Four-Dimensional Planning at the Speed of Relevance

Artificial-Intelligence-Enabled Military Decision-Making Process

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Having a computer partner meant never worrying about making a tactical blunder. The computer could project the consequences of each move we considered, pointing out possible outcomes and countermoves we might otherwise have missed. With that taken care of for us, we could concentrate on strategic planning instead of spending so much time on laborious calculations. Human creativity was even more paramount under these conditions, not less.

—Garry Kasparov, *Deep Thinking*

Decision-making has long been the centerpiece of warfare. Recent increases in the tempo, scale, opacity, nonlinearity, and connectivity of warfare increasingly challenge the contemporary decision-making process. Into the future, this change will simultaneously increase the importance of timely and effective decision-making while further exacerbating many commanders' cognitive and decision-making challenges. Commanders' will search for solutions to ill structured, high-complexity problems extending through the six domains of air, land, maritime, information, cyber, and space. The future state of affairs poses a potential growth to complexity that will increase at an exponential rate as new technologies and applications are realized. Human learning and even the ability of the most-seasoned commander to intuit will not keep pace with the evolving character of war. To shepherd battle-winning insight into the future, there must be an improvement to human cognition, the decision-making process, or its *augmentation*.

The cleaving of decision competence and available support has created a widening capability gap among the analytical decision-making process, commander's intuition, and effective decision-making. The current and future environments demonstrate the need to develop more agile decision support tools that can stem the gap and regain a decisional advantage for commanders. The ability to effectively forecast several engagements ahead in an opaque and complex environment will be essential to success. Simultaneously, the ability to understand and react first in a dynamic environment capable of rapidly invalidating previous plans will be essential to seizing and retaining the initiative.[1]

The science of complexity and study of chaos have wrestled with similar problems and provide relevant

Author and strategist Peter Singer (*left*) discusses new technology with an officer and a Department of Defense civilian on 1 November 2018 at an unnamed Air Force facility. Advances such as artificial intelligence and brain-machine interfacing will change the way the Army conducts war. (Photo courtesy of U.S. Army Acquisition Support Center)

insight to the military commander's emergent challenge. Work with computer modeling and artificial intelligence (AI) has made great gains. In many games, computers have eclipsed a human's ability to make decisions.

Adapting and evolving from AI dominance, human-machine teams in chess have achieved a new pinnacle of decision-making, combining the tactical excellence of algorithms that evaluate future moves several turns in advance with humans' strategic ability. Current U.S. defense efforts related to AI and decision-making appear focused on big data and data analytics. Predictive analytics, however, cannot be capitalized on in the absence of an improved military decision-making framework. Otherwise, increased data and analysis will only exacerbate the challenge of understanding an increasingly complex and dynamic operating environment.

The military decision-making process (MDMP), while analytically sound, is not structured in a way that will keep pace with the future environment. The pace of conflict will outpace a staff's ability to process an analytical contribution.

Modifying and augmenting MDMP with AI will create a process that generates understanding of the environment grounded in a framework of physical information at a far superior speed. Course of action development will not originate, as it does now, from a desired end-state worked backward, applying ways and means in theoretical hindsight to create an imagined future. AI-enabled MDMP will work forward from the current state. It will explore forward through the possible branches of friendly and adversary decision trees toward a gamut of environments and adversary courses of action, brought to life as adaptive agents by means of a minimax-style decision tree.[2] Alternative operational futures will be built through the emergence of feasibility, completed through optimization of the contributions of warfighting functions, inherently distinguishable, then judged by the human component of the man-machine team to be suitable and acceptable. Reenvisioned man-machine MDMP will keep pace with the future operating environment, maintaining relevance by operating at near machine speed, enabling superior vision through a thickening fog of war.

Commanders, while supported by their staff, ultimately use their own faculties for decision-making. When commanders are conducting problem solving to formulate guidance for their staff or subordinates, they are essentially conducting "means-ends analysis, a process of searching for the means or steps to reduce the differences between the current situation and the desired goal."[3] Even intuition, a sudden insightful interpretation of an event or data, works in a similar method. "Despite the apparent sudden flash of insight that seems to yield a solution to problems, research indicates that the thought processes people use when solving insight problems are best described as an incremental, means-ends analysis."[4] Leaders recognize similarities and make connections to personal and studied history that leads to insight. Psychologist, economist, and Nobel Laureate Daniel Kahneman explained the internal, often semiconscious process with the description that "the mental work that produces impressions, intuitions, and many decisions goes on in silence in our mind."[5] Mathematical physicist, philosopher of science, and Nobel Laureate Roger Penrose described an unconscious development of ideas and a conscious judging of those ideas.[6]

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MDMP has a similar and no less human dynamic. The staff generate options through course of action (COA) development, and the commander decides. However, during the generation of options within the COA development process, just as in means-ends reasoning, heuristics, used to simplify calculations as well as some neuropsychological flaws, limit options and inject subjectivity. Ultimately, the current COA development process within MDMP still requires brainstorming a great deal of the solution.

