European Integration Studies, Volume 20, Number 2 (2024), pp. 263-290.
https://doi.org/10.46941/2024.2.11

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Defence capability development optimisation**

Abstract: This article outlines comprehensive research methodologies and practical outcomes aimed at enhancing strategic decision-making processes in defense capability development. It introduces a structured and applicable methodological framework that integrates theoretical principles, advanced technological approaches, and practical experiences. Central to this framework are advanced modeling and simulation techniques, specifically constructive wargaming and operations research methods. These techniques systematically integrate a set of capability optimization tasks exploiting detailed mathematical modeling and simulation, supported by specialized software tools. The article outlines thirteen conceptual steps for optimizing military force structures and capability configurations by evaluating a vast array of combat scenarios by operational effectiveness criteria within established financial and strategic constraints. The proposed framework is the subject of serious research activities and a defense project development aimed at enhancing the practical applicability of the described methods and approaches to computer-aided capability development processes, effectively supporting strategic planning and substantially improving overall military preparedness.

Keywords: Capability planning, operational optimization, constructive wargaming, military capabilities, armed forces development.

1. Introduction

In the wake of rapid scientific and technological advancements, new opportunities and abilities have emerged. Strategic management staff can implement advanced methods and components in real time over large datasets, such as advanced analyses, modelling and simulation (M&S) tools,

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** The research and preparation of this study was supported by the Central European Academy.

operations research optimisation approaches, machine learning technologies, and artificial intelligence (AI) tools, to support optimal decision-making and maintain business competitiveness, public administration, research and technology domains or other areas, particularly in the military.

Armed forces' optimal strategic management and development planning processes are typically complex, driven by various factors, primarily uncertainty surrounding the future security environment and evolution of military technology. Traditionally, strategic decisions in the military domain are influenced by human experience; nevertheless, scientific progress now offers advanced opportunities for strategic decision-making activities that optimise features such as configurations, operational efficiency, available time, minimising material/human resources, cost, etc.

Planning and developing armed forces' capabilities[507] has a decisive impact on the state's defence and formation of regional, i.e. global security environment[508]. Generally, all defence resorts ask the same fundamental question: 'How should armed forces maintain operational effectiveness at the highest possible level annually and in the long term'?

The need for a prompt response (to that question) is amplified by the growing complexity and dynamics of the future battlefield, as well as the need to choose an appropriate focus for (modern/future) technological development. Considering that this decisive technology could take decades to evolve, any mistake in that field could have dramatic outcomes.

The contemporary planning process faces several pitfalls, which can be characterised as follows:

- the planning process at the strategic level primarily uses an empirical–intuitive approach, which expeditiously reaches hypothetical boundaries: even with increased efforts, it is not possible to achieve an outcome close to the 'theoretical optimum', which is attributable to the so-called 'shallow' state space investigation of possible configurations;
- another complication in problem-solving related to 'military capabilities' is the inconsistent level of perception, because variations in identifying significant areas across different countries[509] create hurdles in their development;

[507] MO CR 2002, MO CR 2018, MO CR 2019.
[508] MO CR 2015, MO CR 2019, MO CR 2017.
[509] Procházka, 2018, p. 106, 112.

- 'capability' according to the order of the Czech Ministry of Defence No. 66/2012 Bulletin[510], is defined as 'a set of necessary characteristics of an individual, organisational unit, task force or system characteristics (e.g. weapons) to create the desired effect (e.g. completing a combat mission, achieving a goal). Abilities can acquire quantitative and qualitative attributes and can be characterised as 'hierarchised' (divided into orders or levels, progressively choosing the degree of aggregation). Therefore, the description provided is general and has vast scope for interpretation.

This implies an increased need for further elaboration (solution) of the given issue and eventual implementation of innovative or standardised approaches covering the given area. From the perspective of effective skill implementation or force planning, it is generally accepted that seeking rationalised approaches in all military areas is necessary. In practice, 'optimisation' efforts encounter several challenges, such as:

- high complexity and uncertainty surrounding the environment affected by the solution;
- insufficient knowledge among strategic (defence) personnel regarding modern technology and advanced methodologies;
- high administrative congestion of responsible staff hindering the investigation and development of alternative solutions;
- inclination to establish and adhere to 'old-fashioned' bureaucratic procedures;
- capability planning process is part of a complex procedural legislative framework, making adjustments innately challenging;
- lack of specialised SW solutions adapted to the specific problem;
- possibly others.

These factors contribute to the high degree of conservatism and sluggish and 'alibi' procedures that are usually used, which limits the implementation of advanced techniques in military capability evolution and armed forces development. A similar challenge was identified within the NATO STO SAS-164 working group, which deals with 21st-century Force Development (2020–2022).

This paper presents an algorithm-based methodological framework for strategic decision-making processes, presented several times (by the author) within the North Atlantic Treaty Organization (NATO) CA^2X^2 Forum. It

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[510] RMO 66 – Czech Ministry of Defence. Prague, 2012, p. 3.

drew the attention of governmental institutions, particularly in Germany, Italy and France, because such solutions have yet to be applied. The philosophy behind the solution assumes that computer support could dramatically improve the quality of the solution, driven by the large number of options explored and calculations necessary to determine an optimal solution.

There are various ways to optimise the development of armed forces' capabilities. One of the approaches suggests solution based on searching for the armed forces' optimal 'configuration-investment' strategy to maximise operational efficiency (OE) within the selected financial framework in the set period. Finally, the transformation of these structures into a capability model is addressed. A possible solution with a high degree of approximation includes the initial mathematical apparatus, structures and relationships, quantifying key factors and specifying criteria for the solution through a mathematical algorithmic approach to modelling the problem and searching for optimal configuration via the vast set of simulations.

