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Naval Wargaming as a Requirements Elucidation Tool for Warship Design Teams

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ABSTRACT

This paper discusses some of the challenges of setting the requirements for a future warship program and how manual naval wargaming might be employed to make the process more efficient and structured. It goes on to describe some case studies where UCL's wargame "A Balanced Fleet" was applied to requirements-phase problems, in particular the ASW Barrier wargame conducted for the NATO Specialist Team on Naval Ship Systems Engineering. The paper concludes that wargaming is a useful tool in the requirements phase, in particular for helping to direct subsequent and more detailed operations analysis work.

KEY WORDS

Operations Analysis; Requirements; Wargaming; Warship Design

INTRODUCTION

In 2016 a series of wargames conducted in the UK and focussed on low intensity naval operations demonstrated the initial value of wargaming as a concept assessment tool. In this case, wargaming was used to explore facts of Mission Modularity when applied to a naval force, comparing its effectiveness with a force comprising more traditionally designed ships. The games involved members of the NATO Specialist Team on Naval Ship Systems Engineering (ST/NSSE) who sought to formalise the use of wargaming in their suite of concept assessment and analysis tools.

The work was initiated due to concerns in ST/NSSE, that project teams were launching into expensive and time consuming Operations Analysis (OA) without having conducted their own pre-analysis work aimed at refining the OA questions they were posing. This has the potential to allow the OA to unintentionally stray away from prime areas of interest. ST/NSSE's previous exposure to wargaming as a tool to demonstrate and investigate aspects of Mission Modularity gave rise to the thought that it could be broadly applied by projects at an early stage in concept development to test hypotheses and concepts, and thus allow follow on, comprehensive OA, to be better focussed.

Over the same period, UCL has developed a series of naval wargames as teaching tools for use in its MSc-level warship design programmes. One of these wargames, "A Balanced Fleet" has been further developed from a teaching tool into one suitable for application to requirements elucidation problems and was used in support of ST/NSSE's ongoing research.

This paper outlines the challenges that face a warship design team in the requirements elucidation phase, before going on to describe the development of ABF and how it has been used in several case study applications, including a week-long game series run for ST/NSSE. The paper concludes with the conclusions drawn from these series, indicating that wargaming may be a useful tool to assist requirements elucidation, and highlighting features which are desirable in such a wargame.

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THE REQUIREMENTS ELUCIDATION PROBLEM

Defining the requirements for a new type of a warship is a challenging task. It is oft said in design circles that "the customer doesn't know what they want"; this is meant as no slight on the customer, who usually has to juggle a large set of mutually interacting mission goals while constrained by funding. This is often a complex problem with opaque interactions and synergies between mission goals, to the point where it is often impossible to understand what a sensible compromise design would look like until some design work has been done. The process of setting the requirement is therefore often called Requirements Elucidation since it is less a process of deciding what desired requirement is, and more a process of gaining understanding about how the different requirements interact and what would produce a harmonious compromise that falls within budget.

If using a Systems Engineering framework, requirements are usually initially defined in a User Requirements Document (URD) in terms of Measures of Effectiveness (MoE) - statements of capability which can be expressed numerically and which relate directly to how capable the ship is at completing mission tasks. A MoE might be phrased as "defend a High Value Unit against an attack by X missiles of Y type, with at least Z probability of defeating all missiles." In order to relate these values to things that a ship designer can easily quantify, Measures of Performance (MoP) are defined, being quantities which can be numerically expressed and measured or estimated directly from the design – quantities like top speed, radar horizon, or number of vertical-launch system cells. To relate the MoEs that the customer cares about to the MoPs that engineers can readily provide some kind of model is required. This is usually the domain of Operations Analysis (OA), which can provide mathematical models which take MoPs as inputs and deliver predicted values of MoEs that result.

OA is a powerful field, but the complexity of the problems mean that it is usually reliant on making assumptions, which in turn are reliant on correctly framing the scenario to be modelled. How to frame these scenarios is the first problem of Requirements Elucidation.

The second problem is the complex nature of the interaction between different MoEs and MoPs. A warship will usually have a range of quite disparate missions, the relative importance of which is difficult to define. Different capabilities on the ship will usually contribute, in different degrees, to more than one mission. There may be synergies – an ASW helicopter also provides very useful maritime surveillance, liaison, and resupply capabilities at no additional cost. There may be capabilities which both contribute to a mission but do not synergise well – high ship speed and onboard aviation for a surface search mission, for example. Understanding the interplay of these capabilities is challenging, and typically customers rely on the judgement and experience of subject matter experts (SMEs). SME judgement offers good utility for relatively low cost but can have limitations; bias in favour of systems or approaches the SME is personally familiar with can often be observed, and novel systems can present a problem if there is nobody with experience in operating that kind of system.

An important tool in squaring the Requirements Elucidation circle is the Concept of Employment (CONEMP.) This is a document which outlines the missions that the ship is expected to undertake, and how it will undertake them. As with the requirement set, deciding the CONEMP is not straightforward; it is sensitive to cost/capability trade-offs and interactions between capabilities, and like the requirement set can usually not be pinned down until some exploratory design work has been done to understand the relationship between various Measures of Performance, the relevant Measures of Effectiveness, and procurement cost. The CONEMP should therefore be a living document subject to revision during the early stages of design.

