods will also provide insights into possible limitations of the wargame.

Knowing these factors enables the wargame developer to understand what the randomness in the wargame is. Furthermore, it will also provide insights into mechanics which can lead to game breaking imbalances during the digitization process or theory crafting. Lastly, understanding the mechanics of the wargame will provide insight into the degrees of freedom of the wargame, which will help the development of the AI.

**Use case**

*In the case of "Take That Hill" players command an infantry platoon tasked with destroying an enemy section positioned on a hill. The game's components include a game board, counters representing friendly (blue) and enemy (red) units, six sided dice, and markers for recording hits and turn progression.*

*Playable in both solo and head-to-head modes, players can control either the friendly (blue) or enemy (red) forces. The game board is divided into hexagonal grids that represent various terrains. Each game turn is segmented into four phases: movement, firefight, rally, and enemy action. These phases structure player decisions, with all actions within a turn occurring concurrently. However, the players need to choose between movement or a firefight.*

*During the movement phase, blue elements move to adjacent hexes, while the firefight phase involves attempts*

*to suppress the enemy. The rally phase allows spent (used) blue elements to refresh, restoring their ability to act, and the enemy action phase dictates the red forces' responses and attacks. Victory conditions are determined by the number of turns elapsed and hits incurred, with specific criteria for winning, drawing, or losing the game.*

*The game setup involves positioning the enemy counter on a designated hex and allowing players to strategically place their blue counters. As the game progresses, players navigate through the phases of movement, firefight, rally, and enemy action. Lastly, the full document containing the rules can be found in the appendix B.*

### 3.3.6 Planning the digitization of your wargame

To be able to make a planning several factors must be considered. Firstly, a list of competences must be made to ensure the ability to finish the digitization of the wargame. These competences can vary from wargame design experience to coding experience. Secondly, an assessment must be made to decide what factors of the game to digitize. Minimizing the digitization will retain more of the authenticity. Furthermore, during this process one must consider the interaction between digital and physical aspects of the wargame. An example of this could be the use of simulators to decide the outcome of a battle while the wargame takes place on a board. Lastly, the resources needed to complete the development must be assessed. This ensures the digitization can be developed. Resources means anything required for this digitization to be realized. Examples could be: budget, working hours and hardware. Lastly, an approach must be chosen. Commonly in the digital domain the approaches are either agile or waterfall. The agile approach aims at delivering small changes frequently. This enables reacting to changing requirements or adapting to feedback (Foster, 2021). Waterfall on the other hand is focused on linear and sequential development. This requires less feedback and often works best in projects with well-defined requirements (Foster, 2021).

**Use case**

*The competences needed for this digitization is limited as it is a fairly simple game without many complex aspects. For this implementation a basic knowledge of python or another programming language suited for digitization of wargames suffices. Another competence needed is at least basic knowledge of wargame design. The resources needed for this digitization are also limited a programmer with basic knowledge of python can create a minimal viable product for the development of the AI in approximately 3 weeks of fulltime programming. As for software resources an environment which can run python is a priority. In this case visual studio code was used.*

*For this use case an agile approach was used. By dissecting the bigger digitization into smaller sections to enable smaller but clear goals. This ensures that a minimal viable product is ready to be used for the AI development and training as soon as possible. Furthermore, this provides more adaptability during the digitization process as the framework is not finalized and subject to change.*

*Furthermore, to promote interoperability between the wargame and AI write in the same programming language. It was also decided to remove two parts from the game to limit the amount of randomness in the game. The first part to not be included in the digitization was the platoon HQ. This unit does not provide any combat capabilities and the bonus to rallying is not realistic (US Army, 2007). The second part which was decided to remove from the game was the hit points. This was removed, because hitting the units is based entirely on the roll with the die. This means the player has very limited influence on being hit. Which in turn does not help with the purpose of the wargame, because the player needs to learn about fire an movement and not on how to not get hit. An important* ***activity*** *that takes place is this phase is looking for preexisting digitization efforts. In the case of "Take That Hill" there was a digital copy available in a game simulator called "Tabletop Simulator". However, this simulator did not provide support for the implementation of AI as there was no modification ability or application programming interface. Lastly, another* ***activity*** *that takes place in this step is choosing a programming package. For the wargame it was chosen to digitized the wargame with the python package called Pygame.*

### 3.3.7 Planning the development of your artificial intelligence

Much like the digitization of the wargame the development of the AI needs a list of competences and resource allocation is required. Additionally a closer look is needed on the aspects of time, simplification process, impact of data quality and benchmarking the AI. The aspect of time entails the time it takes to build and train the model. In addition, it also entails factors such as the time it takes to setup the AI when preparing the wargame and the response time of the AI. Furthermore, one should choose an approach to the development. As mentioned before classic approaches for software development are Agile and Waterfall. In the case of AI development an Agile approach is more favorable as the development and training is very iterative and requires small simple steps to gradually improve the AI. This phase also has to take into account what kind of data is used to train the AI and what impact the data quality approximately has on the AI. Another important factor is the creation of key performance indicators (KPI's). This enables the benchmarking of the AI. An example of a KPI would be the response time between command and response. Lastly, one must take into account that the AI must be able to be trained on the digitized version of the wargame. This means that if the game is digitized in python the AI can be written in Python. If another language is used it might be necessary to build a conversion tool to facilitate the interaction between the AI and the digitized wargame.

After a general planning has been made one must think of several AI specific factors for the development. This includes the tradeoff between providing the AI with guidance or letting the AI make connections itself. An example of this would be providing the AI with a path finding algorithm or letting it find a path to the target itself. Another factor to take into account are the objectives and rewards for the AI, what are the objectives the AI aims to achieve and what are rewards the AI gets for achieving the objectives. Furthermore, planning for the training of the AI is also beneficial as training an AI costs a considerable amount of computing power.

**Use case**

*In the case of "Take That Hill" several competences are required. Firstly, similar to the wargame digitalization a basic knowledge of programming is required. More specifically to ensure the interoperability between the wargame and the AI a basic knowledge of python is required. Furthermore, as this entails the development of an AI basic knowledge of the development and training of AI is also required. Concerning the resource allocation the developer (and researcher) has a timeline of about 12 weeks to develop and train the AI. As for the approach taken for the development it was chosen to adapt an Agile approach as this fits the iterative process of building small functionalities. Data quality does not play a role in this case as the AI is generating its own data when training. With the purpose of this implementation being validation of the wargame there is no need for the creation of KPI's. An important* ***activity*** *in this step is choosing a programming language. The programming language chosen for the development of the AI is python. Python was chosen as it the wargame is digitized using Python and Python has existing packages for the development of AI. The package used is called Pytorch.*

*The objectives the AI will have are moving towards the target, shooting at the enemy force and winning before round 16. Moving towards the target is an objective, because the AI will need to move to have a chance at winning. Shooting at the enemy force will help the AI suppress the enemy rendering the enemy unit unable to stop the moving units. Lastly, winning before round 16 is the largest and final objective as this was taken from the rules where the game ends after 16 rounds. The training of the AI is done on a Intel(R) Core(TM) i5-8365U CPU @ 1.60GHz 1.90 GHz processor as this is what TNO provided.*

### 3.3.8 Digitization of your wargame

In this phase the focus lies on digitizing the wargame as planned. Using the correct amount of simplification and dividing the wargame into smaller sections.

**Use case**

*In the case of "Take That Hill" the wargame was divided in several sections. These sections were based on the manner of which the wargame is supposed to be played. These sections were: Setting up the wargame environment, creation of units, implementing the actions and building a running game.*

*Firstly, the hex map was created. This was done by creating six sided hexes in the same pattern as the original map. After rotating the hexes the map can be seen in figure 3:*

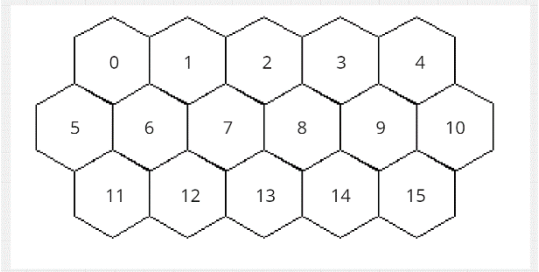


*Figure 3: Hex map*

*After the map the units were created. These consisted of 3 blue units and 1 red unit. The blue units start on the hexes 0, 5 and 11 and the red unit starts on hex 10. In the first instance all blue units were depicted with blue circles. This lead to confusing situations when looking at the board. This was solved by giving the blue units unique shapes and sizes. To prepare for the implementation of the actions the units were also given attributes. These attributes included the size, color, spent, location and rallied. The size, color and location are of the units themselves. The spent attribute if the unit has performed an action. Lastly, the rallied attribute indicates whether the has tried to become unspent.*

*The next step was to enable the actions the units can perform. These consisted of moving, shooting and rallying. To implement these an action instance was created. This instance consisted of an object, action and target. An example of this would be ""Blue1 target red". The object in this case is a unit that needs to do something. The target can either be a location or a unit. As a unit can only perform either moving or shooting the spent attribute is used. This attribute will block the action if the unit has already performed an action or has successfully been targeted. For a shoot action to be successful a random number was picked between one and six. If the random number was equal or larger than the distance towards the target than the action was successful. To disable the spent attribute a unit must rally. Another random number was drawn and if this number is 3 or larger the unit would become unspent. Figure 4 illustrates what the game looks like.*