In contrast to the subjective development of options is the development of options based on measure and calculation that an AI-enabled process would perform. With some calculations based on the available information and data from past conflicts, it is possible to contrast the recommendations AI-enabled MDMP would have provided.

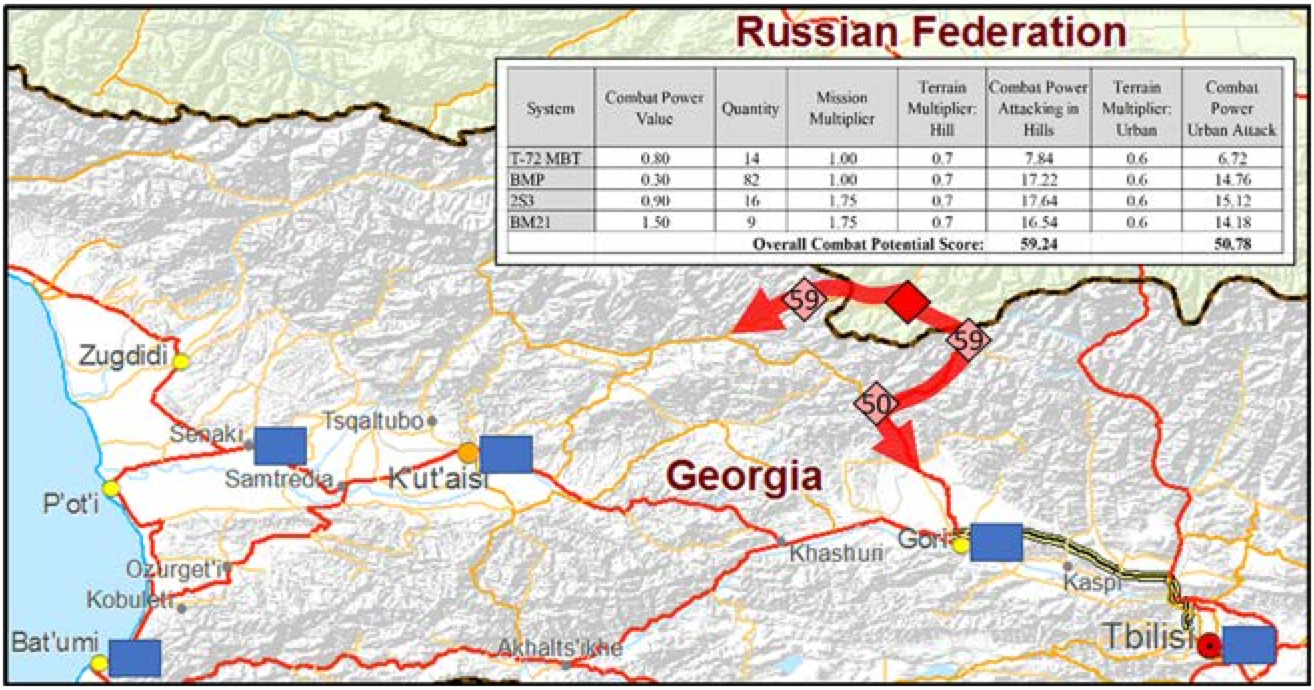
Evaluating decision-making and planning during the 2008 Russo-Georgian War provides insight into the benefit of AI-enabled MDMP when contrasted with historical decisions, actions, and outcomes. What follows is the logic and process behind AI-enabled MDMP.

If intelligence is to drive maneuver, as the saying goes, then the outputs of intelligence preparation of the battlefield must serve as a starting point for COA development, enabling the creation of a friendly COA that achieves asymmetry against the adversary and executes the actions that are most advantageous against the adversary's actions.

From the assessment of enemy forces, it is possible to determine the friendly force required based on the specific mission variables. To do this, a method of measuring the adversary's combat power is required. There are many methods of varying complexity to determine a value to represent combat power.

An AI program can make even the most tedious systems feasible, so it is not limited by complexity as staffs are, especially when time is constrained. While this example uses the theater analysis model (TAM), the TAM is not the point. Whatever the commander, staff, or doctrine recommends can be used.

