Research Article

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Human Interoperability Through Professional Military Education: Standardised Mental Models as Enablers for Data-Centric Warfighting

Abstract: This article examines how Professional Military Education (PME) can strengthen human interoperability as NATO transitions toward data-centric warfighting. While artificial intelligence and data integration drive technological transformation, their effectiveness depends on officers' ability to cooperate across national and institutional boundaries. The central claim of this article is that standardised heuristics – conceptual models taught in PME – function as critical cognitive tools enabling such interoperability. Using a qualitative, conceptual design, this study assesses established frameworks such as Ends-Ways-Means, fighting power, and the interoperability schema. The analysis suggests that these heuristics stabilise cognition, foster shared understanding, and anchor NATO's digital transformation in human coherence.

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Keywords: Professional Military Education (PME); Human Interoperability; Data-Centric Warfighting; NATO Transformation; Standardised Heuristics.

Introduction

The integration of artificial intelligence (AI) and data-driven technologies is reshaping the character of war and the requirements placed on armed forces. NATO has declared its ambition to become a data-centric organisation, a trajectory that began with the Alliance's first Artificial Intelligence Strategy (NATO, 2021) and subsequently evolved through the Data Exploitation Framework Policy, which clarified how data governance and sharing should be organised across the Alliance (NATO, 2022). This progression continues in the revised Artificial Intelligence Strategy (NATO, 2024b) and NATO's Digital Transformation Implementation Strategy (NATO, 2024a), both of which underline that future advantage will rest on the ability to manage and exploit data, accelerate institutional adaptation, and integrate diverse capabilities across domains and nations. Subsequent strategic frameworks reinforce this point, emphasising that advantage will depend as much on governance and education as on technology itself.

Strategic frameworks, such as the *NATO Warfighting Capstone Concept* (NATO Allied Command Transformation, 2021), emphasise the need to develop human capital alongside technological and data-centric innovation. Yet they do not articulate how shared cognition and mutual understanding can be cultivated across national and institutional boundaries – the essence of human interoperability. This conceptual gap motivates the present study, which explores how Professional Military Education (PME) can institutionalise such shared frameworks through standardised heuristics that enable coherent reasoning within NATO's system of systems. The article adopts a conceptual approach, analysing established heuristic models to illuminate these cognitive mechanisms rather than conduction empirical observation.

Interoperability is often described in technical or procedural terms – standards, doctrines, and communication systems. Yet NATO doctrine also

highlights a third dimension: human interoperability – the trust, shared understanding, and compatible ways of thinking that allow multinational forces and institutions to act as one (NATO Standardization Office, 2022a). This human dimension is frequently overshadowed, yet it remains decisive for coherence in both operations and institutional development.

Professional Military Education (PME) represents a primary arena for cultivating this human dimension. Through education, officers internalise not only doctrine but also conceptual tools that enable collaboration across national and institutional boundaries. Among these tools are standardised mental models – portable heuristics that simplify complexity, stabilise cognition, and provide a shared conceptual language, such as the familiar Ends-Ways-Means schema. The article argues that such heuristics strengthen human interoperability and thus represent a critical enabler of NATO's transition toward data-centric warfighting.

This article addresses the following research question: *How can Professional Military Education (PME) strengthen human interoperability as NATO becomes a data-centric organisation?* To answer this question, the article integrates insights from systems theory, organisational learning, and cognitive psychology. The remaining elements of this article are as follows: the theoretical framework section draws on the concepts of system-of-systems, technology as a driver, and organisational adaptation. After which, the article outlines the methodological approach, followed by an analysis of selected frameworks that function as standardised heuristics within NATO and PME. Next, there is a discussion of the findings in light of NATO's ongoing transformation, and the article concludes by reflecting on the strategic significance of PME in an age of technological and institutional change.

Theoretical Framework

This section frames NATO's data-centric transformation through three complementary lenses: system-of-systems, technology as a driver, and

organisational adaptation. Together they show that effectiveness depends not only on technical integration but on how organisations learn and align cognition across national and institutional boundaries – precisely where Professional Military Education (PME) can make a structural difference.

System-of-Systems

General systems theory emphasises emergence and hierarchy: systems at higher levels exhibit properties that cannot be reduced to those of their parts (Ackoff, 1971; Boulding, 1956). The behaviour of the whole depends on the quality of their connections. Meadows (2008) highlights how small interventions in feedback loops – leverage points – can generate disproportionate effects.

This systems thinking forms the basis for the system-of-systems (SoS) perspective which explains why interoperability – especially the human dimension – is decisive for NATO's ability to function coherently in data-centric warfighting. Modern armed forces comprise multiple interdependent subsystems: national militaries, command structures, technologies, and institutions. Each maintains independence yet contributes to the effectiveness of the whole (Jamshidi, 2008; Maier, 1998).

For NATO, this implies that effectiveness rests less on individual strength than on integration across domains and nations. Such integration requires more than technical or procedural alignment. NATO doctrine distinguishes between technical, procedural, and human interoperability (NATO Standardization Office, 2022a). While the first two can be standardised through equipment and processes, the third depends on trust, shared understanding, and compatible mental frameworks – an emergent property of the wider organisational system.

Standardised mental models taught in PME can therefore be seen as cognitive connectors within NATO's SoS. They reduce interpretive gaps among officers educated in different traditions and provide portable heuristics for conceptualising complex operational relationships. As data integration increases interdependence among systems, such shared cognitive tools help maintain coherence within NATO's broader system of systems.

To illustrate, a heuristic model in this context refers to a simple conceptual tool that helps practitioners structure complex problems. A familiar example is the Ends-Ways-Means schema, which condenses strategic reasoning into the alignment of objectives, methods, and available resources. Such models are not predictive theories, but cognitive shortcuts that foster shared understanding and coherent decision-making across diverse professional settings.

Technology as a Driver

Technological innovation has long influenced both the conduct and organisation of war, shaping how states mobilise resources and exercise power (Clausewitz, 1976; Gray, 2010; Krepinevich, 2002). The current wave of artificial intelligence (AI), data integration, and automation is transforming decision-making and increasing both precision and tempo (Horowitz, 2019). At the same time, these technologies introduce new challenges of transparency, ethics, and dependency, requiring institutions that can translate technical potential into responsible use.

NATO (2024a) and NATO (2024b) reflect this duality. Both stress that data-centric transformation depends on governance, common standards, and education - showing that technological integration is as much an institutional process as a technical one. AI and data systems thus act as catalysts that reshape decision-making structures and professional roles rather than as autonomous sources of capability.

Research on military innovation supports this view. Posen (1984) showed that organisational culture conditions adaptation; Farrell and Terriff (2002) highlighted institutional learning as the mechanism through which change is internalised; and Adamsky (2010) demonstrated that culture shapes whether revolutions in military affairs are even recognised. These studies indicate that technological impact depends on the organisational and educational frameworks that accompany it.

PME becomes a crucial interface between technological systems and human judgment. As data volumes grow and algorithmic processes accelerate, officers require conceptual footholds that help them interpret, communicate, and act coherently. Standardised heuristics - simple, portable models - translate technical complexity into shared conceptual understanding. They anchor technological change within stable cognitive frameworks that align perception and action. Technology therefore functions as a structural driver of transformation, while PME provides the cognitive infrastructure to absorb and operationalise it. The two are complementary: data-centric innovation expands decision-making but also increases the demand for shared mental models that sustain human interoperability.

Organisational Adaptation

If technology drives change, organisations determine how that change becomes capability. Research shows that new technologies alone do not produce effectiveness; their impact depends on the doctrines, structures, and professional cultures that accompany them (Farrell and Terriff, 2002; Murray, 2011). Organisational adaptation is the process by which institutions internalise technological and conceptual advances into coherent practice.

This process unfolds through multiple institutional pathways, among which PME plays a central role. Beyond transmitting doctrine or technical knowledge, PME socialises officers into shared cognitive habits and professional norms. It enables reflection on how technology and doctrine interact and provides the conceptual language through which new ideas are interpreted. PME thus functions as a distributed learning system that helps NATO and its member forces maintain coherence across boundaries.

Organisational learning translates technological and conceptual possibilities into practice. Among its mechanisms, shared heuristics are particularly important because they stabilise cognition across individuals and institutions. Learning occurs through exercises, experimentation, and reflection, but also through institutional processes that internalise lessons and align conceptual understanding across organisational boundaries (Tardy, 2020). Some, such as

Clausewitz's Ends-Ways-Means model, are firmly institutionalised; others remain peripheral.