2. Current status of advanced M&S tools in military planning

Advanced M&S tools are primarily used for education, research and development. The use of simulations is almost limitless; every procedure and process can be modelled and reproduced using appropriate simulation methods. However, they are rarely used in the military for complex process optimisation. M&S tools are used for planning and decision support in the army, e.g. in military operations[511,512]. An analysis of operational research activities during the 'Enduring Freedom OEF and Iraqi Freedom OIF' showed that modelling and simulation were used only to a limited extent, because sophisticated computational models were difficult to calibrate to a specific situation, rendering them ineffective in the process of planning operations.

In a report[513], Hanley et al. identified only two modelling and simulation applications applicable to operational planning. These include the 'Peace Support Operation Model (PSOM)' application for evaluating force deployment plans and 'ATHENA' application used by experienced intelligence analysts to predict the potential outcomes of complex operations

[511] Connable, 2014.
[512] Veldhuis, 2020.
[513] Hanley, 2011.

in problem areas of the world[514]. In planning, NATO uses a system analysis tool that is part of the Toolkit for Planning Operations, Force Activation and Simulation. In recent years, NATO has witnessed a renewed interest in planning missions and operations using simulations, as evidenced by several research working groups ((MSG-088, MSG-124, and MSG-155)[515].

The national armed forces of NATO member states, such as the Dutch Armed Forces, employ qualitative modelling methods such as causal loop diagrams and analysis of relationships between variables using enriched loops (called MARVEL)[516,517]. The MARVEL method shares some tools with other established techniques, such as the PSM SODA problem structuring method (creation and analysis of strategic options), system dynamics and fuzzy cognitive maps. In addition, the MARVEL method uses causal loop diagrams enriched with qualitatively labelled values and standardised equations, facilitating the analysis of the structure and behaviour of the model[518].

The German Armed Forces use modelling and simulation to digitise logistics, taking into consideration factors such as flexibility in the models. It is used to identify risks and vulnerabilities in the logistics chain[519]. The German commercial military technology company ESG presents successful simulation and analysis projects. ESG proposes further lines of action, such as simulation-based analysis for optimising military supply systems. This data-driven decision support method (AnyLogic tool, Bundeswehr guidelines for simulation-based analysis and model-based documentation) focuses on critical questions such as the material and operational readiness of a system developed for the future, assuming certain parameters/factors and what improves system performance.

Reviewing operations research applications and military modelling capabilities include research on military training modelling and search for possible methodologies applicable to building trained forces[520]. The Training Force Sustainment Model is designed to assist Army Training Command in identifying critical resource and planning issues to meet training requirements, satisfying training demand efficiently and effectively.

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[514] Chamberlain, 2013.
[515] Horne, 2017.
[516] Veldhuis, 2020.
[517] Barros, 2011.
[518] Veldhuis, 2015.
[519] Kleint, 2021.
[520] Wang, 2005.

Effective force planning is essential for all organisations; for example, for Australian Armed Forces, having a sufficient number of people with the required competencies at a reasonable cost is critical in planning[521]. For example, Markov chain-based methods, computer simulation, optimisation and system dynamics were used and compared in a review of applications for operations research in workforce planning and capability modelling of military forces[522]. These methods focus on different aspects of managing and optimising force planning processes. The Markov chain theory is one of the most widely used mathematical tools for assessing a system's dynamic behaviour. A stochastic process with discrete time that can be used according to Markov chain theory is called Markov process[523]. In the case study 'The modelling of manpower by Markov chains-a case study of the Slovenian armed forces'[524], Markov chain models are used for human resource planning by the Slovenian Armed Forces.

The paper Military Impact of Canadian Operational Research and Analysis[525], refers to the CATCAM methodology developed to support planning in the Canadian Armed Forces. It enables defence planners to list the capabilities of the Canadian Armed Forces. Capability-based planning defines the target Canadian Armed Forces' capabilities to select the right mix of plans, people, equipment and activities, i.e. to optimise the Canadian Armed Forces' ability to perform the assigned tasks. A new cost model for the Canadian Armed Forces was developed in conjunction with CATCAM. While it is relatively easy to determine costs (on an annual basis) such as salaries, purchases and consumables, it is challenging to determine the actual incremental costs. They include support infrastructure, major equipment such as light armoured vehicles, rifles and computers that wear out over time and need to be replaced. The costs are also time-varying. Although it is still under development, the new strategic cost model represents a significant advancement in operational research and analysis (OR&A) and directly impacts complex decision-making. Many of the critical issues facing the Canadian Armed Forces relate to personnel. Personnel intake must correspond to the system's training capacity. Demographic modelling is commonly conducted to support OR&A, with

[521] Sharp, 2003.
[522] Wang, 2005.
[523] Hron, 2018.
[524] Škulj, 2008.
[525] Evans, 2006.

extensive information databases supporting it. Mining this data and employing historically derived attrition and recruitment data allows dynamic predictive models to be developed. These models are used to shape force expansion plans.

Advancements in AI technology have opened vast opportunities and methodologies for application in the strategic decision domain. Generally, AI-driven tools can potentially analyse enormous and complex data sets to forecast threats, optimise resource allocation and enhance readiness for various scenarios. Machine learning algorithms can identify patterns in historical data to predict future conflicts, assess force deployment options and recommend optimal asset utilisation. AI is also integrated into war-gaming simulations, enabling military planners to explore multiple strategic outcomes and stress-test various courses of action.

A review of the application of advanced AI in defence identified a few cases, but none in military capability planning. This is contrary to documents such as national, NATO and EU strategies or concepts that encouraged or recommended AI in defence applications.