Two potential pitfalls arise when defining the CONEMP. First, that it does not describe the whole of the mission and skips past some mission phase which turns out to be a vital driver of capability. (This may be most likely to occur around "boring" mission phases like deployment or extraction rather than the more kinetic central phases of the mission.) Second, it is very important to ensure that the entire design team share the same vision of the CONEMP and easy to get this wrong, especially if the CONEMP is a living document, of which several revised versions have existed.

Finally, humans are in general bad at visualising speeds, distances and times when expressed numerically, and these factor centrally into most CONEMPS. Allowing the team to properly understand the position and movement of the new design, relative to allied and enemy units, is a vital part of ensuring the CONEMP is workable.

WHAT IS WARGAMING

Wargaming is a term for which there is no single agreed definition within the community of practice. For the purposes of this work, the authors have used the definition used in the UK Wargaming Handbook (Ministry of Defence, 2017):

> *"A scenario-based warfare model in which the outcome and sequence of events affect, and are affected by, the decisions made by the players."*

Wargaming may use a computer model or may use a more manual approach with physical maps, pieces representing ship and other units, and a set of rules to adjudicate the outcome of uncertain events. These rules may be based on expert judgement to adjudicate each situation (open mechanics) or the generation of a probabilistic model and generation of random numbers (rigid mechanics.) The wargames described in this paper all used a manual approach, using paper maps, wooden blocks or models to represent ships, and a rigid ruleset. Some subjective adjudication was required, usually to decide edge cases outside the core areas the game rules represented.

The boundaries between wargaming and operational analysis are somewhat blurred, and different definitions draw their boundaries in slightly different places. Operational analysis seeks to provide numerical outputs to inform decision making, which can be obtained through a wide range of analytical approaches. Wargaming exists on a spectrum from very analytical games which seek to provide numerical data, through to very non-mathematical games modelling human interaction, especially in politics, where only very subjective data gathering can occur. Naval wargames used for requirements elucidation tend to fall somewhere between these extremes; the technology-centric nature of naval warfare means that some degree of rigid numerical rule mechanics is required, but the problem space tends to be too poorly defined to allow very analytical wargaming.

"A BALANCED FLEET" – A FAMILY OF WARGAMES

ABF as a Teaching Tool

A Balanced Fleet is a naval wargame which started life a teaching tool for use on UCL's Naval Architecture and Marine Engineering MSc courses (Bradbeer 2022), (Manley 2023). Initially named "A Simple UCL Wargame", or ASUW, it was developed to help student ship designers who often lacked background domain knowledge, to understand the engineering factors which make for a good or bad fighting ship. Initially delivered as a whole-class extra-curricular wargame running through an afternoon and evening, it was soon integrated into the teaching curriculum to meet three objectives:

- Develop students' understanding of the modern naval warfare context
- Allow students to rapidly explore possible design options for their capstone ship design exercise (SDX)
- Allow students to informally assess the effectiveness of their SDX ships at the end of the exercise.

To meet these objectives, a game would need to reflect the impact of design engineering choices on capability, in as transparent and granular a way as possible. It would also have to support a robust and transparent workflow for characterising an arbitrary (and often quite unconventional) student design. Finally, it would have to support between two and twenty-four players, to allow for small group design explorations and whole-class capstone games. A search for a suitable commercially available game turned up nothing, so ABF was developed internally.

The teaching incarnation of the game focussed on missile combat in deep water between surface ships with their organic aviation, with very limited modelling of gunnery combat, land units, land-based aircraft and submarines. Game scale was adjusted over time, but settled on turns representing one hour of time, map hexes representing 10 nautical miles of space, and opposing forces comprising between one and ten ships each. Large games were found to take approximately six hours to play.

Parts of the game were necessarily complex in order to represent the impact of design choices in a meaningful way. To preserve enough simplicity to be playable, other parts of the game were deliberately kept simple. For example, the representation of the ship's layout was kept very detailed, resulting in a complicated control sheet for each ship (Fig. 1), while all anti-ship missiles were considered as one of only three types: lightweight subsonic, subsonic, or supersonic.

