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COMPUTER ASSISTED MILITARY EXPERIMENTATIONS

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ABSTRACT

Computer assisted military experimentation methodology and process are explained. The military processes that can benefit from computer assisted military experimentation are introduced and the best practices for each process are elaborated on. Finally, emerging new concepts and their potential impact on the military experimentation requirements are briefly discussed and the tutorial is concluded. During the tutorial, live demonstrations are made for geostrategic foresight development, defense planning, operational plan analysis, computer assisted military experimentation design and conducting a computer assisted military experiment.

1 INTRODUCTION

Many contemporary conflicts are in grey zone or in other words hybrid. Threats to societies come from multiple directions. Although they may be initiated by separate actors, their effects accumulate and create end states not as intuitive as it used to be. Therefore, we live in a setting characterized with volatility, complexity, uncertainty and ambiguity (VUCA). Timely, coordinated and comprehensive employment of all instruments, as well as innovative and adaptive concepts have become necessity to counter hybrid threats. New tools and approaches are required to forecast, to design, to integrate and to plan. Therefore, concept development and experimentation has emerged as a key function in strategic level military headquarters.

VUCA has increased the need for big data processing, modelling, simulation and other means of computer assistance to military experimentation. Strategic headquarters can conduct computer assisted experimentations for geostrategic foresights, all domain concept and doctrine development, capability design and integration, advance and response planning. Note that we prefer using the term all domain instead of joint, which implies land, air and maritime in any combination. Space and cyber space have been added as the new domains (Cayirci et al. 2017).

Our tutorial consists of the following seven sections:

Section 2 starts with describing all domain military processes for transformation and how they are connected. Then, the process and the outputs of each stage in a military experimentation campaign are explained. We also identify the modelling and simulation tools and methodologies to support various stages in military experimentations.

Section 3 is about computer assisted military experimentations to develop a geostrategic foresight, which is typically first step in all domain warfare development. We define state vector and instruments for the geostrategic actors and give examples for the analytical models to quantify them. A game theoretic approach can be used for geostrategic foresight development. The audience gain an in depth understanding into modelling the state vector (i.e., political, military, economic, social, information, infrastructure) and

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instruments (i.e., diplomatic, information, military, economic, financial, intelligence and law enforcement). They also learn how to use game theory for strategic foresight development.

Section 4 is on modelling and simulation support to defense planning. Strategic foresights make the basis for the future scenarios and contingencies. The audience learn how to transfer a scenario including the belligerents in the scenario to a military constructive simulation system and to use simulation to calculate the optimum set of capability requirements for the scenario while fulfilling the constraints and restraints introduced by the political level.

Section 5 focuses on how to model and simulate a new concept or doctrine for validation. Concepts and doctrines can be on a variety of subjects. Therefore, they may differ significantly in nature from each other, and experimentation for new concepts and doctrines need a rich toolset and a flexible mindset. The types of simulation and the dynamics in their employment for concept testing are explained in this section.

Section 6 focusses on organizations and procedures. A capability package include doctrine, organization, training, material, personnel, leadership, facilities and interoperability. Wargaming is often used to understand military organizational and procedural dynamics. Therefore, we also briefly introduce wargaming methodology.

Section 7 is about computer assisted experimentation methodology by using military constructive simulation systems. Audience understand how to design and run computer assisted military experiments. The examples for computer simulation tools for military experimentations on operational plans are introduced. We elaborate on the dynamics to read an operational plan and transfer it to a military constructive simulation system. The challenges in designing an experiment, executing it, collecting the data and analyzing the collected data are explained, as well as the best practice in tackling with those challenges.

Section 8 discusses new concepts promoted in military circles and their implications specifically on military simulation tool set and their employment in training, exercises, wargames and experimentations, and concludes the tutorial.

2 MILITARY TRANSFORMATION AND EXPERIMENTATION CAMPAIGNS

2.1 Military Transformation Process

Armed forces must continuously transform and adapt both to the conjuncture and the technological developments. The key stages for transformation are depicted in Figure 1, and include the following:

- **Requirements Analysis** is the starting point, and typically carried out in four phases: eliciting, analyzing, documenting requirements and planning their development and/or procurement. The elicited requirements are analyzed, verified and validated through experimentation.
- **Design, Develop and Procure** is the next step where the solutions are designed, developed and procured. The requirements are addressed by capabilities, and a concept of operations is developed for every capability. The proof of concept is very important before starting the implementation of a capability project, and achieved through experimentation.
- **Experimentation** is the key transformational function to determine and verify the requirements and to design and validate the solutions.
- The **integration** of the newly procured capabilities with the overall instrument, i.e., military, typically counts on education, training and exercises.
- **Education, training and exercises** are necessary not only for the integration but also for the maintenance of military capabilities.
- **Evaluation** is for understanding if the military instrument and each individual capability perform as expected and meet their objectives, in other words, fulfil all the requirements.
- Every organization must **learn** from its performance. Learning is integrated every other function related to transformation.

Computer modelling and simulation can be extensively used in support of the transformational processes colored as orange in Figure 1.

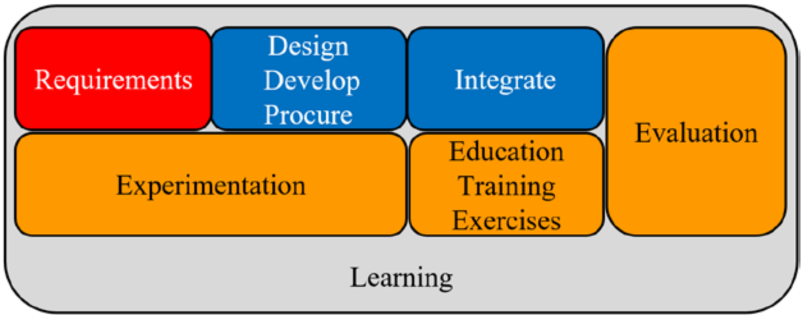

Figure 1: The key transformational processes.