A real-world example is the US Department of Defense's Project Maven[526], which employs AI to analyse drone footage and automatically identify targets, reducing the cognitive load on human analysts. Similarly, NATO is leveraging AI for predictive maintenance[527] of military equipment, evaluating sensor data to anticipate mechanical failures and optimise logistics or operational aspects[528]. The UK Ministry of Defence has also launched the Defence AI Strategy, integrating AI into defence-enhancing capabilities like cybersecurity, intelligence analysis and battlefield decision support[529]. These applications highlight AI's critical role in the military, and

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[526] Available at: https://www.defense.gov/News/News-Stories/Article/Article/1254719/#:~:text=Project%20Maven%20focuses%20on%20computer%20vision%20--%20an%20aspect%20of (Accessed: 02 May 2024).

[527] Available at: https://www.mdpi.com/2076-3417/14/2/898#:~:text=Using%20cutting-edge%20technologies%20like%20data%20analytics%20and%20artificial%20intelligence (Accessed: 02 May 2024).

[528] Available at: https://www.natofoundation.org/wp-content/uploads/2021/12/NDCF-Paper-Berger-NATO-and-Artificial-Intelligence-151121.pdf#:~:text=In%20a%20context%20where%20an%20enhanced%20AI%20adoption%20in%20the (Accessed: 02 May 2024).

[529] Available at: https://www.ft.com/content/94d59a36-099a-4add-80d3-475127b231c7#:~:text=The%20UK%20armed%20forces%20will%20use%20artificial%20intelligence%20to%20predict (Accessed: 02 May 2024).

support its broader application in the capability planning process presented in this paper.

3. Methodology and approaches to problem-solution

The decision-making process in the military usually fulfils management optimisation characteristics, like achieving goals with minimum cost or asset consumption or maximum achievement within an available budget, asset and force disposition. We could take inspiration or analogy from the Japanese management systems, which transformed the country into one of the most technologically-advanced and wealthiest countries in the world. Suppose, there is a method to quantify the decision/optimisation criteria and decision process model, the operations research methodology can be effectively applied, particularly multi-criteria optimisation, where individual criteria are ‘encoded’ within the objective function, to search for minimised or maximised solutions (input parameters). This solution represents the particular settings, steps or actions that bring maximal benefit within the individual decision. The modelling of complex decision problems typically spans more domains, seldom making the solutions straightforward and simple.

The solution described in this paper employs various methods from different fields intersecting the AI domain, including linear algebra, probability theory, statistics, random processes, operational art, algorithm development, modelling and simulation, operational research, linear, nonlinear and dynamic programming, graph theory, automation, AI and software engineering.

The solution architecture can be derived from the intuitive–logical framework of the operational performance graph consolidation and the search for optimal armed forces configuration (CAF) regarding the maximum resilience to future threats, but considering an ‘optimal’ investment plan that also fits within the anticipated defence budget.

Based on historical experience and indicators of the security environment's evolution, it is judicious to balance the armed forces to fulfil a range of capabilities, rather than solely relying on any ‘alliance’ that covers the rest of the undeveloped specialties. This is highly risky if the potential involvement would significantly harm the allays, and thus, a wide range of capabilities is preferred. This assumption is crucial in determining the range of specialisations of the Armed Forces Elementary Construction Entity (ESU).

The solution (to the mentioned problem) is challenging and can be categorised into a tree of independent subproblems with diverse degrees of acceptable approximation. It can also be assumed that the final solution creates further accompanying problems. It is important to realise that the fundamental nature and importance of this approach focuses on discovering the operational configuration of the armed forces in each period (usually years). It highlights the personal and technical resources the armed forces should maintain annually, ensuring adequate combat performance in the future security environment.

There are various options to address this problem. An effective and logical approach is to focus on the development of elementary organisational structures (of the armed forces), constructing the state graph of all possible configurations over time (in individual years) and applying 'constructive wargaming[530]' with a potential enemy. The result will be the mathematical graph (tree) populated with coefficients of OE[531], which subsequently enable the calculation (or estimation) of the financial costs of individual configuration variations.

A series of operational research methods (using dynamic programming) can be applied to the given graph to develop the optimal configuration of the armed forces (organisational structures) in relation to the anticipated threats and the amount of the planned defence budget.

In the past, alternative approaches aimed to optimise capabilities first (instead of force configurations)[532], characteristic of a high degree of abstraction. This approach presents considerable challenges while quantifying the force configuration concerning military capability unambiguously. Transforming the armed forces' configuration into military capabilities is a straightforward, definitive process that logically supports the solution approach focused on modelling the construction of the armed forces in the initial phase, rather than reciprocal action (modelling the

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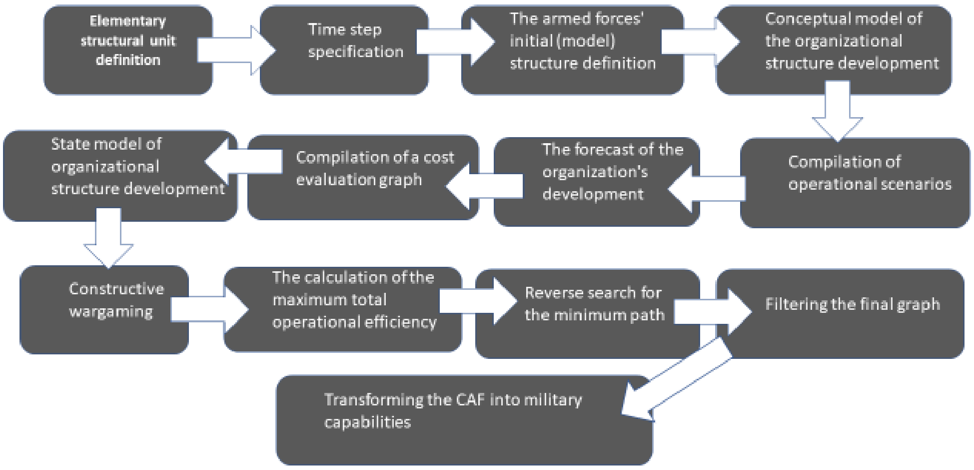
[530] Constructive wargaming is an area of computer simulation of armed conflict, which is based on models of warring parties, technical level and number of their units entities, conceptual or doctrinal models of combat, scenarios and the operational environment in which the conflict takes place.