Prior to the onset of the 2008 Russo-Georgian War, Russian forces were staged in North Ossetia. These forces can be translated to a combat power value by location. For example, Russian forces in vicinity of the Mamison Pass can be tallied by their component pieces such as personnel, T-72 main battle tanks, 2S3 self-propelled artillery pieces, and BM-21 multiple launch rocket systems.[7] Performing correlation of forces and means calculations on that force yields their relative combat power based on type of mission and terrain, resulting in a value of 59 when conducting a deliberate



System	Combat Power Value	Quantity	Mission Multiplier	Terrain Multiplier: Hill	Combat Power Attacking in Hills	Terrain Multiplier: Urban	Combat Power Urban Attack
T-72 MBT	0.80	14	1.00	0.7	7.84	0.6	6.72
BMP	0.30	82	1.00	0.7	17.22	0.6	14.76
2S3	0.90	16	1.75	0.7	17.64	0.6	15.12
BM21	1.50	9	1.75	0.7	16.54	0.6	14.18
				Overall Combat Potential Score:	**59.24**		**50.78**

(Data adapted from author, with data from Alexandros F. Boufesis, *The Russia-Georgia War of 2008*; calculations based on David R. Hogg, *Correlation of Forces: The Quest for a Standardized Model*)

Figure 1. Russian Forces Combat Power Calculation

attack through the rolling terrain south of the Roki Tunnel or 50 when conducting an attack into the city of Tskhinvali.

The range of combat power shown in figure 1 can inform the required combat power, originating from the Georgian force locations, annotated by blue rectangles, to defeat this Russian force in various potential scenarios. The two depicted scenarios in figure 1 are the Russian use of the Mamison Pass to the west or the Roki Tunnel to the east (red line with arrow points).

Like combat power calculations, a calculation derived from computer modeling can be used to forecast casualties based on the corresponding correlation of forces and means.[8] In the algorithm used here, combat power was adjusted for each capability or system based on terrain and type of mission. Once adjustments were made to combat power, the model described equal distribution of casualties at a 1:1 ratio of forces, with a nonlinear curve that flattens out at a roughly 4.4:1 combat power ratio, showing a rough point of diminishing returns.[9] This calculation does not provide a percentage chance of "mission success" but can provide iterations of expected battle damage and casualties, which shows how the combat power of both sides is affected over time. Assumptions must be made about the loss of combat power that will result in a defeat or withdrawal, but this is a great example of where human insight can be forced to provide specificity. The beginnings of insight that emerge from these calculations is that a 1:1 ratio remains attritional, while a 2:1 is likely to grow to a 2.4:1 then a 4.5:1 over two iterations. This creates a mechanism to seek favorable combat ratios in time that can decisively tip the balance. This is not a crystal ball, but are the best estimates available, able to be worked out methodically by a staff, or at machine speed by a program. Since warfare is a distinctly human endeavor, additional modifiers could be included for morale or other factors not included in this example. This appreciation for the application of combat power over time provides a key insight and can inform decision-making on the allocation of forces. At this point, an advantageous combat power requirement for friendly forces corresponding to specific locations can be generated. Figure 2 (on page 68) highlights a desirable combat power for Georgian forces if defending in rolling terrain on either Russian invasion route.

Russian Combat Power (CP)	COFM	Georgian Combat Power (CP)	Forecasted Results of First Engagements based on COFM	Resulting COFM	Forecasted Results of Subsequent Engagements based on Updated COFM	Final COFM
59.24	1:1	39.49	Russian CP: 29.62 (50% Strength)	1:1	Russian CP: 14.81 (25% Strength)	1:1
			Georgian CP: 19.75 (50% Strength)		Georgian CP: 9.87 (25% Strength)	
	1:2	78.98	Russian CP: 29.62 (50% Strength)	1:2.4	Russian CP: 14.81 (25% Strength)	1:4.5
			Georgian CP: 71.08 (90% Strength)		Georgian CP: 66.10 (84% Strength)	
	1:3	118.47	Russian CP: 29.62 (50% Strength)	1:3.8	Russian CP: 14.81 (25% Strength)	1:7.4
			Georgian CP: 112.55 (95% Strength)		Georgian CP: 110.30 (93% Strength)	