The military transformation follows almost the same approach as explained above. The genesis for military transformation is a technology survey and geostrategic analysis, because transformation takes time and therefore smart military transforms for future requirements, which necessitates a medium term geostrategic analysis, in other words predicting the future settings and conjuncture is the starting point for military transformation. This step used to be very difficult and is now almost impossible due to VUCA, nevertheless, when successfully conducted, the benefit is not only timely mission preparedness, but also the opportunity to change the future setting and to evade undesired scenarios when possible.

When the future setting and scenarios are predicted and the political level guidance is obtained, the defense planning process starts for the following:

- **Capability requirements** to tackle with the future challenges are elicited, verified and validated through experimentation.
- **Capability shortfalls,** which are the capability requirements that cannot be addressed by the existing capabilities, are determined.
- **A plan to eliminate the capability shortfalls** is developed.

The following stage in military transformation is the capability management stage, which includes the design, acquisition and lifetime management of capability packages. The concepts and doctrines for the capabilities and their design can be tested through military experimentation campaigns.

The experimentations, training and exercises play key roles also during the integration of new capabilities.

As introduced above, the military transformation is achieved by various procedures conducted by separate functional entities, and often multiple of those processes are executed parallel. However, their connection and interoperability is critical for specific, measurable, attainable, realistic and timely (SMART) capabilities or in other words mission preparedness. One of the main roles of modelling, simulation and computer assisted military experimentation is to connect all these military transformation processes.

2.2 Military Experimentation Campaigns

Military experimentations can be conducted for various purposes and categorized as the following:

- **Discovery experiments**: When the tested concept, doctrine, capability, process or plan is new and the insight into it is not deep enough, discovery experiments are organized. Independent parameters (i.e., the factors of interest that affect the selected performance measures) and their relations with the dependent parameters (i.e., performance measures) are investigated and discovered in discovery experiments. In scientific terms, discovery experiments are based on propositions and conducted for generating hypotheses.

- **Validation experiments**: Validation experiments follow discovery experiments when they provide enough evidence about the significance and usefulness of the concepts and produce well stated hypotheses. The validation experiments are to prove or disprove those hypotheses. In practice, almost all the validation experiments are designed to disprove a set of null hypotheses (i.e., the converse of the hypothesis), which cannot prove the hypotheses but provide sufficient evidence to support it. Validation type of experiments requires a careful design of experiment and statistical analysis of the results, and may take very long time (e.g., months) to execute and analyze.
- **Demonstration experiments**: Demonstration experiments can be conducted with one of the following purposes:
    - Design/Concept Refinement: The subject to experiment is exposed to its potential users to get their feedback. Typically demonstration experiments are about the known facts, therefore, new discoveries are less common comparing to the other forms of experimentations. However, this subcategory of the demonstration experiments is conducted in less controlled environments without manipulating the operational setting much. Simply the new concept is exposed to its users in a realistic layout maybe the first time. Therefore, new discoveries can be made, which may require later validation experiments. Computer assisted exercises are excellent venues for this category of demonstration environments.
    - Education and Training: Demonstration experiments can also be conducted with the education and training purposes, such as getting better insight into it. This type of demonstration experiments are necessary, especially when the users cannot practice enough with the experimentation subject in real life.

As illustrated in Figure 2, validation experiments follow discovery experiments and demonstration experiments follow validation experiments. The experimentation subject gets more mature as the experimentation continues with the later types of experiments. Before the demonstration experiments with education and training purpose, the experimentation subject becomes a known fact. However, every experimentation including the demonstration experiments may reveal new information about the subject and can contribute the knowledge. Every types of experiments may also discover new facts, which may necessitate the organization of new experiments and revision of the concept. Therefore, it is common to organize an experimentation campaign rather than a single experiment for each new concept.

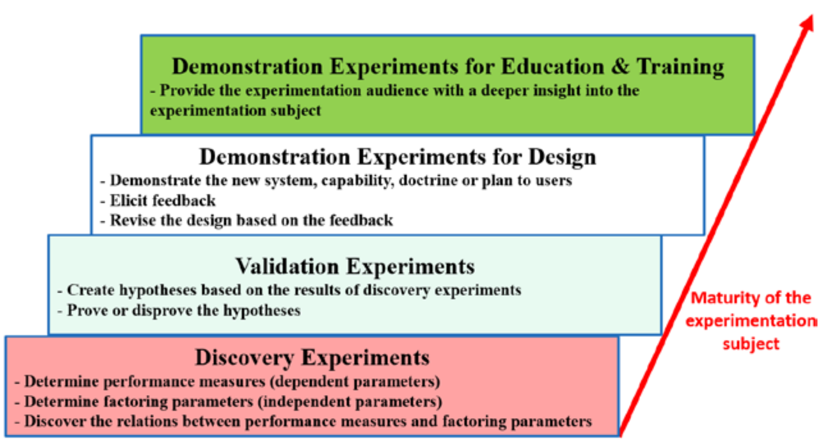

Figure 2: The types of experiments.

