ANALYZING NAVAL FLEET MODELLING WITH A TACTICS PERSPECTIVE – THE CASE OF IMPLEMENTATION OF AUTONOMOUS VESSELS

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SUMMARY

Development of autonomous vessels is expected to create a paradigm shift in how warfare is conducted. Therefore, there is need to explore the possibilities and limitations in developing integrated systems for defence at sea to support innovation. Fleet modelling can analyse functions and other design options such as autonomous platform's and evaluate their added effect in naval operations. However, due to the complexity of naval operations, it is not feasible to create a tool that covers all aspects needed to mimic reality. This study, from the perspective of naval tactics, investigate the value of a tool that analyses potential fleet architectures including autonomous platforms. The study identifies that the tool creates relevant mental models for future naval fleets by identifying feasible fleet compositions. However, the proposed fleet combinations are only tested against a limited set of tactical needs and can only be seen as a starting point for development.

KEYWORDS

Fleet modelling, Ship design, Military systems, Systems science for defence and security, UXV

1. INTRODUCTION

Autonomous vessel development in the 21st century is by many expected to create a paradigm shift in warfare and how conflict situations are resolved (Johnson and Cebrowski, 2005; Hughes, 2018a). An autonomous vessel is in this study understood as a vessel without personnel that at least can operate without direct input from an operator. These solutions offer to remove personnel away from risk, can reduce the loss of human life and increase the tactical options and subsequently protect more vulnerable or strategic defence assets. The vulnerability of many naval fleets is often determined by certain assets that are vital for the fleet and redundancy or robustness in the fleet structure is therefore important. Autonomous platforms can transform multiple large single-purpose vessels into a system of platforms (Debenedetti, 2008).

Recent studies on EU level concerning autonomous platforms have addressed the need for exploration of the possibilities and limitations in developing integrated systems for defence incorporating the use of autonomous platforms (EDA, 2020). Removing humans from direct operations on board a vessel can create smaller, equally capable platforms and introduce new ways of operational control, either from a remote location or when incorporating autonomy. However, the support for how to develop an appropriate implementation of autonomous systems into naval organizations is limited (Tärnholm and Liwång, 2022) and changes in technology, security contexts and innovation policies are creating more complex innovation systems for defence development (Molas-Gallart, 2010).

Fleet modelling can analyse vessels with different functions and other new design options such as autonomous platform's and evaluate their added effect in naval operations (Papakonstantinou *et al.*, 2019). However, due to the complexity and nearly infinite number of variables that have an effect on the outcome of naval operations, it is not feasible to create a tool that covers all aspects to mimic reality. Sinnema (2021) is one of the few that present and describe an example of a fleet modelling tool for early phase naval fleet design. The tool, Des4Ops developed at DAMEN, analyses potential fleet architectures with the inclusion of autonomous platform through a limited selection of operational aspects. The purpose of the tool is to identify fleet combinations that could act as new design input for early-stage naval fleet and naval platform design.

There is a need for creating relevant mental models to support innovation (Modig and Andersson, 2022) and strengthen the management and policy perspective (Liwång, 2022), where the tool Des4Ops possibly could support both. Therefore, to test the tactical relevance and value of the proposed tool and fleet modelling in general Des4Ops is here studied in relation to six analysis perspectives synthesised from the sea power of the coastal state as defined by Børresen (1994) in terms of six prioritized capabilities, the seven joint functions as defined by US Joint Chiefs of Staff (2018), emergent system properties, and performance under degraded system states. These analysis perspectives are used to capture strength and weaknesses of the proposed fleet modelling tool and discuss how it best is put to use in the development of future navies.

2. THEORY AND RESEARCH APPROACH

2.1 FLEET MODELLING

Existing fleet modelling approaches typically stem from the vehicle routing problem (Dantzig and Ramser, 1959) and several quantitative methods have been developed to optimise and simulate the operation of transport fleets to serve customer demands (Bielli, Bielli and Rossi, 2011). Literature is relatively limited when it comes to operational or maritime tactical planning problems. However, examples include a specific decision support for strategic planning in industrial and charter shipping problems (Fagerholt *et al.*, 2010) and an optimization problem for deciding an optimal amount of vessels and vessel routes operating on a liner shipping route (Fagerholt, 1999).