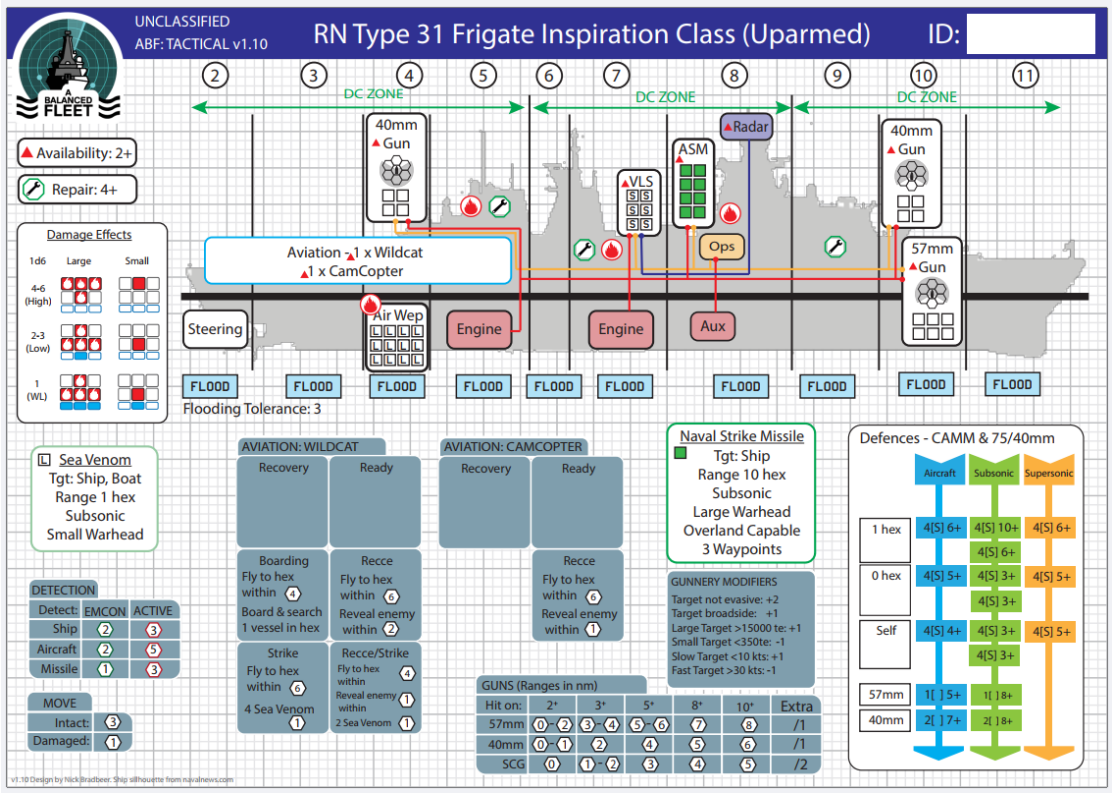

Figure 1: A ship record sheet from ABF: Tactical.

The game was designed with a modular architecture (Fig. 2); the game mechanics themselves were simple models designed to reasonably well match the outputs of more complex OA models, which themselves drew on a database of information about various units and their performance. This structure allowed for transparency in showing why the various game mechanics worked the way they did, as well as allowing the game to be adapted readily, either by changing out an OA model for a different one or by using a different database. This allowed the game to be incrementally improved since, for example, gunnery combat could be improved as better OA models were available, without impacting other parts of the game. While the game was developed around an unclassified database of open-source information, in principle it would be straightforward to substitute a database containing proprietary or classified data if required. (Every incarnation of the game described in this report used the unclassified database, keeping all the games unclassified.)

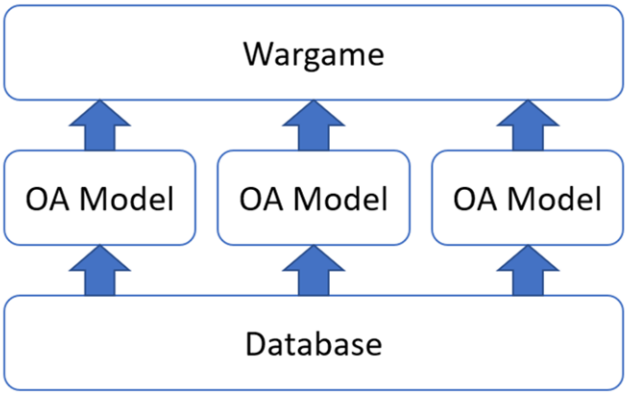

Figure 2: Architectural structure of ABF

Developing ABF Into a Requirements Elucidation Tool

Since 2022, ABF has been developed further to broaden its applicability, including a focus on making it a more useful tool for Requirements Elucidation.

The first major change was in expanding the range of game scales both upwards and downwards from the tactical scale originally chosen. The use of 8-hour game turns and 40 nautical mile hexes allows for play on an operational scale, with task forces in place of individual ships. This expanded scope allows for changes in weather, for ships to return to port after action to rearm, and for logistics chains to matter. Conversely, the use of 6-minute game turns and 1 nautical mile hexes allows for tactical ASW to be modelled in detail. Procedures exist to allow telescoping time scales, allowing operational level games to pause the action elsewhere and zoom in to resolve a tactical ASW engagement.

Secondly, the game was adapted to support a play-redesign-play cycle. This was originally adopted because repetition of scenarios is good practice to support learning, and because the ability of students to make changes to their ships and see the effects of those changes was useful. The first approach taken was to pre-prepare a set of baseline ships and then a set of (usually 3) variant designs which improved some feature. Players would play once with the baseline ships and then use their experience from the first game to select a mix of variants to play again. This was useful but felt limiting and players tended to want to express their own design choices instead. An interim approach was to play the first game, conduct a groupwide brainstorming session to suggest options, apply estimated costs to each option and then allow each team to select options up to a budget limit. Baseline ship sheets would then be modified (rapidly, by hand, using Sharpie markers) and the game replayed. The loss of production value was considered worth the gain in versatility.