A military experimentation campaign (MEC) is an empirical study to reach an in depth understanding and knowledge about a concept of operations (CONOPS) for a defense plan, a doctrine, an operations plan or a military capability package (MCP). Note that an MCP consists of doctrine, organization, training, material, personnel, leadership, facilities, interoperability, and therefore a MEC for an MCP CONOPS may include experimentations to test doctrines, facilities, organizations, etc. A MEC is a series of related experimentations that explore and mature knowledge about a refined draft CONOPS. The MEC Process (MECP) has four stages as illustrated in Figure 3: specification, planning, conducting and reporting. Moreover, each experimentation within a MEC framework has three sub-stages: planning, conducting and reporting. Every experimentation in a MEC is a well planned and carefully executed set of tests to make observations and measurements about the selected performance metrics by manipulating selected factors of interest in a controlled environment in order to establish or track causes and effects.

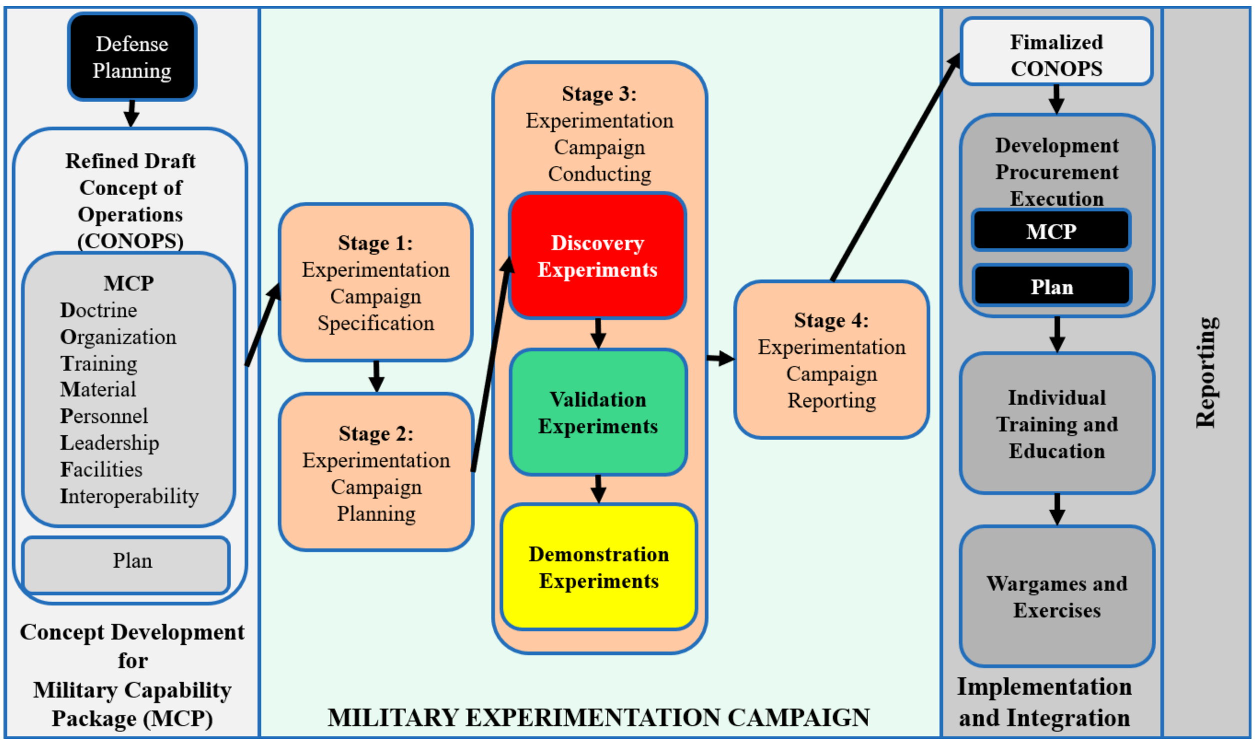

Figure 3: Military experimentation campaign process in concept development context.

3 COMPUTER ASSISTED MILITARY EXPERIMENTATION SUPPORT TO GEOSTRATEGIC FORESIGHT DEVELOPMENT

Military transformation is an expensive and time consuming process. In the era of VUCA, settings change continuously and hence it is often meaningless to transform for the current setting and scenarios. Transformation should be continuous and must be for the time when the transformation is complete. Therefore, geostrategic foresight is necessary before starting a new cycle of strategic transformational planning. The prerequisites for developing a geostrategic foresight are

- an accurate knowledgebase about the current setting, based on facts with minimum aura
- and a good understanding of the state of the art technology and the trends for the future technology.

As depicted in Figure 4, we follow a game theoretic approach to support the process for geostrategic foresight development. In military circles, the status of a geostrategic actor is often modelled by the state vector, i.e., political, military, economic, social, information and infrastructure (PMESII). Actors influence the setting by employing their instruments that consist of diplomacy, intelligence, military, economy, finance, information and law enforcement (DIMEFIL). We merge state vector with instruments and add technology as an additional instrument, and end up with 11 metrics in our game. We quantify these eleven metrics by using stochastic models based on 41 parameters, such as gross domestic product per capita, and several hundred variables, such as the percentage of women with a university degree, and then they are normalized such that the best actor gets 100 and the others are assigned a value that represent their relative power comparing to the best actor as shown in Figure 5.

