Fuzzy AHP Model for Courses of Action Comparison in Military Operations

Clara Maathuis and Leendert Ambtman
Open University of the Netherlands, Heerlen, The Netherlands

clara.maathuis@ou.nl
lambtman@hotmail.com

Abstract: In the realm of military operations, effective decision-making is fundamental, and the integration of advanced intelligent analytical tools can greatly enhance this process. This study introduces an Artificial Intelligence (AI) model based on the Fuzzy Analytic Hierarchy Process (Fuzzy-AHP) for comparing Courses of Action (COAs) in military operations. By combining fuzzy logic with the structured framework of AHP, the model effectively addresses the inherent uncertainty and multifaceted nature of military decision-making processes. Utilizing linguistic variables and fuzzy numbers, the system captures the ambiguity present in expert judgments and operational parameters, allowing for a more nuanced evaluation of various COAs. The proposed model features a hierarchical structure of decision criteria, encompassing technological and operations variables, each assessed using relevant fuzzy representations to reflect varying degrees of importance. The experimental results indicate that such an approach complements traditional decision-making methods in terms of flexibility, consistency, and its capacity to handle complex, multi-criteria scenarios typical in military contexts. Moreover, the model proposed demonstrates particular adaptability to changing operational environments and provides clear, explainable results that are essential for military planners. Therefore, this research contributes to the development of responsible and trustworthy AI-based solutions for military decision-making support, addressing critical challenges in the comparison of COAs.

Keywords: Targeting, Courses of action, Military operations, Military decision-making, Multi-criteria decision-making, Fuzzy AHP, Artificial intelligence

1. Introduction

> *"Computers are incredibly fast, accurate, and stupid: humans are incredibly slow, inaccurate, and brilliant; together they are powerful beyond imagination."*
>
> *(frequently attributed to Albert Einstein, but the attribution is uncertain)*

The integration of Artificial Intelligence (AI) into the military domain signifies a profound transformation, often referred to as the seventh military revolution, which builds upon the foundational stones set up by previous industrial revolutions (Bahcecik, 2023). Unlike earlier advancements that enhanced physical capabilities, AI introduces a multi-dimensional approach that combines data, analytical vision, and various learning paradigms to redefine warfare. This evolution allows for the deployment of intelligent and autonomous systems capable of executing complex tasks with reduced/minimal human intervention, fundamentally altering decision-making processes on the battlefield and enabling rapid responses to threats across various domains, including land, air, and cyber. Moreover, AI's capacity to analyse vast amounts of data enhances military intelligence and the planning, execution, and assessment of military operations, further enabling forces to achieve strategic advantages that were previously unattainable or unimaginable (Morgan et al., 2020).

The ongoing AI race supremacy among global military powers has significant implications for national security and the nature of warfare. As nations invest heavily in AI technologies, the military applications extend beyond traditional combat to encompass enhanced intelligence gathering, decision-making support, and autonomous systems, fundamentally transforming operational capabilities (Garcia, 2024; Zhang, 2024). This technological arms race not only aims to achieve superiority, however, it also raises ethical concerns regarding the deployment of autonomous weapons and the potential erosion of human oversight in critical military decisions. Furthermore, the rapid integration of AI into military strategies could destabilize existing power balances, as adversaries leverage AI for asymmetric advantages, potentially lowering the threshold for conflict and increasing the likelihood of miscalculations in difficult situations (Hassib & Ayad, 2023). Consequently, while AI promises to enhance military effectiveness and efficiency, it simultaneously introduces complex challenges that necessitate careful governance and international cooperation to mitigate risks associated with its deployment in warfare. This implies building and deploying AI-based solutions that are transparent and accountable during planning and execution phases. In particular, in the preparation processes of Courses of Action (CoAs) that could be considered for execution in military operations, the ability to use relevant criteria in a well-understood and transparent mechanism can only further enhance trust and collaboration between military Commanders and their military forces, fact that conducts to making informed decisions that consider both strategic goals and humanitarian implications. Nevertheless, despite the increase use of AI in the military domain, limited attention and existing solutions are dedicated to analysing and comparing CoAs while accounting and representing the uncertainty and dynamism that characterizes this domain. To this end, this research aims to develop a FAHP model for comparing CoAs in military operations. The study adopts a multidisciplinary approach by integrating methods and techniques from AI, software engineering, military science, and military-legal domains within a Design Science Research methodological approach. In this sense, the core research question guiding this research is formulated as follows: How to develop a Fuzzy AHP model for CoAs comparison in military operations? To address this question, a series of methodological phases are implemented to create a comprehensive and effective decision-making tool for decision-making support. This solution contributes to existing efforts for building intelligent solutions in the military domain that are able to deal with various uncertainty factors, able to support decision-making processes, and have an implicit structured approach.

The outline of this article is structured as follows. In Section 2, the context of this research is presented together with relevant research studies conducted in this domain. In Section 3, the methodological approach followed in this research is described. In Section 4, the model proposed is described and further evaluated through demonstration on a use case. At the end, in Section 5 are provided conclusion remarks and future research perspectives.