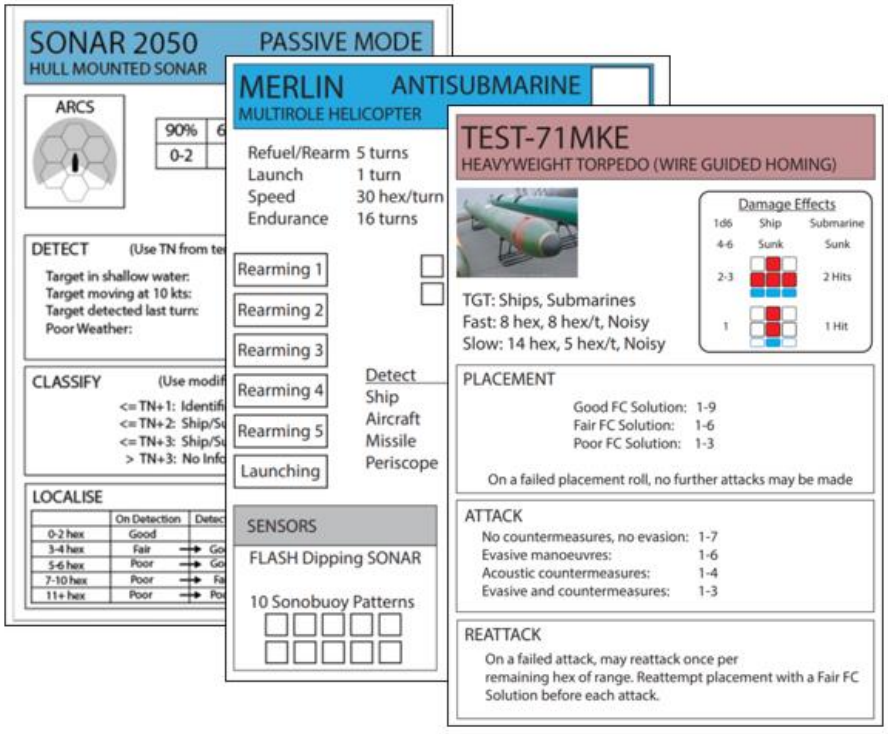

Figure 3: ABF Capability Cards

The most recent iteration of the game disconnects individual capabilities from the ship design. Originally the ship control sheet contained all the data needed to operate the ship, including detection ranges, performance of offensive missiles and the ship's air defence system. These have since been removed from the ship record sheets onto individual capability cards (Fig 3), so a baseline ship might be accompanied by cards for a particular radar and sonar, a particular offensive missile system, helicopter and air defence system. Creating a variant with a different combat system is then just a process of selecting a different combination of payload capability cards. (Within the bounds of practicality, of course.) Variations in layout or subdivision still require adjustment to the ship control sheet, but the use of capability cards certainly simplifies the adoption of different sensor and weapon systems, not to mention increasing legibility over performance numbers scrawled in Sharpie.

The third major change made to the game was to develop rules for additional unit types and operations, to broaden the range of missions ABF could model. The most significant addition was the creation of rules for submarines and ASW, requiring a detection model for sonars, rules for ASW weapons, acoustic signatures and the impact of water depth and weather on ASW detection. Sonar detection is inherently a very complicated process with many important variables, and the game's ASW model is still considerably more involved than the missile combat model, but it does allow for the simulation of tactical ASW engagements in a reasonable time frame.

In part driven by the need to model ASW systems and in part by the demands of a game with 6-minute game turns, a model for persistent aircraft was developed, in contrast to the original ABF model which considered air missions to be essentially instantaneous events. This allowed for helicopters to conduct lengthy ASW search missions, as well as Airborne Warning & Control missions.

Finally, a (very simplified) system for land/amphibious operations was developed, centring on amphibious transport capacity and logistics rather than units' land combat capabilities.

CASE STUDY GAMES

ABF has been applied to a number of problems in the requirements space for a variety of client organisations across several nations. With the exception of the week-long game run for the NATO Specialist Team on Naval Ship Systems Engineering described in the next section, client confidentiality means that only limited detail can be presented about each of these, but they serve to illustrate the range of ways in which wargaming can be employed by design teams in the early stages of specifying a new ship.

Game 1 – Team Building

The authors delivered an event for a shipyard who design and build naval ships. The shipyard was standing up a new team to develop a warship from the outline design provided by their government customer, into a detailed design suitable for building. The team comprised mostly early-career engineers who were specialists in a particular area of ship design.

The wargame event had two functions; first to serve as a teambuilding event, and second to introduce the specialist engineers to the whole-ship design considerations that drive cross-cutting capability areas like survivability. ABF as-designed already had a number of features to support that objective; the centrality of layout and zoning to the ships' representation in the game and how those factors affect survivability required no alteration to the game.

This was the first time that the Play-Redesign-Play cycle was explicitly used in ABF. The sixteen players were divided into four groups of four and each group played the introductory ABF scenario "Shell Game", based around a Board, Inspection, Search & Seizure (BISS) operation in the Western Pacific. Shell Game pits a multinational force of three frigates attempting to find a contraband shipment against three frigates attempting to prevent them. The game used the basic ABF Tactical ruleset (1 hour turns, 10 nautical mile hexes) and took roughly two hours to play through.

After the first playthrough, when the players had a feel for how the game worked and the relative strengths and weaknesses of their ships, they were given the opportunity to replace each ship with one of three pre-prepared variant designs; each variant improving some aspect, generally either offensive weapons, defensive weapons or vulnerability reduction features. Teams were then shuffled so each pair of players had a new opponent, and the scenario was replayed. Increased familiarity with the game meant the second playthrough took roughly one hour, and it was in fact possible to fit three games into the day.

Aside from working well as a teambuilding experience, the game proved to be a useful way to give system specialists an overview of whole-ship considerations like layout and subdivision. In particular, participants said it helped them understand the reasons for some of the demanding naval standards they had to comply with. The event was considered successful and a follow-up event has been requested.

Game 2 – CONEMP Exploration

The authors developed and delivered a wargame for a government warship design project. The project was in a preliminary stage and working on a ship with a relatively novel mission set and incorporating new technologies with which the customer

had limited experience. Lacking experienced personnel who could make informed judgements, the team looked to other approaches to help explore the CONEMP.