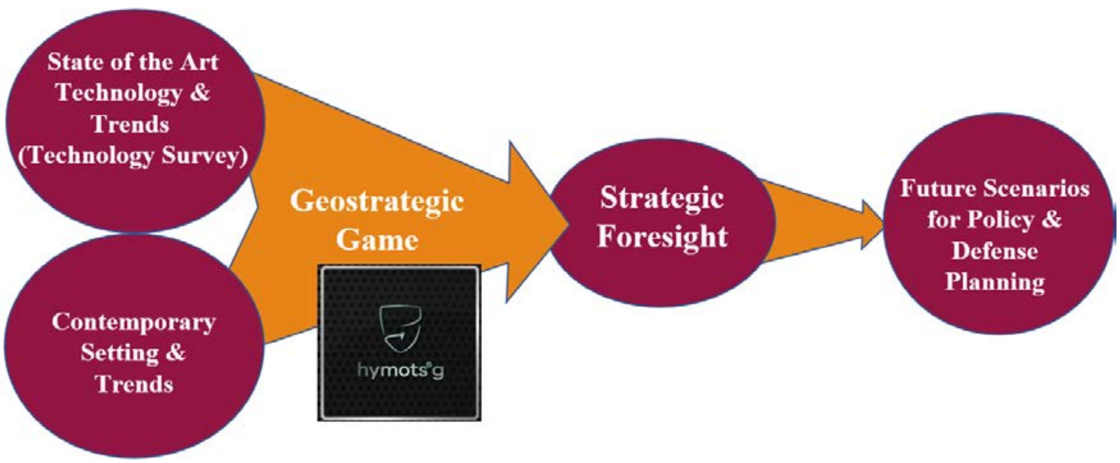

Figure 4: From setting to defence planning scenarios.

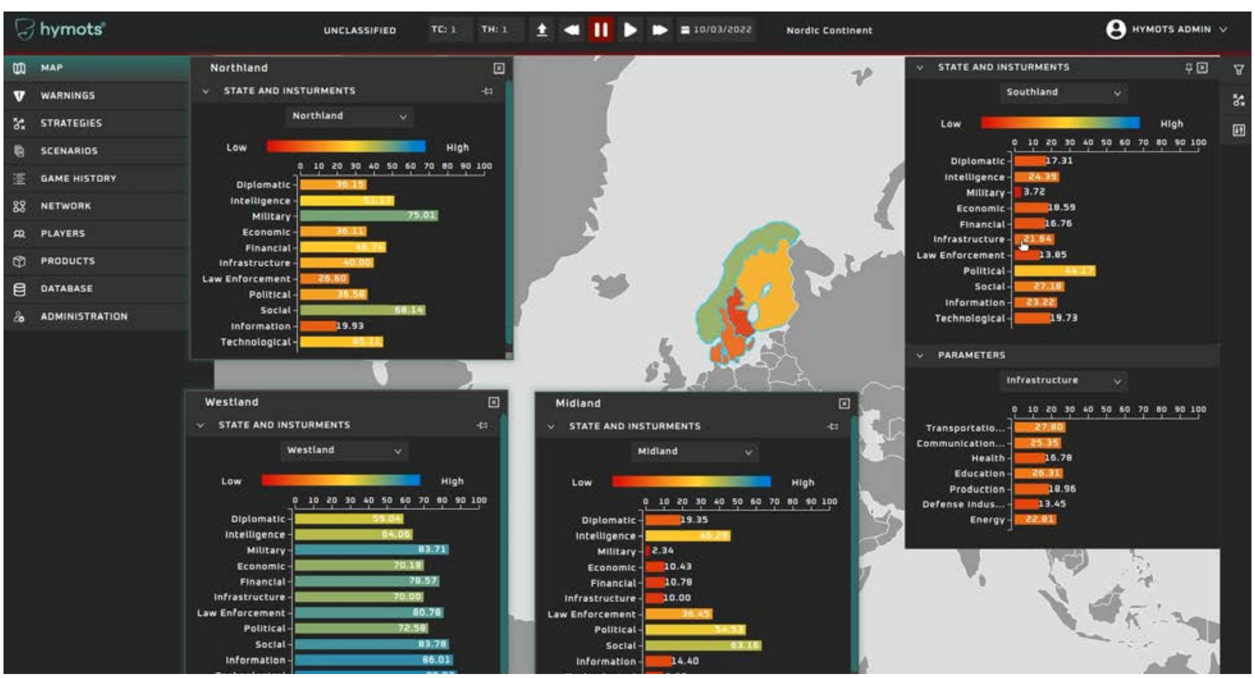

Figure 5: Geostrategic gaming.

In the geostrategic game, there are a variety of geostrategic actors, such as, states, cooperates, international organizations, non-governmental organizations, mercenary firms, terror and criminal organizations. They can implement strategies based on the projection of their 11 instruments. Each strategy has pre conditions, such as a variable or parameter value, and in and out strategies (i.e., the set of strategies that has to be implemented with the selected strategy, and the set of strategies that the strategy cannot be implemented together, respectively). The game is in the category of extensive form Bayesian game with imperfect information (Lasaulce 2011). When the defined scenario conditions are fulfilled, the game generates warnings. For example, if the military and diplomatic instruments of an actor is higher than another actor above a threshold and there is a conflict of interest between them, that implies a risk for an armed conflict. When simulation detects such conditions, it notifies the players.

The geostrategic gaming supports the strategic planners to develop a geostrategic foresight, in other words an insight into the future setting and scenarios, which become the basis for the requirement analysis.

4 COMPUTER ASSISTED MILITARY EXPERIMENTATION SUPPORT TO DEFENSE PLANNING

Defense planning process (DPP) is the key for proactively transforming the military structures for the future scenarios (Cayirci and Ozcakir 2016; Mazarr et al. 2019). In the post cold war era, many nations follow scenario based defense planning approach as shown in Table 1. Therefore, DPP can start when a foresight for the future settings and contingencies is developed and an insight into the latest technological developments is gained. DPP is illustrated in Figure 6. After the political guidance, or in other words a strategic concept for the scenarios, is received, the transformational requirements are analyzed. The main objective is to elicit the capability requirements for future and to develop plans for their timely acquisition and integration to the military. The main outputs of the DPP are: the future scenarios that the military is prepared for, the existing capabilities to be maintained, the new capabilities to be acquired, and the plan for acquiring and integrating new capabilities.