Cognitive psychology offers a further lens on how heuristics enable learning. Simon (1957) describes them as expressions of bounded rationality - rules of thumb for decision-making under constraints. Tversky and Kahneman (1974) sees them as sources of bias, whereas Gigerenzer et al. (1999) and Gigerenzer, Hertwig, and Pachur (2011) reframed them as adaptive strategies: simple, transparent, and portable rules that allow humans to act effectively under uncertainty. Applied to PME, this means standardised heuristics operate as conceptual artefacts for collective sense-making. They can be taught, shared, and carried into practice as portable mental models.

This aligns with Senge's (1990) view that adaptation depends on making mental models explicit and shared. Through this process, PME contributes not only to individual competence but to institutional learning – embedding a repertoire of common heuristics that strengthen cognitive alignment and human interoperability.

Methodology

The study adopts a qualitative, conceptual design. Its purpose is not to test hypotheses but to explore how Professional Military Education (PME) can strengthen human interoperability as NATO transitions toward data-centric warfighting. The analysis identifies and assesses standardised heuristics – frameworks and models already institutionalised in NATO doctrine and PME – that function as shared cognitive tools across national and organisational boundaries.

Analytical Approach

Conceptual analysis was chosen because the phenomenon under study – human interoperability – cannot be captured solely through empirical observations. It involves relationships between cognition, education, and organisational systems that are best illuminated through theory-driven

interpretation. The approach combines insights from systems theory, organisational learning, and cognitive psychology to examine how established models can serve as heuristics for managing complexity.

To structure the assessment, the study applies five criteria of utility derived from research on decision-making and systems thinking:

- **Cognitive Usability** – The extent to which the heuristic is simple, memorable, and easily applied by practitioners in real decision-making contexts.

- **Explanatory Power** – How effectively the heuristic clarifies relationships, mechanisms, or structures within the domain it represents.

- **Predictive Guidance** – The degree to which the heuristic offers forward-looking orientation or helps anticipate implications, trajectories, or potential outcomes.

- **Sharedness & Communicability** – How well the heuristic functions as a shared conceptual reference point across institutional, national, or cultural boundaries.

- **Systemic Awareness** – The extent to which the heuristic captures interaction, adaptation, and emergent dynamics within complex systems.

Each heuristic is examined qualitatively against these criteria to determine how it supports or constrains human interoperability.

Selection of Heuristics

The selection follows a strategic sampling logic. Rather than surveying all models used in PME, the study focuses on a representative subset spanning strategic, operational, and organisational levels. These include Clausewitz's Ends-Ways-Means model, NATO's fighting power triad, the interoperability schema, and related frameworks on systems, adaptation, and learning. The models were chosen because they are doctrinally recognised, visually

standardised, and widely used in PME contexts, making them suitable for comparative assessment.

Interpretive Procedure

Each heuristic is treated as an analytical unit. The analysis proceeds in two steps:

1. The model's internal logic and visual representation are described to identify its key elements and relationships.

2. The model is then evaluated against the five criteria of utility.

This interpretive process draws on literature from decision-making, organisational learning, and systems theory to highlight both cognitive advantages and conceptual limitations. The emphasis is on reasoned interpretation rather than measurement. The goal is to show how these models operate as cognitive artefacts that stabilise understanding and facilitate shared reasoning among officers, linking conceptual frameworks to the practical demands of human interoperability in NATO's data-centric transformation. The assessments are qualitative and interpretive rather than quantitative scores; the categories (High/Moderate/Limited) express comparative judgement, not measurement.

Scope and Limitations

This study is conceptual rather than empirical. It offers a structured analytical lens to clarify how cognitive tools contribute to interoperability but does not observe their practical use or claim statistical generalisation. The findings should be understood as theoretically grounded propositions that can inform future empirical research on PME curricula, classroom interaction, and multinational staff education.

Portable Heuristics

This section builds on the methodological framework outlined in the previous section to analyse a strategic selection of frameworks that function as standardised mental models – or *heuristics* – within NATO doctrine and Professional Military Education (PME). Each framework is treated as an analytical unit: its core logic and visualisation are presented, followed by an assessment against five criteria of utility – cognitive usability, explanatory power, predictive guidance, sharedness and communicability, and systemic awareness.

The purpose is not to rank the frameworks but to clarify their distinctive contributions to human interoperability. The selection is strategic rather than exhaustive and does not measure frequency of use; instead, it evaluates their potential utility as heuristics that can support NATO's broader transformation into a data-centric organisation.

Note: All figures in this section are adapted and redrawn by the author for analytical and educational purposes, based on the doctrinal and academic sources cited in each subsection. They are illustrative, intended to visualise the frameworks' core logic rather than reproduce original graphics.
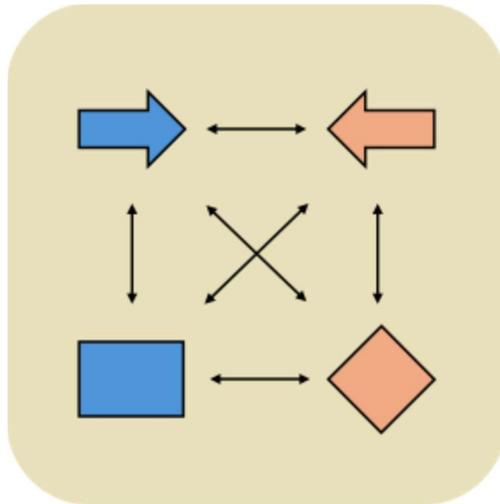
Ends-Ways-Means

The Ends-Ways-Means model, presented by Storr (2009), builds on Clausewitz's conception of war as an instrumental clash of wills (Clausewitz, 1976). Clausewitz emphasised that war is never autonomous but a continuation of policy, and that success depends on coherence between political objectives and the military resources available. Storr translated this abstract idea into a compact, visual heuristic.

Based on Storr's figure, one's own ends are represented as a blue arrow and the means as a square. The adversary is mirrored with a red arrow for ends and a red diamond for means. Horizontal arrows connect ends and means on each side, illustrating the internal relationship between goals and resources. Vertical arrows between the two ends express the incompatibility of political

purposes that underlies conflict, while horizontal arrows between the means depict the direct clash of force. Diagonal arrows crossing the centre symbolise indirect approaches, where each side seeks to influence the other without direct confrontation.

The model is typically drawn as a simple sketch with four elements and a network of connecting arrows. This visualisation maps how objectives relate to available capabilities and how these interact with an adversary's political aims and resources. It captures both the bilateral structure of war and the possibility of direct or indirect approaches.

Figure 1 – Portable Heuristic: Ends-Ways-Means.
Adapted and redrawn by the author from Storr (2009).

Beyond its graphical clarity, the model has gained influence because it condenses several strands of classical military thought. It echoes Clausewitz's insistence on aligning political purpose with means while resonating with Liddell Hart's emphasis on the indirect approach (Liddell Hart, 1954). In PME contexts, instructors use the schema to illustrate mismatches - when expansive political goals are not matched by resources or when adversaries exploit

asymmetries between ends and means. By turning a dense theoretical argument into a diagram that can be taught and shared, Storr provided a portable tool that continues to circulate in educational and doctrinal discussions.

Assessment of Ends-Ways-Means: The model scores high on cognitive usability, reducing Clausewitz's dialectic to a compact schema that is easy to grasp and recall across professional and educational settings. Its explanatory power is moderate, clarifying the instrumental relationship between ends and means and the implications of (mis)alignment between political objectives and resources. Predictive guidance is limited, as it helps identify mismatches but does not forecast how contests evolve over time. Sharedness and communicability are high, as the schema's simplicity supports use as a common reference in PME and multinational dialogue. Systemic awareness is limited, as the model illustrates relationships but not how interaction, adaptation, friction or emergent dynamics shape outcomes over time. In sum, its strength is portability and clarity; its weakness is a tendency to oversimplify if treated as more than a heuristic.

Combat Potential and Combat Power

Vego (2009) distinguishes between *combat potential* and *combat power* to clarify the difference between latent resources and realised military effect. *Combat potential* refers to the designed and available capabilities possessed in peacetime, including material resources, trained personnel, logistics infrastructure, industrial capacity, and morale. Within this category, Vego differentiates between *designed potential* - the planned and structured force elements created through long-term investment – and *available potential*, the portion of forces ready for deployment at a given time.