The purpose of the game was twofold; to allow an initial workthrough of the CONEMP with the whole team, and to evaluate whether wargaming was a worthwhile tool to apply to the problem.

This game used the basic ABF Tactical ruleset, although a new scenario was developed around the candidate ship's CONEMP. The one-day event contained a briefing in the morning followed by 2v2 playthroughs of the introductory "Shell Game" scenario to give the participants familiarity with the game rules. This was followed after lunch by a playthrough of the CONEMP scenario, with the group divided between four simultaneous games.

While there was no repeated play of the CONEMP scenario, the outcomes of the four games were fed back in a hot washup discussion. While this sort of wargaming should never be considered predictive, the fact that several of the games identified the same difficulties with certain parts of the CONEMP was useful, directing focus and further analysis onto those parts. The event was considered successful in meeting both its objectives; participants reported an increased understanding of their CONEMP and the team's design goals, and a more formal follow-up program of analytical wargaming was initiated.

Game 3 – Force Development

A third client was a national defence research agency interested in conducting exploratory force development experimentation with a view to shaping the requirements of future platforms procured across the sea, air and littoral/land domains. The objective of this game was primarily to explore how useful wargaming could be to assist with these force development planning activities.

The ABF Tactical ruleset was modified slightly for this game to include maps of the desired areas of operation and current platforms for the client and potential adversary forces. A scenario was designed to model a typical operation of interest to the customer. The wargame could then be used to play that scenario through with existing platforms and weapon systems, then replayed using potential future force mix options, to better understand how the capabilities offered by each option contributed to the mission, against current and expected future adversary forces.

At the time of writing, this project was still ongoing, so no conclusions can be reported.

ST/NSSE WARGAME CASE STUDY

The NATO Specialist Team on Naval Ship Systems Engineering (ST/NSSE) requested a wargame to explore whether wargaming could form a useful part the concept assessment and requirements elucidation process, specifically whether it could help give shape and structure to the initial stages of operational analysis, saving time and cost in the programme. The team were of the opinion that wargaming could be used as a "precursor" event, allowing projects to conduct initial evaluation of the value of their developing concepts, allowing initially attractive but unfeasible options to be discounted, whilst more credible options were refined and developed. This would allow for a more targeted approach to the conduct of formal OA, making more effective use of OA resource and enabling savings and efficiency in the use of research budgets. The outcome of these considerations was the proposal of a wargaming element within ST/NSSE's programme of work (Manley & Logtmeijer 2023).

In order to maximise the benefit of the work it was felt that any wargames conducted should be based on areas of interest to the NATO maritime community, although it was accepted that, at this stage, any work would need to be conducted at an unclassified level. This would create an atmosphere of familiarity with the subject when calling for support and discussing outputs with seniors. It was decided to use Anti Submarine Warfare (ASW) as the subject for study, and more specifically the conduct of ASW using uncrewed offboard systems in place of or supporting more traditional ASW assets. This is an area of considerable current interest, with a dedicated NATO Strategic Defence Initiative (SDI) project in place as well as several independent national studies being undertaken. It was hoped that, as well as demonstrating the validity or otherwise of wargaming in the intended role, that the outputs could inform, albeit at low classification, these various work streams.

UCL's ABF wargame formed the core of the wargaming engine, but this required significant development to cover some of the specialist areas required for the ASW-focussed games. These included the mechanics, sensors, weapons and tactics of ASW itself as well as a more detailed consideration of the management of uncrewed systems, in particular launch and

recovery. Environmental aspects were felt to have a more significant impact on smaller uncrewed assets hence a meteorological model was required to be developed.

NSSE Case Study Scenario

The specific operation chosen as the subject for the wargames was the use of an ASW barrier protecting a naval force against potentially hostile submarines and mine warfare forces. The series of games to be played would test the deployment, sustain and eventual recovery of the ASW assets through a number of stages of a mission.

Two forces would be considered, a “future force” comprising vessels designed specifically to operate uncrewed assets, and a “legacy force” made up of vessels broadly comparable to vessels currently in service. This would allow a direct comparison of the relative effectiveness of the new approach and the old. The future force was allowed to iterate, in that lessons identified in one game could give rise to mitigations that were then implemented in following games. The scope of improvements was moderated by the game management team to keep developments within realistic scopes in terms of cost and performance (the sudden development of “wonder weapons” was not allowed).

The overall campaign scenario selected was a Non-combatant Evacuation Operation (NEO) conducted in an environment where there was a potentially hostile submarine threat (surface threats were also considered as these could have an effect on the ASW assets, but the primary focus was the enemy’s submarines. The wargame campaign was set in the fictional countries of Florin and Guilder (it was felt that assigning names to countries and locations would create a deeper player engagement). Florin was a nation in the grip of both a civil war and the outbreak of a deadly epidemic. Meanwhile, Guilder was a nation seeking to benefit from florin’s misfortunes up to and including the use of military force to force territorial gains. “Blue Force”, the ASW-focussed side, was asked with conducting an evacuation of NATO citizens from a port in Florin, protecting the evacuation force from the threat of Guilder’s submarines (which constituted “Red Force”)

Blue Force was required to escort the high value units (HVUs) conducting the NEO to the area, protect them for five days of operations, and then depart. This provided a particular challenge for handling time throughout the scenario since the game would have to cover a week, but ASW operations have a decision cycle measured in minutes. This required a new “telescopic” approach to managing game turns, where time would be stepped through in units of 8 hours, 1 hour or 6 minutes depending on how much detail was required at any given moment. During phases where Red was waiting for a weather window to attack, large timesteps were used, stepping down to smaller ones as submarines manoeuvred into position and smaller again at time when there was a risk of detection and ASW combat.