Table 1: Defense planning approaches.

Orientation	**Organization**	**Threat**	**Scenario**
Period	Pre-Cold War	During Cold War	Post Cold War
Concept	Create and equip units/ organizations	Calculate forces to counter the enemy	Determine the capability shortfalls for a given scenario
Outcome	Units and weapons	Conventional and special forces	Joint, agile and expeditionary capabilities

We use static and deterministic simulation based optimization tools in Step 2 for determining the future requirements to support DPP. The main aim of these tools is to figure out the optimum set of capabilities required to meet the political objectives in a given scenario. The optimization metrics can be various including minimizing the cost, the human casualties, the time to acquire the military capability shortfalls and maximizing the sustainability and practicality of the military instrument. It is also critical that the experimentation audience can run a sensitivity analysis on the results because the optimum solution is often not followed due to the unquantifiable political and diplomatic constraints.

5 COMPUTER ASSISTED MILITARY EXPERIMENTATION SUPPORT TO CONCEPT / DOCTRINE VALIDATION

A concept is "*an agreed notion or idea normally set out in a document that provides guidance for different working domains and which may lead to the development of a policy. With a focus on capability* *development, a concept is a solution-oriented transformational idea that addresses a capability shortfall or gap* (ACT, 2021)." A concept development process is depicted in Figure 7.

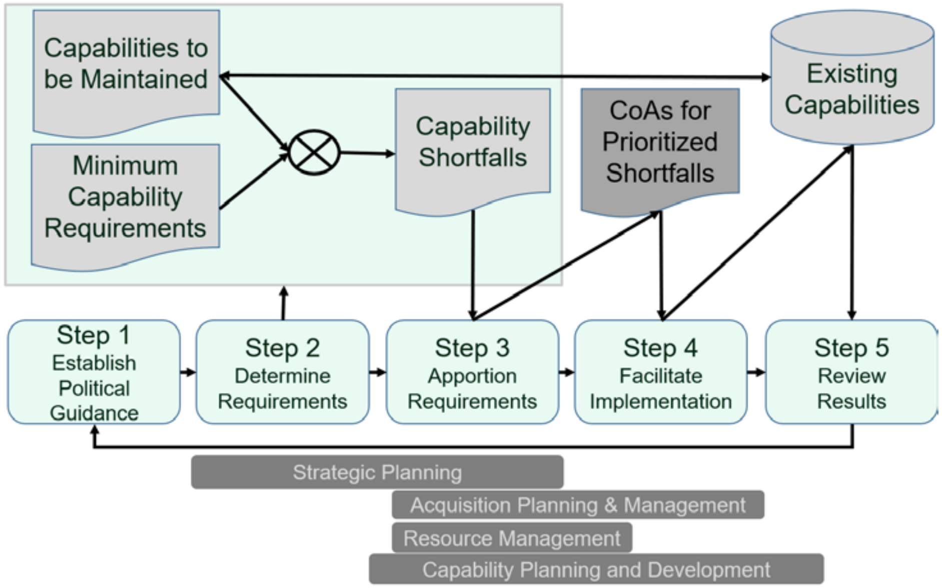

Figure 6: Defense planning process.

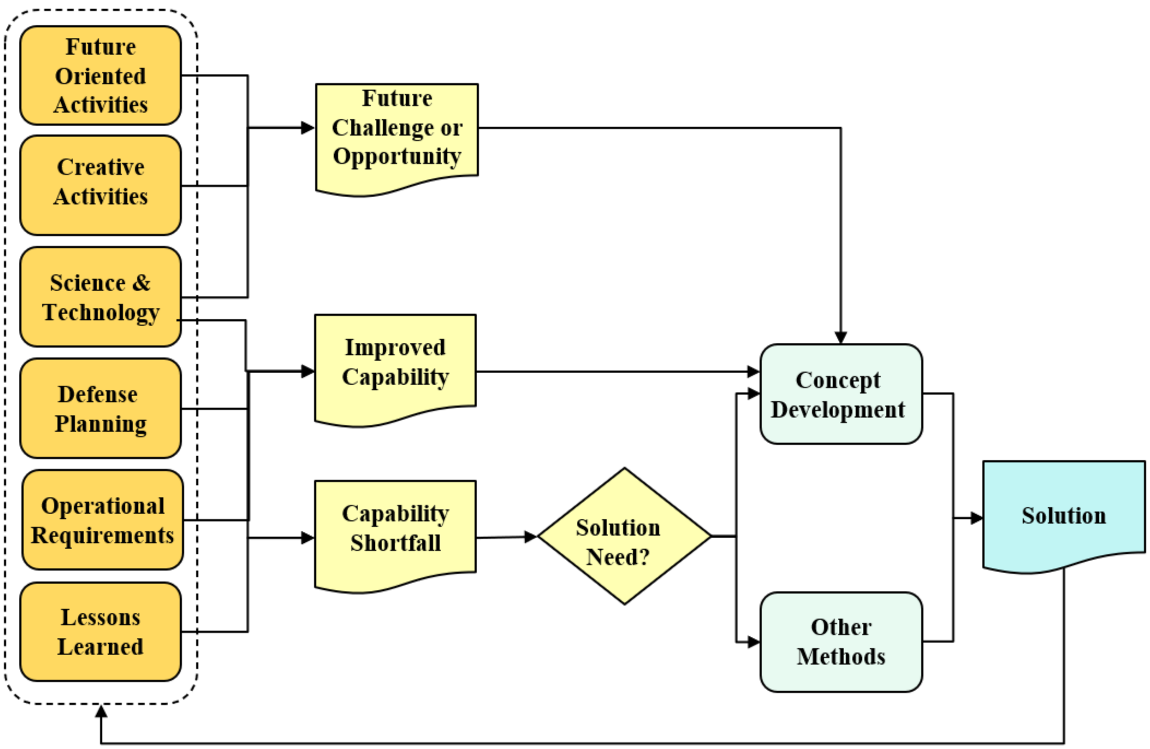

Figure 7: Concept development.