Combat power, by contrast, denotes the effective strength that emerges when these resources are mobilised, commanded, and applied in time and space. It represents the transformation of dormant capabilities into operational effect. This activation of combat power occurs only when forces are organised, coordinated, and directed against an adversary. Potential is static and preparatory; power is dynamic and contextual.
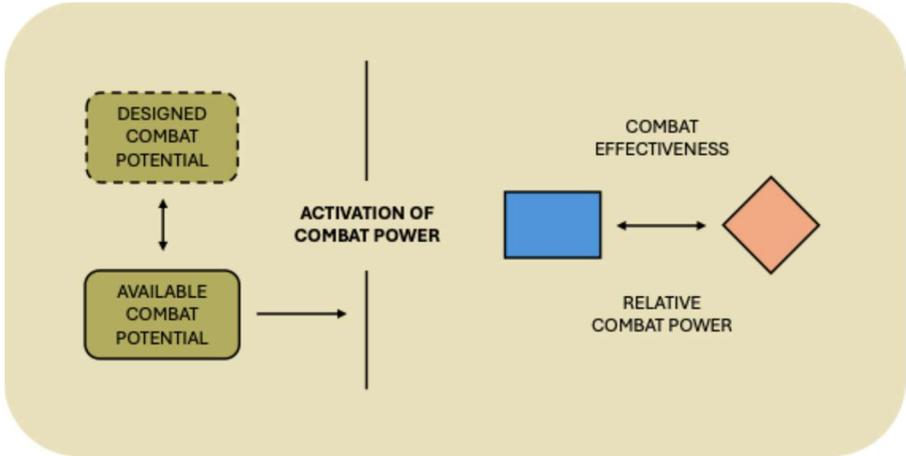
Figure 2 – Portable Heuristic: Combat Potential and Combat Power.
Adapted and redrawn by the author from Vego (2009).

The distinction between combat potential and combat power has both analytical and practical significance. In strategic planning, states often express strength in terms of potential - numbers of divisions, platforms, or personnel - while in operations, much of this potential may remain untapped due to readiness gaps or mobilisation delays.

This framework also highlights the relational nature of military strength. Once activated, combat power only has meaning relative to an adversary. Concepts such as relative combat power and combat effectiveness illustrate that power is never absolute but depends on context, timing, and interaction. In PME contexts, Vego's distinction is often used to show why stockpiles of equipment or nominal force structures cannot be equated with usable power. The model thus functions as a heuristic for distinguishing between latent resources, readiness, and the operational strength realised once forces are mobilised.

Assessment of Combat Potential and Combat Power: The model is high in cognitive usability, offering a clear distinction between latent resources and realised effect that can be quickly grasped. Its explanatory power is high,

clarifying the transformation of potential into power through mobilisation and command. Predictive guidance is moderate: it highlights readiness gaps but cannot anticipate outcomes of adversarial interaction. Sharedness and communicability are high, as the distinction is intuitive and easily conveyed in PME and multinational dialogue. Systemic awareness is moderate, showing mobilisation processes but in a relatively linear way. Its strength lies in clarifying how resources become operational effect; its weakness is a tendency to underplay iterative and political aspects of readiness.
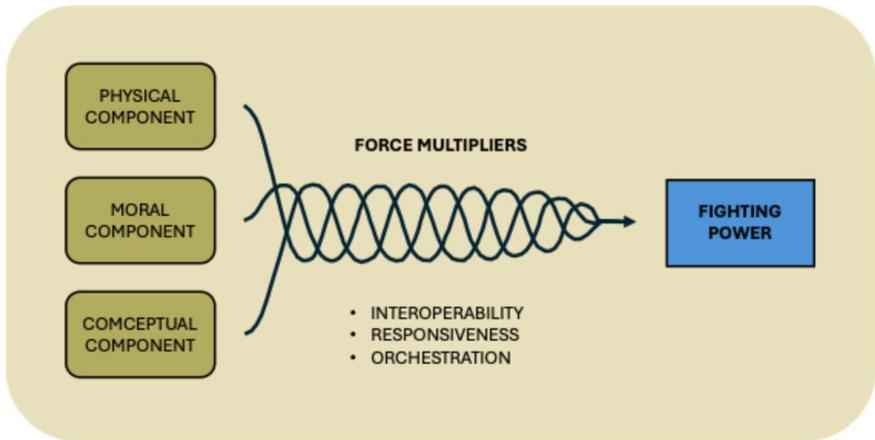
Fighting Power

NATO doctrine defines *fighting power* as the operational effectiveness and capability of armed forces, resting on three mutually dependent components: moral, conceptual, and physical (NATO Standardization Office, 2022a; NATO Standardization Office, 2022b). The triad expresses the idea that effectiveness derives not from any single dimension in isolation but from their interaction as a whole.

The moral component refers to the ability to motivate people to fight appropriately. It includes leadership, discipline, ethos, ethical standards, morale, and cohesion. Classical authors such as Sun Tzu and Clausewitz emphasised will as a decisive factor, and contemporary doctrine continues to stress that without moral strength, even technically advanced forces cannot sustain effectiveness.

The conceptual component concerns intellectual foundations: doctrine, training methods, operational concepts, and adaptability. Here education and learning feature most strongly, ensuring that officers share common approaches. In multinational settings this extends to compatibility of doctrines and concepts across nations, making the conceptual element particularly important for NATO.

The physical component relates to the tangible means of fighting: personnel, equipment, logistics, infrastructure, and sustainment. It ensures that intentions and concepts can be realised in practice.

These components are interdependent. Morale depends partly on adequate equipment and training, while the conceptual component shapes how physical resources are used. Training integrates the moral, conceptual, and physical aspects by preparing individuals and units, maintaining readiness, and cultivating shared standards.

Figure 3 – Portable Heuristic: Fighting Power
Adapted and redrawn by the author from NATO Standardization Office (2022a).

Within this triad, *force multipliers* offer an additional heuristic for understanding interaction. A force multiplier increases effectiveness without increasing size - amplifying what exists rather than adding mass. Classical examples include leadership, surprise, morale, superior training, and information advantage. Modern equivalents encompass networked sensors, precision targeting, and AI-enabled decision support. From a system-of-systems perspective, such multipliers operate through interaction effects, improving coupling between subsystems or enhancing leverage points where small interventions yield disproportionate outcomes (Meadows, 2008). Force multipliers thus emerge from synergy: morale can multiply physical strength, conceptual clarity can multiply tempo, and technology can multiply perception.

For PME, the concept is pedagogically valuable. It encourages officers to distinguish between additive and multiplicative improvements – between adding resources and enhancing how resources interact. In multinational contexts, human and cognitive factors themselves act as force multipliers: trust, shared understanding, and standardised mental models enable allied forces to coordinate and decide faster. Seen this way, PME contributes directly to fighting power by cultivating cognitive and moral multipliers that magnify collective effectiveness across the Alliance.

The triad is often presented as a triangle, highlighting that neglect of any component risks undermining the whole. It reminds practitioners that effectiveness emerges from a balance of human, intellectual, and material factors. In multinational contexts, the triad stimulates discussion about where nations place emphasis – equipment, doctrine, or professional culture – and how to reconcile these in combined forces.

Assessment of Fighting Power: The model has high cognitive usability, offering a triad (moral, conceptual, physical) that is easy to employ in professional dialogue. Its explanatory power is moderate, clarifying how effectiveness depends on interplay between tangible and intangible factors, though it risks obscuring uneven dynamics. Predictive guidance is limited: it categorises elements but does not forecast outcomes. Sharedness and communicability are high, being doctrinally embedded and easily visualised. Systemic awareness is moderate: it acknowledges integration but underplays adaptive change. Its strength is holistic framing; its weakness is that the moral component often remains underdeveloped in practice.

Opportunity Space

The Swedish Military Strategic Doctrine (*militärstrategisk doktrin*) (Försvarsmakten, 2016) emphasises that warfare is shaped by the dynamic interplay of time, space, forces, and information. The battlespace is not a fixed geographical container, but a relative, situational field of action defined by asymmetries that actors can exploit. The concept of opportunity space highlights that military effectiveness depends less on static strength than on the ability to adapt and exploit changing conditions. Although MSD-16 has

since been superseded by MSD-22, the opportunity space construct remains analytically useful as a heuristic.