To design a naval fleet that is resilient enough to cope with future threats multiple possible developments has to be considered and find commonalities between them that will act as a base for setting up future fleet requirements (Johnson and Cebrowski, 2005). Limited defence budgets lead to compromises especially in relation to the number of vessels and their respective range of functions. Developing portfolios of specific future scenarios with current knowledge aid significantly in preparing for and finding commonalities for fleet requirements and Johnson and Cebrowski (2005) argue that an architecture that tests well against several stated futures should be favoured over an architecture that tests well against only one.

Naval fleet design modelling can be seen as a subset of naval battle modelling. This in turn is often based on Hughes' theory, described in four simple statements (Hughes, 1989):

- Naval warfare is attrition centred. Attrition comes from successful delivery of firepower.
- Scouting is a crucial and integral part of the tactical process.
- Command and control transform firepower and scouting potential into delivered force upon the enemy.
- Naval combat is a force-on-force process involving, in the threat or realization, the simultaneous attrition of both sides. To achieve tactical victory, one must attack effectively first.

This theory is the base for a number of subsequent studies; one of the earliest is Beall (1990), where the author creates a naval battle model and uses 14 historical naval battles to validate the model. Hughes later defined the so called salvo model, which represents the interaction between offensive and defensive missile firepower. The salvo model can be used to model attrition during a naval battle, and is included in many models, including in Sinnema (2021).

Naval fleet design modelling and fleet optimization has been described in Pruijn et al. (2020). In that study the focus is put on designing a fleet optimization tool concept that is based on systems engineering principles. The goal of the tool is to provide information about early-stage fleet composition and platform design requirements in which the method is able to create platform and system combinations that are subjected to certain mission requirements minimized for the total costs of the fleet. Applying systems engineering to the idea of considering a fleet of vessels as a system of systems has been shown to offer early insights into fleet composition (Fagerholt, 1999; Knegt, 2018).

2.2 MILITARY CAPABILITY

Capability is a central concept for a military organization to assess and communicate the abilities and performance of the organization (De Spiegeleire, 2011). The capability perspective represent a shift from the platform/system centric focus and consider military capability as something that outlives the duration of an individual technical system (Tärnholm and Liwång, 2022). This study takes a system perspective on military capability and naval capability is here understood as the total possible capability by a fleet of ships and other platforms including functions, such as a sensor for information gathering or a weapon for fire, as well as organization and tactics.

There are several ways to conceptualize military capability, one is in terms of seven joint functions to integrate, synchronize, and direct operations: command and control (JF1), information (JF2), intelligence (JF3), fires (JF4), movement and manoeuvre (JF5), protection (JF6), and sustainment (JF7) (US Joint Chiefs of Staff 2018). Other ways of understanding defence capability include Doctrine, Organization, Training, Materiel, Leadership and education, Personnel, and Facilities (DOTMLPF) and similar concepts (U.S. DoD, 2008; Australian MoD, 2014). Such approaches also highlight the importance of the interaction between technical systems and social aspects such as organization and doctrine and therefore stresses the sociotechnical system perspectives.

Modelling of naval fleets and systems introduce several simplifications, similar limitations are also associated with the systems engineering perspective. Both modelling and systems engineering typically consider capability in terms of the sum of the performance of individual idealized technical system components. However, research has shown that for military and naval operations emergent system properties (Bakx and Nyce, 2015; Papakonstantinou *et al.*, 2019; Liwång, 2022) as well as the performance in heavy degraded states (Liwång, 2020) are of great importance. These two aspects are not as dominant in civilian fleet characteristics where the operation typically is performed in a situation close to the design state and capability of the fleet can be treated as the sum of the contribution from each ship. It is also identified that it is important to understand the complexity of the military organization and its tasks especially when implementing innovative technology, i.e., to understand the fleet as a sociotechnical system that produce and enable the desired capability (Tärnholm and Liwång, 2022).