2. Research Background and Related Research

The Military Decision Making Process (MDMP) is a structured approach designed to identify the necessary actions, effects, decisive conditions, and objectives required for accomplishing missions when conducting military operations. The MDMP results in the creation of plans that articulate how actions (ways) and resources (means) will be employed to achieve objectives (ends) (NATO, 2019). Central to the MDMP is the role of the military commander, who bears responsibility for mission accomplishment. The commander must develop a comprehensive understanding of the operational environment, define the problem together with its corresponding objectives, devise a lawful and reliable approach, and develop feasible options with the staff officers to establish a common understanding and a reliable approach to reach effects in the mission (NATO, 2017). In the context of the MDMP, Courses of Action (CoAs) play a crucial role in operational planning. The development and analysis of CoAs is a well-structured process that ensures a comprehensive evaluation of potential strategies as alternatives together with their implications. The process begins with the definition of possible CoAs, followed by their development into more detailed plans. Subsequently, these CoAs undergo rigorous analysis to assess their feasibility, acceptability, and suitability in achieving the objectives defined for the mission. This process results in an approved operating plan/order which represents the fundament for military action. Moreover, the CoA development and analysis phase provides military commanders with a range of well-vetted options from which to choose the most effective approach for mission accomplishment (Davis & Kahan, 2007; Marr, 2021; CALL, 2023).

Given the objective of this research, a focus on three critical components and corresponding phases is established on the CoAs development, analysis and comparison. CoA development involves creating multiple viable options to achieve mission objectives, considering factors such as feasibility, acceptability, completeness, doctrinal consistency, and suitability. In this process, each CoA goes through an in-depth analysis through wargaming, allowing to the military commanders and their staff to visualize operations, assess opposing capabilities, and understand environmental conditions. The comparison phase evaluates CoAs against established criteria, balancing ends, means, ways, and risks to identify the option with the highest probability of mission success (CALL, 2023). These three phases enable commanders to make informed decisions by recommending the most suitable CoA for enhancing operational effectiveness and assuring strategic alignment.

Existing methods for implementing Courses of Action (CoAs) in military operations typically involve comparative analysis techniques. The most common approach is the Weighted Numerical Comparison Technique (WNCT), which assigns weights to criteria during mission analysis and calculates total scores for each CoA. Nevertheless, this method requires caution due to its inherent subjectivity. Alternative methods include the Non-Weighted Numerical Comparison Technique (NWNCT), which follows a similar process without weighting criteria, and qualitative approaches such as Narrative or Bulletized Descriptive Comparison (BDC) of strengths and weaknesses. Moreover, the Plus/Minus/Neutral Comparison offers a simplified evaluation, using symbols to indicate positive, neutral, or negative influences of each CoA on selected criteria (US Army, 2020).

Holzgrefe (2015) proposes a framework to choose alternative analysis and selection methods in a given context. In particular, when using the WNCT it was not possible to capture the preference magnitude between one CoAs performance in an evaluation criterion over another. Kasim, Ibrahim and Baitaneh (2011) use the Simple Additive Weighting Method to rank different computers in a MCDM approach. This study can be considered when translating an ordinal ranking of a number of criteria in numerical weights to capture the order of magnitude of preference between evaluation criteria. Ardil (2023) builds a fuzzy-based MCDM solution for determine the most suitable Unmanned Aerial Vehicle (UAV) in an operation by considering various factors such as payload capacity, maximum speed, endurance, altitude, avionics systems price, economic life, and maximum range. Goztepe & Kahraman (2022) design a MDMP solution for CoAs comparison using the AHP methodology and consider as a valuable future research avenue the design and implementation of such as solution using the FAHP approach. This represents the knowledge gap that the present research aims to tackle using this technique.

Multi-Criteria Decision-Making (MCDM) methods, while useful in military decision-making processes, require careful application due to their inherent limitations. The subjective nature of assigning values and weights to criteria in MCDM may not properly or adequately capture the complexity and uncertainty of military operational environments. To address these shortcomings, integrating AI with MCDM approaches offers a promising solution. This combination could potentially enhance the ability to handle uncertainty, provide a more accurate representation of the operational landscape, and mitigate subjectivity in the assignment of weights and values (Maathuis & Chockalingam, 2023b). Through an AI-based approach, military decision-makers could improve the robustness and reliability of their CoA evaluations in complex and dynamic scenarios. Such a powerful method is FAHP which represents a way to model complex MCDM in the military domain by incorporating fuzzy logic (Zadeh, 1965) into the traditional AHP framework (Saaty, 2004). Hence, this approach allows decision-makers to better handle uncertainty and vagueness that characterizes this domain. This approach decomposes complex decision problems into hierarchical structures of objectives, criteria, and alternatives, enabling a systematic evaluation process. The method uses fuzzy numbers and linguistic variables to represent subjective judgments, which is particularly valuable in military contexts where precise quantitative data may be scarce or unreliable. Furthermore, the method employs pairwise comparisons and fuzzy preference relations to generate priority weights for different criteria and alternatives, facilitating a more nuanced analysis of the alternatives.