Opportunity arises when one side brings its strengths to bear against the opponent's vulnerabilities. This perspective aligns with established principles of manoeuvre warfare, where agility, timing, and positional advantage can offset superior material resources (see Leonhard, 1991; U.S. Marine Corps, 1997). It also reflects discussions of hybrid threats and multi-domain interaction, where windows of opportunity may be brief and contingent on situational awareness.
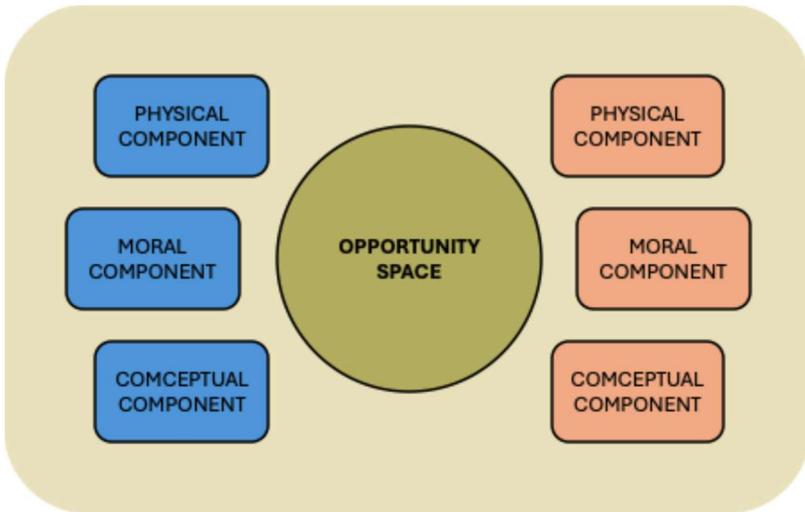
Figure 4 – Portable Heuristic: Opportunity Space
Adapted and redrawn by the author from Försvarsmakten (2016).

The concept is typically represented as the interaction of time, space, force, and information, each of which can become an advantage or liability depending on context. For instance, superior information can compensate for limited force, or time pressure can erode favourable positions. In PME contexts, instructors use the framework to illustrate how effective command

depends on identifying and seizing fleeting advantages rather than merely matching strength with strength.

This perspective also has implications for coalition operations. Different national forces may perceive opportunity differently depending on doctrine, culture, and capabilities. A common conceptual framework allows officers to align their understanding of when and how to act, reducing the risk of missed opportunities or contradictory moves. The *opportunity space* heuristic thus reminds practitioners that war is not fought on a static field but in a constantly shifting environment where asymmetry is the norm.

Assessment of Opportunity Space: Cognitive usability is moderate, requiring abstraction to grasp the battlespace as a relative and situational field. Explanatory power is moderate, clarifying how asymmetries of time, space, forces, and information create opportunities. Predictive guidance is limited: it identifies conditions but does not prescribe action. Sharedness and communicability are moderate, while systemic awareness is high, sensitising officers to relational dynamics and contextual dependence. Its strength lies in orienting attention to environmental dynamics; its weakness is the absence of clear operational guidance.
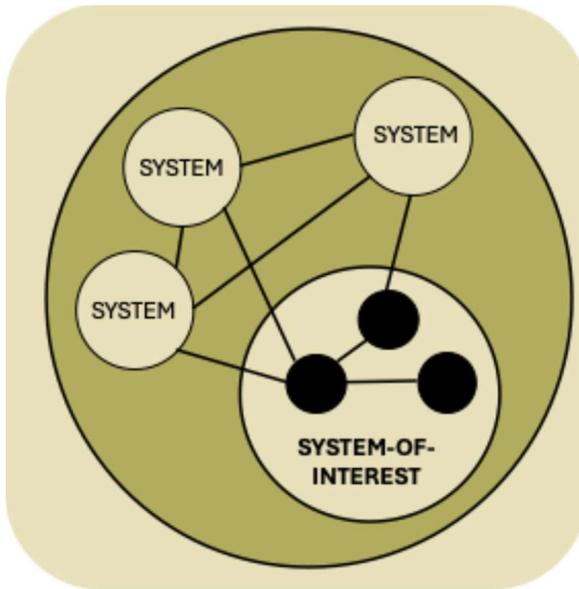
System-of-Interest

In systems engineering, the concept of a *system-of-interest* (SoI) specifies which system is the focus of development, operation, or analysis. According to ISO/IEC/IEEE 15288:2015, a system-of-interest is 'the system whose life cycle is under consideration' (2015, p.9). The *Systems Engineering Body of Knowledge* (SEBoK, 2025) adds that the SoI includes all elements required for development and use, while distinguishing it from enabling systems and the broader operational environment.

Defining a SoI requires explicit boundary-setting: identifying which subsystems are included, which interfaces must be managed, and which external factors belong to the wider environment. By drawing such boundaries, analysts clarify scope, responsibilities, and dependencies. In defence contexts, a SoI might include a command-and-control network with

hardware, software, operators, and training programmes, while treating supporting logistics or allied systems as enabling but external.

The SoI perspective shows that capabilities should be viewed as socio-technical systems of interacting elements. An artillery unit, for instance, is not only guns and ammunition but also crews, command processes, communication links, and maintenance arrangements. System performance depends on how these components interact within boundaries and connect to other systems in the larger force structure.

Figure 5 – Portable Heuristic: System-of-Interest
Adapted and redrawn by the author from SEBoK, (2025).

The heuristic value of the SoI concept lies in making boundaries explicit. By specifying what is inside and what is outside, the model helps decision-makers clarify assumptions and avoid category errors – such as treating an enabling system as part of the SoI itself. In PME, this framework is introduced in systems engineering and capability development courses, teaching officers to

think critically about scope, interfaces, and interdependencies. It is particularly relevant in multinational contexts, where nations may define capability boundaries differently, risking misalignment unless jointly clarified.

Assessment of System-of-Interest: Cognitive usability is moderate, as defining boundaries and interfaces requires training. Explanatory power is high, clarifying how performance emerges from subsystem interaction rather than individual components. Predictive guidance is limited, describing structure without forecasting outcomes. Sharedness and communicability are moderate – well established in systems engineering but less familiar in PME. Systemic awareness is high, highlighting boundaries, interfaces, and emergent properties. Its strength is systemic framing; its weakness is abstraction without operational tools for application.
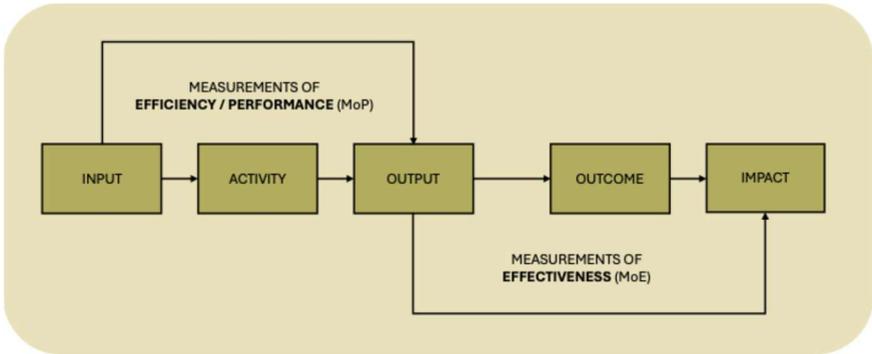
Logic Model

The logic model (input → activities → output → outcome → impact) originated in evaluation research to clarify how resources are expected to generate effects (Weiss, 1972; Wholey, 1979). Popularised by the W.K. Kellogg Foundation's *Logic Model Development Guide* (W.K. Kellogg Foundation, 2004), it is now widely used across sectors. Read through a systems lens, the model represents two coupled systems: an inner system – the *system-of-interest (SoI)* - and an outer system - the operational environment where effects materialise.

Inner system (combat potential / performance): Inputs enter the SoI through its interfaces with the environment (funding, personnel, data, materiel, constraints, stakeholder requirements). Within this boundary, *activities* transform these inputs into *outputs* - products, services, or capabilities. This chain describes the SoI's performance, corresponding to what Vego (2009) terms *combat potential*: the latent ability of organised resources to generate effect once activated. Performance is internal and depends on how efficiently components and people interact within the system boundary.

Outer system (combat power / effectiveness): When outputs leave the SoI and interact with users, allies, adversaries, or environment, they produce *outcomes* and ultimately *impact*. This expresses effectiveness in the outer system – the transformation of potential into operational effect. Here Vego's *combat power*

provides a useful analogue: power emerges only when internal potential is coordinated and applied in real interaction. Effectiveness therefore depends on fit between the SoI's outputs and environmental conditions, interoperability with other systems, and on feedback loops that enable further adaptation.