According to Mumford (2006) sociotechnical methods and approaches can contribute to better understanding on how human, social and organizational factors affect how work is done. This counteracts technocentric approaches which do not sufficiently address the complex relationships between the organization, the people and the technology (Baxter and Sommerville, 2011). Therefore, here military capability is understood as the ability of the sociotechnical system (vessels, organization and tactics etc.) to solve military tasks. This understanding includes emergent system properties, i.e., properties that are characteristic of the system as a whole and not its component parts.

2.3 NAVAL TACTICS

Tactics is here understood as ”the handling of forces in battle” (Hughes, 2018b). It is argued that the technical development has changed the balance of the forces and that, based on sea power theories, planning must “consider the possibility that the gap between large and small navies has narrowed and that the latter represent a much greater threat to the former than they used to” (Till, 2009). According to Børresen (1994) the seapower of the coastal state is defined by six prioritized naval capabilities (PNC 1-6):

- Mine warfare (PNC1)
- Maritime traffic control (PNC2)
- Maritime Intelligence, Surveillance, and Reconnaissance (PNC3)
- Meet a three dimensional (air, subsurface and surface) threat (PNC4)
- Communication in an electronic warfare environment (PNC5)
- Theatre coordination with air force, army and allies (PNC6)

Also, Børresen defines that the main task for coastal states during war is coastal defence operations and maritime control operations, i.e., operations to secure own territory and supply shipments, which creates a need for creating the system aspects deterrence and sustainability.

2.4 RESEARCH APPROACH

The focus of this study is to analyse how the studied fleet modelling tool address prioritized capabilities and central system properties for a naval fleet. The aim is to understand and interpret the phenomena of fleet modelling to gain a deeper understanding of fleet modelling in relation to capability and tactical needs. Therefore, the study take a qualitative system perspective on naval capability which here is understood as the capability of the sociotechnical system as discussed in Section 2.2. In this study the terms platform, function and performance are used for the respective technical systems such as ship or a sensor.

The system perspective on capability and the theory for naval tactics presented in Section 2.2 and Section 2.3 is the lens by which the value of modelling of fleet structure is measured. Therefore, the structure, rationality, and results of the modelling tool Des4Ops is analysed in relation to a range of perspectives that are a synthesis of the following frameworks:

- The need for addressing emergent system properties (Baxter and Sommerville, 2011; Bakx and Nyce, 2015) and the systemic performance under degraded system states (Liwång, 2020).
- The six prioritized naval capabilities (PNC 1-6) complemented with the called for system aspects deterrence and sustainability (Børresen, 1994).
- The seven joint functions (JF 1-7) (U.S. Joint Chiefs of Staff, 2018).

This specific range of frameworks is selected because there is a need to capture both specific and generic capability aspects and these perspectives are needed to analyse the operational value of a naval fleet. These frameworks are here synthesised into six analysis perspectives (AP1-6) used for the qualitative conceptual analysis in Section 4:

- AP1. Command and control (JF1), in general and including communication in an electronic warfare environment (PNC5) and theatre coordination with air force, army and allies (PNC6). These are internal aspects that are dependent of fleet structure and are therefore needed to analyse fleet compositions.
- AP2. Information (JF2) and Intelligence (JF3), in general and including maritime intelligence, surveillance, and reconnaissance (PNC3) and maritime traffic control (PNC2). These are external aspects effected by fleet structure and are therefore needed to analyse fleet compositions.
- AP3. Fires (JF4), in general and including mine warfare (PNC1). This perspectives deals with how weapon systems and sensors are implemented into the platforms and tactics.
- AP4. Movement and manoeuvre (JF5) in general. This perspective investigates the performance of each platform, but also the possibility for the fleet to manoeuvre as a unit.
- AP5. Emergent system properties, in general and including sustainment (JF7), the capability to meet a three dimensional threat (PNC4), creating deterrence effect and achieving sustainability. The emergent

properties does not connect to any specific fleet component but rather the total effect of the fleet as a sociotechnical system.
- AP6. Protection (JF6) and performance under degraded system states. This perspective both relate to implemented protective system components and the system performance after damage.