We follow the NATO concept development and experimentation (CD&E) process. In NATO CD&E, there are two main concept development paradigms or in other words orientations:

- Concept development for transformation: In our center, this is closely linked with DPP. The main inputs are the scenarios coming from the geostrategic foresight and the results from an extensive technology survey. Insights from academia and industry, lessons identified lessons learned (LILL) databases, the results of previous experimentations, the other strategic and operational concepts provide the knowledgebase required for developing novel and original ideas, which leads to a new concept.
- Concept development for a solution: When the military capability shortfalls are identified, concepts are developed as solutions for the various aspects of the capabilities. New concepts may be required not only for the new capabilities but also for the existing capabilities.

Concepts can be defined as either strategic, operating, or functional (ACT 2021):

- Strategic Concepts are essential inputs to the DPP as explained in the previous section, and they contain political or high-level politico-military assessments, objectives, and guidance for the emerging or forecasted future scenarios. They may be standing, generic and applicable to many scenarios of the similar nature or may be developed specifically for a new scenario. They outline purpose, nature, and fundamental security tasks and identify central features of the security environment and provide guidelines for the adaptation of the military instrument.
- Operating Concepts describe how military capabilities operate. They provide the guidelines for operational artists and affect the level where campaigns and joint operations are planned.
- Functional Concepts are the fundamentals in the planning and the employment of tactics, techniques, and procedures (TTP) when capabilities are engaging with a specific scenario.

The modelling and simulation requirements for concept development and experimentation, as well as the possibilities, are very rich. In addition to a game theoretic approach for geostrategic foresight generation and a static deterministic simulation based optimization tool that we already mentioned in the previous sections, we use various simulation tools for concept development including but not limited to the following:

- For operating and functional concepts which are related to operational theaters, we use a constructive dynamic continuous interactive and stochastic combat model designed for military experimentation purposes.
- For operating and functional concepts which are related to organizations, facilities and business process, we use various business process modelling and simulation tools.
- For data analytics, we use a set of data mining and statistics packages.

The modelling and simulation as a service (MSaaS) approach (Cayirci 2013; Cayirci et al. 2017) is very helpful for addressing the need for a rich set of modelling and simulation tools.

6 COMPUTER ASSISTED MILITARY EXPERIMENTATION SUPPORT TO CAPABILITY DESIGN

A capability package requires solution across doctrine, organization, training, material, personnel, leadership, facilities and interoperability (DOTMPLFI) lines of development (NATO 1997). An operating concept for a capability package and functional concepts for each of DOTMPLFI are the starting point for the design of a capability. Through a solution oriented concept development, solutions for the capability are developed. These concepts, both the operating and functional, are then proven through computer assisted military experimentations.

A template for the capability package management process is shown in Figure 8. It starts with the identification of a capability package requirement, which is typically the result of DPP. Then the concepts for the capability requirement are developed and tested. When those concepts are mature enough and approved by the decision authority, the capability is designed, implemented, tested and integrated with the military instrument. Then it becomes operational. During its lifetime, the requirements may change, which may imply modifications to the existing capabilities. When such modifications are required, that may necessitate new concepts and an experimentation campaign for testing the new concepts.

Discovery and validation experiments are employed at the development stage of a capability package process. Later during user testing and capability package integration phases, demonstration experiments become very useful tools. Therefore, a well planned and programmed military experimentation campaign is a necessity for every new capability. The same tool set as the tools for concept development are also employed for capability package process because computer assisted military experimentation for capability package process is typically for testing the concepts developed for the capability packages.