Figure 6 – Portable Heuristic: Logic Model
Adapted and redrawn by the author from W.K. Kellogg Foundation (2004)

This nested view clarifies the link between *doing things right* (performance) and *doing the right things* (effectiveness). For PME, the distinction is diagnostic: it helps officers locate whether a failure stems from an internal performance gap (inputs poorly transformed to outputs) or an external effectiveness gap (outputs that fail to deliver outcomes because of misaligned interfaces, poor human interoperability, or adversary adaptation). In multinational contexts, making the SoI boundary explicit enables shared assumptions about how outputs are expected to generate collective effects across nations and institutions.

Assessment of the Logic Model: Cognitive usability is high: the model is memorable and easy to apply. Explanatory power is high when interpreted as two coupled systems, linking internal performance (combat potential) to external effectiveness (combat power). Predictive guidance is moderate – useful for locating failure points but not for forecasting adversarial dynamics.

Sharedness and communicability are high across civil–military settings. Systemic awareness is high when SoI boundaries and feedback with the environment are made explicit; misused as a simple pipeline, the model can obscure co-production at interfaces. Its strength lies in clarifying where value and coherence are generated; its weakness is a tendency toward linear 'boxology' if feedback and human factors are ignored.

Functional Chains

At the boundary between an inner system and its environment, interaction occurs through a set of linked functions that transform inputs into outputs. In a systems perspective, these functions express the relationships through which resources, processes, and human actions generate performance. The concept of *functional chains* therefore describes how transformations across the system boundary convert potential into effect, and how overall effectiveness depends on the coherence among these linked activities.

Swedish military-technical literature provides two illustrative heuristics. The protection onion (*skyddslöken*) depicts the defensive process through layers of protective measures, including avoidance, signature management, active countermeasures, hardening, and damage mitigation (Andersson et al., 2009). The engagement or kill chain (*bekämpningskedja*) describes the offensive process: detection, localisation, identification, decision, engagement, and assessment (Axberg et al., 2013). Together, these heuristics show how both attack and defence can be conceptualised as stepwise processes in which each stage contributes to the outcome.

$$P_{function} = P_1 * P_2 * P_3 * P_4 * P_5 * P_6 * P_7$$
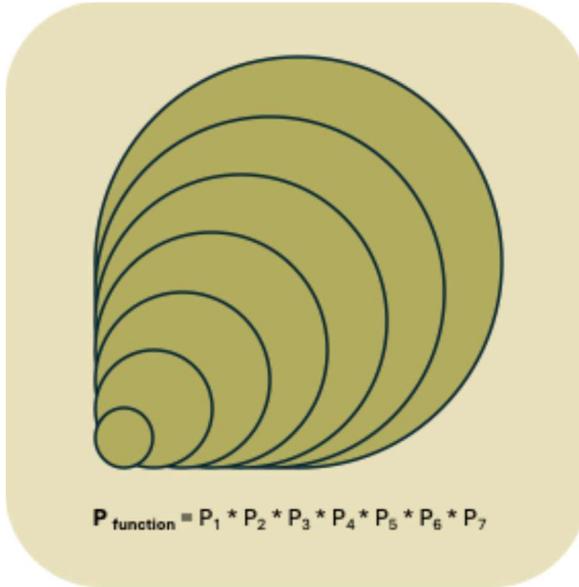
Figure 7 – Portable heuristic: Functional Chains

Viewed systemically, such chains illustrate how functional performance along the system boundary determines effectiveness. Each link represents both an internal process and an interface: detection depends on sensors and networks that bridge systems; decision connects human cognition with command architectures; and engagement requires coordination between fire units, data systems, and target effects. When one function fails, the flow of transformation across the boundary is disrupted; when coherence is achieved, the system transmits power effectively into its environment.

In PME, the concept of functional chains helps officers visualise how military systems operate through coupled transformations rather than isolated actions. It directs analytical attention to the seams - those points where information, authority, and material pass between systems - and trains officers to diagnose where coupling fails or can be strengthened. By combining linear heuristics such as the kill chain with a systems-oriented understanding of boundaries,

PME can bridge technical processes and cognitive reasoning in operational education.

Assessment of Functional Chains: Cognitive usability is high, as the chain form is intuitive and transferable. Explanatory power is high, clarifying how effectiveness arises from the quality of transformations along the system boundary. Predictive guidance is moderate – useful for identifying bottlenecks but limited for dynamic feedback. Sharedness and communicability are high, combining familiar operational chains with systems logic. Systemic awareness is high, emphasising interfaces, coupling, and emergent coherence. Its strength lies in revealing where potential becomes power; its weakness is that it may appear mechanistic unless complemented by human and organisational analysis.

Interoperability

Interoperability is identified in NATO doctrine as a decisive condition for effective multinational cooperation. It is both a goal and a systemic property - the ability of distinct national, organisational, and technological systems to function coherently as one. NATO distinguishes between three dimensions (NATO Standardization Office, 2022a). *Technical interoperability* concerns the compatibility of systems, standards, and data formats. *Procedural interoperability* relates to the alignment of doctrines, processes, and rules of engagement. *Human interoperability* highlights trust, shared understanding, and cultural adaptation among individuals and organisations. Together these dimensions form the basis for integrating diverse national forces into a coherent whole.

In addition to dimensions, NATO recognises levels of interoperability. At level 0, forces are non-interoperable and unable to cooperate. Level 1 denotes deconflicted operations, where forces act in parallel without interference. Level 2 describes compatible operations, in which forces can exchange selected systems, procedures, or data. Level 3 represents integrated operations, where forces act as a unified ensemble. This schema provides a graduated understanding of cooperation – from minimal coordination to full integration.
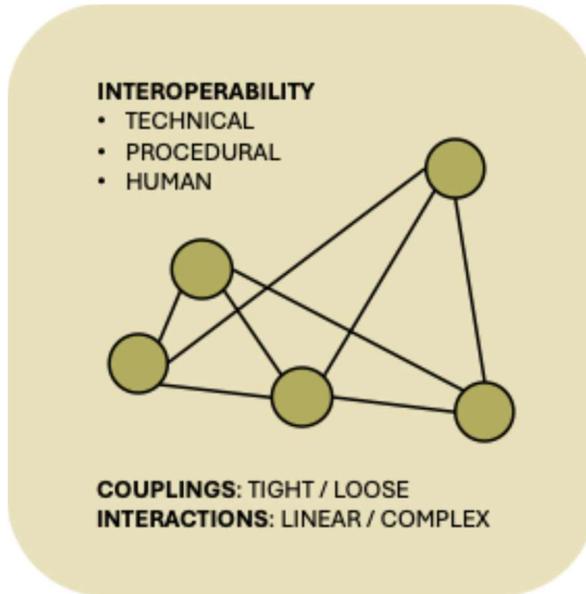
Figure 8 – Portable Heuristic: Interoperability

From a systems perspective, interoperability occurs along the boundaries between systems-of-interest. Functional chains link these systems through exchanges of information, materiel, and decision authority. Perrow (1999) provides a useful lens for analysing such coupling: systems can be *tightly* or *loosely* coupled, and their interactions can be *linear* or *complex*. Tightly coupled systems create efficiency but also vulnerability, as changes in one part can cascade rapidly through the whole. Loosely coupled systems allow redundancy and resilience but may reduce tempo. Managing this balance is central to interoperability.

In PME contexts, interoperability is often explored through combined operations, joint exercises, and multinational staff work. The schema of dimensions and levels provides officers with a vocabulary for diagnosing where frictions arise and what forms of integration are feasible. The systemic perspective adds a cognitive dimension: officers learn that interoperability is

not only about connecting systems but about understanding and managing the coupling among them. Human interoperability thus becomes the essential enabler - it allows professionals to operate across institutional and cultural boundaries with sufficient shared mental models to keep the wider system adaptive and coherent.

Assessment of Interoperability: Cognitive usability is high, as the schema of three dimensions and four levels is easily retained and applied. Explanatory power is high, clarifying both sources of friction and conditions for cooperation. Predictive guidance is moderate: it illustrates how different forms of coupling shape risk and performance without forecasting outcomes. Sharedness and communicability are high, being doctrinally embedded and widely taught. Systemic awareness is high, linking interoperability to coupling and complexity. Its strength lies in diagnostic clarity; its weakness is a tendency to treat dimensions as static categories rather than dynamic relationships.

Socio-Technical Systems

The socio-technical perspective emerged from research at the Tavistock Institute in the mid-20th century. Trist and Bamforth (1951) observed in their study of British coal mines that technical design and social organisation could not be optimised in isolation. Attempts to improve efficiency by introducing new machinery often failed unless work organisation, group structures, and human relations were also redesigned. Performance improved only when the technical and social dimensions were conceived together.