The analysis is performed on fleet modelling, and the specific modelling tool and cases, described in Section 3 developed and performed by Sinnema (2021).

3. FLEET MODELLING

Pruijn et al. (2020) suggest that fleet modelling can be particularly of interest if the objective is to model novel technological advancements such as autonomous platforms into naval fleets. The specific tool studied here, Des4Ops, applies a systems engineering perspective on a fleet of platforms as a system of systems based on previous developments described in Pruijn et al. (2020), Fagerholt (1999) and Knegt (2018). However, compared to previous studies where the attribution of capabilities to the fleet of ships was already fixed Des4Ops re-frame the problem to allow for more design freedom (Sinnema, 2021).

3.1 THE TOOL DES4OPS

This section gives an overview description of the fleet modelling tool Des4Ops presented and developed by Sinnema (2021) at Damen. Des4Ops consists of five areas of input data and three modules that have to be programmed in order to identify an optimized fleet architecture with a minimized cost objective function as the governing optimization variable. The five key elements that have to be considered and specified in detail by the user are:

- Scenario:
  - A set of locations including sea state statistics for each location.
  - A location specific set of tasks including task specific performance criteria.
  - The maximum allowed time for a scenario of tasks.
- Possible fleet components in terms of platforms:
  - A range of platforms with platform specific endurance, available weight, available space, performance in terms of speed, performance in terms of motion at different sea-states, and operational cost per day.
  - A range of functions and function specific weight, required space and performance in relation to areas such as the domains, type of threat, range, requirement on other functions, and operational cost per day.

The method is constructed in a manner in which it is scenario and task dependent. The scenarios are general descriptions about a situation that can be quantified in terms of time, distance and task required firepower.

3.2 MODELLING OF AN ESCORT MISSION AND A FORWARD-DEPLOYED MISSION WITHIN ENEMY TERRITORY

In order to generate a naval fleet for the specified scenario a range of platforms and functions have to be described. The fleet modelling described is based on three crewed surface platforms (ships) and three autonomous platforms (Sinnema, 2021). The autonomous platform systems include multiple individual platforms for creating 24 hour coverage and at least one platform operational at any time (Sinnema, 2021). Platforms and autonomous platform systems are described in Table 1.

Functions, or system-specific capabilities, are technical components that are central to solving the defined tasks. Des4Ops treats functions as modules that need to be added together to meet the defined tasks. These modules can therefore be carried by either traditional ships or autonomous platforms. The fleet modelling described below is based on the following available functions for each platform (Sinnema, 2021):

- For the small autonomous helicopter: An anti-drone system, a radar relay system, and a sonar buoy system.
- For the large autonomous helicopter: A very light-weight torpedo system, and a short range anti-ship missile system.
- For the medium size autonomous surface vessel: A decoy system, a very light-weight torpedo system, and a short range anti-ship missile system.
- For the crewed surface platforms: A torpedo and anti-submarine rockets system, anti-aircraft missile system, an anti-ship missile system, a short-range mortar for sonar buoys, chaff, and infrared decoys, a close-in weapon system, a 127 mm naval gun, and a 3D multibeam radar for long-range air, surface surveillance and target designation.

The different functions described above have different performance, size etc. dependent on for which platform they are intended.

The input on cost of platforms and functions is based on the following four types of cost: research and development costs, engineering costs, production costs, and operational costs. The costs are used to create an estimation of the total operational cost in terms of cost per day for each platform and function (Sinnema, 2021).