Bojanic et al., (2018) proposes a FAHP model for establishing the optimal fighting position of a guided anti-tank missile battery. In the maritime domain, Lumaksono & Tukan (2019) build a FAHP model for evaluating six main factors and twenty-nine sub-factors to provide a comprehensive analysis of the Indonesia's maritime security landscape. By quantifying the relative importance of these factors, the study offers evidence-based recommendations to guide government policy-making and resource processes. Meixner (2009) proposes a FAHP methodology for assessing energy alternatives to enhance the decision-making process based on human judgements and create a realistic and cognitively aligned evaluation framework for complex energy policy decisions. In the supply chain domain, Perçin (2008) develops a FAHP model for accounting the uncertainty inherent in human judgement when sharing information among supply chain partners. The author focuses on ranking different categories of information, e.g., customer requirements, operational data, planning, and financial information, based on their importance for sharing among supply chain partners. Üsküdar et al., (2019) proposes a FAHP method to select the most suitable cargo helicopter for the armed forces, addressing a complex multi-criteria decision-making problem in military project management. The research employs trapezoidal fuzzy numbers and the Center of Gravity method to evaluate three helicopter alternatives based on 28 criteria, incorporating input from multiple decision-makers. In the context of UAVs, Radovanović et al. (2021) develop a FAHP model for the selection of optimal UAVs for tactical units in military and police operations. By defining relevant tactical, technical, and economic criteria, calculating their weight coefficients, and evaluating UAV alternatives, the authors seek to provide a robust framework for identifying the most suitable UAV systems. Furthermore, in the context of conducting military operations other than war in case of natural disaster management, Moningka et al., (2022) build a FAHP model that seeks to evaluate the organizational capacity, operational management, and inter-agency cooperation in disaster response, while determining key criteria and sub-criteria for effective implementation of such military operations. This facilitates the definition of evidence-based recommendations for enhancing the disaster management capabilities and inform decision-making processes regarding resource allocation and collaborative efforts in disaster response. Chang, Chang & Cheng (2015) propose a comprehensive FAHP method for assessing the benefits of military simulation training systems. The authors aim to demonstrate the effectiveness of their approach through a numerical example and compare it to traditional AHP methods, ultimately providing decision-makers with a more robust tool for evaluating and improving military simulation training systems.

From the extensive literature review conducted in this domain, one can see that various studies consider and apply the FAHP mechanism for building different decision-making systems. Nevertheless, in the context of MDMP and in particular in relation to comparing CoAs, limited efforts exist in relation to such AI techniques that are able to capture and represent the uncertainty and dynamism that characterizes this domain, addresses the subjective judgement of the experts involved, and embeds the group or collective meaning in relation to the decisions that need to be made. Hence, this article aims to contribute to this domain by building a FAHP model for comparing CoAs in military operations through a transparent, responsible, and trustworthy AI-based approach.

3. Research Methodology

The aim of this research is to build a Fuzzy AHP model for comparison of CoAs in military operations. To this end, a multidisciplinary research is conducted in the AI, software engineering, military, and military-legal domains in a Design Science Research methodological approach (Kuechler & Vaishnavi, 2012; Peffers, Tuunanen & Niehaves, 2018). On this behalf, the following research question is formulated: How to develop a Fuzzy AHP model for CoAs comparison in military operations? Taking this methodological approach and building on previous efforts in this domain (Maathuis, Pieters & Van den Berg, 2018a; Maathuis, Pieters & Van den Berg, 2018b; Maathuis & Chockalingam, 2023a), the following research phases are carried out to achieve the goal of this research:

Phase 1 – Design: in this phase, the context of this research is analysed through multidisciplinary lenses and an in-depth study is carried out for understanding the existing types of operations, classes of alternatives that could be defined for reaching goals for these operations, and further capturing and representing relevant criteria that could be considered for comparing CoAs in military operations. Hence, the evaluation criteria are selected while assuring that they are representative and various AI methods are analysed on this behalf. Given its vast application across domains and various decision-making processes, the Fuzzy AHP method is selected. Together with the capability of assessing decision-making processes as complex systems, integrating both qualitative and quantitative data, and expert judgement, this technique facilitates handling critical aspects that characterize the planning and execution of military operations: uncertainty and imprecision. Moreover, the roles of experts participating in this process and the use cases of military operations to be considered for evaluation and demonstration are established.

Phase 2 – Development and Evaluation: once the design considerations are established, the architecture of the solution proposed is built and the implementation choices are made. The model is built in a MCDM approach using the Fuzzy AHP technique in Python and relying on PostgreSQL. Given the roles and use cases established, an in-depth evaluation through demonstration is conducted on a simulated military operation with three CoAs and three military experts that advice the military Commander in the process of selecting the most effective CoA. The evaluation is successful and is compliant with previous results obtained in this domain.