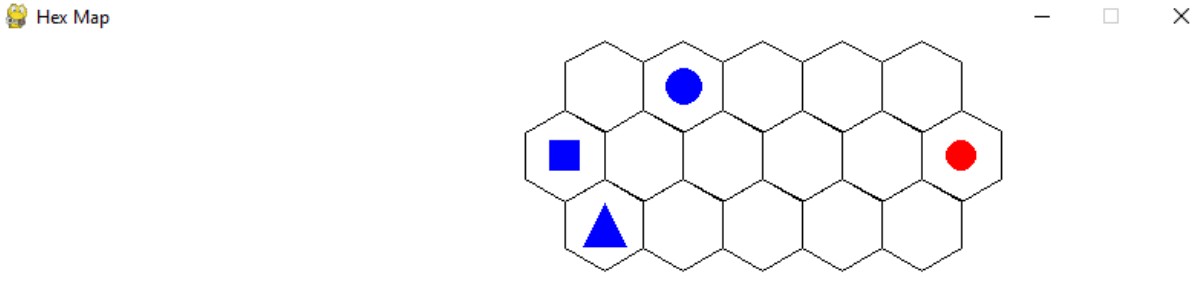


*Figure 4: Running version of the wargame*

*Lastly, to enable the wargame to run via commands several steps had to be taken. Firstly, a terminal was created to enable user inputs. Secondly, a function needed to be created to take the user inputs and perform the desired actions. Thirdly, a loop was created that checked whether there was user input or if all units had performed an action. If all unit have performed an action the next round starts and the wargame ends if it reaches the desired objective or 16 rounds have been played. Figure 5 illustrates what the command terminal looks like when the wargame is played.*

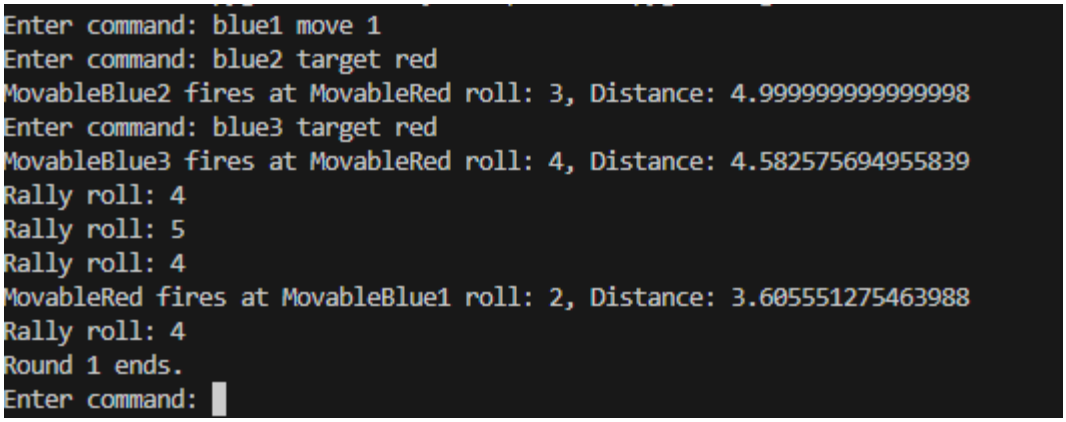

*Figure 5: Command terminal*

### 3.3.9 Development of your AI

For the development of the AI two important factors need to be considered. Firstly, the developer needs to find a data source for the training of their AI. In the case of wargaming the data often needs to be generated by the developers. As for wargaming there is no open source way to gather this data unlike games which are open for the public such as in the paper Pearce & Zhy (2022). However, there is an exception: if the game has previously been digitized it is possible that the data generated by previous instances is saved and can be used. Secondly, the developer needs to take into account that every change in the wargaming environment or the AI model requires the entire model to be retrained.

**Use case**

*Before starting the development an important **activity** must take place. The developer ought to look for preexisting software which could make the development easier. In the case of "Take That Hill" the development of the AI is based on the tutorial developed by Patrick Loeber who is senior developer advocate at assembly AI (2020). The license for the usage of his software can be found in appendix C. This tutorial has three distinct parts. Firstly, the environment. This is an adapted version of the game which enables the AI to interact with the game. Secondly, there is the agent. The agent is the part of the code which mediates between the environment and the model. Lastly, there is the model. The model contains the AI's algorithm and data.*

*To create the environment the wargame needed to be adapted. Firstly, as the AI would be playing as the blue forces in the wargame the wargame had to be able to be played by a single entity. Therefore it was decided to automate the red unit to automatically engage the closest blue unit. Furthermore, the red unit needed to rally itself when it was spent. While automating the rallying for the red unit it was decided to also automate the rallying for the blue units. This was decided as the rallying function should always be done as there are no penalties to rallying in the original wargame. Furthermore, eliminating this degree of freedom will limit the actions the AI can chose from, which in turn leads to shorter training times. The last part that was also automated was the pathfinding for the blue units. As the computing resources for this Thesis was limited the training time needed to be limited further. Furthermore, the pathfinding in this wargame is very straight forward. It was done by having the unit move to the closest hex to the red unit.*

*Another adaptation to the wargame was a wrapper around the wargame so that the agent in another file can access the wargame. After this rewards were added to the action methods. When an action succeeded the agent received a reward and when an action failed it got a punishment. The reward for succeeding in moving was 100 points. The penalty for not succeeding in moving were 10 points. The reward for successful firing was 10 points. The punishment was 1 point. The reward for finishing the game was 10.000 points. It was decided to make the penalties smaller than the rewards to encourage the AI to keep moving.*

*Another part that needed to be added was the ' game over' function. This enables the AI to restart with a clean game after it failed or succeeded to finish the game. This was done by creating a function that would end the game if it reached round 16 or when a blue unit managed to reach the red units tile. After this function ended the game it automatically resets the wargame for the AI. Lastly, a score had to be created. This score was the sum of all points collected in one run of the wargame. This was needed for the AI to be able to learn from the choices it made.*

*The agent provides the interaction between the wargame and the AI model. It takes the state of the wargame, evaluates it and then asks the model for a prediction of the next best actions. Which it than implements in the wargame. Firstly, a function to get the game state was needed. This was done by getting the positions from units on the board and the current score. Based on this information the agent asked the model to make a prediction by accessing the long term memory of the model. When a prediction was made the agent would make the move in the wargame. This is repeated for all blue units and every round until the game was finished. The total of states, moves were stored in the short term memory until the wargame ended. When the game finished the agent would update the long term memory of the model if the score improved.*

*In this case the AI was classified as the agent and the model. This can be compared to the "body" and "mind" of the AI. The AI could choose between the following inputs:*

- *Blue1 move X*
- *Blue1 target red*
- *Blue2 move X*
- *Blue2 target red*
- *Blue3 move X*
- *Blue3 target red*

*During the training of the AI the AI would assign values to these moves based on what it learned previously. These values would in turn alter the likelihood of the AI choosing input. While adapting the code provided by Patrick Loeber (2020) some issues arose as the AI had multiple objects compared to the single object in the standard code. This was solved by repeating the prediction process for each blue unit.*

*An important **activity** in this phase is choosing an algorithm. The choice for an algorithm was based on a paper by Arulkumaran et al,. (2017). In this paper the researchers compare Q-network algorithms to policy optimization algorithms. In the model section of the code the algorithm and neural network are set up. In the first versions the Proximal Policy Optimization (PPO) algorithm was chosen. This algorithm learns by exploration while optimizing the expected return. However, PPO is relatively slow and requires more training time and computation power. That's why in it was decided to go for the Q-learning algorithm. This algorithm learns a value function and takes actions based on this function. Compared to PPO it is faster and requires less computation power. Furthermore, where PPO can handle continuous action environments Q-learning is limited to step based action environments. For the case of "Take That Hill" Q-learning is sufficient as it is step based and has limited degrees of freedom.*