Figure 4: Playing area and pieces for the NATO ASW Wargame

Game Management

The game's players were divided into three teams, broadly in accordance with normal professional wargaming practice. The teams, or "cells" comprised the Blue Team (ASW team), Red Team (Guilder's submarine force) and the White Team, where the game management staff and controllers sat. Each cell was located in a different room in the building so that they could not overlook each other's playing areas. Red and Blue cell players were restricted to their rooms, White cell were able to roam if needed to confirm their view and knowledge of the game state of play if necessary.

The White Cell was made up of the following participants:

- The Game Controller – responsible for maintaining the overall running of the game, timekeeping, turn flow, etc. They were also responsible for managing "injects" – specific events that both sides would need to react to, and for resolving any ambiguous or conflicting situations that may arise, often by drawing on the judgement and experience of SMEs.
- Green Cell Controller: controlling the actions of civilian units in the area, "background noise" and the friction of war. The Green Cell controller was necessary to turn the battlespace from a sterile environment containing only Red and Blue units into a more realistic situation where units could hide among everyday activity.
- The Adjudicators, or "Team Runners". At least one and ideally two members were allocated to act in this role as the link between the White Cell and Blue and Red Cells. They collected orders and other information from the cells and resolved the outcome of those on the White Cell map. They then fed back the results of their adjudications to their respective cells. Their roles became quite demanding when interaction between Red and Blue occurred, for example when Red was conducting a torpedo attack, or Blue ASW assets had detected and were prosecuting one of Red's submarines.

Red and Blue Cell participants comprised two to three players dedicated solely to the actions of their side in the game.

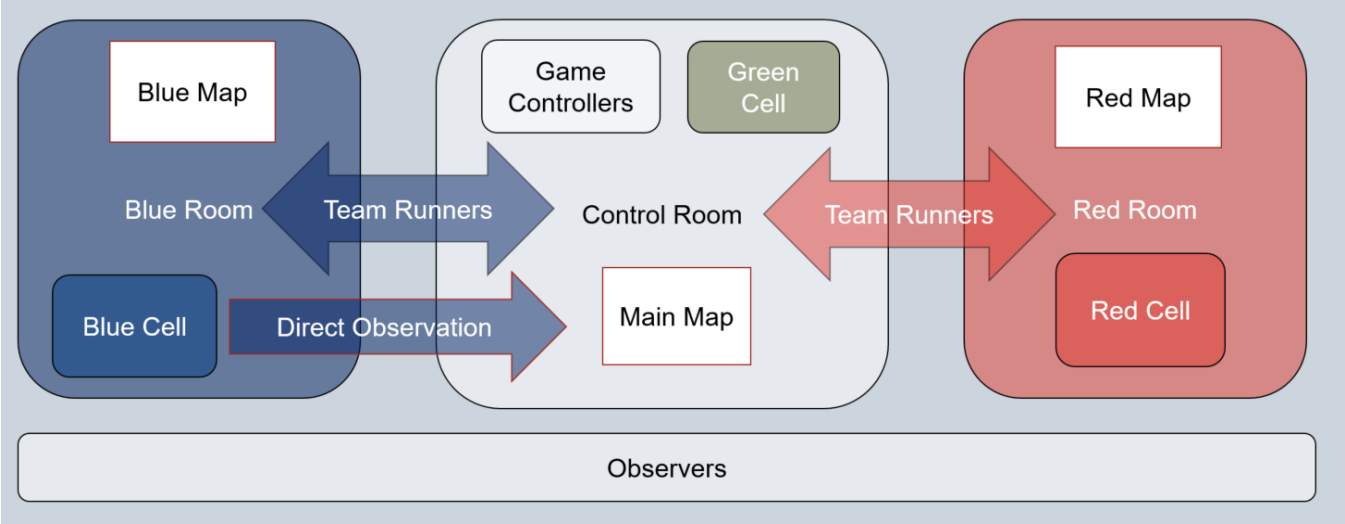

Figure 5: ASW Game Team/Cell Organisation

Game Execution

The wargame campaign was executed over a three-day period, with a fourth day set aside for evaluation, analysis and planning the next steps. Each playing day was made up of two sessions, one in the morning, the second in the afternoon, with a "wash up" taking place after each session.

A session was made up of the following events:

- A briefing for all players at the White Cell map, explaining the broad outline of the scenario. On completion all participants withdrew to their respective cells.

- Mission Planning; teams developed plans for their assets including locations, courses, speeds, and action to be taken in the event of a contact with enemy forces.
- Mission Execution; Adjudicators would then compare plans in the White Cell to determine where encounters occurred and would then begin resolution of those events, feeding back to Red and Blue as necessary and receiving updates orders or reactions to events. Missions were played to their conclusion, i.e. to the point where either Red or Blue had successfully completed their mission, or where mission completion was clearly not achievable.
- Recording – during each element of the games, players would record the rationale for their actions and decisions. This would form a key element of post-game analysis.
- Post game wash up; all cells were brought together at the White Cell map where the Game Controller briefed on what had actually in the game. This was also the opportunity for feedback, consideration of concept details and consideration for amendments. Again, this was recorded for post-game analysis.