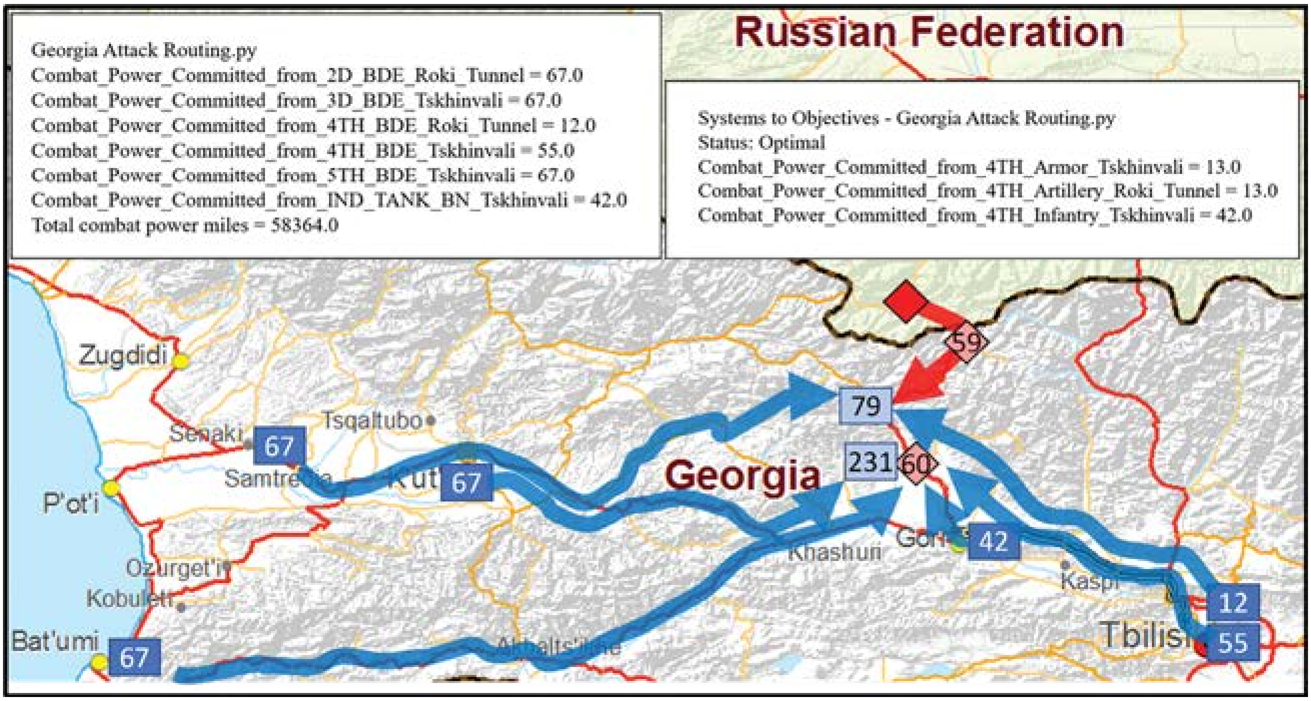
(Data adapted from author, with data from Alexandros F. Boufesis, *The Russia-Georgia War of 2008*; calculations based on David R. Hogg, *Correlation of Forces: The Quest for a Standardized Model*)

Figure 2. The Positive Feedback Loop of Force Ratios

With escalation of the situation in South Ossetia, Georgian President Mikheil Saakashvili defined three objectives for the military on 7 August 2008. He directed them "first, to prevent all military vehicles from entering Georgia from Russia through the Roki Tunnel; second, to suppress all positions that were attacking Georgian peacekeepers and Interior Ministry posts, or Georgian villages; and third, to protect the interests and security of the civilian population while implementing these orders."[10] As the secretary of the Georgian National Security Council, Alexander Lomaia, later testified, "The logic of our actions was to neutralize firing positions on the outskirts of Tskhinvali and try to advance closer to the Roki tunnel as soon as possible by circling around Tskhinvali."[11] This directive and the logic that underpinned the Georgian military response provide a helpful contrast to the continued development of an AI-enabled COA in this article.

The previously analyzed Russian forces from figure 1 accounted for the first echelon forces that would later attempt to enter Georgia through the Roki Tunnel. The forces described as firing on Georgian forces and villages were operating in vicinity of Tskhinvali and consisted of Ossetians aided by the Russian and Ossetian "peacekeeping" battalions, which were increased in number to 830 soldiers, approximately 300 mercenaries, and more substantial artillery.[12] Because of their considerable infantry, different mission, and terrain of hastily defending from the urban center of Tskhinvali, their combat potential through the same method used previously is calculated at 60.

Turning to the Georgian forces and the continued development of their most favorable course of action, the combat power and locations of the Georgian 2nd, 3rd, 4th, and 5th Infantry Brigades, as well as a separate tank battalion in Gori, serve as the start point for calculations. Their distances and travel times to Russian forces, or key terrain, can be calculated. Combining this information with the previously outlined Russian forces and the previously discussed knowledge of force ratios enables goal programming to be used to mathematically optimize the combat power routed from each Georgian location to either the Roki Tunnel or Tskhinvali to meet favorable force ratios while minimizing the overall



(Original programs by author)

Figure 3. Results of Combat Potential Optimization Python Program and Recommended Split Task Organization of 4th Brigade

distance travelled and thus minimizing both time and logistics requirements.