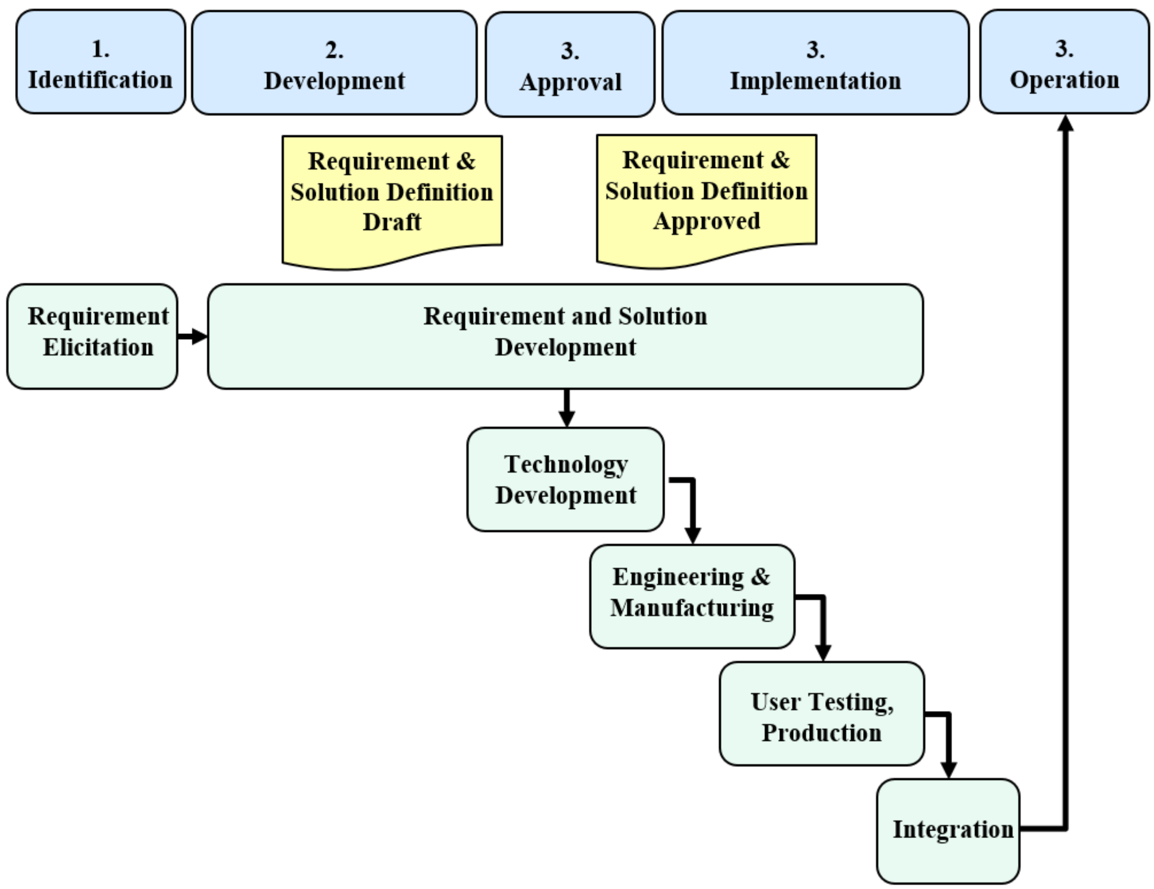

Figure 8: Capability package process.

7 COMPUTER ASSISTED MILITARY EXPERIMENTATION SUPPORT TO ADVANCE AND RESPONSE PLANNING

Doctrines, military capabilities, procedures and operation plans can be tested in computer assisted experimentations as shown in Figure 9. Moreover, computer assisted military experimentations are usually the only option to test with them before they are actually deployed to a battlefield. Wargaming methodology can be used to gain further insight into alternative courses of actions before developing a concept of operations (CONOPS). When an operations plan is developed following the CONOPS, the plan can be tested rigorously through a computer assisted military experimentation campaign, which needs a structured and focused procedure and resources, especially, time. The time constraint to test with an advance plan, such as a standing defense plan or a contingency plan is typically less stringent than a response plan.

Wargaming methodology requires less effort and time to conduct comparing to computer assisted military experiments, and can be applied as a discovery experiment. Constructive simulation systems can support also wargames, nevertheless, the results from wargaming typically cannot provide enough evidence to evaluate and validate a response plan. In addition to these challenges, military constructive simulation systems (Cayirci and Marincic 2009; Cayirci 2013; Tolk 2012) which are developed to support computer assisted command post exercises has the following weaknesses in supporting military experiments:

- It may take months to prepare and validate the database of a constructive simulation system.
- Significant effort is required to collect and analyze data in experiments supported by them.
- When a piece of plan, i.e., an order such as flying a mission, is not complied by the combat model due to reasons like lack of supplies, human interference is required to take the adjusting action.
- Constructive simulation systems are typically stochastic, dynamic and continuous, and therefore they may sometimes produce realistic but atypical results (i.e., outliers). Therefore, the same plan needs to be run multiple times with different random seeds to obtain a confidence interval for every experiment configuration, which is often cumbersome, and render the task as almost impossible for sensitivity analysis.

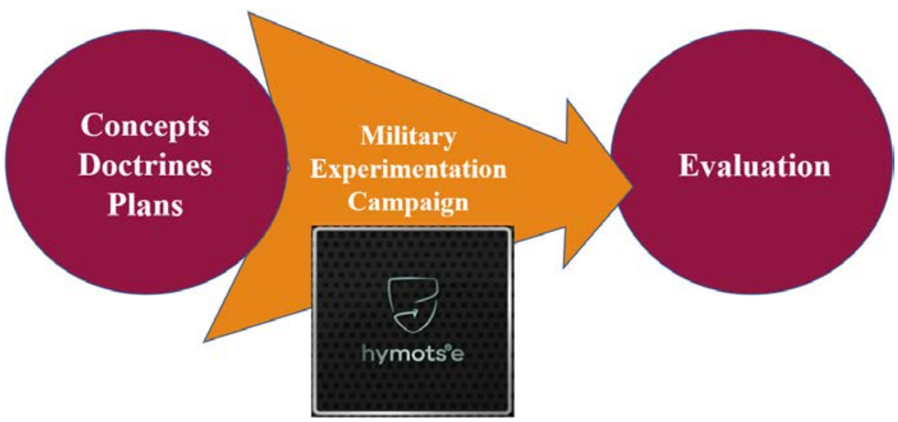

Figure 9: Concept, doctrine and plan analysis.

Therefore, a military constructive simulation system developed for military experimentation purposes are needed. This category of military constructive simulation systems can generate confidence intervals. It must be easy to develop and validate the databases for them and more importantly, the models in the simulation system should be well understood and validated by the analysts. We use the simulation system shown in Figure 10 when experimenting with the operational plans and new capabilities.