3.3 SCENARIOS AND MODELLING OUTPUT

This section presents the two scenarios and the fleet and results achieved with Des4Ops according to Sinnema

Table 1. Available platforms in the tool Des4Ops (Sinnema, 2021)

Crewed surface platforms (ships)		
Type	**Illustration**	**Description**
Small size ship		Displacement 900 tons and length 74 m (based on the Damen SIGMA 7513).
Medium size ship		Displacement 2,400 tons and length 105 m (based on the Damen SIGMA 10514).
Large size ship		Displacement 6,000 tons and length 144 m (based on the Damen LCF Frigate).
Autonomous platform systems		
Type	**Illustration**	**Description**
Small size helicopter system		Weight 0.2 ton (based on SAAB Skeldar V-200). One system consists of four platforms.
Large size helicopter system		Weight 1 ton (based on Northrop Grumman MQ8-B). One system consists of three platforms.
Medium size surface vessel system		Displacement 8 tons and length 11 m (based on Meteksan Defense Systems ULAQ USV). One system consists of two platforms.

(2021). For each of the fleets described the platform structure is illustrated in Table 2.

Scenario 1, escort of two cargo ships: Total transit 2150 Nm of which 150 Nm in high threat area. Sea state ranging from 1 to 4 and 40% in sea state 2. The threat is defined by one reconnaissance aircraft, two fighter-jets, one submarine, two fast patrol boats, and two drones. Based on the threat a minimum requirement of the fleet functions is defined including requirements on anti-aircraft missiles, torpedoes, anti-submarine rockets, sonar buoys, naval gun, chaff, anti-drone systems, and radar (Sinnema, 2021).

Scenario 2, under heavy fire: Total transit 1800 Nm of which 300 Nm in high threat area. Sea state ranging from 1 to 4 and 50% in sea state 3. The threat is defined by 12 fighter-jets, two reconnaissance aircraft, one large destroyer, one helicopter, 12 fighter bomber attackers, and one tanker. Based on the threat a minimum requirement of the fleet functions is defined including requirements on anti-aircraft missiles, anti-ship missiles, sonar buoys, chaff, and radar (Sinnema, 2021).

For each scenario, and for a combined scenario where Scenario 1 and Scenario 2 should be sequentially by the same fleet composition, the optimization objective is to identify a fleet composition defined by platforms and functions with a minimal cost optimization objective (Sinnema, 2021).

3.3 (a) Identified mission fleet, scenario 1

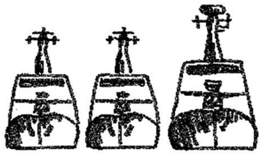
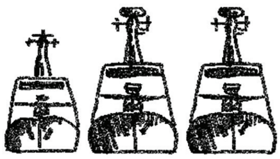
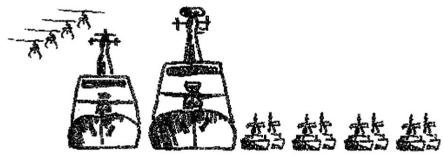
Two small ships of 74 m, one focused on anti-aircraft functions and one on anti-submarine functions. For this scenario the mission fleet is not changed if there is a possibility for autonomous platforms.

3.3 (b) Identified mission fleet, scenario 2

Alt 1, without the possibility for autonomous platforms: Two small 74-m ships, one focused on anti-aircraft functions and one on anti-ship functions, and one medium size 105-m ship with both anti-aircraft functions and anti-ship functions.

Alt 2, with the possibility for autonomous platforms: One small autonomous helicopter system (four platforms) focused on sonar buoy functions, three medium size autonomous surface vessel systems (three times two platforms), one system focused on decoy systems and two systems focused on combined short range anti-aircraft and anti-ship functions, one small 74-m ships focused on anti-ship functions, and one medium size 105-m ship with both

Table 2. Summary and illustration of the identified mission fleets by the fleet modelling tool Des4Ops (Sinnema, 2021)

Scenario	Identified mission fleet *without* the possibility for autonomous platforms	Identified mission fleet *with* the possibility for autonomous platforms
Scenario 1		
Scenario 2		
Combined scenario 1 and 2		

anti-aircraft and anti-ship functions. Estimated mission cost 80% of Alt 1.

3.3 (c) Identified mission fleet, combined scenario 1 and 2

Alt 1, without the possibility for autonomous platforms: One small 74-m ships focused on anti-submarine functions, and two medium size 105-m ships with both anti-aircraft, anti-ship and anti-submarine functions.