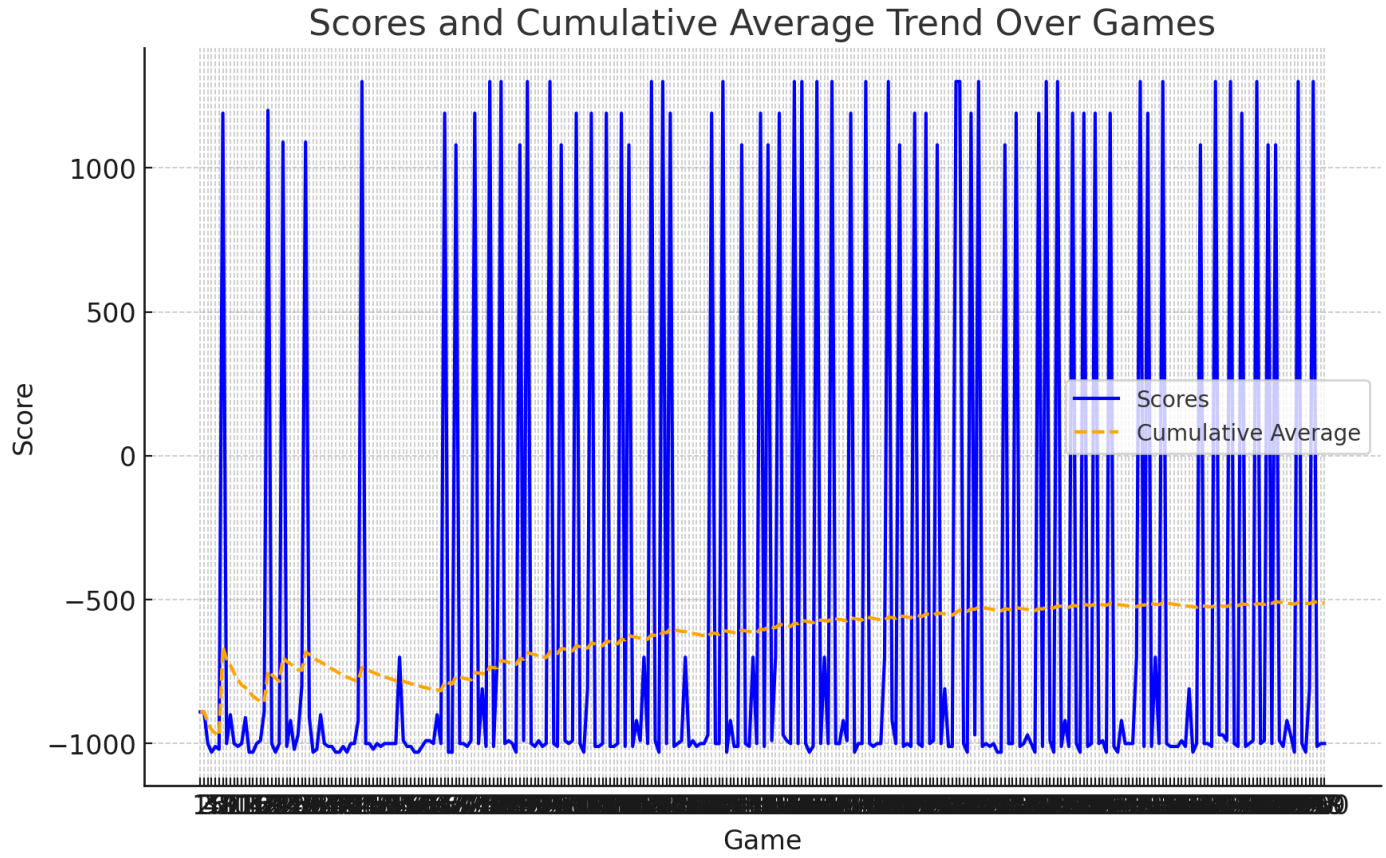


*Figure 6: Training data*

*After the code for the AI was completed it was tested and trained. The pseudocode for the wargame and AI is available is appendix D. Figure 6 shows the training data of the AI. The data contains the score of the AI over 300 runs of the game. The orange line illustrates the Average score of the AI over these runs. This data shows that in the first 40 games the AI is exploring and gathering information for its algorithm. The data shows that the AI wins the wargame about 5 times and starts committing to a tactic. This it is shown as the average score of the AI gradually increases until it evens out around a score of -500 points. The evening out of the average shows that the AI has reached is optimum. Interestingly even after the AI researches its optimum there are still games which it loses. This is due to the fact that this wargame relies on quite some randomness. The rallying of the troops is random and the successful firing of the red unit is also random.*

### 3.3.10 Implementation of AI into the wargame

When the digitization of the wargame and training of the AI is complete the implementation needs to take place. For this to be successful, it is important that the end product is as playable as possible compared to the original wargame. This means it needs an interaction interface for the players through which they can easily use the wargame and the interaction interface also helps with the players emergence into the wargame.

Lastly, when the implementation is finished the AI and wargame need to be verified and validated. The verification can be done by playtesting the finished product. By playtesting the most obvious faults and bugs can be detected. The playtesting is done by the perspective users of the wargame. The validation of the finished product can be done by comparing the end product to the KPI's developed in the "Planning the development of your Artificial Intelligence" phase.

**Use case**

*In the case of "Take That Hill" the final product was not required as the intention was to test the wargame and find imbalances. The main imbalance found was the fact that the tactic of just running towards the red object wins the game within 6 rounds. Even if the red unit hit a blue unit, which is statistically unlikely, every instance the game would be won by the blue units. Even if the original rules of counting hits towards the total count were followed the blue units would still win. This indicates that the wargame is not properly balanced as the intended use of the wargame is to teach about fire and movement. From a wargame developers perspective it is recommended that the wargame would be rebalanced. For example shortening to less rounds to it become harder to win. When comparing this imbalance to the data in figure 6 it can be concluded that winning the wargame has a great deal of luck to it even with an optimized strategy. For this it is recommended that some of the randomness is removed from the wargame. For example, the fire from the red unit could be redefined to be suppressive fire and always achieve that goal instead of "hitting".*

### 3.3.11 Maintenance, security and Updates

As with all software applications, the final product must be maintained to be able to stay in working order. Maintenance can be done by either the IT department, the department by whom the product was build or the end users of the product. The security around this product is two sided. Firstly, there is the normal IT security protocols to follow to ensure the product is not stolen or hacked. Secondly, as the product is based on a military wargame it can contain restricted information. To enable usage of the product the security officer of the organization where it was produced must be contacted to ask which extra protocols need to be followed. Lastly, in the future it might be needed to update the wargame or the product as a whole. If there is a need to alter the AI it is recommended to restart at the "Understanding the purpose of your wargame" phase. This is recommended, because it is important to assess the need and potential costs of the update, before committing to it.

## 3.4 Conclusion of the use case

With the use case completed several changes to the framework are needed. The changes are written out in depth below, but in short:

1. Centralizing the cost benefit analysis.
2. Removing redundant requirements.
3. Adding a risk and security analysis earlier in the framework.
4. Discovery of core activities.

After completing the use case several changes to the framework were deemed necessary. Firstly, it was decided to add a central cost benefit analysis. This contains the resource allocation, benchmarking requirements and needed competences. Merging these together provides a central analysis for the total cost of the implementation leading to better decision making. This stems from the “Planning the development of your Artificial Intelligence” and “Planning the digitalization of your wargame” phases in the use case.

Secondly, two requirements were deemed redundant. The requirement of taking into account the aspect of time can be included in the resources allocation and benchmarking requirements this stems from the “Planning the development of your Artificial Intelligence” and “Planning the digitalization of your wargame” phases in the use case. Furthermore the requirement regarding the desired behavior of the AI is included in the normal development process of AI. This is done in the “Developing your AI” phase by the objectives and assigning the rewards.

Thirdly, a risk and security analysis needs to be performed earlier in the implementation process. During the development the security protocols regarding classified information already need to be followed. This was found out during the last phase where in the use case there was no need to maintain, secure or update the AI.

In addition to the phases, several activities were found which were not apparent from the preliminary framework. During the “Planning the development of your Artificial Intelligence” phase the activity of “choosing a programming language: was found. This activity is important as it is vital for the progress of the implementation. During the “Planning the digitization of your wargame” two more activities were deemed essential for the implementation. The first is “look for previous digitalization efforts”. This activity has the potential to save time and resources during the development process. The second activity is “choose a programming language”. This activity is important, because it impacts the limitations of the digitization on the wargame itself. Two further activities were deemed vital in the “Development of your Artificial intelligence” phase. The first of which is looking for preexisting software. Having software on hand that has been used before on other AI implementations has the potential to save time and resources. The second activity is choosing an algorithm. The algorithm impacts the abilities the AI will have in the final product. That is why this activity must be done carefully and thoughtfully.

Aside from the direct influence of the use case on the final product there is also some academic considerations to take into account. The application of the use case illustrates the need to apply the theoretical framework as in this case a new dimension was added to the framework which was not apparent from the requirements alone. The use of the framework enabled the framework to be translated from a theoretical framework into a practical to be used by wargame developers.

Lastly, several requirements were not in the most appropriate location. Taking all these findings into account the new framework can be seen in figure 7 with the changes highlighted in green.

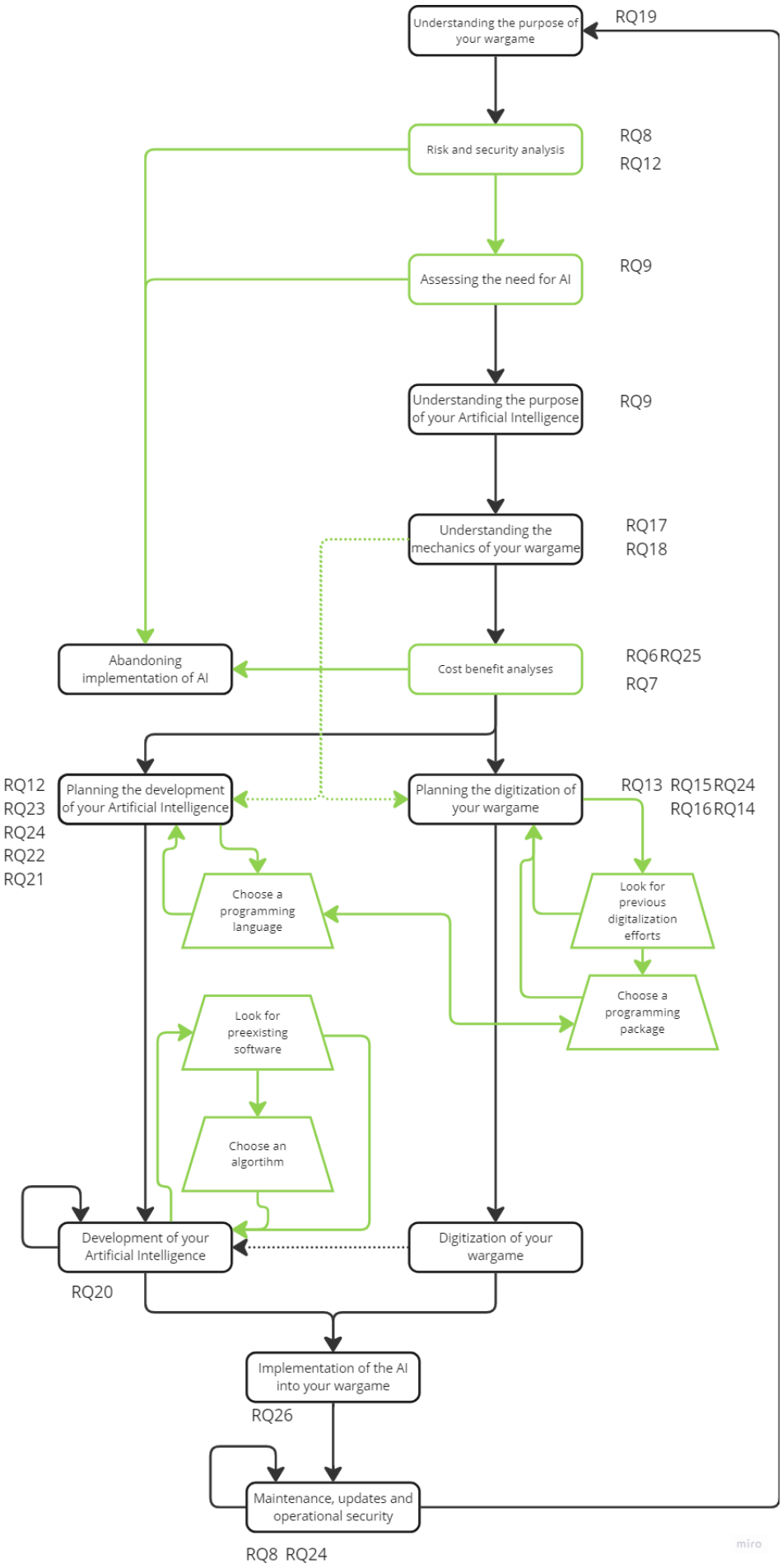


*Figure 7: Framework after use case*

# Chapter 4: Validation of the framework

This chapter aims answer sub question 4: “What is validity of the designed framework? ”. This is achieved by conducting expert interviews and comparing the framework to the previously found requirements. By the end of this chapter the framework has gained validity and is deemed valuable to wargame developers. In this chapter the interview protocol, questions and findings are presented.