[531] Operational efficiency reflects the level of ability to face the selected threat at a given time in a given territory, the threat in the case is represented by the enemy's armed forces in at least two variants, namely optimistic and pessimistic.

development of military capabilities). The solution architecture is demonstrated in Figure 1:

Figure 1 *The solution process architecture.*



As already mentioned, the problem of modelling armed forces architecture can be perceived as an optimisation task to maximise 'OE' in the context of the engagement of potential threats, while considering the constraints emerging from the planned defence budget. In this context, the following objective function of OE can be defined, describing a multi-criteria 'compromise' of priorities and constraints imposed on the solution. Considering the effort to maximise overall OE of the system of individual CAF configurations, it is imperative to 'maximise' the purpose function, with the fact that the cost in individual years must remain within the available resource plan (for the particular year):

$$\mathbf{max} \rightarrow \sum_{i=1}^{n} \boldsymbol{OE}(\boldsymbol{DM}_{\boldsymbol{KOS}\ \boldsymbol{i}}) \quad \wedge \quad \boldsymbol{FN}(\boldsymbol{DM}_{\boldsymbol{KOS}\ \boldsymbol{i}}) \leq \boldsymbol{ZDR}_{\boldsymbol{i}}\ \forall\ \boldsymbol{i} \in \langle \mathbf{1}, \boldsymbol{n} \rangle\,,$$
(1)

where

OE() – *operational effectiveness function*

DM_{KOS} – *data model of individual configurations, or the sequence of CAF in particular years,*

FN() – *cost function configuration of the armed forces,*
ZDR – *available resource framework in the corresponding year,*
n – *total number of years,*
i – *index.*

The logically intuitive approach for the chosen problem solution illustrated in Figure 1, which aggregates armed forces architecture optimisation through the operations research methodology and M&S approach (constructive wargaming), is described in the following steps:

3.1. Elementary structural unit definition

Determining the elementary structural unit (ESU) of the armed forces organisational structure (initially, we recommend battalion level as the optimal choice for that purpose). This represents a pragmatic–logical compromise between practical resolution and computational operations for search and state space consolidation.

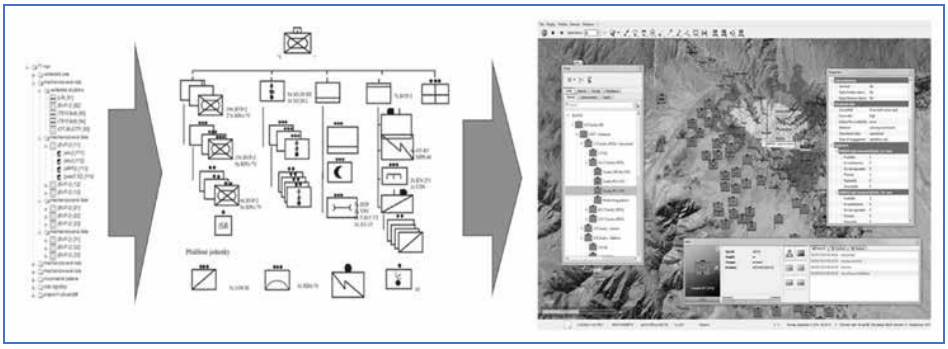
3.2. Time step specification

It is possible to determine a discrete time step for an ESU's evolvement or ‘upgrade’. Given the length of acquisition processes and the defence sector's conservative development, it is likely that it may change in the future. The initial (discrete) time step can be set minimally for one year.

3.3. The armed forces' initial (model) structure definition

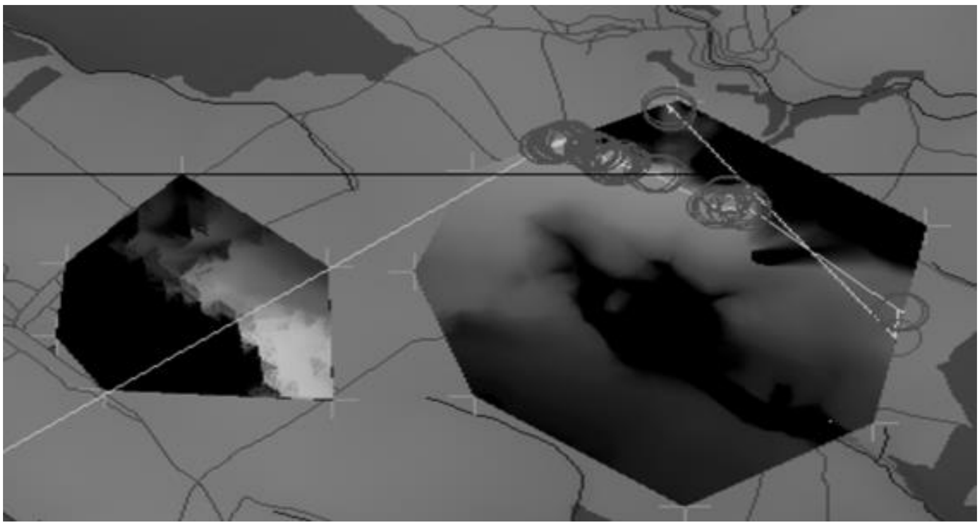
The armed forces' initial (model) structure has to be created from the ESU and its ‘operational-efficiency calibration’, which is based on its current state. It quantifies the coefficients of operational efficiency of individual components or systems within the organisational structure. In this case, the quantities and technical capabilities of ESUs are similar, instead of being appropriately arranged within the hierarchical structure of command and control (which may be a bit unusual for operational commanders, but necessary to simplify the process). A model example of the transformation of organisational structure into tactical entities in the synthetic environment is illustrated in Figure 2, reflecting the transformation of the (entity) data model (containing operational–tactical parameters) into organisational (hierarchical) infrastructure and then doctrinal deployment in a specific position in the simulation environment.