4. Model and System Design

The following evaluation criteria are considered in this research based on extensive literature review conducted in the military domain: simplicity, maneuver, security, surprise, stealth, and proportionality. Simplicity refers to the ease of understanding and executing a plan to reduce the likelihood of confusion and errors. Maneuver refers to the ability of military forces to gain positional advantage in front of the enemy through flexibily, adaptivity, and dynamism. Security points out to the measures taken to protect friendly and neutral forces as well as preparations made to achieving effects while assuring the protection of civilian and civilian objects. Surprise relates to the capacity to catch the enemy off-guard. Stealth represents the ability to conduct operations by minimizing detection. Lastly, proportionality considers the balance between the military advantage gained and the potential collateral damage cause to civilian and civilian objects, ensuring that the use of force is justified and appropiate in relation to the objective(s) established (Litton, 2000; Parks & Duggan, 2011; Holzgrefe & Hester, 2014; CALL, 2015; US Army, 2020; US Army, 2020b).

Once that the evaluation criteria are established, the algorithm is applied in seven steps, as follows (Liu, Eckert & Earl, 2020; Luthfi et al., 2018):

Step 1: Select a team of experts.

Step 2: Determine the evaluation criteria and construct the hierarchy including the alternatives from which a choice has to be made.

Step 3. Construct the pairwise comparison matrices and evaluate the relative importance of criteria and alternatives on those criteria. For each expert the comparison matrix of the criteria is provided in equation 1:

$$\tilde{C}_{\mathrm{k}} = \begin{bmatrix} 1 & \tilde{c}_{12} & \cdots & \tilde{c}_{1\mathrm{n}} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{c}_{\mathrm{n}1} & \tilde{c}_{\mathrm{n}2} & \cdots & 1 \end{bmatrix} \quad (1)$$

where n is the number of the criterion for the pairwise comparison matrix belonging to the k-th expert for k = 1, 2,..k. Further, the comparison matrices for the alternatives are constructed in a similar manner.

Step 4: Transform the linguistic terms into traingular fuzzy membership functions and aggregate. Then the aggregation of the opinions of the experts is carried out using the arithmetic mean calculated with the formula defined in equation 2:

$$\tilde{C}_{\mathrm{ij}} = \frac{1}{q}\left(\tilde{C}^{1}{}_{\mathrm{ij}} \oplus \tilde{C}^{2}{}_{\mathrm{ij}} \oplus \ldots \oplus \tilde{C}^{\mathrm{q}}{}_{\mathrm{ij}}\right) \quad (2)$$

Step 5. Calculate the fuzzy weight matrix and check the consistency of the pairwise comparison matrix. The consistency of the weight matrix is checked because judgments are subjective. Accordingly, the weights are calculated as in equation 3:

$$\tilde{w}_{\mathrm{i}} = \tilde{r}_{\mathrm{i}} \otimes (\tilde{r}_1 + \tilde{r}_2 + \ldots + \tilde{r}_{\mathrm{n}})^{-1} \quad (3)$$

Step 6: The normalization procedure is applied for maintaininig consistency in the decision making-process.

Step 7: The best alternative is selected by multiplying the weights of the criteria with the scores of the alternatives on those criteria and adding the results for a total score.

To implement the system, four use cases are defined considering the roles of the experts involved as illustrated in Figure 1 concerning the following operational flow being characterized by the domain model captured in Figure 2. The system is implemented in Python using an open source MCDM library (Valdecy, 2023) and the PostgreSQL database management system. First, start CoA comparison describes the creation of a comparison process and its properties: the operation name, its CoAs, its evaluation criteria, and the number of experts. Second, the criteria weights are established by experts who judge the pairwise comparisons of criteria. Third, the experts judge the pairwise comparisons of the CoAs on the criteria. The comparison module will then calculate the weights, scores, and totals for the criteria by using the FAHP except for the criterion proportionality. The score for proportionality is calculated based on a Machine Learning-based approach which is out of scope in this research. At the end, the results of the comparison process are presented.