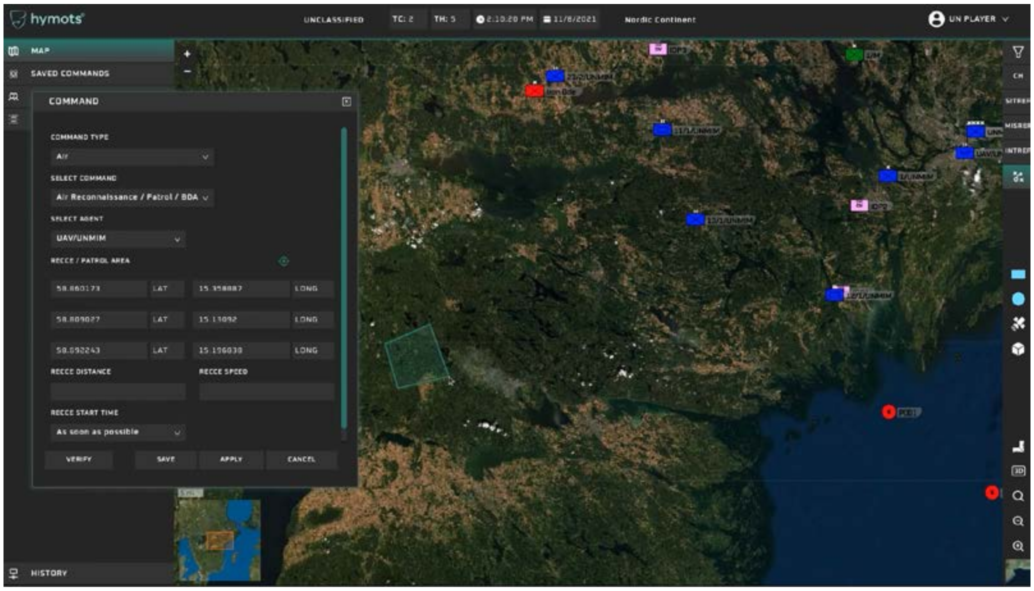

Figure 10: A military constructive simulation system in support of military experimentations.

Designing an experiment, collecting data from constructive simulation systems, analyzing them and presenting the results by using clear graphics are also time consuming but critical tasks of experimentation controllers and analysts. Therefore, experimentation design and management tools integrated with the constructive simulation systems, such as the one shown in Figure 11, are great aids.

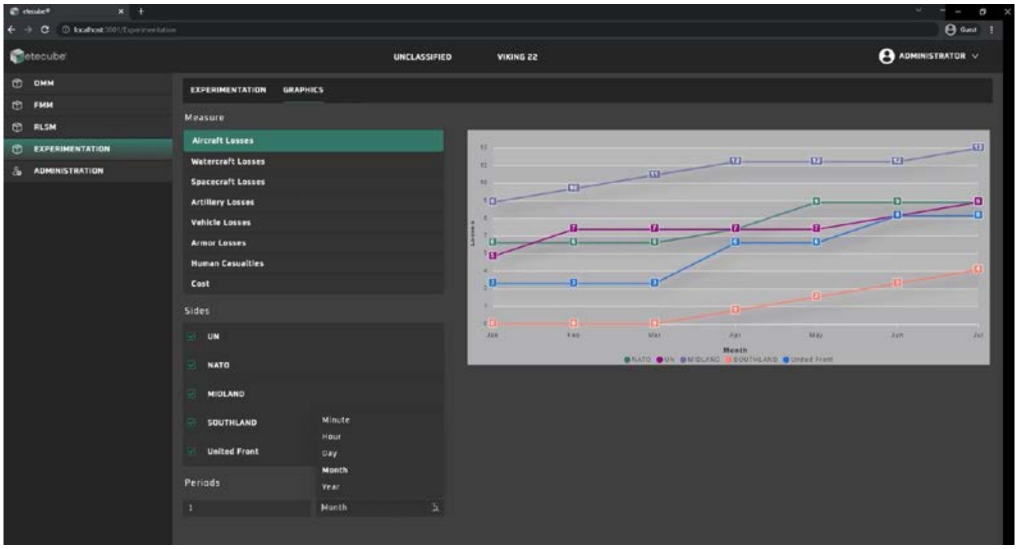

Figure 11: Experimentation design and management.

8 CONCLUSIONS, EMERGING CONCEPTS AND THEIR IMPLICATIONS

Military is expected to be prepared for the mission whenever it emerges, therefore military should continuously transform and adapt to the latest setting and conjuncture, which are nowadays characterized as volatile, uncertain, complex and ambiguous. Computer assisted military experimentation is a critical methodology to meet this objective and it can support the transformation and operations from the very beginning to the end. The transformational processes that computer assisted military experimentations can be employed include but not limited to the following:

- Geostrategic foresight, i.e., future setting and scenarios, development
- Defense planning
- Concept/doctrine validation
- Capability testing
- Operation plan testing

New concepts, models and tools emerge to assist military experiments. Their examples and the best practices in their employment are demonstrated during the tutorial.

Technology evolves continuously and rapidly, as well as, international affairs. New strategic concepts emerge, and as we test with them, new requirements to support future military experimentations are elicited. Digital twins, explainable artificial intelligence (Murshida 2019), swarm intelligence and prediction (Parpinelli 2011), augmented intelligence (Yau et al. 2021), big data fusion and analytics, miniaturization, broadband wireless ad hoc communications (Akyildiz 2002; Atzori 2010), multi channel human machine interfaces, space, hypersonic platforms, collaborating autonomous objects, democratization are among the technology related components that impact on the employment of the military instrument in future conflicts. These have already made major impact on the strategic concepts developed recently (Clark 2020). As we experiment with these new concepts, it becomes more clear to us that the need for multi resolution simulation systems that include smart agents, which can simulate smaller autonomous units and entities increase day by day.

ACKNOWLEDGMENTS

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