Figure 2 *Example of data model transformation into organisational structures and basic tactical entities in the SWORD simulator.*



ESU deployment is relatively complex, but can be addressed by geo-tactical analyses that support ESU's doctrinal behaviour in a particular operational situation. For example, Figure 3 could demonstrate the convenient observation/shooting positions identified with the intent to cover a particular area by ground observation or fire.

Figure 3 *Observation optimisation.*



3.4. Conceptual model of the organisational structure development

The organisational structure development conceptual model is primarily related to the ESU. It should determine possible generic options for ESU modifications within the organisational structure (in the context of individual ESU upgrades). Let us assume the following possibilities:

- ESU status remains unchanged;
- ESU status increased (incrementing - technological or organisational attributes);
- ESU is cancelled;
- A new ESU is created.

In the wake of rapid technological advancements, some ESUs could start at different times, and processes based on DTAG/CDAG (well-established in NATO) can potentially be used to identify configurations of these high-tech ESUs.

3.5. State model of organisational structure development

The next step is to create a state model of organisational structure development based on the conceptual model. It includes all possible configurations of individual ESUs within the selected time and a set of rules for discretising individual qualitative levels. The transition between adjacent ESU states is also limited to prevent the excessive expansion of option tree. In practice, ESU upgrades are long-term processes. The following options are expected to address the problem of state graph development of organisational structure variants:

The organisational structure[533] model works with elementary units of the ESU, reaching the following states in the selected periods:

- incremental – additional resources and efforts are invested to enhance ESU quality (quality is increased by +1);
- stagnant – the ESU is maintained at current operational costs (the quality level does not change);
- destructive – the ESU is cancelled;
- constructive – a new ESU with a corresponding quality level is created.

[533] For the purposes of the solution, it is primarily a flat organizational structure, focusing on individual battalions of combat forces, combat support forces and combat security forces.

The option of stepwise degradation of ESU is not considered within the modelling of the rules of ESU evolvement. This approach seems practically illogical, as it essentially involves the rearmament of the organisational unit (ESU) to a qualitatively lower level. In any case, prolonged stagnation could result in some degradation of ESU. If reducing maintenance cost of the ESU is the primary goal, it is effective to cancel the entire ESU and invest the saved funds in the development of other ESUs or for the creation of an entirely new ESU.

3.6. Compilation of a cost evaluation graph

The next step involves compiling a ‘shadow’ cost evaluation graph of all configuration transitions at time n to the state n + i, where i denotes a discrete time step. It is possible to calculate the financial demands of a particular armed forces configuration and determine whether a given strategy[534] fits within the planned budget, see Figure 2. All transitions between individual discrete periods (ESU transformations) are necessary to assess their financial demands. It is worth noting that it is challenging to accurately quantify financial investments representing the relationship between the transformation of individual ESUs to higher quality levels. Each ESU can acquire specifics that cannot be easily generalised, or all the factors for accurate calculation are unknown. In any case, for the initial solution and automation of the vast configuration’s assessment, the cost could be empirically estimated or statistically evaluated based on previous experience of modernisation of individual capabilities. In case of further estimation improvement and simulation fidelity, an advanced algorithm can be developed, taking into account other circumstances. Considering the overall complexity of the realistic estimation, the initial approximative cost options can be calculated for the need for an expeditious initial solution, such as:

- Investments to enhance ESU quality.
- Investments to maintain ESU quality.
- Investments leading to ESU abolition.
- Investments to create a new ESU.

The advanced calculation algorithm necessary for the ‘debugging’ phase of the final solution should consider various variable conditions and

[534] In this respect, the strategy means a path in the state graph of armed forces configurations.

environment development dynamics, especially investments in qualitative transformations of individual ESU across different years, which may not necessarily require the same amount of resources (the latter ESU upgrades will likely lead to 'nonlinear' spending increase, compared to previous years).

The following proposal can be used as one of the possible flat-rate approaches to calculate the costs of ESU transformations in individual years, which requires determining a matrix of coefficients in individual years (r-year, i-index ESU):

- Financial costs of transforming the ESU to a higher level of quality: $FTVKE_{ri}$.
- Financial cost of maintaining the quality level of the ESU: $FUKE_{ri}$.
- Financial costs of dissolving the ESU: FZE_{ri}.
- Financial costs of setting up the ESU: FVE_{ri}.

Consolidation of a (3D) RV matrix containing line vectors defining a transformation variant of the armed forces configuration (according to the conceptual model, individual components usually take values of 1 or 0). The total costs for a given year form the sum of linear combinations of the vector RV_{ri}, and other individual components of the transformation costs, according to:

$$\boldsymbol{FN_r} = \sum_{i=0}^{n} (\boldsymbol{RV_{ri0}} * \boldsymbol{FTVKE_{ri}} + \boldsymbol{RV_{ri1}} * \boldsymbol{FUKE_{ri}} + \boldsymbol{RV_{ri2}FZE_{ri}} + \boldsymbol{RV_{ri3}FVE_{ri}}), \quad (2)$$

where

FN_r - *total investment costs for the year (for all ESU),*

RV_{ri} - *transformation vectors for each year and each ESU,*

i - index of individual ESU,

R - *index corresponding to individual years.*

Based on the calculation of the financial complexity of the evaluation of individual configurations of organisational structures in the status chart, it is possible to calculate the total costs of all potentially promising and other 'investment strategies[1]', mainly those covered and not covered by the estimated budget. It is necessary to realise that the set of promising (perspective) and set of other investment strategies should be subjected to further analysis, as some other strategies may have significantly higher cost/benefit ratios (CBRs) than those in the promising set. Therefore, appropriate evaluation is vital. In particular cases, a marginal increase in the defence budget can exponentially influence the OE of the armed forces and the security environment.