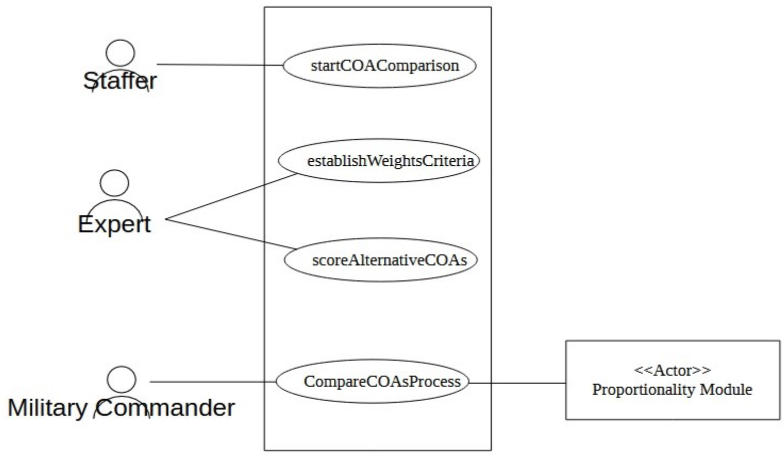

Figure 1: Use case diagram for CoAs comparison

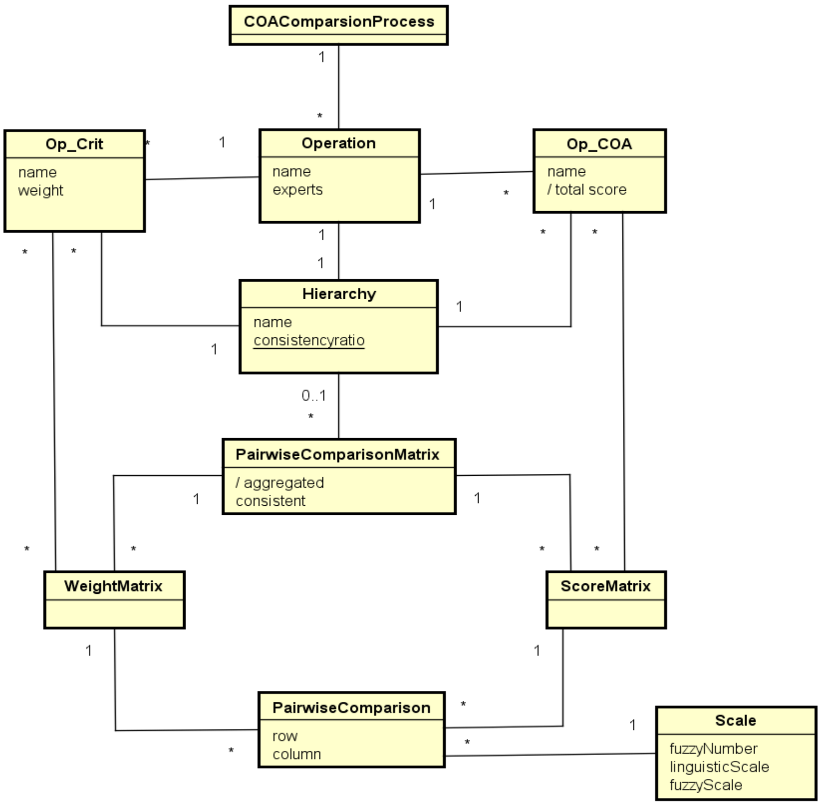

Figure 2: Domain model for CoAs comparison

The fuzzy scale consider a 9-point Likert scale and the calculation of the weights is done using a geometric mean which is less affected by extreme values and is more suitable for averaging normalized values. The architectural view of obtaining the results once running the model is provided in Figure 3. In particular, in this figure the user and algorithm perspectives are shown in relation to the comparison of the CoAs considered and the proportionality assessment criteria.