In parallel – and consistent with this perspective – Leavitt (1965) proposed his *diamond model*, identifying four interdependent elements in any organisation: *tasks, people, structure, and technology*. Change in one element inevitably affects the others, meaning that modernisation must consider the whole system. Later, Bostrom and Heinen (1977) extended this reasoning to information systems, coining the concept of *joint optimisation* – the alignment of social and technical subsystems as a condition for effective performance.
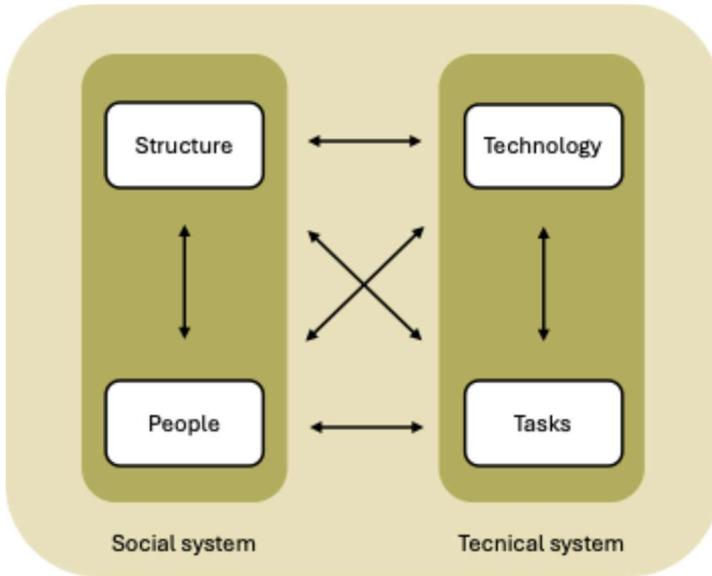
Figure 9 – Portable Heuristic: Socio-Technical System
Adapted and redrawn by the author from Leavitt (1965).

Applied to military contexts, the socio-technical perspective underscores that combat systems are never purely technical. New command-and-control technologies require not only technical integration but also adaptation in leadership, procedures, and training. Similarly, advanced weapon systems depend on logistics, organisational arrangements, and operator competence.

The heuristic is often represented through Leavitt's diamond, where tasks, people, structure, and technology form four interlinked corners. It conveys that no single corner can change without consequences for the others. In PME, socio-technical perspectives sensitise officers to the organisational implications of technological change. Instead of treating technology as a stand-alone enabler, the model encourages reflection on how tasks, structures, and competencies must be redesigned in concert.

In multinational contexts, the socio-technical lens helps explain why similar technologies may yield different results across nations. Divergent cultures, training systems, or institutional structures mean that what succeeds in one setting may fail in another. By providing a shared framework for such discussions, the socio-technical model supports more coherent planning and cooperation.

Assessment of the Socio-Technical System: Cognitive usability is moderate, as the model requires familiarity with organisational theory, though visual heuristics such as Leavitt's diamond aid recall. Explanatory power is high, clarifying that technical and social systems must be jointly optimised. Predictive guidance is limited, highlighting dependencies without forecasting outcomes. Sharedness and communicability are moderate – well established in organisational studies but less common in PME unless explicitly taught. Systemic awareness is high, stressing the inseparability of technical, organisational, and human dimensions. Its strength is holistic socio-technical framing; its weakness is that it may remain generic without concrete design tools.

Learning Loops

Argyris & Schön (1978) introduced the concept of *learning loops* to explain how organisations adapt and change over time. They distinguished between *single-loop*, *double-loop*, and *triple-loop* learning - each representing a progressively deeper form of reflection and adaptation.

Single-loop learning occurs when behaviour is corrected within existing routines and assumptions. For example, if an exercise reveals a shortfall in coordination, adjustments might be made to standard operating procedures without questioning underlying doctrine. *Double-loop learning* goes further by examining the assumptions, goals, or frameworks that shape action. Officers might ask whether the doctrine itself is adequate, or whether organisational change is needed. *Triple-loop learning* adds another layer of reflexivity by interrogating the learning process itself – how the organisation generates, shares, and institutionalises knowledge, and whether its approach to learning requires redesign.
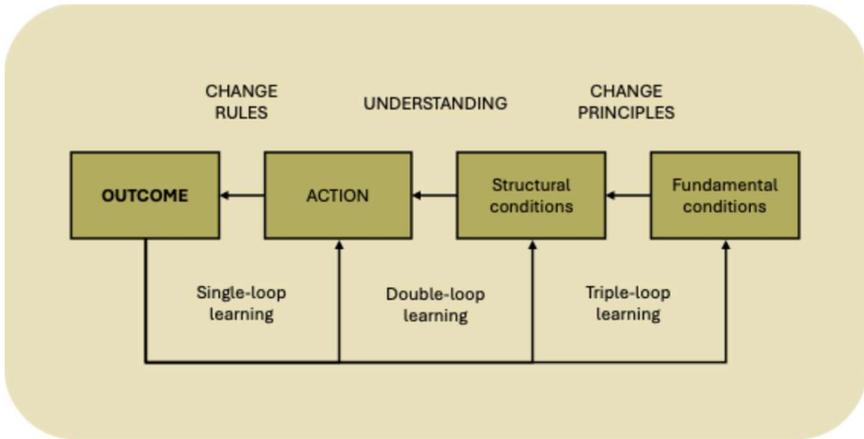
Figure 10 – Portable heuristic: Learning Loops
Adapted and redrawn by the author from Argyris & Schön (1978).

The model emphasises that learning is not linear but iterative. Organisations rarely progress stepwise from one loop to the next; they move back and forth, revisiting assumptions and routines as contexts evolve. It is often visualised as three nested loops, with each deeper level representing a higher degree of reflection.

In military contexts, learning loops are visible in after-action reviews, lessons-learned systems, and experimentation. *Single-loop learning* occurs when a unit refines its tactics after training. *Double-loop learning* appears when a service questions doctrine or operational concepts. *Triple-loop learning* occurs when entire defence institutions reform their education or innovation systems. PME plays a critical role in enabling such deeper learning by providing conceptual tools and reflective spaces where officers can move from correcting errors to questioning assumptions and institutions.

In multinational contexts, learning loops illuminate why alliances may struggle to institutionalise collective lessons. Nations often engage in *single-loop learning* to correct local practices, while fewer mechanisms exist for joint reflection on shared assumptions or learning systems. The framework thus serves as a

heuristic for diagnosing the *depth* of adaptation and identifying where systemic learning can be strengthened across the Alliance.

Assessment of Learning Loops: Cognitive usability is moderate, as distinguishing between the three loops requires conceptual effort. Explanatory power is high, clarifying how different levels of learning relate to adaptation and change. Predictive guidance is moderate, helping anticipate whether adaptation will remain shallow or reach deeper levels, though it does not predict transitions. Sharedness and communicability are moderate – the framework is established in organisational theory but less embedded in PME unless explicitly included. Systemic awareness is high, drawing attention to feedback and reflexivity as prerequisites for sustained organisational learning. Its strength lies in differentiating learning depth; its weakness is that real learning often lags behind operational tempo, creating a gap between heuristic and practice.

Concept-Led Capability Development (CLCD)

NATO's Warfighting Capstone Concept (NWCC) defines capability development as *concept-led* (NATO Allied Command Transformation, 2021). In this view, concepts articulate operational problems and outline envisioned solutions, serving as a meta-level driver between strategy and force design. Rather than prescribing detailed plans, concepts provide a shared framework within which experimentation, doctrine, and capability development occur. They thus function as a bridge between strategic guidance and the adaptation of concrete capabilities.