Alt 2, with the possibility for autonomous platforms: One small autonomous helicopter system (four platforms) focused on sonar buoy functions, four medium size autonomous surface vessel systems (4 x two platforms), two systems focused on decoy systems and two systems focused on combined short range anti-aircraft and anti-ship functions, one small 7-m ships focused on anti-submarine functions, and medium size 105-m ship with anti-aircraft, anti-ship and anti-submarine functions. Estimated mission cost 80% of Alt 1.

4. ANALYSIS OF THE IMPLICATIONS FOR NAVAL TACTICS

The analysis is performed in relation to the six synthesised analyse perspectives presented in Section 2.4 Research approach.

4.1 AP1 COMMAND AND CONTROL

The process of command and control aims at the *what* and *how* a mission is to be conducted in order to reach a certain end state in un unfriendly environment (Hughes, 2018c). The contest with a thinking opponent that is able to adapt and make decisions is what defines military command and control. When planning for a mission it is done in a static environment and the actual engagements are in a dynamic environment, all plans to some extent need to be altered and adapted depending on how the situation unfolds. Training and other preparations aim to mitigating this.

Aspects of this captured with Des4Ops is that fleet compositions with the possibility for autonomous platforms can gather more information and are more adaptable for the changing environment. The number of units also provides redundancy to the network. However the need for active transmissions of all the data makes it vulnerable to any sort of electronic warfare interference. On the other hand, the disruption of network traffic does not mean that the asset is neutralized. The autonomous vehicles can have the ability to continue the mission and then return to the ship or base autonomously where the information can be retrieved. If the collected information is time sensitive this could be a challenge. The physical destruction of the platforms is always a risk but the more platforms the more resilient the network. The computer models will need to handle the loss of platforms and to what extent it impedes gathering of information and how that affects the ability to achieve the mission. The fact that the operator is far away from the autonomous platform could also affect the operators' spatial awareness so the actions taken by the operator could perhaps not be as creative as with a crewed platform.

The mathematical model is not able to handle the dynamics of any tactical engagement after the static plan is created. As discussed in Washburn and Kress (2009), uncertainty regarding the opponent's actions differs from other uncertainties, since the opponent actively pursues other results than our own side. Managing multi-sided decision making problems has been made possible by introducing game theory. The number of possible dynamic choices an opponent may make provides many possible outcomes. However, Des4Ops does not consider different possible opponent actions. Therefore, it is difficult to know that the selected opponent actions will be suitable, i.e. that they collectively cover the significant possibilities that will affect the model of own forces.

Also, the Des4Ops assumes linear effects of fleet structure on communication increases and that the communication effectiveness is the same for all cases. These are simplifications that effect the model validity negatively, especially for the fleets with autonomous platforms.

4.2 AP2 INFORMATION AND INTELLIGENCE

The information that needs to be collected for the mission to be completed is the same whether or not autonomous vehicles are used. But the more assets that are available and if they are airborne provides the ability to have continuous monitoring over areas that are not available for surface based or crewed systems. One problem that occurs is that all the collected information needs to be transferred and disseminated and then analyzed in order to be used for decision making. The need for dynamic networks is paramount in order to transfer the enormous amounts of data that is collected. The scenarios that are used does not provide enough information of the size of the areas to be monitored or the traffic density. Information analysis is therefor only possible in very broad terms. It is very clear that the fleet with autonomous assets creates specific information challenges. The number of flying assets also provides the capability to take pictures and video so that identification is possible. The model can probably predict the possibility of target detection in the different scenarios.

Intelligence can be seen as information that is processed. The processing can be done, excluding the needed signal processing, to a small extent on board the autonomous platforms but in both fleets in all scenarios it has to be done onboard the major ships where computers can aid in the handling of the data. This can be described in terms of edge computing, where a majority of calculations and evaluations are done close to each sensor, and cloud computing, where raw data is transmitted to a central computing capability. Edge computing saves bandwidth, and in the military case will therefore lower the risk of detection. This could be included in improved models of the autonomous assets, though affecting the cost of the system. The model does not covers such differences between the two fleets in the scenarios.