3.7. Forecasting the organisation's development

The next step involves forecasting the development of the organisation's potential enemy (to increase the probability of estimating actual development), which is usually processed in several variants, between which the states can be interpolated. Creating a model of organisational structures of the presumed enemy should be based on a qualified forecast, or extrapolation of the current state of forces and resources in individual years (or periods). Considering the high level of uncertainty of any (especially long-term) socio-economic forecasts in the dynamic security environment, it is recommended to count on a minimally optimistic and pessimistic version of the prognosis. Professional models usually work with five or more options based on interpolation or separate estimates (advancement in particular capabilities, orientation to different types of combat, applied technology, level of command and control, etc.). The reason for processing multiple options of the enemy configuration is to obtain a comprehensive data set for determining the 'so-called' solution stability coefficient, which expresses resistance to multi-spectral threats. A comprehensive description of (organisational structures) model development of a potential enemy goes

[1] The investment strategy is a sequence of expenditures on the development of armed forces over time.

beyond the scope of this paper and acquires the character of a separate project.

The development of enemy organisational structures is a particular analogy to the process of the own structure's configuration elaboration and generation of possible ESU configurations in individual years. As we expect the development and integration of new units and capabilities on the friendly side, the enemy will develop, too, in many cases, with higher dynamics. A database of unit configurations is generated for our forces and the enemy concurrently and qualitatively over time. The pessimistic option of the enemy's development (from their perspective) is usually characterised by the fact that the qualitative development of the enemy's units (ESU) shifts over time (i.e. technological development is delayed).

3.8. Compiling operational scenarios

The next step involves compiling an array of operational scenarios (for our units and the enemy) and potential areas for their implementation. Creating operational scenarios and their automation is key to establishing the overall architecture of constructive 'wargaming' processes and their subsequent implementation. Operational scenarios should represent the expected operational spectrum of the use of the CAF and the means for securing the military–strategic objectives of the defence of a particular territory. It is necessary to highlight that the set of operational scenarios must be designed to verify the operational effectiveness of all possible configurations of CAF in combat activities with the presumed enemy. Therefore, the primary focus is not on determining an optimal (tactical) course of action, but rather evaluating the ability of personnel and technology to engage against enemy units. The operational scenarios model the assumed spatiotemporal structure of the assumed conflict in the operational domains like LAND, AIR, SEA, CYBER and potentially SPACE. Although the number of operational scenarios is not theoretically limited, it is preferable to restrict the number to a maximum of ten, ideally three, to achieve practical results in a reasonable time. The next step in the architecture of wargaming processes is to select locations for individual scenarios. It can theoretically be a large territory of the whole state or continent, but even parts can be selected as the most likely scenarios[2] (based on military–strategic goals of individual states) to

[2] In the study of military history, we frequently encounter cases highlighting some of the successes of risky 'operational' intentions and the surprise of a counterpart unprepared to fight in unlikely locations or a way of fighting that does not follow established convention.

reduce calculations significantly, thereby shortening the solution time. For example, the concentration of NATO member states' defence efforts in Eastern Europe, where the main defence focus is on the border with a potential enemy. In this regard, it is necessary to analyse the areas suitable for effective employment of the particular military capabilities or other potential (focus areas will differ if the enemy has a predominance of tanks or light combat units, etc.). Identifying the anticipated areas for military combat can be automated based on initial criteria imposed on the scenario and character of the operation through computer geographical analysis; in specific cases, areas can be identified empirically or intuitively. Generally, automated processing algorithms are in the initial stage and require further research; conversely, the conceptual methodologies are already well defined and can be found; for example, ATP 2-01.3 / 2019 (Intelligence Preparation of the Battlefield). A possible example of an algorithmic approach to this problem can be found in the publication[3,4].

3.9. Constructive wargaming

Another step is constructive wargaming of all configurations of CAF with the assumed enemy configuration (all options, minimally-optimistic and pessimistic) for each operational scenario and selected geographical area in a statistically representative amount (ideally a hundred times or more for each operational scenario). Evaluation and quantification of the 'operational efficiency' (OE) of each force configuration and substitution of the given coefficient (1/OE) into the mathematical graph of force development. For now, constructive wargaming is the only possible and logically acceptable main component of the rational evaluation of many operational courses of action (COAs). Automating all parts of the solution chain is necessary to calculate the solution's intended scope and depth.

For a statistically representative data sample necessary for the relevant assessment, it is vital to repeat each simulated alternative with moderately modified initial conditions (shifted location boundaries, different unit

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This moment of surprise was usually based on the enemy's 'static-conservative' behaviour and its underestimation of ISR (Intelligence Surveillance and Recognition), with this factor already being used in today's globalised news (Internet, satellites, long-range radars and similarly), cannot be relied upon, although there are nevertheless some chances of deceiving the enemy and moving primarily to the cyber operational domain.

[3] Mazal, 2012.

[4] Mazal, 2010.

positions, etc.). Next, to increase the ‘stability’ of the solution, it is also important to choose the appropriate operational simulator, which should implement the appropriate degree of stochasticity already within the simulation. Essentially, two simulations with the same initial parameters in the operational dimension/environment do not have the same results as in real situations.