The results of an optimization program included in the top left of figure 3 allocate Georgian combat power sufficient to reach a 2:1 force ratio against attacking Russian forces. For the 4th Infantry Brigade, which is recommended to split combat power between objectives, a follow-on optimization was run to determine the quantities of different combat systems by warfighting function to each objective, shown in the top right of figure 3. What results is a rational choice solution grounded in doctrine and formed through the type of calculations reserved for adjudicating wargames in the later MDMP step of COA analysis. What AI-enabled MDMP has achieved is the use of detailed analysis to inform the initial development of the course of action, preventing future path dependency on a suboptimal COA.

This output is like analyzing data to create information. Merging these component pieces of information can create knowledge, to which the commander or staff can apply wisdom. Instead of possessing an element of inexplicability, as intuition would inject, this approach is explainable and can be modified with specific commander's planning guidance.[13] In this case, the effectiveness of armor, infantry, and artillery in both the attack and defense, as well as hills and urban terrain, were factored into the optimization, and the output prioritized artillery to the Roki Tunnel. This recommendation, while originating algorithmically, abides by human military judgment that would recognize the comparative difficulty of employing artillery in a city as well as the relative advantage of infantry. Not surprising, after action reviews noted the effectiveness of Georgian artillery when employed against the advancing Russian columns in the hilly terrain.

Again, the types of calculations that are ordinarily reserved for the later step of COA analysis are applied in the initial development of the COA in this modification. As Garry Kasparov described the benefits of teaming with a computer, so too can humans apply operational art to a concept that has already incorporated the science.

One example of the many calculations that can be integrated into a program that will reduce cognitive burden and allow staffs to progress to higher-level human analysis is travel time. For each of the travel legs recommended, a calculation can be performed to determine a more accurate travel time based on the number of vehicles and other variables.

Comparing the output of a rudimentary man-machine-developed COA described above with what the Georgian National Security Council articulated about its general course of action highlights the advantage AI-enabled MDMP could provide. The AI-enabled recommendation directed a more formidable Georgian force to the Roki Tunnel simultaneous to the commitment of forces toward Tskhinvali. It is likely that an earlier and more significant commitment of forces to a defense in vicinity of the Roki Tunnel would have significantly disrupted the invading Russian forces, which were already canalized, as well as prevented them from moving their rocket systems within range of Tskhinvali and ballistic missile batteries through the tunnel to range further into Georgia, which proved decisive for the Russians.[14]

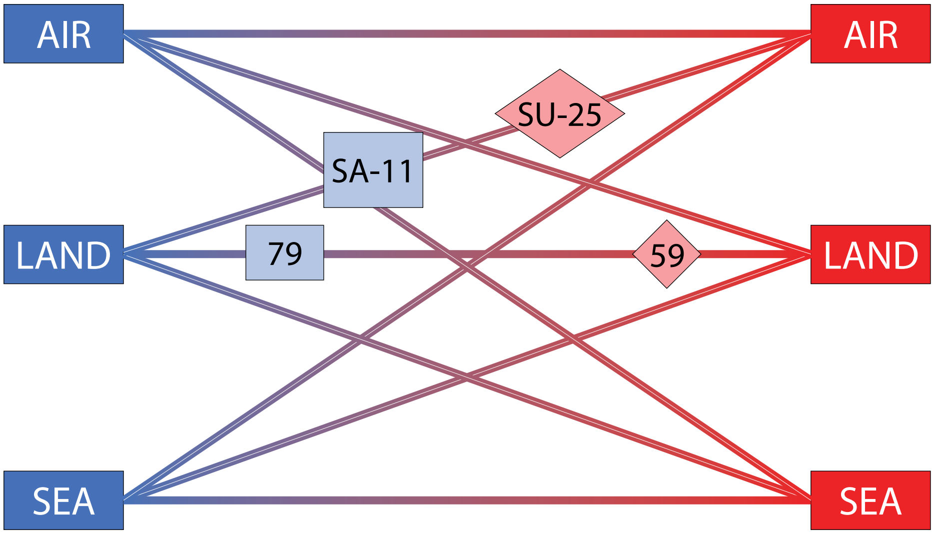
The modified method thus far has established a way to develop the "next move" based on an appreciation for friendly and adversary combat power by location, how that combat power is affected by mission type and terrain, and the time relationship between forces both during movement and maneuver in contact. These examples of ground forces must naturally extend to the application of combat power and effects from all domains. This technique enables simultaneous analysis of individual domains and provides a mechanism for the integration of cross-domain effects. Sorties of close air support may be integrated into the ground domain to provide a better combat power ratio at key locations and times in the ground fight. Additionally, air-to-air combat calculations can be carried out with ground-based air defense assets factored into the air-to-air calculations. Figure 4 (on page 71) shows the combat power for Russian ground forces attacking through the Roki Tunnel and recommended Georgian ground forces, and additionally highlights how the Russian SU-25s or Georgian SA-11 systems could be incorporated. This creates a multidimensional framework for combat operations conducted within and across domains and provides a method for synchronizing convergence. As conditions in one domain change, the impact on other domains and operations can be carried through at a level of complexity that begins to greatly outpace staff calculations.