## 4.1 Interview Protocol

For the interviews the same protocol as the interviews previously conducted was followed to ensure wargame designers find the framework valuable for their implementation purposes. However, in this instance the interviews were for the validation of the framework. As done previously, to setup the semi-structured interviews the paper of Newsomer et al, (2015) was used. They state that semi-structured interviews are particularly well suited for situations where multiple open-ended questions might require follow-up questions. For these interviews it was chosen to interview other new wargame developers with more experience in the field of wargaming and developing, but less experience with AI, compared to the experts interviewed in chapter 2. For this interview the interviewees were asked for their consent using an informed consent form. In table 5 more details are provided.

| Interviewee | Experience | Date | Medium |
|---|---|---|---|
| 3 | 5 Years | 14-7-2024 | Face to Face |
| 4 | 10+ Years | 14-8-2024 | Face to Face |

*Table 5: Interviewee information*

## 4.2 Questions

The first questions are designed to ask them about previous experience in the fields of AI and wargaming. To gauge the experience they had and what angle they would look at the framework .

Have you worked with wargames before, if yes in what capacity?

Have you worked with AI before, if yes in what capacity?

The second set of questions are designed to ask them about their view regarding possible solutions and hurdles concerning the implementation of AI into military wargaming.

In your eyes what could be potential benefits of implementing AI into military wargaming?

In your eyes what could be potential hurdles during the implementation process?

With the experts now thinking about benefits and potential hurdles a question is designed to ask them about what requirements they would have for a framework guiding military wargame developers with the implementation of AI into their wargames.

In your eyes what would be requirements regarding a framework designed to guide wargame developers during the implementation process?

The last question is designed to specifically ask them about the previously developed design principles and requirements.

What do you is your professional opinion of this framework?

## 4.3 Results

The information gained from the interviews was analyzed by using conversation analyses as per Talja (1999). This analysis aims to generate insights while taking into account the interviewees personal experiences. The full report of the interviews can be found in appendix E.

Interviewee 3 noted that the framework was generally complete and concise. In addition to this, according to the interviewee, a few aspects of the framework were incomplete or missing. Firstly, the actions taken by the AI need to be validated in the context of the wargame as a whole. Furthermore, before the AI is developed it is important to ensure that moral principles for building an AI are taken into account. Lastly, when the implemented AI is ready for use it must be clear what rules the AI was built upon, in that way the end user knows what kind of behavior to expect from the AI.

Interviewee 4 also had three points of concern. Firstly, the interviewee illustrated the need for moral decision making on whether the AI should be created. Secondly, the interviewee noted that the phases of "Assessing the need for AI" and "Understanding the purpose of your AI" are interdependent. Merging these into one phase makes the framework more concise. Lastly, the interviewee noted that user of the framework should not only need to know the benefits or purpose of the AI, but also the limitations.

Lastly, as for the comparison with the requirements. The comparison and assessment was done by the researcher. Nearly all requirements are implemented in the current version of the framework. The only requirement not directly implemented is the requirement to take the aspect of time into account. This was done, because it was discovered that it was indirectly covered by other requirements. In table 6 the requirements are assessed on their implementation. This was done on a scale of insufficient (i), sufficient (s) or good (g). The only requirement not met is requirement 14. This requirement concerns the guidance in finding the level of abstraction needed for the digitization process. The requirement is included in the digitization phase, but the framework does not provide extra guidance hence scoring insufficient. Notably requirements 1, 2, 3, 4, 5 and 10 are not in the framework itself as these requirements create the approach and context needed for the use of the framework by military wargame developers. They are included in section 3.3.1 "*Preconditions for the usage of the framework*".

| Design principle | Requirement | Assessment |
|---|---|---|
| An academic design for a framework | 1. The framework must build on the work of other authors to integrate their knowledge into a conceptual framework. | good |
| | 2. The framework must indicate its purpose. | good |
| | 3. It must be clear to what system of interest the framework is applicable. | good |
| | 4. The framework should specify the process needed to navigate the framework. | good |
| | 5. The framework should suggest an approach which entails the angle of which the framework approaches the process. | sufficient |
| | 6. The framework must illustrated the needed competences to successfully apply the framework. | sufficient |
| | 7. The framework must provide insight into resource requirements for the development of an artificial intelligence algorithm. | sufficient |
| | 8. The framework must provide the wargame developer with guidance to ensure the security of the model. This entails the operational security during use of the model, but also the data used during the development process. | sufficient |
| | 9. The framework should provide the wargame developers with guidance on where to implement the AI in the wargame. | good |
| | 10. The framework could provide the wargame developers with the possibility to update the framework in the future. | sufficient |
| | 11. The framework must take into account the aspect of time. This entails the time it take to build and train the model. Furthermore, it also entails factors such as the time it takes to setup the AI while deploying the wargame and the response time of the AI. | good |
| | 12. The framework would need to provide the wargame developers with the insights needed to source data for the training of their AI model. | sufficient |
| Authenticity preservation for wargame digitalization | 13. The framework must provide guidance in finding the balance in the trade-off between the authenticity of the game and the amount of digitization needed. | sufficient |
| | 14. The framework should provide guidance in finding the level of abstraction needed for the digitization process. | insufficient |
| | 15. The framework must provide a handle for the correct digitization of the randomness of a game. | sufficient |
| | 16. The framework should provide guidance on tackling game breaking imbalances during the digitization process. | sufficient |
| | 17. The framework should provide insight into game mechanics leading to theory crafting. | sufficient |
| | 18. The framework should provide insight into the interaction between digital and (semi)physical domains of the game. | sufficient |
| | 19. The framework must provide the wargame developers with the insight that the focus of a wargame is to keep the players thinking and learning. | good |
| Iterative simplification for AI development | 20. The framework should provide the wargame developers with guidance on how to implement the behavior the AI should replicate. | good |
| | 21. The framework must provide insight into the simplification process used to enable the algorithm to learn in steps. | sufficient |

| | | |
|---|---|---|
| | 22. The framework should provide an insight as what the impact of different quality of data would have on the AI. | good |
| | 23. The framework should provide a way to assess the degrees of freedom the wargame has. | sufficient |
| | 24. The framework must illustrate the impact of change in the algorithm or wargame. | good |
| | 25. The framework should provide insight into the process of benchmarking the AI. | sufficient |
| | 26. The framework must provide guidance into the verification and validation of the AI. | sufficient |

*Table 6: Requirement analysis*

## 4.4 Conclusion

The sub-question for this chapter is: "What is the validity of the designed framework?". With the interviews conducted and the requirements met the framework can be seen as valid and valuable to the wargame developers. It provides a previously nonexistent guideline for the implementation of AI into military wargames. However, incorporating their feedback would increase the validity even further. That is why it was decided that the framework needed another update. The updated framework can be found in figure 8.

Academically something interesting happens. As both sets of interviews are conducted with wargame developers at TNO the validation interviews yielded different results than the requirement interviews. The validation interviews focused on ethical and moral implications of the implementation of AI into wargaming while this did not come forward in the requirement interviews. This illustrates the need for a diverse group of interviewees and more interviews in general, when using expert interviews in research where the academic literature is not abundant.