Six game scenarios were planned as follows:

- Game 0 – A simple training game for all participants to give them familiarity with the game mechanisms. This game was not part of the formal concept assessment and hence was not recorded
- Game 1 – Approach Phase- Blue Force, using the conventional fleet construct, enters the Operational Area (OA) and clears the evacuation point and approaches of any Red submarines.
- Game 1a – a repeat of Game 1 but Blue Force uses the new modular force employing offboard systems.
- Game 2 – Evacuation Phase – Blue uses the conventional force to establish and maintain its ASW Barrier whilst Red submarines attempt to penetrate and interrupt the ongoing NEO.
- Game 3 – Evacuation Phase – a repeat of Game 2 but with Blue using the modular offboard-enabled force.
- Game 4 – Evacuation Phase – a modified version of game 3, with Blue able to amend its force mix based on experience from Game 3
- Game 5 - Exfiltration phase – Blue uses its evolved force from Game 4 and tempts to bring the evacuation force away from shore to safety.

It was originally intended to run each game once, but the players quickly became familiar with the rules and game execution so it was decided to tun two parallel instances of games 2 to 5 in order to increase experience, evidence and learning opportunities

At the end of each day a more extensive “hot wash” discussion was carried out to consider learning points for the day and to consider whether any changes were required for the following day’s games, including the inclusion of any new capabilities. An example of this was a deployable seabed sonar array (based loosely on a system advertised by Sonardyne), and a mobile hard kill anti torpedo system for defence of the evacuation anchorage (which was named “Palisade”). In both cases relevant SMEs were consulted for likely performance parameters and these were converted into game parameters overnight.

Capabilities Investigated

Blue Force was initially made up of conventional anti-submarine frigates, analogous to UK Type 23 or the Canadian Halifax class. They were equipped with towed array and hull mounted sonars and a capable ASW helicopter. After the initial games these were replaced with frigates using mission modularity concepts to embark offboard systems as well as their integral sensors. The offboard capabilities examined included:

- Uncrewed Undersea Vehicles (UUV). These were equipped with thin line towed array sonars. They were able to operate at the same depths as the threat submarines, but being small they were unable to process their own data. As a result they were required to go to periscope depth at preset intervals to transmit their recorded data back to their motherships for processing. This introduced inevitable data latency into the ASW problem. Being small and slow, however, meant they were extremely quiet and difficult to detect so a threat submarine was unlikely to be aware of their presence.

- Uncrewed Surface Vehicles (USV). These were small (8-11m) fast craft using the same thin line towed arrays as the UUVs. Again, due to their small size and lack of power they were unable to process their own

sonar data, but as they were operating on the sea surface they were able to transmit data back for processing on a continual basis.

- Uncrewed Aerial Vehicles (UAV). Large quadcopters or small helicopter-style aircraft capable of embarking and deploying up to four sonobuoys or a single lightweight torpedo. Their speed and endurance was limited whilst carrying heavy payloads such as torpedoes, but they were able to stay in flight for long periods of time and could work effectively in concert with each other or supplementing larger manned helicopters (the latter being Blue's preferred mode of use).

As mentioned earlier, lessons identified in the games led to proposals for new capabilities to be fielded. These included:

- Deployable seabed sonar system – a "spoke and hub" design was suggested featuring six passive hydrophone arrays ("spokes") radiating from a central buoy ("hub|) that maintained communications with command and control assets such as the modular frigates where signal data processing could take place. The system parameters set by the White Cell proved to be too effective, forming an impenetrable screen (although this did demonstrate the considerable benefit should such a high capability system be developed). The system was cumbersome and took time to deploy and recover, hence the Blue Team abandoned many of their arrays during the final scenario as recovering them would have left the force exposed for a significant time.
- USV-based torpedo defence system. In early games Blue was required to position its ASW frigates some distance from the evacuation port in order to be able to react quickly to submarine detections. Unfortunately this left the evacuation anchorage undefended and if a submarine could get within torpedo range there was nothing available to protect the evacuation ships. The frigates were already able to select a modular torpedo hard kill system so it was suggested that such a system could also be deployed in an 11m surface craft to provide local protection.
- Seabed communications network – a portable sonar based undersea communications network was discussed during the game but not fielded as it was felt this was more appropriate for use in a fixed location, such as a friendly harbour and its approaches, rather than in an expeditionary scenario as the campaign presented. If it had been used then the data latency issues of the UUVs could be mitigated.