With the core COA developed, the best integration of each warfighting function can be algorithmically identified. For example, with routes and distances to objectives, as well as burn rates and other planning factors, elements of the concept of support can be calculated.

This example has shown the ability to integrate planning for all warfighting functions across multiple domains. With sufficient detail accounting for the completion and the breadth of the COA, the explanation can now turn to depth. To create a COA at the operational level that has depth in both time and space, it must forecast several engagements ahead to achieve positions of relative advantage and seek to achieve a defeat mechanism that translates to success. Whereas the previous processes have largely been creations of algorithmically linking existing military doctrine or scholarship, they struggle to make the leap beyond immediate decisions and create operational art. For this, existing artificial intelligence provides applicable examples.

The basic minimax used in chess AI scores all board dispositions two moves ahead, action and reaction, and then compares the scores based on the program.[15] The one with the worst score is pruned as an option. Having eliminated the worst future option two moves ahead, the best remaining option is selected. The pruning and eliminations process prevents a scenario where one could take a low-value piece in the immediate move but would then lose a high-value piece on the next move. The algorithm repeats the process based on each subsequent move. In many programs, the algorithm analyzes many more moves ahead, exponentially adding board dispositions to evaluate and rank potential moves.[16] To ease calculations on the computer, a process known as alpha-beta pruning can remove branches when it becomes clear that they will not be the best option and stop evaluating them. Based on the demonstrated ability to valuate military formations based on their correlation of forces and means, it is possible to see how even simple chess AI methodology could form the basis for developing operational art.

When using a decision tree and the minimax algorithm for chess AI, the program appraises the board for most, or all, alternative futures and generates a comparable value. Russian forces initially attacking over the Mamison Pass to the west instead of the Roki



(Figure by author)