As mentioned, according to the statistical rules, it is recommended to repeat the simulation of the operating scenario at least 100 times (preferably 1,000 times or more) for all possible configurations. Based on the results of a large number of simulations, it is possible to perform its overall evaluation and quantification of ‘operational efficiency[5]’ (OE) of each organisational configuration and substitution of the coefficient $OE^{-1} = \frac{1}{OE}$ into the mathematical graph of force development[6]. Figure 4 demonstrates the development of losses (in time) of friendly forces and enemies within a series of simulations of one scenario using the operational simulator MASA-SWORD:

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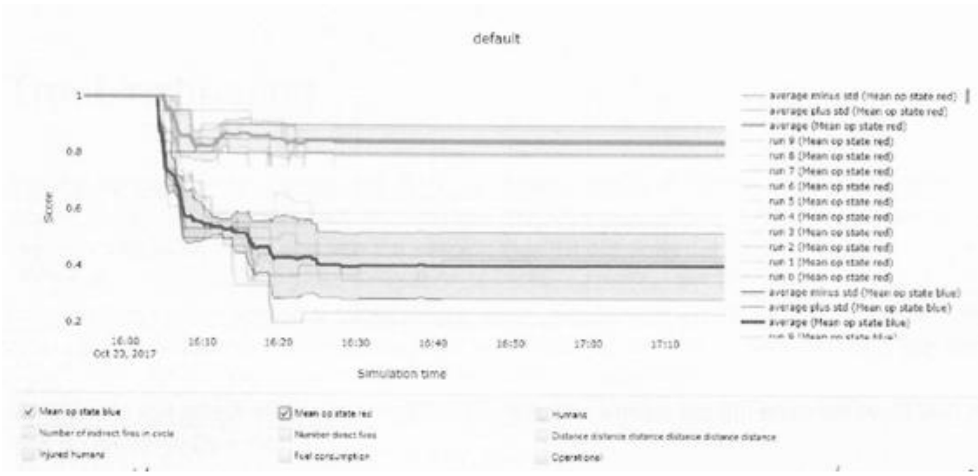
[5] According to available information from MASA, the frequent use of SW SWORD is for analytical purposes of prepared acquisitions, which is in a way similar to the case described in this section (examination of operational efficiency of variant types of acquired technology in the entire operating spectrum of defined scenarios). The NATO working group – MSG-179 mentioned in the analytical part –also deals with the same topic.

[6] In the graph of the development of the armed forces, the minimum path is then sought; therefore, it is necessary to substitute, for example, inverted OEx values, in this case we can initially choose OE^{-1}.

Figure 4 *Graph of the percentage of losses of own units (blue) and enemy units (red)*



The resulting analysis and determination of the coefficient of OE can take various approaches; for example, by a statistical mean value (from all simulations) of the original and final ratio of losses of friendly and enemy forces:

$$OE_{v1} = \frac{CP_v}{PP_v}, \tag{3}$$

$$OE_{n1} = \frac{CP_n}{PP_n}, \tag{4}$$

where

$OE_{v1} -$ $operational\ efficiency\ of\ friendly\ forces, variant\ no.1$,

$OE_{n1} -$ $operational\ efficiency\ of\ enemy\ forces, variant\ no.1$,

$CP_v -$ $final\ number\ of\ friendly\ forces,$

$CP_n -$ $final\ number\ of\ enemy\ forces,$

$PP_v -$ $initial\ number\ of\ friendly\ forces,$

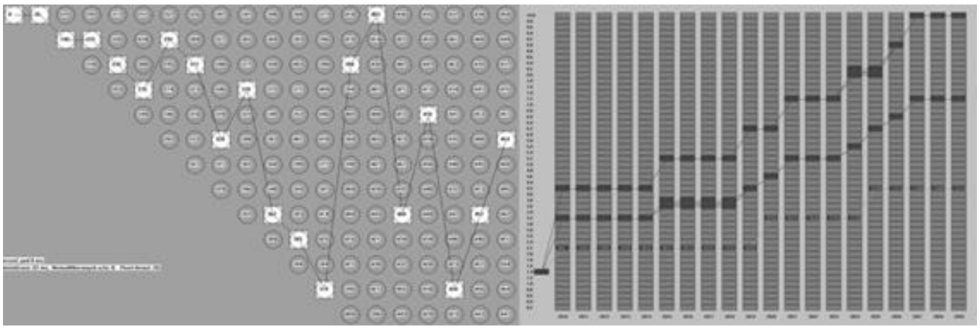
$PP_n -$ $initial\ number\ of\ enemy\ forces.$

Selected criteria for the future development of the armed forces organisation depend on optimisation goals and strategic approach. Constructive wargaming, a simulation-based technique, offers a significantly higher fidelity of OE estimation compared to alternative model-based techniques. Wargaming simulations are critical for evaluating future technologies aggregated in particular tactical entities (tanks, BMPs, jetfighters, etc.) that has yet to be developed. They can estimate the future effectiveness or combat potential of this technology in advance, thereby contributing to technological evaluation and affecting military planning.

3.10. Calculation of maximum total operational efficiency

The next step is calculating the maximum OE of each node of the development graph of CAF (for each configuration). It uses, for example, the Critical Path Method (CPM), Dijkstra, or A* algorithm to determine the minimum path to each node in the directed mathematical graph (see Figure 4). The procedure for calculating the first part of the solution can be categorised into two phases. The first seeks optimal solution as a minimum path to each organisational structure configuration graph node through the minimal sum of OE coefficients (by storing 1 / OE values because the maximum total efficiency is pursued), while the financial cost of the given configuration is also calculated. The second (described further) is preceded by the solution stability analysis of the resulting graph, to determine an optimal sequence for the configuration of the CAF within a selected time period (usually decades). In principle, this is a multi-criteria problem solution based on the fusion of a modified CPM approach/method with other solutions or constraints. The problem solution is characterised by the primary factor of maximal OE pursued, which should usually be maximised from a long-term perspective. The same but secondary aim is followed for the financial demands of capability investments, which, according to the expected plan of the military budget, set restrictive limits for the development of the CAF and indirectly for capability development. Most prospective strategies (paths) can easily hit the financial limit. However, their total pragmatism (CBA = OE /financial costs) may be higher than the partial development strategies falling within the ‘fundable’ interval. Another important step is to determine the minimum financial cost of the target configuration of CAF, which can be calculated either during the ‘forward’ phase or within the second phase of the ‘backward’ search of the minimum path for each node of the graph or only for target nodes. Calculating the minimal path for each node of the graph allows for greater depth in subsequent analysis, and the results can be subjected to further operations, such as the mentioned CBA, which is always recommended, at least for the final (fine-tuned) development models of the CAF.