A parallel logic appears in the U.S. Army Training and Doctrine Command (TRADOC) *operations process* (2011), a cyclical model of planning, preparation, execution, and assessment. Its distinctive contribution lies in four command verbs – *understand, describe, visualise,* and *direct* – which illustrate how leaders translate strategic intent into operational design. Seen through the CLCD lens, they exemplify concept-led meta-governance: rather than prescribing action, concepts shape how organisations perceive, frame, and steer adaptation across levels of command.
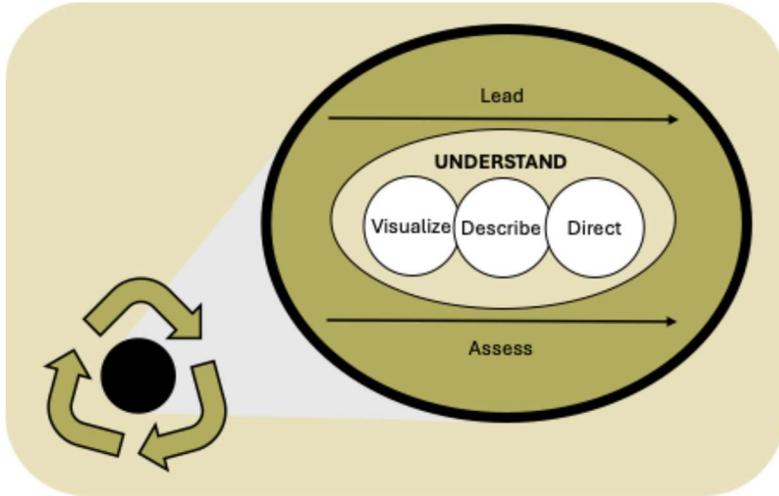
Figure 11 – Portable Heuristic: Concept-Led Capability Development (CLCD)
Adapted and redrawn by the author from U.S. Army TRADOC (2011).

Together, these approaches underscore that concepts operate as a form of meta-governance. They define the cognitive and organisational space within which innovation, doctrinal adaptation, and learning take place. Without such conceptual frames, capability development risks fragmenting into disconnected initiatives. With them, innovation can be aligned across national and institutional actors, sustaining coherence even as technologies and structures evolve.

In PME, CLCD is introduced in courses on doctrine development, force planning, and capability design. Students learn how concepts structure debate, guide experimentation, and provide a shared vocabulary for innovation. In multinational settings, this approach is especially valuable: it allows nations with different priorities to align within a common conceptual frame before standardisation occurs.

Assessment of Concept-Led Capability Development: Cognitive usability is moderate, as CLCD's staged and abstract nature requires study and experience

to internalise. Explanatory power is high, clarifying the link between strategic guidance, concepts, and capability design. Predictive guidance is moderate, identifying risks when concepts are not carried through but not forecasting innovation outcomes. Sharedness and communicability are high, as the approach is institutionalised in NATO and reflected in national processes (e.g., TRADOC's operations process). Systemic awareness is moderate, bridging strategy and organisation while requiring experimentation to stay grounded. Its strength lies in serving as meta-governance that aligns innovation and adaptation; its weakness is the risk of abstraction if concepts drift from practical anchoring.

Military Technical Revolutions (MTR)

The model of *military technical revolutions* (MTRs) frames history as punctuated by periods in which new technologies, combined with operational innovation and organisational adaptation, produce step-changes in military effectiveness. Classic examples include the introduction of gunpowder, mechanisation, and nuclear weapons. Each case involved, not only novel technologies, but also new ways of organising and fighting that transformed the character of war.

Krepinevich (2002) emphasises that MTRs are not revolutions in the moment. They are retrospective constructs, recognised only once incremental advances have accumulated into systemic transformation. The mechanisation of land warfare, for example, was not the product of a single invention but of decades of experimentation with tanks, motorised logistics, combined arms tactics, and new organisational structures. Similarly, the nuclear revolution reshaped strategy not because of the weapon alone, but through the doctrines, institutions, and deterrence frameworks that developed around it.
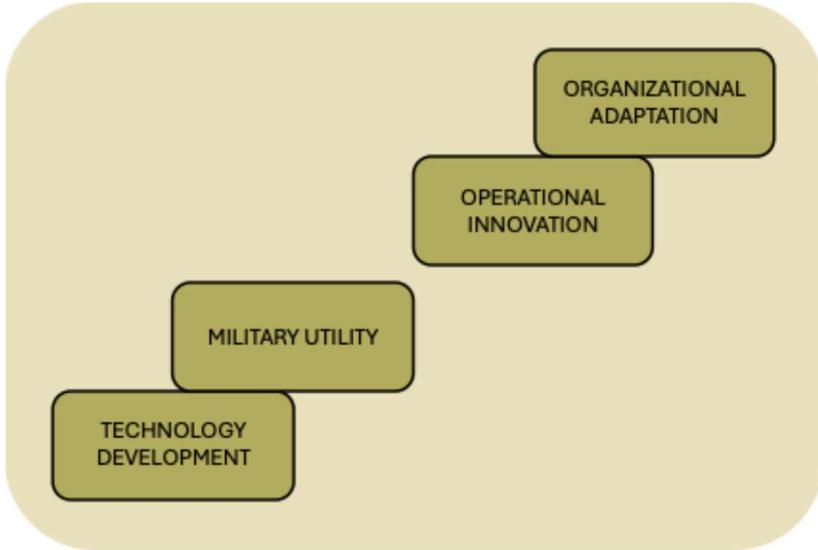
Figure 12 – Portable Heuristic: Military Technical Revolutions (MTR).

The central insight of the MTR model is that technological breakthroughs by themselves are insufficient to change the character of war. True revolutions occur only when new technologies are integrated with operational concepts and organisational adaptations that exploit their potential. This perspective contrasts with technological determinism, which assumes that new weapons automatically generate new forms of warfare. The MTR model instead situates technological change within a broader socio-technical system of doctrine, organisation, and culture.

As a heuristic, the MTR model provides a way of situating contemporary developments – such as artificial intelligence, autonomy, and data-centric warfighting – within a longer historical trajectory. It reminds practitioners and analysts that the significance of emerging technologies depends less on their novelty than on how effectively they are embedded in concepts and organisational practices that yield operational advantage. In PME contexts, the model is used to compare historical cases and to caution students against assuming linear or automatic transformation. By encouraging officers to view

technological change as contingent, cumulative, and socially embedded, it supports a more reflective and adaptive approach to assessing current innovations.

Assessment of Military Technical Revolutions: Cognitive usability is high, as historical examples make the model memorable and accessible. Explanatory power is high, situating technological change within broader patterns of operational innovation and organisational adaptation. Predictive guidance is limited, since revolutions are recognised mainly in hindsight. Sharedness and communicability are high, given its wide use in academic and military debates. Systemic awareness is moderate, acknowledging the interplay of technology, organisation, and doctrine but occasionally sliding toward determinism if misapplied. The model's strength is its historical perspective on systemic change; its weakness is its retrospective bias, which limits its ability to guide ongoing innovation.

Comparative Overview of the Heuristic Models

To consolidate the individual assessments presented above, Table 1 summarises all twelve heuristic models against the five evaluative criteria applied in this study: cognitive usability, explanatory power, predictive guidance, sharedness and communicability, and systemic awareness. The table also highlights each model's overall strengths and limitations, providing a comparative overview that complements the more detailed, model-specific analyses offered in the preceding subsections.

Model	Cognitive Usability	Explanatory Power	Predictive Guidance	Sharedness & Communicability	Systemic Awareness
Ends–Ways–Means	High	Moderate	Limited	High	Limited
Combat potential vs. Combat power	High	High	Moderate	High	Moderate
Fighting power	High	Moderate	Limited	High	Moderate
Opportunity space	Moderate	Moderate	Limited	Moderate	High
System-of-Interest	Moderate	High	Limited	Moderate	High
Logic model	High	High	Moderate	High	High
Functional chains	High	High	Moderate	High	High
Interoperability schema	High	High	Moderate	High	High
Socio-technical system (Leavitt)	Moderate	High	Limited	Moderate	High
Learning loops	Moderate	High	Moderate	Moderate	High
CLCD (Concept-led capability development)	Moderate	High	Moderate	High	Moderate
Military technical revolutions (MTR)	High	High	Limited	High	Moderate

Table 1 - Comparative overview of all twelve heuristic models assessed against the five evaluative criteria, highlighting their main strengths and limitations.

Read together, the models exhibit complementary strengths. Simple heuristics such as Ends-Ways-Means, Fighting Power, and the Interoperability schema offer high cognitive usability and communicability, making them effective tools for shared understanding. More abstract models – such as the socio-technical system, system-of-interest, and learning loops – provide higher systemic awareness but require greater conceptual investment. Across the set, predictive guidance is generally modest, reflecting the inherent constraints of heuristic tools when applied to dynamic and adversarial environments. Collectively, the models provide greatest value as cognitive stabilisers that enable shared reasoning within NATO's system of systems, while offering more limited support for anticipating dynamic change.