4.3 AP2 FIRES

When the autonomous platforms have torpedoes and anti-ship missiles it provides longer ranges and more distributed lethality on platforms that are harder to engage. As long as the communication works, the target detection as well as engagements orders will enable joint fires and therefor better and more effective engagements. However, there will be multiple asymmetric duels between the autonomous assets and the enemy where details, such as specific actions and detection ranges, will affect the outcome. The conclusion is that to calculate fires, more details are needed or else the conclusions will only be superficial and the simplifications will affect traditional and autonomous fleets differently. An important aspect is whether the autonomous systems should be dependent on communication, or able to take on other tasks when working in solitude. In the latter case, it could be argued that they dynamically change into another class of system with slightly different capabilities. They could perform e.g., Intelligence, Surveillance and Reconnaissance whilst the manned systems take care of less predictable opponents.

For the special, but important, case of mine warfare the effect is highly dependent on specific geographic circumstances that cannot be dealt with a general model such as Des4Ops. A possible solution to this would be to introduce geographically dependent models.

4.4 AP 4 MOVEMENT AND MANOEUVRE

The planning of a fleets movements and maneuvers differs from the actual conduct of operations. Hence the two perspectives needs different analysis. When planning the operation all the units movements and maneuvers are to support the tasks given. Whether it is to transit to an area or in order to cover an area with sensors the calculations are well covered in the model. It is perhaps even the best task to give to a program to calculate as is shown in the scenarios. However, the actual movements and maneuvers of the units when faced with an opponent, i.e., how to react and make new calculations, the dynamic environment of the model has its limitations. Currently the model assumes that the scenarios play out on the open sea, with no limitations, where a more realistic model would consider that the own forces' freedom of action would be limited both by geographical aspects and by enemy actions and presence.

4.5 AP5 EMERGENT SYSTEM PROPERTIES

The Des4Ops creates solutions that minimise cost and the time to achieve the mission. Operational cost is always an important factor, however, the importance of time is not as straight forward. A defensive force under attack may not have the possibility to decide the time of events. The variable time can also be understood in terms of how many tasks that can be handled in parallel, and a maximum allowed time then set the minimum parallel tasks. Solving the scenario faster therefore implies that more tasks can be solved in parallel. Such capability to solve several parallel tasks lead to a reduced probability of being saturated and thus increased capability to meet the tempo of the aggressor. A good understanding of how time affects the outcome will provide the foundation for the timing and tempo of the mission execution in the dynamic environment.

However, despite Des4Ops consideration of time for operation completion emergent system properties are not considered for the different identified fleet compositions to any extent. Functions are treated linearly.

4.6 AP6 PROTECTION AND PERFORMANCE UNDER DEGRADED SYSTEM STATES

This Section analyses to what extent the studies of fleet modelling take the effects of opponent weapons and degraded system states into account. In relation to probability for degradation and operation under degraded states, the Des4Ops models fleets in a deterministic way assuming a fixed state, not effected by the scenario or combination of functions. Therefore, degraded states, or redundancy, is not considered.

How this simplification affects the assessment of a fleets capability differs between fleet compositions. Generally, distributing capability over a larger amount of platforms and functions creates protection and redundancy (Liwång, Ringsberg and Norsell, 2012). This would then make the assessment of distributed fleet concepts more conservative compared to assessment of traditional large platform centric fleet concepts. However, studies have also shown that personnel are crucial for keeping platforms and functions operational despite considerable damage (Liwång, 2020). This favours crewed platforms.

However, given a known dependency between platforms and functions and crewed platforms ability for recoverability, a probabilistic module could be developed to estimate the performance under degraded system states, at least in relative terms between proposed fleets. It could consider which of the joint functions and prioritized naval capabilities would be most likely to degrade, but also which ones would be possible to recover. Such an extension would also need to consider the protection level of system components as a result of size, speed and physical protection.