Figure 4 *Demonstration of optimal investment strategies.*



3.11. Reverse search for the minimum path

According to the reverse search for the minimum path for all nodes of the graph (covering all CAF configurations), each configuration's minimum (total) financial demands can be calculated.

The final analysis of the CAF configurations graph and their OE in the context of the achievable maximum or acceptable level of defence is one of the key steps in the entire algorithmic framework. It primarily aims to determine whether the acceptable configuration in the target year/s is/is not achievable, the efficiency trend of optimal development of CAF in individual years (balanced, unbalanced) and whether this trend does not represent another risk (for example, initial concentration to technologies that will prove their effectiveness later and until then the defence system will not be sufficiently effective to face a potential threat). The search for optimal strategies (there may be more than one with the same total operational efficiency) for the development of the CAF is realised by selecting target configurations with the highest values of OE from those options that still fall within the area covered by the expected budget in individual years. In a situation where the financial limit for CAF development exceeds a state that would be able to counter the predicted threats effectively, it is possible to proceed inversely until the efficiency of the configurations of CAF reaches acceptable values. Secondarily, the stability of the solution should be analysed for each CAF configuration within the determined optimal configuration sequence. Stability analysis comprises processing differential characteristics of each configuration's neighbourhood values (surroundings) in the CAF development graph and assessing the development trend of OE coefficients around the target node. If the values around the target node differ significantly, it indicates a potentially unstable configuration, and it is necessary to prioritise the given strategy during subsequent evaluation (further analyses are usually needed).

3.12. Filtering the final graph

The final step is filtering the resulting graph into two parts of configurations. One can be financed within the assumed defence budget plan, while the other cannot. The necessary step is a final analysis of the (graph) CAF configurations and their OE in the context of achievable and acceptable level of defence. The efficiency trend of optimal development of CAF in individual years (balanced, unbalanced) should be analysed to determine whether this trend does not impose another risk (for example, initially focusing on technologies that prove their effectiveness much later, and until then, the defence system cannot effectively avert a possible threat).

3.13. Transforming CAF into military capabilities

A force configuration data model can be relatively easily transformed into a capability level model if the mapping vector function is known FS(), which extracts individual components from the armed forces configuration model according to:

$$MS = FS(DM_{KOS}) \tag{5}$$

MS – Capability Model
FS – Function to map the model of armed forces organisational structures to a capability level vector.
DM_{KOS} – Armed Forces Configuration Data Model

The capability model consolidates the states of individual capability levels developed within a given army/system, which express the corresponding coverage of a given capability by specific army ‘components’ (select units, command levels, special equipment, troop types, etc.) within the components of ‘vector’ capabilities. The capabilities model can be defined as a linear data structure representing the levels of individual components of military capabilities, and the given structure is best represented by a mathematical vector.

The specific identification of individual military capabilities and possibly its other components (sub-capabilities) may differ within the particular NATO armies. Therefore, the data model represented by the vector is sufficiently generic and not constrained by the number of identified capabilities. However, the transformation of configuration of armed forces into capabilities depends on the definition of the FS() function, and is driven by the specifics of the individual capability components. It must be balanced in the context of national specifics.

3.14. Brief summary

The algorithmic framework demonstrates a variable degree of precision and complexity of individual parts. Even though the system concept of the solution theoretically follows purely logical steps leading to the desired solution, its practical implementation exposes various challenges and difficulties, primarily dependent on the fidelity of constructive wargaming and from the development of the security environment forecast (especially the enemy). To mitigate the negative factors of inaccurate estimates and error accumulation within one simulation, virtual experimentations are repeated several times, and operating environment forecast intervals (in which the experimentation takes place) are variably chosen, so that the resulting solution reaches the state space character of potential solutions rather than a specific option. In any case, the process transforms the spectrum of all possible cases to potentially promising ones, recommending that the set of perspective solutions should be further analysed. This aspect should be the subject of further research.

4. Conclusion

Computer support for decision-making processes at all levels of command is currently highly actual; it generally offers a significant increase in efficiency in various human domains, and with the rapid development of modern technologies, its importance continues to grow. This phenomenon is reflected in today's vast area of real applications, which were unthinkable several years ago.

The primary objective of this paper is to design a basic algorithmic framework (approach) for the armed forces' capability development and optimisation (implementing advanced approaches and tools from the field of modelling, simulation and operational research), which creates optional opportunities for its subsequent evolvement within following projects or activities. In this context, a conceptual framework of individual steps was proposed, most of these steps represent a separate complex problem by itself. Potential solutions were described at the appropriate level of approximation, and some steps may be modified according to current needs or findings. From the perspective of overall operational performance, the key processes pursue the quantification of operational efficiency, where the most logical approach of constructive wargaming evaluation is applied. The quality of the final results depends on various aspects, potentially presenting another topic for future research.

From a pragmatic point of view, even the contemporary strategic planning process is complex and systematic. It lacks the vast state space search of potential strategic solution paths count, and no such alternative has been introduced yet to a presented concept architecture.

The main SW components and theoretical procedures are available for initial solution of the mentioned problem, and all that remains is to integrate them correctly. The correlation to the reality of the solution is highly dependent on several components, such as the fidelity of the wargaming simulations and the prognosis of future opponent evolution. This creates the centre of gravity of the potential future research and development of the presented concept.

However, the overall concept is very challenging, and its implementation is feasible over several years, and the research and development investment will undoubtedly yield positive outcomes.

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