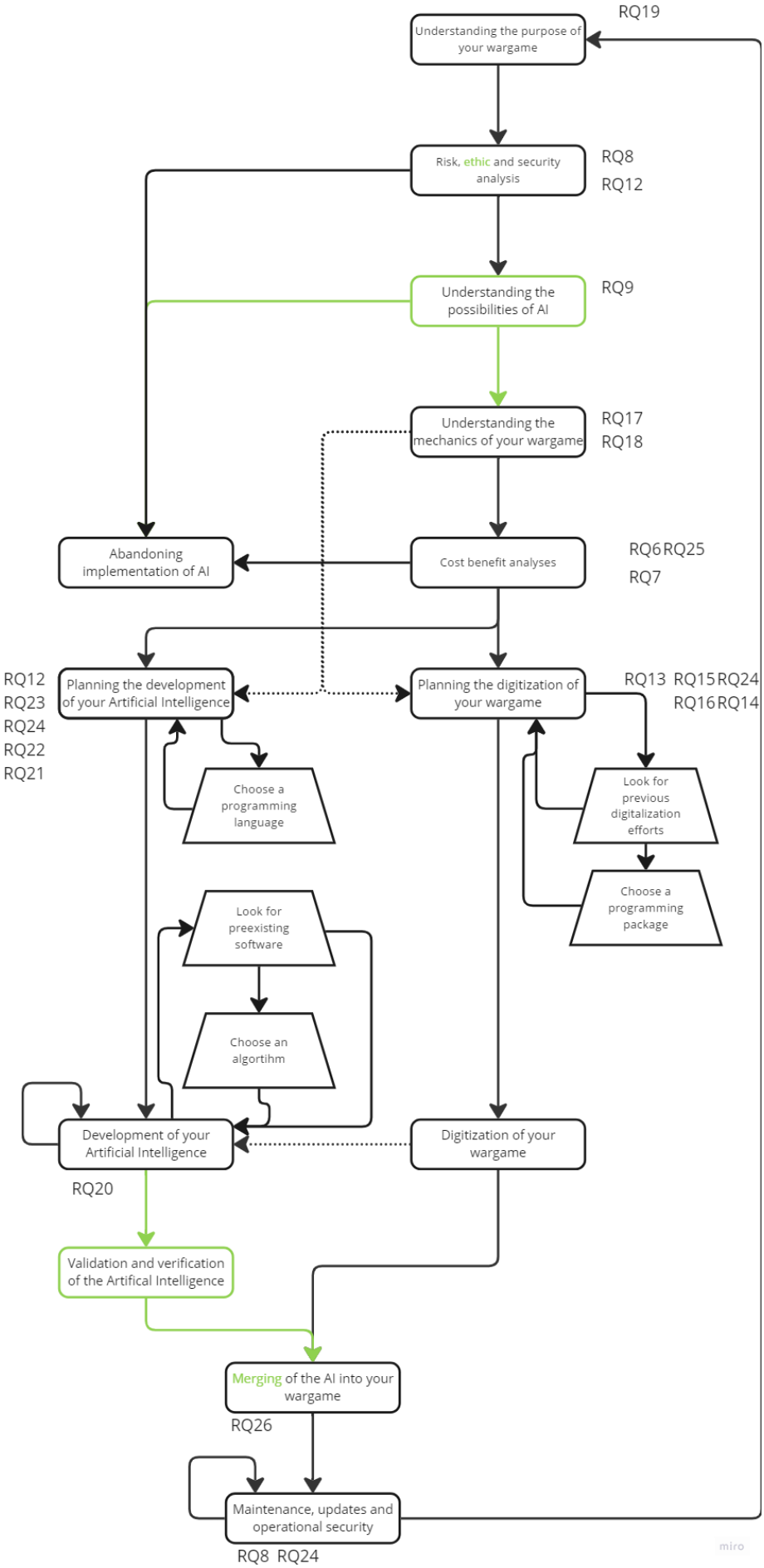


*Figure 8: Framework after validation*

# Conclusion

This chapter aims to answer the main research questions, sub questions and summarize the performed research, while also highlighting the societal and academic relevance of this thesis. Lastly, this chapter will highlight the limitations of this thesis and provide areas for future research.

## Problem statement

With global tensions rising there is a need to train the military to prepare for the very real possibility of a peer to peer war on the European continent. With war always evolving and becoming more complex over time the tools used to train soldiers and build doctrines also become more complex. This is due to the addition of new technologies and emerging threats. One of the tools that is impacted by growing complexity is military wargaming. While wargaming is an ancient practice it has developed to follow the growing complexities of war. In the context of military training wargames portray multi-domain battlefield containing artillery, helicopters, tanks, infantry, planes, terrain and much more. To keep the wargames significant and executable the implementation of AI into military wargames was explored. This proved to have an impact on aspects such as data processing, decision making and strategies. Further research shows that while possible and useful the implementation of AI into military wargaming is of an ad hoc nature and lacks any guidance or standardization. That is why this thesis set out to develop a practical framework for wargame developers for the implementation of AI into military wargaming.

## Research gap and main research question

The literature review in section 1.3 has pointed towards existing literature exploring the possibility and feasibility of AI in gaming, wargaming in military training and the integration of simulation into wargaming. While AI in gaming has been looked into by academics, AI in military wargaming remains to fall behind with only a limited number of academic papers indicating a possibility and feasibility. Furthermore, with wargaming being one of the oldest and widespread tools available to militaries across the world it fulfills an important role. However, as illustrated in the literature review there is still potential for advancement with integration of AI. Furthermore, from the literature review a need for a practical and guiding framework arose. More specifically a practical and guiding framework for wargame developers to make the implementation of AI into their wargames more accessible. This lead to the follow main research question for this thesis: “Which framework can guide wargame developers in the field of AI and military wargaming through the implementation process?”.

## Answering the sub questions

To answer the main research question four sub questions were devised. When all sub questions are answered an answer can be devised to the main research question.

The first of which is: “What are the current challenges and constraints in the implementation of AI into military wargaming and how can they be addressed?”. This sub question is answered in chapter 1. Furthermore, this question sets the scope and core concepts for the rest of this thesis. This is visible in section 1.2. The most prominent source for the answer to this question was Goodman et al., (2020). In their paper they state that the largest challenge and constraint to the implementation of AI into military wargaming is the lack of a framework on which to base the implementation on.

The second sub question is: “What are the requirements, objectives and goals that the framework aims to achieve?” To answer this sub question an exploratory literature review was conducted to build on the literature review done for SQ1. To validate the requirements and find more requirements two expert interviews were conducted. The outcome of these methods is a list of design principles and requirements for the framework visible in table 4. Furthermore, this chapter illustrates the importance of doing expert interviews when there is a lack of academic sources available. Ten of the twenty six requirements stem from the expert interviews.

The answers of sub questions 1 and 2 were used in the answer to sub question three: “How can the design principles and requirements be translated into a framework?”. Firstly, the requirements were translated into phases. These phases were put into logical order and formed the preliminary framework, which can be seen in figure 1. Combined with the a use case where AI was implemented into the military wargame “Take That Hill” this lead to the development of a framework applicable to the implementation of AI into military wargaming. Academically, the use case highlighted the importance of applying the theoretical framework to turn it into a practical and guiding framework. This is proven by the fact that the use case provided another dimension to the framework with the addition of core activities. The framework after the application of the use case can be found in figure 8.

The last sub question is: “What is validity of the designed framework?”. ”. This sub question was answered by conducting expert interviews and comparing the framework to the previously found requirements. The answer to this question resulted into the framework gaining validity and being deemed valuable to wargame developers. The framework after the validation can be found in figure 8. Interestingly, the interviews used to validate the focused on an entire different aspect than the interviews used for the requirements. The interviews for the requirements focused on the aspect of time and security, where validation interviews focused more on the ethical and moral aspects of AI implementation into military wargaming. This highlights the importance of using a diverse group of interviewees when using expert interviews.

## Answering the main research question

Circling back to the main research question: “Which framework can guide wargame developers in the field of AI and military wargaming through the implementation process?”

To answer this question this thesis successfully developed and validated a framework for the implementation of Artificial Intelligence (AI) into military wargaming, specifically demonstrated through the "Take That Hill" use case. The framework addresses the increasing complexity of modern military operations, ensuring that AI can be utilized to enhance both the value and realism of military wargames. The key findings emphasize that AI, when guided by a framework, can significantly improve the value of military wargames, enabling more realistic and challenging scenarios that better prepare military personnel for real-world operations. The final version of the developed framework can be found in figure 8.

## Societal relevance

The societal relevance of this research lies in the potential of the framework to enhance military wargames for the better, increasing the preparation of military personnel and their ability to defend the Netherlands and their allies. This research also supports the ongoing work at TNO by offering a practical and guiding framework that aligns with their mission of advancing military capabilities through innovation. The wargame developers at TNO should be able to use this framework to further their research in the implementation of AI into military wargames.

## Academic relevance

Academically, this research fills a gap in the existing literature on AI implementation in military wargaming. Previous studies have explored AI in gaming and military simulations separately, but few have combined these domains to create a practical and guiding framework for AI implementation in wargaming. This was particularly supported by Goodman et al., (2020). They stated that the domain of AI in wargaming would greatly benefit from a practical and guiding framework. The framework provides future research a basis to start from.

Furthermore, during this thesis several other academically relevant findings were made. Firstly, in chapter 2 the expert interviews illustrated the need for additional methods when academic literature is scarce. Secondly, in chapter 3 the use case illustrates the need for applying a theoretical framework to be able to translate it into a practical framework. Lastly, chapter 4 illustrates the importance of using a diverse group of interviewees when using expert interviews.

## Limitations and future research

During the writing process of this thesis several limitations were identified. Firstly, the framework has been developed with a single wargame. “Take That Hill”, which in turn does not fully represent the diversity and complexity of military wargames. “Take That Hill” specifically is a turn based strategy wargame with limited units and map size. Furthermore, the map is not only 16 hexes but also does not include different terrain types. Applying the framework to a broader and more complex range of wargames would help validate and refine the framework further. One of such wargames could be VR forces. This wargame is continuous, has more units and different kinds of units and a dynamic map.

Secondly, the model that was developed used a relatively simple algorithm, which resulted in a simplified AI model. The algorithm used is Q-learning. As mentioned before this algorithm suits the needs when implementing AI into a wargame limited in complexity, such as “Take That Hill”. When using a more complicated algorithm, such as Proximal Policy Optimization (PPO). The outcome of the analysis after implementation could result in different and more complex behavior. Furthermore, when implementing AI into a more complex wargame the need for a more capable, but more complex algorithm surely arises. It is recommended that future research aims to use a more complex algorithm when applying to framework to identify areas which did not come to light during this use case.