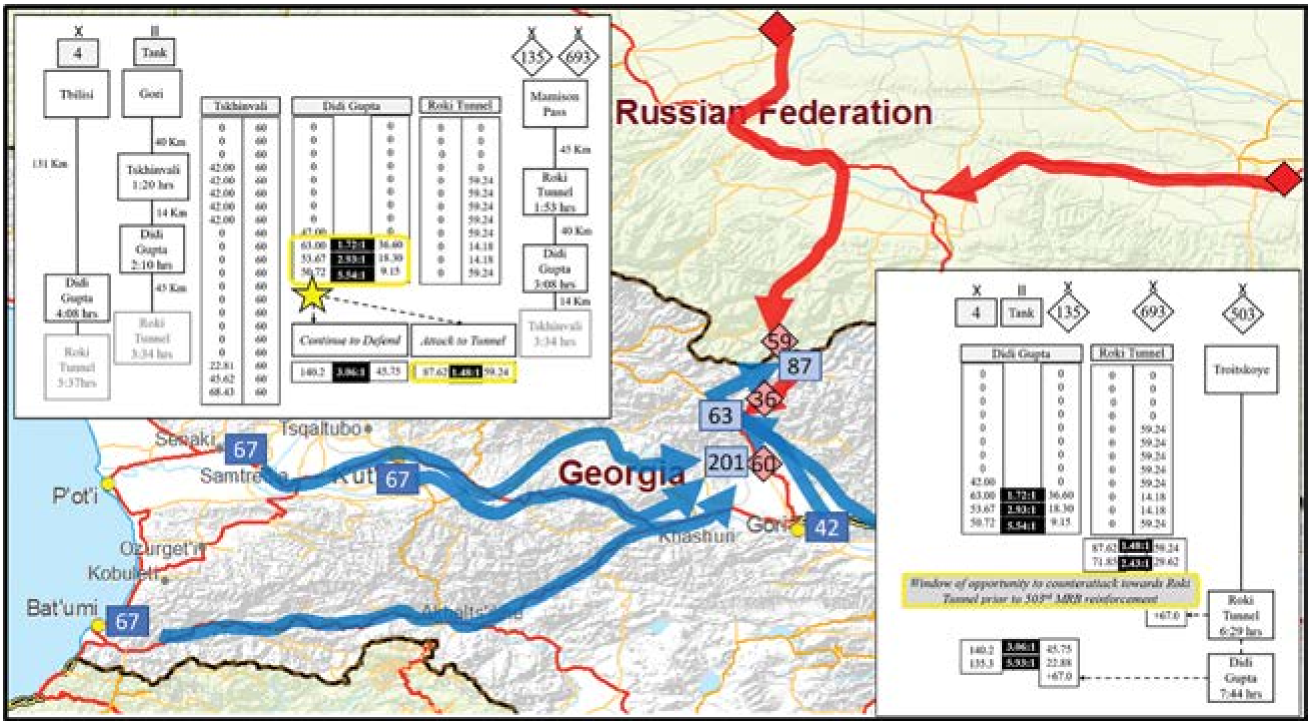
Figure 4. Multi-Domain COFM Framework

Tunnel to the east is an example of an option. This would have created a different move that Georgian forces would have needed to react to. In addition to the aggregated value of pieces in chess AI, modifiers for positions are also often used. The method of valuating the remaining pieces for each side is conceptually like the TAM calculations of combat power previously used to analyze the Russian and Georgian forces. Instead of values for individual chess pieces, combat power of military formations would be considered. This mechanism design at first appears to be attrition focused, preserving friendly combat power, removing the opponent's, and prioritizing based on value. The remarkable trait that emerges from what looks very mechanical at first is the creation and linking of favorable force ratios in time and space, which achieve asymmetry to heavily attrit the adversary and preserve friendly combat power. In short, it creates operational art.

When multiple Georgian COAs are compared in this fashion, a course of action different from what was depicted in figure 3 emerges. Due to variations in travel time toward the Roki Tunnel and how engagements were forecasted to unfold down their respective decision trees, a change to the units directed to the Roki Tunnel was identified and is depicted in figure 5 (on page 72).

When the AI-enabled COA development process continues to search even further ahead, the Russian 503rd Motor Rifle Regiment (MRR) in Troitskye and the 42nd Motor Rifle Division and 50th Self Propelled Artillery Regiment in Khankala are identified as Russian combat power to be considered. In minimax fashion, this event further along the decision tree is considered prior to the initial decision of allocating forces between the Roki Tunnel and Tskhinvali. Once an understanding of forces in time and second- and third-order effects emerge, a nonintuitive decision to attack toward the Roki Tunnel with the tank battalion in Gori and the 4th Brigade in Tbilisi is identified due to forecasted actions with respect to Russian second echelon forces further in the future.

The original disposition of Georgian forces as depicted in figure 3 could not get to the Roki Tunnel



(Data adapted from author, with data from Alexandros F. Boufesis, *The Russia-Georgia War of 2008*)

Figure 5. Combined Russo-Georgian Decision Tree and Evolution

in time to defend there should the Russian forces commence movement at the same time. However, a favorable force was able to defend in vicinity of Didi Gupta or Java when employing the tank battalion in Gori or 4th Infantry Brigade, keeping Russian forces canalized in the hills, with sufficient combat power to forecast a defeat of the Russian attack. This defense could withstand the 503rd MRR from the Russian second echelon, but not the 42nd Motorized Rifle Division, which would be on the heels of the 503rd, depicted in the top right of figure 5. Because of this, the Georgian defense needed to counterattack to the tunnel prior to the 503 MRR's arrival to defend at the heavily canalizing tunnel if they were to accomplish their mission. With these connections emerging from the complexity, Georgian leadership could think in time and generate battle-winning insight.

The algorithmic process for establishing available COAs goes a long way to mitigate the gap created by insufficient time while introducing a level of academic rigor to MDMP that may have otherwise amounted to little more than subjective assessment, with all the implicitly unknown dangers buried within such an assessment.

In the present operating environment, there is often no time available to develop multiple COAs, wargame all developed COAs, apply COA evaluation criteria, then identify a recommended COA. With AI-enabled MDMP, COA analysis and comparison are baked in and take maximum advantage of available technology, all before a conventional staff could gather the tools.

Merging and modifying the COA development step through the COA analysis and COA comparison steps to take advantage of the speed, power, and insights of current AI capabilities will enhance the ability to forecast multiple alternative futures and choices, enabling the commander to not just think in three dimensions but in time. Understanding time, given its increasing rarity, and having the tools to work with and through it in multiple domains, may be the greatest advantage AI provides.