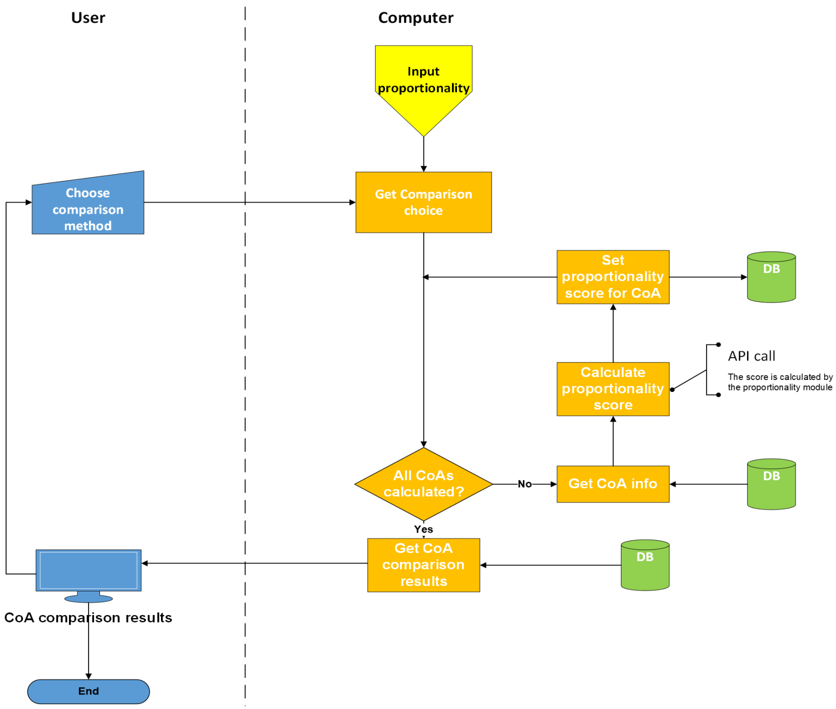

Figure 3: System architecture

For evaluation and demonstration, a virtually simulated Cyber Operation conducted as a counter-terrorism operation is considered (Maathuis, Pieters & van den Berg, 2021). In this operation, a coalition of 12 countries is planning an offensive Cyber Operation against the terrorist group Terrmisous to prevent an imminent drone attack on the president of Aricikland. Intelligence gathered indicates that Terrmisous intends to deploy a suicide drone carrying 3 kg of explosives, capable of both manual and automatic operation, to target the president during a speech at the National Security Centre. The Coalition aims to exploit Terrmisous' limited defensive cyber capabilities to neutralize this threat. This counter-terrorism effort is part of a broader initiative to address the ongoing conflict and humanitarian crisis in Aricikland, with the operation's primary objective being the protection of Aricikland's head of state through preemptive cyber intervention. For this operation, the following three CoAs are considered:

- CoA 1 aims to bring down the power grid of Aricikland's capital and thus in the Conference Hall of the Aricikland National Security Centre which will lead to cancelling of president's speech and will prevent the terrorist attack. The cyber weapon used in this case is based on the BlackEnergy 3 malware which was used to attack the Ukrainian power grid (Case, 2016; Khan et al., 2016).
- CoA 2 aims to prevent the terrorist drone attack by manipulating the operator control of the ground control station of the drone by manipulating/altering the position and speed of the drone so that it will have a random flight pattern and will be prevented to reach its target. The cyber weapon is a malware exploiting an existing 0-day (i.e., unknown and unpatched vulnerability) for automatically altering the direction and speed of the UAV during flight by inserting a random factor.
- CoA 3 aims at to prevent the terrorist drone attack by jamming the communication and navigation links of the drone and thus prevent that it reaches its target. The cyber weapon is used for a combination of radio frequency jamming and Global Navigation Satellite System (GNSS) jamming for disrupting communication links between the UCAV and its operator.

Furthermore, three experts are considered for analysing and comparing the experts: a Cyber Operations specialist, a military operations specialist, and a military-legal specialist. For each of them, the pairwise comparison of criteria using the linguistic values is provided in Figure 4.

	Simplicity	Maneuver	Security	Surprise	Stealth	Proportionality
Simplicity	9	5	13	10	11	8
Maneuver	13	9	15	13	15	15
Security	5	3	9	8	6	7
Surprise	8	5	10	9	11	10
Stealth	7	3	12	7	9	9
Proportionality	10	3	11	8	9	9

	Simplicity	Maneuver	Security	Surprise	Stealth	Proportionality
Simplicity	9	4	11	7	11	9
Maneuver	14	9	15	11	15	12
Security	7	3	9	5	9	7
Surprise	11	7	13	9	12	10
Stealth	7	3	9	6	9	7
Proportionality	9	6	11	8	11	9

	Simplicity	Maneuver	Security	Surprise	Stealth	Proportionality
Simplicity	9	8	13	8	13	10
Maneuver	10	9	15	9	14	11
Security	5	3	9	7	9	7
Surprise	10	9	11	9	14	11
Stealth	5	4	9	4	9	6
Proportionality	8	7	11	7	12	9

Figure 4: Pairwise comparison of criteria for the Cyber Operations specialist (up), military operations specialist (middle), and military-legal specialist (bottom)

The obtained results for comparing the three CoAs considered are shown in Figure 5. The results show the final score in the last column of this table which represents a crisp (i.e., non-fuzzy) number that reflects the overall performance of each alternative across all criteria. Therefore, the alternative with the highest final score is considered to be the one preffered or is seen as the optimal choice. In this operation, this means CoA 2. These results reflect the effectiveness of using an intelligent modelling perspective for comparing CoAs in military operations while capturing various undertainty elements that play a role in this domain in a transparent manner.

	Simplicity	Maneuver	Security	Surprise	Stealth	Proportionality	
Weights	0.121	0.038	0.358	0.077	0.277	0.13	
	Scores						Total
CoA 1	0.12	0.11	0.12	0.2	0.15	0.77	0.219
CoA 2	0.23	0.29	0.41	0.43	0.69	0.97	0.536
CoA 3	0.66	0.59	0.47	0.38	0.16	0.99	0.473

Figure 5: Fuzzy weights for the criteria considered

5. Conclusions

The establishment of critical lessons learned in military operations necessitate a comprehensive approach that integrates ethical, social, and legal dimensions throughout the planning, execution, and assessment phases. This multifaceted analysis is essential for developing a nuanced understanding of operational efficacy and impact assessment. Ethical considerations require a thorough examination of moral implications, adherence to professional military ethos, and potential consequences for both combatants and non-combatants. Social factors demand an in-depth comprehension of cultural contexts, maintenance of forces' morale, and management of public perception. Legal aspects involve strict compliance with international law, adherence to Rules of Engagement, and alignment with war principles. By systematically evaluating these interconnected dimensions, armed forces and decision-makers can identify potential pitfalls, refine decision-making processes, and from there enhance operational success while minimizing unintended negative consequences on civilians and civilian objects, in other words, collateral damage.