For this thesis the wargame “Take That Hill” was chosen. One of the reasons for this choice was the fact that it is a publicly available wargame with a military history. A limitation here is that there is no source linking the wargame to current military training. This in turn limits the actual usefulness of the implementation of AI into “Take That Hill”. Future research at TNO should apply the framework to wargames currently in use with the military to ensure that the implementation of AI is actually beneficial to the wargame. Furthermore, the purpose of the implementation of AI into “Take That Hill”, was to identify imbalances in the wargame and validate the current version of the wargame. The outcome was that the wargame was not sufficiently balanced and using the tactic of running towards the objective would be a valid strategy. This finding, might have also been found using a different method besides AI implementation. Which in turn would have taken less resources to complete. To conclude, the implementation of AI into “Take That Hill” has limited value for the wargame itself and mostly provides value to the development of the framework.

Additionally, the expert interviews were only done with personnel at TNO. The impact of this can be seen in the different aspects highlighted during the two sets of interviews. Where the first group focused on time and security the second focused on ethical and moral implications of implementing AI into military wargames. Including a more diverse group of experts could increase the validity of the framework. Interviews with for example the end users of the wargame could bring new insights for the framework.

Furthermore, this framework focused on the implementation of AI into military wargaming, without taking into account the ethical consideration of the implementation of AI into military wargaming. As

mentioned during the interviews in chapter 4. Future research, exploring the ethical implications of AI in military wargaming and developing guidelines for the responsible use of AI in this domain would provide more insight whether the use of AI in this domain is something that should even be entertained.

As mentioned in section 3.3.1. The framework comes with preconditions before the framework can be used. This framework is designed to guide wargame developers in implementing AI into digitized wargames. It takes a developer's perspective, focusing on the entire process and is accessible to those with limited knowledge of digitization or AI. For physical wargames, some digitization is needed before AI can be implemented, while digitized wargames require exploring AI integration. The framework is adaptable to various types of military wargames, from real-time to turn-based. Wargame developers should start at "Understanding the purpose of your wargame" and progress through phases, some of which, like digitization and AI development, can occur in parallel. Once a minimal viable product is ready, AI development can begin. This means that not in all cases of AI implementation into military wargaming this framework can be used. Furthermore, the focus on wargame developers specifically limits the amount of people who can use this framework. Had the framework been more generic more people would might have found the framework valuable.

Lastly, the domain of AI technology is rapidly advancing. To keep the framework relevant indefinitely would require updating the framework. Thus it is recommended that future research aims to keep the framework relevant by assessing its value through time and improve on it where necessary. One area making big progress is AI being able to code. It is not unthinkable that some parts of this framework might become entirely irrelevant as large AI model might be able to do steps al by itself. One aspect which can be explored in future research to keep this framework relevant is the digitization of the framework. This could make it easier for wargame developers to integrate the framework into their work as the implementation of AI into a military wargame is inherently digital.

The research fits within the master's program of Complex Systems Engineering and Management by offering a multidisciplinary approach to designing a framework for a complex socio-technical system. The interdisciplinary nature of the research is underscored by its integration of a complex domain, military wargaming, and a complicated domain, AI. This fusion of domains exemplifies the program’s goal of addressing complex problems by bridging the gap between technical innovation and strategic application.

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# Appendix A

Including the full report of the interviews into the main text would take away from the readability of the thesis. Provided below is the full report of interviews 1&2.

Interview one was with an expert which currently worked in the area of military simulation, however in the past attended them and supported several games with the implementation of simulation sections. Secondly the expert had experience with the implementation of AI into these simulations.

Regarding the potential benefits of AI in military wargaming the expert saw opportunities for the supporting role of AI. From taking out randomness by having the AI encompass many models and simulations to provide real time intel to the players to having a large language model (LLM) answering questions which military planners might have during their planning phase. As for the opposing force the expert saw to potential to having the AI trained on the military doctrine of the opposing force, which in turn would eliminate the need of having a trained expert on this doctrine on site. Furthermore, both in the supporting and opposing roles the expert highlighted the potential for more immersion and potentially less time needed to setup and play a military wargame.

The expert also saw some hurdles concerning the implementation process. First of all the width of military operations is quite large which in turn would require a large AI model. Secondly, there is little to no data to train the AI on as most of it is generated through models as doctrine and other information is often classified. Lastly, it would be hard to require enough information from military experts to build AI models as they are not always available.

Possible requirements the expert came up with were standards the framework should make the developer attentive of. Such included the fact that the framework should be in English as this enhances the interoperability with models and people from different nations. On the wargame side the expert mentioned that it should be able to be integrated with current systems the military uses so that the wargame can work with current information. Furthermore, the expert mentioned that security should also be high on the priority list. With the model often handling classified information the expert proposed having the AI run on a local network, which in turn would require advanced IT architecture. Lastly, the expert circled back to the dimension of time. For the different roles which AI could fill in military wargaming different performance metrics should be included focusing mostly on response time and time it takes to setup the system as a whole.

Concerning the design principles the expert provided feedback on the fact that the focus of a wargame is to make the players think about the process and that authenticity of the game takes a secondary role. The expert also mentions that the game can be digital or physical as long as the primary focus is on the thinking process. Regarding the previously developed requirements the expert was positive with the addition that requirements concerning the aspects of modularity, security and time should be added to complete the list.

The second interview was with an expert who mostly had experience with building simulators which in turn were used to in training scenario's. In addition, this expert has worked as a project leader on the topic of AI implementation in into these simulators.
This expert also saw the same two potential benefits of the implementation of AI into military wargaming. In the supporting role AI could provide different plans which the commander of the allied force could use to base is own plans on. As for the opposing force the expert also agreed that it would be possible to eliminate the military expert. The expert also saw shared the opinion about the potential hurdles such as the cost and time it takes to build an AI model. However, a unique insight of this expert was the fact that it is hard to include human intuition into the AI and with this the AI could make unpredictable moves often not looking like a suitable move to the human player.
Concerning potential requirements this expert also illustrated the need for benchmarking and the aspect of time. Furthermore, including standard operating procedures and their doctrine of opposing forces would be beneficial for the development of the AI.

As for the design principles the expert agreed with the developed principles, only providing feedback on using the word tacit in the context of the framework.
Regarding the previously developed requirements the expert once more illustrated the need to include the aspect of time and benchmarking for the framework.
Lastly, the expert mentioned the DSEEP framework for the development of simulation models, which in turn might be useful for military wargame designers developing their came. The expert was of the opinion that the implementation of AI turns the wargame more into a simulator than a game.

## Appendix B

To ensure that the rules on which the wargame was digitized and the AI developed are accessible for other researchers it was decided to include the whole text in the appendix. This text it directly quoted from the manual of the game available on https://www.fightclubinternational.org/take-that-hill-old.

1. Introduction.

This is a short wargame primer to introduce non-wargamers to basic wargame concepts in the context of a simple dismounted platoon attack. You command an Infantry Platoon made up of three sections and a Pl HQ. Your mission is to DESTROY an enemy section hastily dug in on the hill 500m away as quickly as possible. The ground in front of your position is open and offers no cover from view or fire. To do this you will need to fire and manoeuvre your platoon into an assault position adjacent to the hill whilst keeping the enemy suppressed.

1.1 Game Components:

• 1x Game board representing the operating area approx. 500m x 300m overlayed with a hexagonal grid system of Alpha-Numeric coordinates A-C on the vertical and 1-6 on the horizontal. • 4x Blue Counters representing the friendly platoon elements • 1x Red Counter representing the enemy section • 3x Smoke Counters (advanced rules) • 9x Mine Counter (advanced rules) force elements of friendly and enemy • 4x Depth Counters (advanced rules) • 4x Wire Counters (advanced rules) • 8x Hit markers; 4x direct, 4x indirect (advanced rules) • 1x Illumination counter (advanced rules) • 2x Dice (Red and Blue) • 1x Counter to mark the progress of time. • 1x Counter to mark the number of hits on blue

1.2 Methods of Play.

The wargame can be played solo or head-to-head. In solo mode the player controls the blue, or friendly side, with the red, or enemy side, being automated by a simple set of tactical choices. In head to head mode the second player controls the red side and makes all decisions therein.

1.3 Force Element (counters) and states.

Counters are used to represent combat elements in the wargame. For simplicity each counter represents a group of combatants between 4-10 in number. This aggregation is simpler than representing every soldier involved. The counters used in this wargame are two-sided (a plain coloured side and coloured side with a grey stripe through it). The plain side denotes a combat element as ‘Fresh’ and the grey stripe as ‘Spent’. Fresh denotes an element with the capacity to GAME RULES 2 undertake an action such as move or fire. Spent denotes an element that, for whatever reason, is unable to act because it is has lost this capacity. Elements become spent after taking an action or when successfully engaged by direct, indirect fire or other weapons. There is no stacking limit to the number of counters that can be in the same hex.

1.4 The Map.

The wargame uses a very simple and abstracted terrain map of 16 hexes in three rows of five, six, and five hexagons respectively. The left-hand column of hexes of wooded terrain and the extreme centre right hex is a hill. All the other hexes are open grassland. In this wargame, for simplicity's sake, the terrain does not affect the actions of the players.

1.5 Game Turns.

The wargame is bounded in time by a set number of turns, segments of ‘game time’ in which activity on the map takes place. This is recorded on a separate track below the map numbered 0 to 16 using the turn counter (the watch). Each game turn represents between 1-3 minutes of real time combat. A separate counter (3 bullets) records hits on friendly (blue) forces using the same track. The combined total of turn and hits is used to determine the player (blue player’s) success.

2. Turn Phases.

Turns are often subdivided into phases to guide player decisions and actions. Although often a turn looks very phased in time the general principle is that all actions in the same turn are occurring simultaneously. A turn has four phases that occur in sequence; three concern the actions of the friendly forces or ‘Blue’ player and one concerns the reactions of the enemy or ‘Red’ player. It is important that the phases occur in the sequence shown; if firefight occurs before movement then a player will know if the fire has been effective before moving – this removes a key aspect of uncertainty from the wargame and so should be avoided.