An addition of a probabilistic module would also provide quantitative values on the sensitivity to disturbances for different fleet compositions.

5. DISCUSSION

From a tactical perspective, the analysis of the two fleets in the three scenarios is sometimes too detailed and sometimes too limited. The current model and scenarios do more to provide cost analysis in relation to the implemented functions rather than the tactical performance. Therefore, the tools primarily identify technically and economically feasible fleet combinations.

One central factor is the communication between ship and autonomous platform. The description in the scenarios of electronic warfare capabilities therefor needs to be better formulated in order to have really meaningful results.

By studying the fleet modelling tool it is identified that the multitude of technical properties and properties that represent naval tactics is a challenge to represent in modelling transparently, i.e., to both implement and be able to explain how they are implemented and how different simplifications affect the modelling output. The studied tool has many necessary simplifications. These simplifications create a modelling result that is generic and does not give detailed input to central questions. For example, the result does not give input on the characteristics of the autonomy of the different platforms. Such information is needed to define the complexity of the needed autonomy development. There is a large difference between autonomy for a pre-defined sensor sweep and actions that require response to enemy actions.

The missing factors in the scenarios include areas, traffic density, detection and identification ranges, probability for damage, number of missiles etc., The chain detect-classify-identify-neutralize could possibly be used to tie functions, actions and probability together.

The model does provide a mathematical tool for gaining new insights. As mentioned by Sinnema (2021) the addition of more variables will be more demanding for computers and algorithms but not impossible. The problem will be to add the relevant variables and of the right type. The Des4Ops can handle binary, continuous and integer variables but if it possible to add the dynamic variables needed to take more complex perspectives of combat into account is not clear from the documentation. How to calculate the actions taken by a creative opponent? The mathematical model of Des4Ops finds the optimal solution by bringing in different types of data to find the local or global maxima or minima in 2D graph. The problem is such a point is only the solution to the set problem. In order to have systems that are useful for other tasks or missions, as all military units have more than one, either the model has to cover all areas or there is a need for several models. One way to improve the first is to allow divergences from the local or maxima points, without making the model so extensive that it becomes unusable. More advanced models can introduce AI as well as 3D graphs/models, however, to the cost of lower transparency.

To meet some of the identified weaknesses in relation to capability and naval tactics we propose two alternatives:

Alt 1. Re-design the tool to take tactics as a starting point. However, this will add complexity to the model and decrease the results explainability.

Alt 2. Complement the tool with additional steps to make sure that central system characteristics and naval tactics are captured.

The steps Alternative 2 could be: Step 1: Tool that identifies technically and economically feasible fleet combinations (Des4Ops). Step 2: Test identified fleet compositions in terms of system properties related to command and control, sustainment, protection and degradation. Step 3: Wargame on the most promising fleet compositions to also capture the dynamics the scenarios and an enemy. In such an alternative the Des4Ops tool is used for fleet generation, i.e. fleet modelling in its purest form. Based on the analysis above, a few of the identified needed improvements could be introduced in a new version of the tool, whilst others could be included in the consecutive tools in steps 2 and 3.

It is identified that the proposed tool supports creating relevant mental models for future naval fleets and therefore supports innovation and the management and policy perspective. However, they are not tested against tactical needs.

6. CONCLUSIONS

It is identified that there is a need for creating relevant mental models for future naval fleets to support innovation and strengthen the management and policy perspective. The proposed tool supports both needs with feasible fleet compositions. As the proposed fleet combinations are not tested against tactical needs, they should be seen as a starting point for development. However, despite the tools limitations one alternative is to complement the tool with two additional steps to make sure that central system characteristics and naval tactics is captured. One suggestion is that in the second step, identified fleet compositions are tested in terms of system properties related to command and control, sustainment, protection and degradation. In the third step war-games challenge the most promising fleet compositions in order to also capture the dynamics the scenarios and an enemy. Such an option uses the Des4Ops tool for fleet generation, i.e., fleet modelling in its purest form.

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