The development and implementation of responsible intelligent solutions for comparing CoAs in military operations is important in contemporary and future warfare. These systems can significantly augment decision-making processes by incorporating ethical frameworks, conducting social impact analyses, ensuring legal compliance, providing data-driven insights, and enabling rapid scenario modelling. Through an AI-based approach, this research brings a contribution to this domain by building and proposing a novel Fuzzy AHP model for CoAs comparison in military operations as a responsible and transparent approach that aims at providing decision-making support to military Commanders and their officers while capturing elements that represent the dynamism and uncertainty that surround this domain. Accordingly, the solution proposed offers a comprehensive, transparent, and objective analyse of potential outcomes through the consideration of several alternatives, thereby reducing cognitive biases and improving the decision-making processes. Furthermore, the model proposed allows for the evaluation of multiple COAs in compressed timeframes, which is crucial in dynamic operational environments. This research continues by building an advanced modelling and simulation environment (Maathuis, 2022; Maathuis, 2023) for executing and analysing the solution proposed in various cases. Conclusively, building and deploying responsible intelligent solutions not only enhances mission success, but also reinforces the military's commitment to its core values and societal responsibilities, fostering a more ethical and effective approach to military operations in complex landscapes.

References

Ardil, C. (2023). Unmanned Aerial Vehicle Selection Using Fuzzy Multiple Criteria Decision Making Analysis. *International Journal of Aerospace and Mechanical Engineering*, *17*(8), 303-311.

Bahcecik, S. O. (2023). TRENDS Security Politics and Artificial Intelligence: Key Trends and Debates. *International Political Science Abstracts*, *73*(3), 329-338.

Bojanic, D., Kovač, M., Bojanic, M., & Ristic, V. (2018). Multi-criteria decision-making in a defensive operation of the guided anti-tank missile battery: An example of the hybrid model fuzzy AHP-MABAC. *Decision Making: Applications in Management and Engineering*, *1*(1), 51-66.

Case, D. U. (2016). Analysis of the cyber-attack on the Ukrainian power grid. *Electricity information sharing and analysis center (E-ISAC)*, *388*(1-29), 3.

Center for Army Lessons Learned (2023). Military decision-making process: organizing and conducting planning.

Chang, K. H., Chang, Y. C., & Chung, H. Y. (2015). A Novel AHP-Based Benefit Evaluation Model of Military Simulation Training Systems. *Mathematical Problems in Engineering*, *2015*(1), 956757.

Davis, P. K., & Kahan, J. P. (2007). Theory and methods for supporting high level military decision-making (Vol. 422). Rand Corporation.

Garcia, D. (2024). *The AI Military Race: Common Good Governance in the Age of Artificial Intelligence*. Oxford University Press.

Hassib, B., & Ayad, F. (2023). The challenges and implications of military cyber and AI capabilities in the Middle East: the geopolitical, ethical, and technological dimensions. In *The Arms Race in the Middle East: Contemporary Security Dynamics* (pp. 49-65). Cham: Springer International Publishing.

Holzgrefe, J. P., & Hester, P. T. (2014). Inconsistencies in Joint and Allied Methods for Course of Action Comparison. *Phalanx*, *47*(1), 35-42.

Holzgrefe, J. P. L. (2015). *A framework to simplify the choice of alternative analysis and selection methods*. Old Dominion University.

Goztepe, K. & Kahraman, K. G. C. (2022). A New Approach to Military Decision Making Process: Suggestions from MCDM Point of View.

Khan, R., Maynard, P., McLaughlin, K., Laverty, D., & Sezer, S. (2016, August). Threat analysis of blackenergy malware for synchrophasor based real-time control and monitoring in smart grid. In *4th International Symposium for ICS & SCADA Cyber Security Research 2016* (pp. 53-63). BCS.

Kasim, M. M., Ibrahim, H., & Bataineh, M. S. B. (2011). Multi-criteria decision making methods for determining computer preference index. *Journal of Information and Communication Technology Volume 10, 2011, Pages 137-148*.

Kuechler, W., & Vaishnavi, V. (2012). A framework for theory development in design science research: multiple perspectives. *Journal of the Association for Information systems*, *13*(6), 3.

Litton, L. G. (2000). The information-based RMA and the principles of war. *Air & Space Power Chronicles*, 1-12.

Liu, Y., Eckert, C. M., & Earl, C. (2020). A review of fuzzy AHP methods for decision-making with subjective judgements. *Expert systems with applications*, *161*, 113738.

Luthfi, A., Rehena, Z., Janssen, M., & Crompvoets, J. (2018, October). A fuzzy multi-criteria decision making approach for analyzing the risks and benefits of opening data. In *Conference on e-Business, e-Services and e-Society* (pp. 397-412). Cham: Springer International Publishing.