2.1 Movement.

This phase allows blue elements to move from one hex to another. Each fresh element may ‘move’ to any adjacent hex and become spent (flipped to its grey stripe side). Alternatively, a fresh element may remain in its current hex and stay fresh. Spent elements cannot move in this phase2.2 Firefight. This phase allows blue elements (and fire support assets in the advanced rules) to fire on the enemy to attempt to suppress it. Each fresh section (not the Pl HQ) may fire to suppress the enemy if desired, and is then flipped to its spent side. A section that starts the phase spent may not fire. To fire roll a dice, if the number exceeds the range in hexes from the firers to the hill the enemy section is hit and is flipped to its spent side. If the roll is equal to or less than the range the fire is ineffective. Fire is blocked if there is a friendly element in the same row between the firing element and the target.

2.3 Rally.

This phase allows spent blue elements to become fresh, ready for the next turn. The Pl HQ automatically rallies from spent to fresh as do any sections that are in the same hex. Any other spent sections must roll a dice to ‘rally’. A section must roll 3-6 to rally itself. If adjacent to the Platoon HQ the section rallies on 2-6. An unsuccessful roll results in the section remaining spent. Spent sections adjacent to the enemy hex, if the enemy section is not spent, can only rally if the Pl HQ is collocated in the same hex as them.

2.4 Enemy Action.

If the enemy section starts this phase spent (having been successfully engaged by suppressive fire by the platoon) it now becomes fresh and the phase ends. If it starts the phase fresh then it fires on the closest section (prioritising fresh over spent) and any additional sections in that hex. The enemy will also target the next closest section if it is in an adjacent hex, thereby giving it a beaten zone of fire no more than two hexes in total. Roll a die for each targeted section. The enemy hits if the roll is equal to or greater than the range in hexes. A hit flips the target section to its spent side if it was fresh and the hits counter is moved one space along the tracker. Spent sections are not flipped but are recorded as hits. If the roll is less than the range to the target the fire is ineffective. The Pl HQ is not specifically targeted and does not count as an additional hit if the section they are with is successfully engaged. The enemy section always finishes the turn fresh (unless using advanced morale rules).

2.5 End of Turn.

Once all four phases have been completed move the turn counter along one space on the game track and then repeat the phases again, in order.

3. Set Up.

Place the enemy counter on the B6 hex on the side. Place the blue platoon counters in any of extreme left hexes (A1, B1, C1) on their fresh side. Place the turn counter (watch) on the ’1’ space and the hits counter on the ‘0’ space of the game track. Figure 6: Example set up for the base game. Blue sections do not need to be placed as shown and could all start in the same hex.

4. Victory Conditions.

Each time a turn elapses move the ‘turn’ counter one space on the numbered track. Each time a section is hit move the ‘hits’ counter along the track on space. If the combined total (hits plus turns) reaches 16 the Blue player lose the game. If a blue section moves into the hill hex and the total is 10 or less blue win, if it is between 11 and 15 the game is declared a draw.

## Appendix C

The tutorial and code was used as a source for  the implementation of the AI into the wargame one requirement for the usage of the code was to list the software license from Patrick Loeber as found on github.

# Appendix D

For future research it can be beneficial to understand what code was used and how it was constructed. The pseudocode for all aspects of this thesis aims to make this insightful and easy to read.

## Pseudocode wargame:

```
Import necessary libraries:
    pygame (for game display and rendering)
    math (for geometric calculations)
    threading (for multithreading user input)
    random (for random number generation)

Initialize Pygame

Define constants for game dimensions, hexagon size, FPS, and colors

Set up display:
    Create a screen with width and height, set a window caption

Function hexagon_points(center_x, center_y, size, rotation):
    Initialize an empty points list
    For each of the 6 points of the hexagon:
        Calculate the angle in radians (adjusted by rotation)
        Compute the x and y coordinates for each point
        Append the coordinates to the points list
    Return the list of points

Function draw_hexagon(surface, center_x, center_y, size, rotation, color):
    Get the hexagon points from hexagon_points function
    Draw the hexagon on the surface using the specified color

Function create_hex_map(surface, size, rotation):
    Initialize an empty list for hex centers
    Calculate starting x and y positions for the top layer of hexagons

    For top layer (5 hexagons):
        Calculate the center positions and draw each hexagon
        Add the center positions to the hex_centers list

    For middle layer (6 hexagons):
        Adjust the y position for the next layer
        Calculate the center positions and draw each hexagon
        Add the center positions to the hex_centers list

    For bottom layer (5 hexagons):
        Adjust the y position for the bottom layer
        Calculate the center positions and draw each hexagon
        Add the center positions to the hex_centers list
```

```
    Return the hex_centers list

Function calculate_distance(hex1, hex2):
    Extract the x and y coordinates of both hexagons
    Calculate and return the Euclidean distance between them

Class MovableUnit:
    Function __init__(surface, size, color, spent_color):
        Initialize the unit with size, color, spent_color, and surface
        Set current_hex, rect, and spent state to default values

    Function place_object(hex_centers, start_hex_index):
        Place the unit on the grid at the specified start hex
        Draw the unit as an ellipse or rectangle based on its size

    Function move_to_hex(hex_centers, target_hex_index):
        If the unit is spent, prevent movement
        If the target hex is valid and adjacent:
            Move the unit to the target hex and mark it as spent

    Function spend():
        Mark the unit as spent and change its color to spent_color

    Function rally():
        If the unit is spent:
            Roll a dice, and if the result is greater than or equal to 3, reset the spent state and color

Class MovableRed (inherits from MovableUnit):
    Function __init__(surface):
        Initialize a red unit with a specific size and color

    Function fire(target):
        If the red unit is spent, prevent firing
        Calculate the distance to the target
        Roll a dice and check if the roll is greater than or equal to the distance
        If successful, mark the target as spent

Class MovableBlue1, MovableBlue2, MovableBlue3 (inherits from MovableUnit):
    Initialize each blue unit with specific sizes and colors
    For MovableBlue2 and MovableBlue3:
        Override place_object method to draw the unit as a rectangle (Blue2) or a polygon (Blue3)

Function handle_command(command, objects, hex_centers, round_counter):
    Split the command into parts and validate the format
    Extract the object name, action, and target from the command

    If the object name is not in objects, print an error message
    If the action is "move":
        Convert the target to a hex index
        If valid, move the object to the specified hex
    If the action is "target":
        If the attacker is spent, print an error message
```

```
        Else, determine the target and check if the red unit can fire
        If successful, increment the round counter
    If the action is "rally":
        Call the rally function for the specified object

    Return the updated round counter

Function check_game_end(objects):
    For each blue unit:
        If a blue unit occupies the same hex as the red unit, return True (game over)
    Return False (game continues)

Function get_input_thread(objects, hex_centers):
    Initialize round counter
    While the round counter is less than 16:
        Get user input and handle the command using handle_command function
        If the game ends (blue unit reaches the red unit), print "Red wins" and exit

Function main():
    Create a clock for FPS control
    Create the hex map and hex centers

    Initialize red and blue units and place them on the grid
    Create and start a thread to handle user input (get_input_thread)

    While the game is running:
        For each event in Pygame's event queue:
            If the event is quitting the game, stop the game loop
        Clear the screen and redraw the hex map and units
        Update the display and control the frame rate

    Quit Pygame when the game loop ends

If script is run directly:
    Call the main function to start the game
```

## Pseudocode wargame AI:

```
Initialize the Pygame environment
Set game window dimensions and FPS
Define hexagon properties and colors

Create the GameAI class:
    Function __init__():
        Initialize the display and clock
        Create the hex map
        Initialize round counter and reset the game state

    Function reset():
        Create a new hex map
        Initialize blue units
        Reset the state of red and blue units
```

```
    Place the red and blue units on specific hexes
    Reset the round counter

Function hexagon_points(center_x, center_y, size, rotation):
    Calculate the six points of a hexagon based on center, size, and rotation
    Return the list of points

Function draw_hexagon(surface, center_x, center_y, size, rotation, color):
    Get the points of the hexagon
    Draw the hexagon on the surface

Function create_hex_map(surface, size, rotation):
    Initialize hex centers list
    Create three layers of hexagons: top (5 tiles), middle (6 tiles), bottom (5 tiles)
    Draw hexagons and append their centers to the hex centers list
    Return hex centers

Static Function calculate_distance(hex1, hex2):
    Calculate and return the Euclidean distance between two hexagons

Class MovableUnit:
    Function __init__(surface, size, color, spent_color, game_ai):
        Initialize the unit with its size, color, position, and game reference

    Function reset_spent():
        Reset the unit's state to unspent

    Function place_object(hex_centers, start_hex_index):
        Place the unit at the specified hex on the grid

    Function move_to_hex(hex_centers):
        If the unit is spent, prevent movement
        Get valid adjacent hexes
        Move to the closest hex if possible and mark as spent

    Function get_valid_moves(hex_centers):
        Find valid adjacent hexes and calculate distances
        Return the closest hex

    Function spent():
        Mark the unit as spent

    Function rally():
        If the unit is spent and not rallied, roll a dice to determine if it can reset the spent state

    Function reset_rally():
        Reset the rally state

    Function fire(hex_centers, target):
        If the unit is spent, rally it and prevent firing
        Calculate distance to target and determine if the fire hits
        Mark the unit as spent after firing
```

Class MovableRed(MovableUnit):
Function __init__(surface, blue_units, game_ai):
Initialize a red unit

Function target_closest_blue(hex_centers):
Find the closest blue unit and fire at it if valid

Class MovableBlue1, MovableBlue2, MovableBlue3 (inherits from MovableUnit):
Initialize each blue unit and handle placement based on their size and shape (ellipse, rectangle, or polygon)