Artificial intelligence tools in other sectors already demonstrate their aptitude for the task of providing quick, consistent, and accurate calculations.

To be of value, AI does not need to operate autonomously or replicate a sentient being. AI only needs to bridge the widening gap between the suitability of the current planning and decision tools and the effectiveness of human cognition in complex adaptive systems. A modest improvement to handling complexity, even one that merely reduces cognitive burden that leads to errors, will ensure a decisional advantage over unaided commanders.

Taking the implications of AI-enabled MDMP even further, AI could complete MDMP semi-autonomously following the first iteration, conducting the full MDMP process near continuously, without fatigue, incorporating every new development. A continuous AI-run MDMP would provide feedback about the current positions and actions of forces. Near real-time feedback would enable the tracking of subordinate units with respect to current operations, control measure compliance, and progress.

Second, near continuous MDMP can anticipate branches by evaluating what COA should be executed based on the current conditions, and even forecast the setup of future decisive engagements as conditions change. Continuous AI-enabled MDMP will fight the enemy and not the plan. An AI-enabled process will have the additional benefit of integrating resources for any emerging COA, synchronizing and optimizing effects from all domains, and making the transition to a new branch plan more feasible. Such an ability would make incredible progress toward enabling forces to rapidly adapt to thrive at the edge of chaos in a volatile future environment. ■

Notes

Epigraph. Garry Kasparov, *Deep Thinking: Where Machine Intelligence Ends and Human Creativity Begins* (New York: PublicAffairs, 2017), 245.

1. "The Changing Character of Warfare," *Mad Scientist* (blog), U.S. Army Training and Doctrine Command, 9 April 2018, accessed 5 July 2022, https://madsciblog.tradoc.army.mil/43-the-changing-character-of-warfare-takeaways-for-the-future/; Alan P. Hastings, "Coping with Complexity: Analyzing Unified Land Operations Through the Lens of Complex Adaptive Systems Theory" (monograph, Fort Leavenworth, KS: U.S. Army Command and General Staff College, 2019), 4–6, accessed 5 July 2022, https://apps.dtic.mil/sti/pdfs/AD1083415.pdf; John D. Rosenberger, "The Burden our Soldiers Bear: Observations of a Senior Trainer," *Combat Training Center Quarterly Bulletin* (1995): 13, 16, 22, accessed 5 July 2022, https://www.globalsecurity.org/military/library/report/call/call_95-11_ctc1-01.htm.

2. Rune Djurhuus, "Chess Algorithms Theory and Practice" (PowerPoint presentation, Oslo, NO: University of Oslo, 2013), slides 6–12, accessed 5 July 2022, https://www.uio.no/studier/emner/matnat/ifi/INF4130/h13/undervisningsmateriale/chess-algorithms---theory-and-practice_ver2013.pdf.

3. Daniel Schacter et al., *Psychology*, 3rd ed. (New York: Worth Publishers, 2014), 382.

4. Ibid., 386.

5. Daniel Kahneman, *Thinking, Fast and Slow* (New York: Farrar, Straus and Giroux, 2013), 4.

6. Roger Penrose, *The Emperor's New Mind* (Oxford: Oxford University Press, 1989), 546.

7. Alexandros Fox Boufesis, *The Russia-Georgia War of 2008: Russia's Geostrategic Ascension* (Ann Arbor, MI: Nimble Books, 2015), 45.

8. Reiner Huber, Lynn F. Jones, and Egil Reine, eds., *Military Strategy and Tactics: Computer Modeling of Land War Problems* (New York: Plenum Press, 1975), 113.

9. Modifying combat potential by terrain and mission type shows where the typical force ratio heuristics of attack at a 3:1 or 5:1 in urban operations, as well as the ability to defend at a 1:3, comes from.

10. Svante E. Cornell and S. Frederick Star, *Guns of August 2008: Russia's War in Georgia* (Oxford, UK: Routledge, 2009), 169.

11. Ibid.

12. Ibid., 73–74.

13. The desired and acceptable range of correlation of forces and means is a great example of a commander's planning guidance.

14. Cornell and Star, *Guns of August 2008*, 174.

15. Djurhuus, "Chess Algorithms Theory and Practice," slides 6–12.

16. Bart Selman, "Foundations in Artificial Intelligence" (PowerPoint presentation, Ithaca, NY: Cornell University, 2014), slides 21–50, accessed 5 July 2022, http://www.cs.cornell.edu/courses/cs4700/2014fa/slides/CS4700-Games1_v5.pdf.