Lumaksono, H., & Tukan, M. (2019). Assessment of the most influential factors on indonesian maritime security using fuzzy analytical hierarchy process. In *2019 International Conference on Computer Science, Information Technology, and Electrical Engineering (ICOMITEE)* (pp. 74-81). IEEE.

Maathuis, C., Pieters, W., & van den Berg, J. (2021). Decision support model for effects estimation and proportionality assessment for targeting in cyber operations. *Defence Technology*, *17*(2), 352-374.

Maathuis, C., Pieters, W., & Van den Berg, J. (2018a). Assessment methodology for collateral damage and military (Dis) Advantage in cyber operations. In *MILCOM 2018-2018 IEEE Military Communications Conference (MILCOM)* (pp. 1-6). IEEE.

Maathuis, C., Pieters, W., & van den Berg, J. (2018b). A knowledge-based model for assessing the effects of cyber warfare. In *Proceedings of the 12th NATO Conference on Operations Research and Analysis*.

Maathuis, C. (2022). An Outlook of Digital Twins in Offensive Military Cyber Operations. In *European Conference on the Impact of Artificial Intelligence and Robotics* (Vol. 4, No. 1, pp. 45-53).

Maathuis, C. (2023). Human Centered Explainable AI Framework for Military Cyber Operations. In *MILCOM 2023-2023 IEEE Military Communications Conference (MILCOM)* (pp. 260-267). IEEE.

Maathuis, C., & Chockalingam, S. (2023a). Modelling the influential factors embedded in the proportionality assessment in military operations. In *International Conference on Cyber Warfare and Security* (Vol. 18, No. 1, pp. 218-226).

Maathuis, C., & Chockalingam, S. (2023b). Tackling Uncertainty Through Probabilistic Modelling of Proportionality in Military Operations.

Meixner, O. (2009). Fuzzy AHP group decision analysis and its application for the evaluation of energy sources. In *Proceedings of the 10th International Symposium on the Analytic Hierarchy/Network Process, Pittsburgh, PA, USA* (Vol. 29, pp. 2-16).

Marr, J. J. (2001). The military decision making process: Making better decisions versus making decisions better. School of Advanced Military Studies, US Army Command and General Staff College.

Moningka, R. I., Praditya, E., Budiastawa, K., Panggabean, J. U., Kumara, A., Yusgiantoro, P., & Midhio, I. W. (2023). Structure of the Analytic Hierarchy Process (AHP) for Natural Disaster Management in Making Decisions on Military Operations Other than War in the TNI. *Jurnal Public Policy*, *9*(4), 254-260.

Morgan, F. E., Boudreaux, B., Lohn, A. J., Ashby, M., Curriden, C., Klima, K., & Grossman, D. (2020). Military applications of artificial intelligence. *Santa Monica: RAND Corporation*.

NATO (2017). NATO Standard AJP-01 Allied Joint Doctrine. NATO Standardization Office.

NATO (2019). NATO Standard AJP-5 Allied Joint Doctrine for Planning of Operations. NATO Standardization Office.

Peffers, K., Tuunanen, T., & Niehaves, B. (2018). Design science research genres: introduction to the special issue on exemplars and criteria for applicable design science research.

Perçin, S. (2008). Use of fuzzy AHP for evaluating the benefits of information-sharing decisions in a supply chain. *Journal of Enterprise Information Management*, *21*(3), 263-284.

Parks, R. C., & Duggan, D. P. (2011). Principles of cyberwarfare. *IEEE Security & Privacy*, *9*(5), 30-35.

Radovanović, M., Petrovski, A., Žindrašič, V., & Ranđelović, A. (2021). Application of the fuzzy AHP-VIKOR hybrid model in the selection of an unmanned aircraft for the needs of tactical units of the armed forces. *Scientific Technical Review*, *71*(2), 26-35.

Saaty, T. L. (2004). Decision making—the analytic hierarchy and network processes (AHP/ANP). *Journal of systems science and systems engineering*, *13*, 1-35.

U.S. Army (2020). Joint Publication 5-0: Joint Planning.

U.S. Army (2020b). ATP 5-0.2-1: Staff Reference Guide Volume 1 Unclassified Resources.

Üsküdar, A., Türkan, Y. S., Özdemir, Y. S., & Öz, A. H. (2019). Fuzzy ahp-center of gravity method helicopter selection and application. In *2019 8th International Conference on Industrial Technology and Management (ICITM)* (pp. 170-174). IEEE.

Valdecy (2023). PyDecision, https://github.com/Valdecy/pyDecision

Zadeh, L.. (1965). "Fuzzy sets," *Information and Control*, vol. 8, no. 3, pp. 338-353, 35, 85.

Zhang, M. Y. (2024). Cold War 2.0: Artificial Intelligence in the New War between China, Russia, and America: by George S. Takach, Pegasus Books, 15 March 2024, 432 pp., RRP $49.99 (hardback), ISBN: 9781639365630.