Function handle_command(command, objects, hex_centers, round_counter):
Parse the input command and validate the format
Execute the command:
- If move action, move the specified unit to the target hex
- If target action, fire at the specified target
- If rally action, rally the specified unit
Return the updated round counter

Function check_game_end(objects):
Check if any blue unit reached the same hex as the red unit
Return True if the game ends, otherwise False

Function all_blue_spent(objects):
Check if all blue units are spent
Return True if all blue units are spent, otherwise False

Function rally_all_blue(objects):
Reset rally state for all blue units and rally them

Function get_input_thread(objects, hex_centers):
Initialize round counter
Continuously take user input commands and process them until the game ends or the round limit is reached

Function play_step(actions):
Process each event in Pygame's event queue
Initialize reward and done flag
For each action, move or fire with the corresponding blue unit
Red unit targets and rallies after blue units have moved
Update the screen display and redraw hexagons and units
Check if the game ends or the round limit is reached
Return the reward, done flag, and round counter

Main Game Loop:
Continuously update game state, process player commands, and run the simulation until the game ends or a condition is met

## Pseudocode Model:

Import necessary libraries:
torch (for deep learning operations)

```
    torch.nn (for defining neural network layers)
    torch.optim (for optimization algorithms)
    os (for file handling)

Define class Linear_QNet (Neural Network for Q-learning):
    Function __init__(input_size, hidden_size, output_size):
        Initialize the neural network with:
            - An input layer of size input_size
            - A hidden layer of size hidden_size
            - An output layer of size output_size

    Function forward(x):
        Pass input x through the network:
            - Apply ReLU activation to the hidden layer output
            - Pass the result to the output layer
        Return the final output

    Function save(file_name='model1.pth'):
        Define the folder path './model1' to save the model
        If the folder does not exist, create it
        Save the model's state (weights) in the specified file

Define class QTrainer (Training logic for Q-learning):
    Function __init__(model, lr, gamma):
        Initialize the trainer with:
            - The Q-learning model (Linear_QNet)
            - Learning rate (lr)
            - Discount factor (gamma)
        Initialize the Adam optimizer using the model's parameters and learning rate
        Initialize the loss function (Mean Squared Error)

    Function train_step(state, action, reward, next_state, done):
        Convert state, action, reward, next_state to tensors of float or long type

        If the state is a single instance (1D tensor):
            Unsqueeze (add a dimension) to convert it into a batch of size 1

        # Step 1: Predict Q values for the current state
        Predict Q values using the model on the current state

        # Step 2: Calculate target Q values
        Create a copy of the predicted Q values
        For each experience in the batch:
            If the episode is done:
                Set Q_new to the reward
            If not done:
                Set Q_new to the reward + gamma * max(next state's Q value)

            Ensure that the correct action's Q value is updated with Q_new in the target

        # Step 3: Train the model
        Zero out the gradients of the optimizer
```

Calculate the loss between the target Q values and the predicted Q values
Perform backpropagation to compute the gradients
Update the model's parameters using the optimizer

## Pseudocode Agent:

```
Import necessary libraries:
    torch (for neural network operations)
    random, math, numpy (for numerical operations)
    deque (for memory management)
    GameAI from hexgameAI (game environment)
    Linear_QNet, QTrainer from model (Q-learning model and training system)

Define constants:
    MAX_MEMORY = 100,000  # Maximum size of memory buffer
    BATCH_SIZE = 1000     # Size of mini-batches for training
    LR = 0.001            # Learning rate for the neural network

Class Agent:
    Function __init__():
        Initialize number of games played (n_games = 0)
        Initialize epsilon (exploration factor)
        Set gamma (discount rate) to 0.9
        Initialize memory as a deque with MAX_MEMORY capacity
        Initialize the model using Linear_QNet with input size 10, hidden size 256, and output size 3
        Initialize QTrainer with model, learning rate LR, and gamma

    Function calculate_distance(point1, point2):
        Extract x and y coordinates of two points (hex centers)
        Calculate and return the Euclidean distance between them

    Function get_state(game: GameAI):
        Get red unit's current hex position
        Get blue units' hex positions
        Calculate distances between red unit and each blue unit
        Create the state array containing:
            - Distances from blue units to red unit
            - Positions of the blue units
            - Position of the red unit
            - Whether each blue unit is spent
        Return the state as a numpy array

    Function remember(state, action, reward, next_state, done):
        Add (state, action, reward, next_state, done) to the memory buffer
        If the buffer reaches MAX_MEMORY, remove the oldest entry

    Function train_long_memory():
        If memory contains more than BATCH_SIZE entries:
            Randomly sample a mini-batch of size BATCH_SIZE from memory
        Otherwise:
            Use the entire memory
        Unpack the mini-batch into states, actions, rewards, next_states, and dones
```

```
        Call trainer.train_step with these unpacked components to train the model

    Function train_short_memory(state, action, reward, next_state, done):
        Call trainer.train_step with the single experience tuple to train the model

    Function get_action(state, hex_centers_len):
        Set epsilon to 80 - n_games (decrease randomness as games progress)
        Initialize final_moves as an empty list
        For each blue unit (3 iterations):
            Initialize final_move as [0, 0, 0] (no move/action)
            If a random number is less than epsilon (explore):
                Randomly select a move (one of the actions)
                Randomly select a target hex index from the available hex centers
                Append the target hex index to final_move
            Otherwise (exploit using the model):
                Convert the state to a tensor and pass it through the model
                Select the action with the highest predicted Q-value
                Append the target hex index to final_move
            Add the final_move to final_moves
        Return final_moves (actions for all blue units)

Function train():
    Initialize plot_scores, plot_mean_scores, total_score, and record
    Initialize an instance of Agent and GameAI

    While True (infinite loop):
        Get the current state from the game using agent.get_state
        Use agent.get_action to decide the moves for blue units
        Play a step in the game using game.play_step with the chosen actions
        Get the new state from the game
        Train the agent's short memory with the old state, actions, reward, new state, and whether the game is
done
        Store this experience in memory using agent.remember

        Update the score based on the current game round and reward

        If the game is done:
            Reset the game
            Increment n_games by 1
            Train the agent's long memory (experience replay)
            If the reward is greater than 100:
                Print that the game was won in a certain number of rounds
            If the score is better than the current record:
                Update the record and save the model
            Print the current game number, score, and record
            Append the score to plot_scores
            Update total_score and calculate mean_score
            Append the mean_score to plot_mean_scores

If script is run directly:
    Call train function to start training the agent
```

# Appendix E

Including the full report of the interviews into the main text would take away from the readability of the thesis. Provided below is the full report of interviews 3&4.

Interview three was done with an expert in the field of military simulation. The interviewee attended multiple wargames in a supporting role. This role entailed simulation of the battlefield and presenting the results to the playing military personnel. In the domain of AI the interviewee had experience writing theoretical and technical requirements for AI applications. As for the potential benefits of AI in the context of military wargaming the interviewee saw the potential for a chat incorporation for questions during the wargame about the terrain or creating routes. Something which ordinarily would be done on the spot by the wargame leaders. Using AI here would give more accurate answers according to the interviewee. Furthermore, the interviewee illustrated the development of AI for the use of opponent modelling based on doctrine or information available to train the AI on. The interviewee also saw some hurdles concerning the implementation of AI into military wargaming. The first was the general lack of available data to train the AI on. This would lead to longer training times and in turn development cost. The second hurdle was the "Black Box" nature of the AI. It is hard to interpretate reasoning behind the actions of the AI.
When asked about the framework the interviewee was generally positive, while also mentioning some points for improvement. Firstly, the interviewee said that there might be a need for the validation of the AI after it has been developed to ensure it is still in line with the original reason for the development of the AI. Secondly, the interviewee said that there specified limitations on when and where the AI can be used. The third point for improvement would be informing the players of the wargame on which rules the AI had been given when trained as this could lead to situations where the players make assumptions only to be caught of guard be the actions of the AI. In turn depending on the purpose of the wargame this can also be a feature of the AI. Lastly, the interviewee mentioned the need for guidance to develop an ethically responsible AI.

Interview four was conducted with an expert from the field of military technology, specifically in the area of IT and simulation. The interviewee has been involved in wargames through research at TNO, where they played a supporting role as a developer for the simulator used during these exercises. Regarding AI, the interviewee had practical experience using AI tools, including ChatGPT and neural networks.
When discussing the potential benefits of implementing AI into military wargaming, the interviewee highlighted the ability of AI to model behaviors using machine learning (ML) algorithms. AI could help simplify complex models, covering both blue force and red force behaviors in a more accurate and realistic way. By incorporating AI, the simulation could provide better modeling of various combat actions.
However, the interviewee also pointed out several hurdles to implementing AI in this context. One major concern was the ethical implications of using AI in wargames, particularly in scenarios involving life and death. The need for explainability becomes crucial, even in training environments, as people need to understand how the AI reached certain decisions. While this could be acceptable in teaching scenarios, it becomes challenging when the AI is used to build doctrines. Additionally, combining expert knowledge with AI-driven models is difficult due to the lack of data in this area, making it hard to create reliable analytical models. The interviewee emphasized the importance of aligning AI behavior closely with real-world systems to maintain a strong connection to reality during wargames.
When asked about the framework, the interviewee stressed the importance of making ethical considerations a core part of assessing the need for AI, especially in academic contexts. Limitations of both AI and physical systems must also be factored into this assessment. The interviewee suggested that understanding both the purpose and the limitations of AI is essential before deciding whether AI is necessary. They also recommended including unclassified and classified modules in the framework to ensure that security considerations are addressed more prominently.

# Appendix F

## AI statement:

For parts of this thesis ChatGPT version 3.5 has been used. This includes only the writing and the coding.