Discussion

Theory and Findings

The three theoretical perspectives from the theoretical framework section provide complementary lenses for interpreting the findings. The system-of-systems view explains why interoperability is decisive: no capability, however sophisticated, generates effect in isolation. The heuristics analysed in the previous section function as tools for reducing complexity and enabling officers to orient themselves within interconnected organisational systems. The technology perspective shows how the integration of data and AI increases the cognitive and institutional demands placed on officers and organisations alike. Finally, the perspective of organisational adaptation highlights PME as the mechanism through which such conceptual tools are transmitted, internalised, and standardised.

Taken together, the analysis shows that the examined heuristics share features that make them suitable for strengthening human interoperability. They simplify complexity, can be retained mentally, communicated easily, and used across institutional and national boundaries. Their value lies in three forms of utility – cognitive, communicative, and systemic. Cognitively, they help individuals stabilise perception under complexity; communicatively, they provide a shared language for coordination and reflection; systemically, they

connect understanding to organisational structures that enable coherent action.

Yet their strengths also reveal limitations. Most rely on linear or static representations, which can obscure adaptive dynamics. Several offer strong explanatory clarity but limited predictive guidance. Others are memorable but abstract. This tension reflects a broader paradox: heuristics stabilise cognition but can also narrow interpretation if treated as rigid templates. Their institutional value therefore depends on being used reflexively – as flexible tools for shared understanding rather than prescriptive models of reality.

Human Interoperability in NATO

Human interoperability extends beyond operational contexts. It shapes how institutions learn collectively, develop concepts, and adapt to emerging challenges. For NATO, this human dimension remains an essential yet underdeveloped component of collective effectiveness. Technical interoperability can be established through compatible systems and data standards, while procedural interoperability depends on aligned doctrines and processes. But trust, shared understanding, and cognitive compatibility cannot be engineered – they must be cultivated through education, experience, and reflection.

While NATO's strategic frameworks recognise the human dimension of transformation, they remain largely silent on the mechanisms that enable it in practice. Documents such as the *NATO Warfighting Capstone Concept* (NATO Allied Command Transformation, 2021) highlight the importance of developing human capital but do not specify how shared cognition and mutual intelligibility should be fostered. The heuristics analysed here illustrate how PME can fill this gap by providing cognitive architectures – portable models and shared conceptual languages – that link education, mutual understanding, and institutional adaptation across the Alliance.

Many heuristics function as cognitive interfaces across national and institutional boundaries, offering common frames for sense-making that

precede and enable technical and procedural coordination. They help officers from diverse professional cultures interpret concepts and problems through compatible mental frameworks. This capacity for mutual intelligibility allows NATO's system of systems to function coherently in planning, education, and institutional development.

PME institutions and multinational staffs rely on such conceptual anchors to facilitate dialogue among officers educated in different traditions. Frameworks such as *ends-ways-means*, *fighting power*, and the *interoperability schema* provide stable points of reference.

Some heuristics already function as de facto standards within NATO doctrine. The fighting power triad, for example, provides a shared and codified vocabulary for discussing moral, conceptual, and physical components of effectiveness, making it one of the clearest illustrations of how conceptual standardisation can support human interoperability.

By being simple, memorable, and transferable, heuristics sustain conceptual coherence that underpins trust and communication across the Alliance. These anchors form the human layer of NATO's data infrastructure – where shared understanding precedes and enables digital integration.

Institutionalising portable heuristics thus represents a form of cognitive infrastructure. It does not replace technical or procedural alignment but enables it by ensuring that those who design, employ, and govern systems can think together. Interoperability, therefore, is not merely a property of systems but a product of shared cognition.

A practical implication follows from this. NATO does not operate a unified PME system, and responsibility for education remains national. Nonetheless, institutions such as the NATO Defence College, the School of NATO, and the various Centres of Excellence function as connective nodes where shared doctrine, professional development, and conceptual alignment already take place. These platforms could provide a realistic pathway for disseminating, refining, and sustaining a common suite of heuristic models across the Alliance. This would also enable NATO-accredited institutions to teach these shared concepts, widening diffusion through existing structures. Such an

approach does not require a centralised PME authority; rather, it leverages NATO's existing distributed architecture to cultivate a shared cognitive infrastructure that supports enduring human interoperability.

PME in a Time of Change

The findings point to a renewed significance of PME in an era of accelerating technological and institutional transformation. As armed forces integrate AI, automation, and data-driven systems, the conditions for command, cooperation, and judgment are changing. Yet such developments do not reduce the need for PME; they amplify it. When technology alters the informational environment faster than doctrine and experience can adjust, education becomes the main mechanism for maintaining coherence between innovation and professional identity.

PME provides the institutional space where officers can critically engage with new concepts, translate them into professional language, and connect emerging technologies with enduring principles of military thought. PME thus prepares officers not only to employ technology but to interpret and govern it responsibly within the wider system of the Alliance. The data-centric turn expands the technical infrastructure of warfighting; PME expands the cognitive infrastructure that allows this transformation to be understood, debated, and directed.

Standardised heuristics play a key role in this process, translating the complexity of data-centric command environments into forms that officers can debate and refine collectively. Frameworks such as the logic model, socio-technical systems, and learning loops offer stable reference points amid change, helping officers connect the abstract logic of systems and data to practical reasoning and institutional learning. As Argyris & Schön (1978) emphasise, learning becomes meaningful when assumptions are made explicit; as Senge (1990) adds, adaptation depends on shared mental models that make complexity communicable. PME provides the environment where such shared understanding can be cultivated and renewed across generations of officers.

Seen in this light, PME is not a static institution but a dynamic interface between stability and change. It anchors NATO's technological and organisational evolution in a coherent professional discourse grounded in human judgment and ethical awareness – preserving continuity while equipping the Alliance to adapt collectively in an age of continual transformation.

Limitations and Future Research

The study's limitations concern scope rather than conceptual validity. It examined the potential utility of heuristics rather than their observed use, and the selection was strategic, not exhaustive. These constraints do not weaken the findings but indicate areas for further inquiry.

Future research could employ empirical designs to observe how officers use heuristics in practice - during exercises, classroom discussions, or multinational planning. It could explore how heuristics evolve when transferred between institutions or interact with AI-supported systems. Comparative studies across national PME institutions might reveal which heuristics most effectively promote shared understanding and which risk becoming rigid.

Ethnographic or mixed-method approaches could help capture how cognitive tools operate in real contexts of professional reasoning. Such studies would complement the conceptual analysis presented here, providing empirical depth to the argument that shared mental models form the cognitive basis of interoperability. These observations point to PME as a strategic mechanism for conceptual adaptation – a theme summarised in the conclusion.

Conclusion

This article examined how Professional Military Education (PME) can use heuristics to strengthen human interoperability as NATO adapts to data-centric warfighting. Through a conceptual analysis combining systems theory, technological drivers, and organisational adaptation, it found that technological transformation requires corresponding cognitive and institutional change if it is to yield operational coherence.

Models already embedded in NATO doctrine and PME – such as *ends-ways-means*, *fighting power*, and *interoperability* – function as portable heuristics that simplify complexity and provide a shared conceptual vocabulary. These heuristics are not substitutes for doctrine or judgment but cognitive tools that help officers align understanding across national and organisational boundaries. Their collective strength lies in making complex systems thinkable and communicable, allowing multinational forces to cooperate effectively amid rapid change.

Viewed across the three perspectives, these heuristics act as 'connective tissue' within NATO's organisational architecture: they translate data-centric processes into human comprehension and link conceptual learning to institutional evolution. In an age of constant change, coherence depends less on uniformity than on shared interpretive capacity. The integration of AI and data systems intensifies the need for mental frameworks through which officers can interpret information, coordinate action, and reflect on consequences.

For NATO, investing in PME is therefore a matter of strategic governance as much as education. As the Alliance moves toward data-centric operations, it will require officers who can navigate complexity conceptually as well as technically. Institutionalising a common repertoire of heuristics within PME can provide the cognitive foundation for this transformation – allowing coherence to emerge through interpretation rather than standardisation.

Addressing this gap requires NATO to complement its technological and human-capital initiatives with a coherent framework for human interoperability – anchored in education, shared heuristics, and institutional learning. PME thus becomes the Alliance's *cognitive infrastructure*, aligning technological innovation with professional judgment and ensuring that adaptation does not outpace understanding. It stands as both the stabilising memory and the adaptive intelligence of the Alliance, bridging data, doctrine, and decision through shared human understanding.

AI Statement: During the preparation of this work, the author used ChatGPT (OpenAI) in order to assist with translation and minor language editing. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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