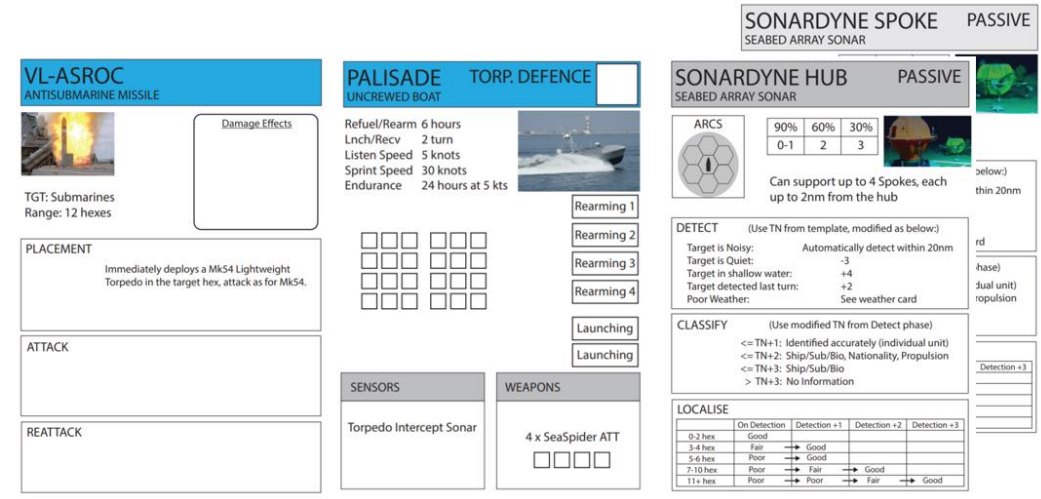

Figure 6: Examples of Capability cards created during the games

Results and Conclusions from the NSSE Wargame

At the end of the three days of gaming it was concluded that the game system worked effectively and had given realistic results. Several ASW SMEs were in attendance and confirmed that the events in the game and various conclusions drawn were in accord with their own understandings. This was considered by some to be quite remarkable given the unclassified nature of the games.

On day 4 the UCL wargaming team and the game's NSSE sponsors conducted a deeper review of the various lessons identified during each game. The NSSE team's view was unanimous; the wargames had successfully allowed a range of ASW and force mix options to be considered, evaluated and developed in such a way that a hypothetical OA study could begin from a more focussed staring point. From the NATO customer's perspective the applicability to the concept phase of project was clear (NATO 2023).

It was noted that, as well as achieving the stated aim, wargaming brought with it a number of other benefits. System designers and stakeholders were able to observe how elements of the various concepts interacted with each other, allowing synergies (and issues) to be identified. SMEs were able to see how their particular areas of expertise fitted into the overall ASW system, providing essential operational context that they had been previously unaware of. The multi-faceted makeup of the players involved – wargamers, operators, designers and deep experts - meant that each had an opportunity for interaction with their fellow players from different backgrounds, promoting learning and development. These were seen as essential elements over and above the primary objectives of the event. In its summing up of the event the NATO team was satisfied that wargaming had been shown to be capable of being used effectively as a concept analysis and elucidation tool whilst also delivering the potential for wider benefit. As a result, ST/NSSE is now moving working to include wargaming as an essential domain-specific activity in its new naval ship design NATO standard. As an additional spinoff the UCL team has been in discussion with other UK and NATO project teams on the possibility of using ABF and other tools for "real world" project analysis.

Noting that ST/NSSE's primary objective was to demonstrate and explore the role of wargames the outcome from the games and the discussions that surrounded them and the game process were (within the restrictions imposed by the unclassified nature of the event) felt to have shown:

- the potential for an effective anti-submarine barrier using offboard assets compared with a traditional arrangement when used in a defensive posture;
- benefits and drawbacks of the component elements of the system as proposed;
- capability gaps that existed in the ASW system as well as some in wider maritime operations, along with possible mitigations and solutions;
- the power of wargaming as a method for investigating the criticality or otherwise of components and characteristics of a system;
- how complex element such as sensor interaction, data processing and reliable communications are likely to impact the viability of a solution;

It was also demonstrated that:

- wargaming requires support from experienced wargamers to ensure that the learning points, including those arising from negative experiences, are relevant,
- wargaming and modelling and simulation (M&S) serve distinct and different purposes: wargaming considers the "big picture" and therefore should not be used for the study of extensive variations of the operational problem (it would take far too much time); M&S can be used to study an operational problem in great detail with many variations, with a much smaller problem scope compared with wargaming,
- the results of modelling and simulation can be condensed into game artifacts and used to develop the wargaming model.

CONCLUSIONS

The case studies described in this paper show four examples of ways that technically-focused manual naval wargaming has been applied to practical problems facing design teams in the requirements elucidation phase of ship design. The authors and clients have concluded that wargaming offers significant utility as a tool in this phase, in particular:

- Wargaming can help a design team understand which areas of performance will be most critical to ensuring mission success, helping to allocate subsequent and more in-depth operations analysis effort more efficiently.
- Wargaming can be an effective tool for exploring a warship's CONEMP, as well as ensuring that the CONEMP is fully understood by the whole team. Wargaming can be used as a form of active learning, which has shown to be more effective for communicating complex subjects than reading written material.
- Wargaming allows low-level technical models of novel systems to be integrated into higher level tactical or operational models, allowing assessment of those systems' effectiveness without access to prior operational experience.
- Wargaming allows the interactions between subsystems to be explored and better understood (in conjunction with subject matter experts, who remain a vitally useful resource).
- Wargaming allows the rapid exploration of the "arms race" of countermeasures and counter-countermeasures to a novel system, which can help to anticipate the future operational environment.

Some common useful features have been identified for wargames intended for use in requirements elucidation:

- Transparency about how game statistics are derived from real-world measures of performance.
- The ability to rapidly incorporate new systems and capabilities into the game.
- The ability to readily adjust the game mechanics to model different scenarios of interest.
- Credibility allowing faith in the results – most easily obtained by involvement of subject matter experts, historical data and OA models in creation and adjudication of the game.
- The ability to rapidly play the same scenario multiple times.

CONTRIBUTION STATEMENT

Nick Bradbeer: Conceptualization, investigation, resources, writing – original draft, writing – review & editing.

David Manley: Conceptualization, investigation, writing – original draft, writing – review & editing

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